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# Static and dynamic characterization of tied arch bridges

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STATIC AND DYNAMIC CHARACTERIZATION OF TIED ARCH BRIDGES

by

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## ABSTRACT

Tied arch bridges have been designed and constructed since the late 19th century. With their open vista owing to minimalist features tied arch bridges continue to appeal the public. Tied arch bridges are both aesthetic and economical alternates to long span bridges holding a place in the hierarchy of major bridges. They fit in a niche between viable and economical plate girder spans and short cable stayed bridge spans. There are several variations of the tied arch with the most common form being those having vertical hangers, stiff tie girders and slender arch ribs. This tied arch variation is examined in-depth using three-dimensional finite element analysis to determine both static and dynamic characteristics. Moreover, contemporary evolutions and innovations are presented as are comparisons between Load Factor Design and Load and Resistance Factor Design.

Four bridges, all spanning major rivers in the Midwest, are at the core of this study. The bridges have different spans, widths, arch rise, hanger number and spacing as well as wind bracing arrangments. The spans for these bridges range from 535 feet to just over 900 feet. The weight of structural steel per square foot of bridge deck ranges from 111 $lb_f$/square feet to 184 $lb_f$/square feet. The total dead load ranges from 244 $lb_f$/square feet to 311 $lb_f$/square feet. Though there is an increase in the live load for the current AASHTO LRFD code over those codes used to design these bridges, the older member sections have acceptable capacity-demand ratios. This is especially true for bridges designed using the HS20 modified live load. The fundamental frequency for the bridges ranges from 0.282 Hz to 0.514 Hz with a corresponding mode shape of a full sine wave. Additional frequencies and mode shapes are reported based on their mass participation. The influence of key element stiffness on frequency is also examined.

## ACKNOWLEDGEMENTS

"There is great joy in achieving what others deem impossible"

Major General Leif J. Sverdrup

The path leading to the completion of the doctoral program and this dissertation has without a doubt proved to be equally as rewarding as the completion. Along this path I have been privileged to meet many professors who shared their insight and passion for numerous subjects, making complex topics both practical and immediately useful. Additionally, many colleagues have selflessly shared their knowledge and enthusiasm for bridge structural engineering. In recognition of my gratitude to these mentors I will strive to impress upon others the knowledge and experience I have gained.

No journey progresses well without a proper start and support along the way. As such I am greatly indebted to my parents for fostering my inquisitive nature and honing my persistence. Similarly I'm grateful to my sister for passing along her enthusiasm for computers and knack for programming. I thank my advising committee for their insights and patience over the years especially those of Dr. Genda Chen and Dr. Victor Birman. Lastly, I wish to gratefully acknowledge the support of my wife and children who have supported my efforts, for better or worse, to completion. Paula, Emily, Amy, Kelly and Kyle, you are my inspiration, I love you and you all have a very special place in my heart and thoughts.

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# 1. INTRODUCTION

## 1.1. BACKGROUND

Tied Arch bridges have been designed and constructed since the late 19th century. They continue to be an economical and sound transportation link for river crossings requiring a medium span over navigation channels. However, little has been written about the analysis, design or construction of such bridges and even less on their dynamic behavior. The dynamic behavior of such bridges is of interest particularly as earthquake, wind, and traffic loadings are a concern. Moreover, damage detection in bridges or structural heath monitoring requires knowledge of the vibration characteristics of bridges. The dynamic properties of the bridge of interest are natural frequencies, damping ratios, and mode shapes. To address these gaps, this project presents:

1. A focus on tied arches with the following characteristics:
    a. Through Arches, having two, parallel arch ribs
    b. Vertical Hangers
    c. Primary structural members of steel construction.
    d. Single span in the range of 500 feet to 900 feet.
2. Primary and secondary structural components which characterize tied arch bridges are defined.
3. The dynamic characteristics of tied arch bridges including natural frequencies and mode shapes.
4. Construction techniques for tied arch bridges with consideration to design impacts.
5. Contemporary developments for this bridge type are also presented including fracture critical and redundancy issues.

6. Baselines for Structural Health Monitoring and applications to Tied Arch bridges will be discussed as part of the dynamic portion of this project.

Presenting a comprehensive, single source, for the static and dynamic engineering and construction of tied arch bridges will close the existing knowledge gap and provide a solid foundation for future efforts to improve on the performance of these economical bridges. A priori knowledge of the magnitude and distribution of service loads through the elements of the tied arch produces confident, cost effective bridge arrangements. Similarly, knowledge of the dynamic performance of the bridge and components result in improved performance for wind, earthquake and traffic induced vibrations. Moreover the dynamic behavior of the bridge and components will provide a baseline for the structural health of the elements without deterioration. As a result, vibration data collected from similar existing bridges with deterioration may find a comparative baseline. All bridge and construction engineers will benefit from a single collection of contemporary innovations in tied arch design and construction or erection techniques. Closing the existing knowledge gap, will advance the knowledge base for tied arch bridges with students, owners, and bridge consultants to apply and improve on the state of the practice captured in this single resource.

This research will provide a deeper, broader understanding of tied arch bridges for students, owners and bridge consultants. Given the economy and aesthetics of tied arch bridges, a better understanding of the structural performance including benefits and limitations will lead to improvements and greater use of this bridge type could lead to less expenditure of scarcely available transportation funds.

Through the data presented students, owners, and bridge consultants may determine the dynamic effects of wind, seismic, or traffic events on the performance of the bridges.

The study may be used a means to triage the existing tied arch bridges in inventory, which may have been designed and constructed with, or susceptible to, to poor details, to determine if additional studies for structural health monitoring are necessary to further characterize the specific bridge performance.

Though this study targets long span river bridges, the material presented herein can be applied to smaller tied arch bridges used for primarily for aesthetics. Recently several tied arch bridges have been designed and erected for smaller rivers such as the Virginia Street Bridge over the Truckee River in Reno, Nevada and the Rapid Transit Denver Light Rail over the 6$^{th}$ Avenue Freeway Bridge in Denver, Colorado.

Finally, within the greater building community there are multiple interest groups whose members are involved in planning, designing and constructing a major river crossing. Arguably one of the most important of those groups is the contractors or their construction engineers. Construction engineers are responsible for coordinating with contractors to develop a safe erection design and plans for buildings or bridges. This study presents several erection schemes along with contemporary methods, to demonstrate the range of schemes available to contractors/engineers. These methods include erecting via falsework, cables and strong-backs, and float-ins with and without self-propelled-modular-transporters (SPMTs). As a result this study transcends the bridge design interest and should be of interest to contractors and their engineers.

## 1.2. OBJECTIVES

1. Complete a literature search and provide a description for pertinent published work.
2. Define the Tied Arch system and components.
3. Provide preliminary results of the static analysis and design for service loads

4. Provide a dynamic analysis of the bridge and components
5. Develop recent improvements to tied arch components
6. Develop erection schemes and contemporary alternates
7. Discussion on the potential application for Structural Health Monitoring

# 2. THE TIED ARCH BRIDGE

## 2.1. HISTORICAL POINTS

History documents arch bridges of stone construction dating to 2,200 B.C. in the middle-eastern valleys of the Tigris and Euphrates rivers (Tyrrell, 1911). Though these stone arch bridges of Babylon do not exist today there are many that have stood the test of time. Such bridges include the Pont Du Gard, the Ponte Vecchio and the Jade Belt Bridge. The renown Pont Du Gard is a Roman aqueduct, built in Gard, France over the Gardon River, 18 B.C. (Dupre, 1997) The Italian Ponte Vecchio, spans the Arno River in the City of Florence and was completed in 1345 (Dupre, 1997). The XiuYi (Jade Belt) bridge is located at the summer palace in Beijing and was completed in 1764 (Cortright, 2003). In short, these durable bridges convey a sense of beauty, solidity, stability and constancy. All are characteristics bestowed on modern arch bridges that are forged iron and steel.

The history of the modern arch bridges begins in 1779 Coalbrookedale, now Ironbridge, where the first such iron arch bridge exists today spanning the Severn River (Cortright, 2003). The bridge at Coalbrookedale is an open spandrel bridge with the iron ribs supporting the travelway from the underneath. This bridge is both functionally and aesthetically lighter than its masonry predecessors while it supports nearly the same live load as before. The new materials permit arch bridges to span longer distances and carry more load. As arch bridges and their materials evolved to provide greater capacity to span more open waterways, the ribs were configured above the travelway. Longer spans and providing for greater traffic meant greater forces exerted to the foundations. Construction of foundations in rivers in the 19$^{th}$ century was perilous and generally larger foundations often translated to more deaths. In St. Louis, circa 1870, fourteen men died constructing the foundations for the Eads Bridge.

The Luiz I bridge over the Douro River, with main span of 566 feet, near Porto, Portugal, completed in 1885, is one of the first applications of a tension tie to reduce the outward, lateral thrust on the bridge's foundations (Tyrrell, 1911). The innovative tied-arch bridge would not become common place until the early 1900s with applications in Germany. Two bridges spanning the Rhine River, the first, a railroad bridge comprised of a series of three tied arches at Worms and the second at Mainz also with three tied arch spans. Today the tied arch bridge is an aesthetical and economical bridge for span requirements in the 400 to 1000 feet range. This paper will review the characteristics, specifically the dynamic behavior of the tied arch with ancillary focus on the static characteristics for design, fabrication and erection of the tied arch bridges with a note for recent innovations.

## 2.2. ARCH BRIDGES

Definitions of arches often summon to mind masonry units constructed to curved lines of a bygone era. Though poetic, definitions of this type provide little insight for defining the structural effect of arches or arch bridges. For a more practical structural understanding of arch behavior, Xanthakos (1994) provides the following defining criteria for arches:

- The arch as a structural unit shall be shaped and supported such that intermediate transverse loads are transmitted to the supports primarily through axial compressive thrusts.
- The arch member must be sustained by supports capable of developing lateral and well as normal reactions.
- The arch member should be shaped to avoid the introduction of bending moments for downward loads.

These requirements are presented in Figure 2.1. The arch is acted upon by intermediate, transverse, downward point loads. Under this loading the arch deflects, shortening along the longitudinal axis to create axial thrust which is, in turn, resisted by inclined reactions, $R_1$ and $R_2$. Those reactions have the vertical and horizontal components also shown in . Resisting the vertical and horizontal components require sizeable foundations or abutments, depending on the subsurface foundation material. This is especially true as the span of the arch increases.

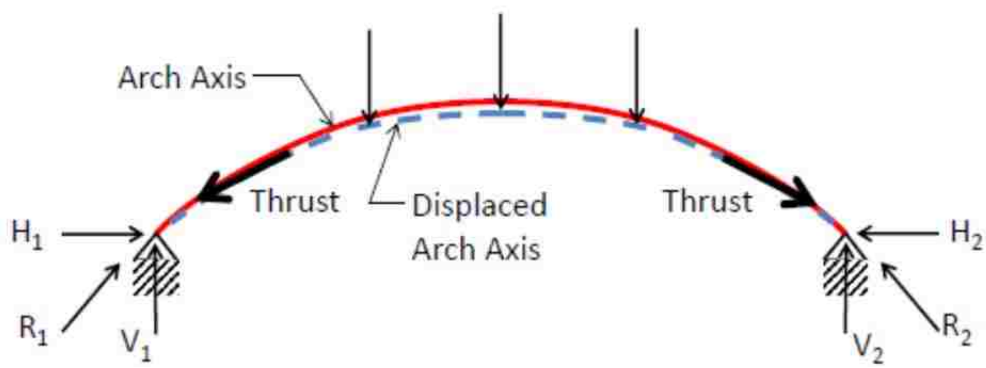



Figure 2.1. Two Hinged Arch

The final criterion for the arch requires the arch member to be shaped to avoid bending moments in the rib for downward loads. Maxima or minima for the internal reactions of a specific arch having a particular circular or parabolic shape may be developed for a unique set of external loads but not for all external loading combinations. That is, for a specific arch shape and loading, the axial thrust may be maximized while the bending moment is minimized. Moreover, fabrication and construction techniques for arches commonly involve connecting straight members on chords to for the best fit to the mathematical arch shape. For this reason internal bending moments cannot be entirely eliminated in arch structures. Brockenbrough and Merritt (1994), Sack (1988), Xanthakos (1994) provide detailed analysis demonstrating the presence of bending moments for several arch structures for a given set of external loads. As a result, the best outcome is to minimize bending moments in the arch rib for many arch structures including the tied arch structure.

The present day tied arch arrangement evolved from early work to internally resist the outward thrust common to arch structures which in turn eliminates large foundations otherwise required to resist the outward thrust. The internal resistance is provided via a tension tie connecting the base of the arch rib. With the tension tie resisting the outward thrust, this results in only a vertical reaction at each end of the arch. Figure 2.6 shows a tied arch subject to external loads and the resulting structural reactions.

The tied arch continued evolving into the 20$^{th}$ century with the tension tie evolving into a tie girder, from the bowstring arch system to the Langer arch system to the more complex Tevit network tied arch. The early development of the tied arch focused on the ratio of tie-beam to arch-rib stiffness such as Chandrangsu and Sparks (1954) to aid engineers in achieving more optimal structural actions in both the arch-rib and tie-girder. The results showed very little effect on the moment in the arch rib due to variations in the ratio of second moments of area for the tie-girder to arch rib. This early report further noted that presumption of the pin connection for the arch and tie girder results in appreciable error thereby justifying nearly all future work to use a fixed or moment connection. Lastly the report results favor a smaller, more flexible arch cross section compared to that of the arch-tie. This last point will be examined further into this study.

## 2.3. TIED ARCH BRIDGE

Prior to examining the analysis of the arch bridge, the specific bridge arrangement will be presented. The present day tied arch derives from centuries of arch bridge construction. Over the years arch bridges have three forms, closed spandrel, open spandrel and through arches. Closed spandrel arch bridges, see Figure 2.2, carry the roadway or weight above the arch, which is made of masonry blocks or concrete, which in turn transfer the load via compression

Figure 2.2. Example of a Closed Spandrel Arch Bridge, Virginia Street Bridge, Reno, NV

to the foundations. The region between the roadway and arch is closed with fill material. Open spandrel, see Figure 2.3, also carry the roadway or weight above the arch but are distinct in transferring load via a finite number of columns that, in turn, transfer the load to the arch which then transfers the load to the foundation via compression in the arch. In each of these cases, the foundations are necessarily massive to resist the thrust of the arch at the ends. Figure 2.4 depicts details from a true arch planned for a bridge spanning I-74 over the Mississippi River. The footprint of this foundation for one arch rib is 81 feet long and 70 feet wide. The third form places the roadway under the arch, suspended by cables from the arch. The third form still required large foundations to resist the arch thrust and gravity loads. Finally in the late 19th century a tension tie girder connecting the ends of the arch rib and thus resisting the arch

Figure 2.3. Example of Open Spandrel Bridge, Hoover Dam By-Pass Bridge, NV

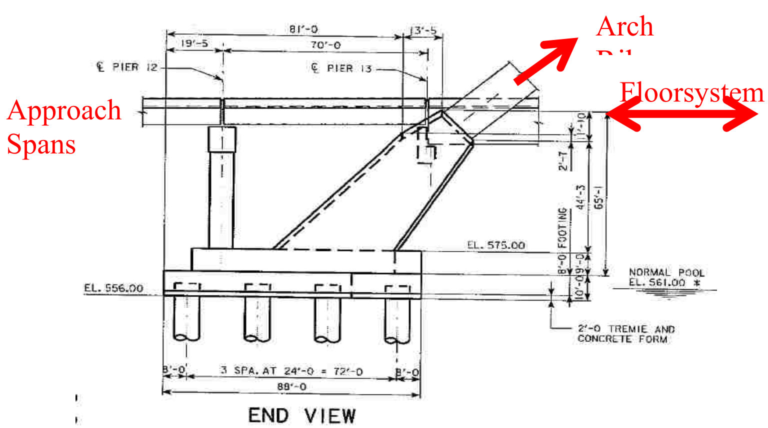
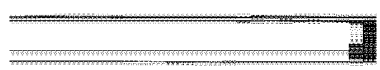


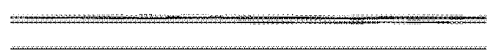

Figure 2.4. True Arch Foundation - I-74 over the Mississippi River - Preliminary

thrust internally. This development permitted the newly coined “bow-string arch” to rest on a much smaller foundation which supported only gravity loads.

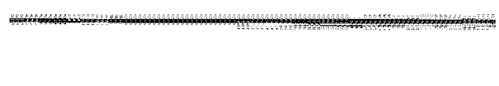
Tied arch bridges can consist of a single span or be configured as continuous span systems. The single span bridges are almost always through arches with the tie girder at the deck level. The continuous systems usually consist of three spans with a center full arch and the flanking spans being half arches. These bridges can be arranged as half-through arches or as deck arches. See Figure 2.5. This paper is focused on the single span tied arch with some occasional references to other tied systems.



a) Through Tied Arch



b) Continuous Through Tied Arch



c) Continuous Deck Tied Arch

Figure 2.5. Tied Arches

The tied arch is composed of the arch rib, tension tie-girder, and hangers as the primary components. The tension tie-girder connects the ends of the arch rib converting the arch thrust to tension through the large, rigid, end connection referred to as the arch “knuckle”. The arch supports the bridge deck and it’s supporting members via the hangers which connect to the tension tie-girder. At each hanger/tie-girder connection, a floorbeam is connected to the tie-girder. The floorbeam supports the stringers that support the concrete roadway deck and barrier curbs. Between the arches lies a system of bracing. The upper bracing lies between the arch ribs and resists wind loading and buckling of the arch rib members. The lower bracings serve a similar purpose as the upper bracing in resisting wind loading. Both bracing systems provide resistance to any longitudinal distortion or “racking”.

## 2.4. TIED ARCH STRUCTURAL BEHAVIOR

Overall structural arch behavior is demonstrated in Figure 2.1, a two hinged arch. An arch having this type of loading and support conditions is shown in Figure 2.3 which depicts an open spandrel arch bridge. The columns extending from the roadway deck to the arch below are easily envisioned as the point loads applied in Figure 2.1. Moreover, the pin connections shown for the two-hinged arch of Figure 2.1 are also easily envisioned by the supports affixed to the canyon walls in Figure 2.3. If, for Figure 2.1, we replace the three point loads with a uniform load and the pinned support conditions with fixed support conditions, the resulting structural arrangement is more typical of the closed spandrel arch bridge shown in Figure 2.2. This section will focus on the structural action of tied arch bridges providing the reader with a general overview of the structural behavior of these bridges.

Figure 2.6 portrays the member, loading and displaced shape for the tied arch bridge. The uniform load acts on the concrete roadway deck that is ultimately transferred to the arch hangers.

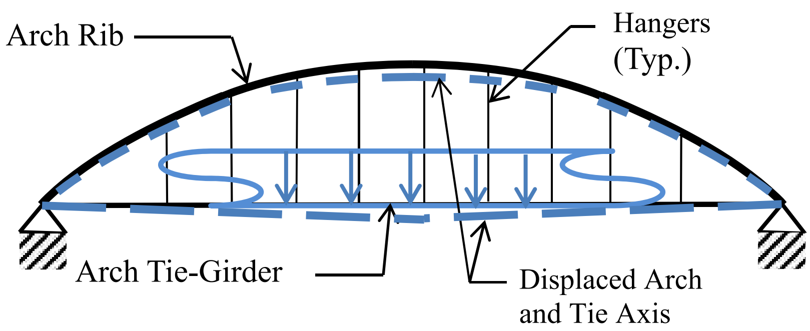



Figure 2.6. Tied Arch Structural Arrangement

The loading places the hangers in tension and displaces the arch rib downward. The arch rib is restrained at each end, which as for the two hinged arch, produced an axial shortening and develops a compressive thrust in the arch rib. See Figure 2.7b.

Finally, as the arch rib exerts an outward thrust on the supports, the arch tie pulls the supports into equilibrium loading the tie in tension as shown in Figure 2.7c.

From the standpoint of external statics the single span tied arch behaves in a determinant manner and reacts on the supporting substructure as if it were a simply supported beam. Internally, however, the system is indeterminate with the behavior being dependent on the ratio of the tie stiffness to the rib stiffness. In the classic bowstring arch the tie is predominantly a tension member with minimal bending stiffness. In this system the vertical loads are carried almost exclusively by the arch rib. The resulting proportions of the rib and lateral bracing are similar to what they would be if the system were in fact a “true” arch using a compression thrust block instead of a tension tie. Many older steel tied arches are of the bowstring type, perhaps due to the more direct correlation of the analysis techniques for this system with those of a true arch. As the stiffness of the tie, $K_{tie}$, is

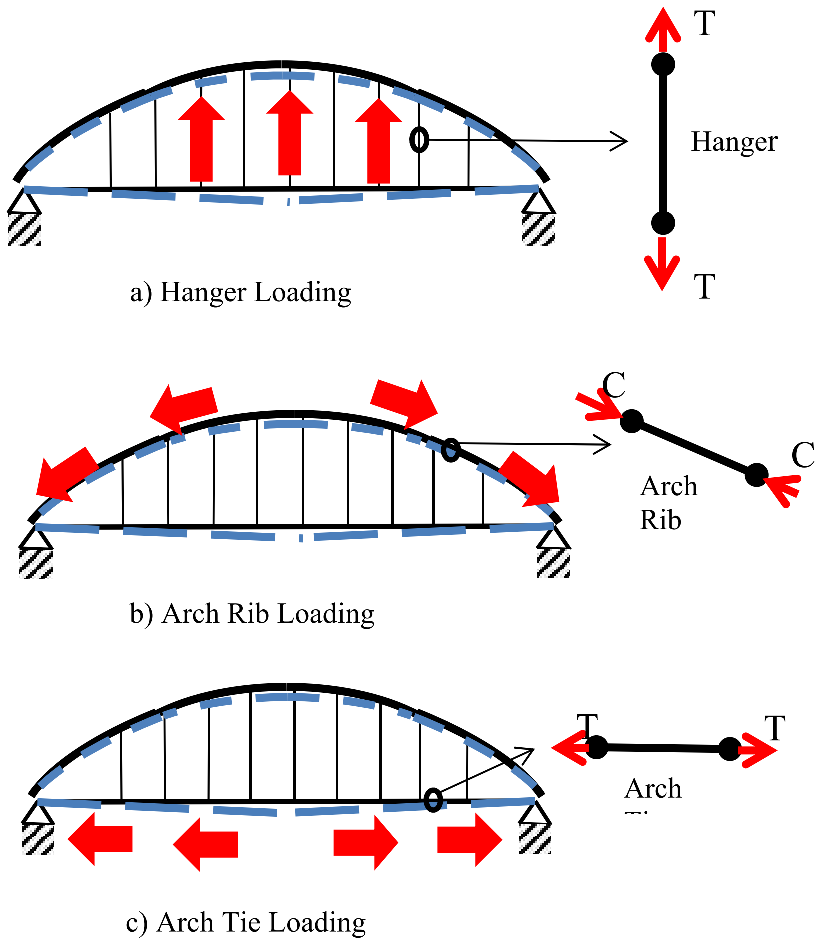



Figure 2.7. Tied Arch Structural Action

increased relative to that of the arch rib, $K_{arch}$, it begins to function as a beam and to participate in carrying vertical loads to the supports. Accordingly, the demands on the arch rib are reduced allowing its size to be reduced significantly as compared to that of a true arch of comparable span length. Taken to the extreme, of course, higher values of $K_{tie}/K_{arch}$ imply the resulting tied arches would simply be beams with vestigial arches.

While the two systems differ somewhat structurally, there are no great advantages of one system over the other. Economics may favor the moment-tie types particularly where wide bridges are involved due to the smaller rib and bracing members. From an appearance standpoint the resulting rather large arch rib and accompanying large lateral bracing members of the bowstring arch may be at a disadvantage compared to the thinner ribs and lighter bracing of the moment tie systems. Spreng (2003) has investigated the structural efficiency of tied arches and has developed recommendations for tie and arch proportions using a definition of efficiency as the ratio of "structural output" over "structural input". He defines "output" as the loading supported when the stress reaches the allowable level and "input" as the self-weight of the arch.

One significant overall design parameter for arch design is the rise-to-span ratio. Spreng has investigated this parameter and concluded that for loading over half of the bridge a relatively flat arch with a rise-to-span ratio of 1:7 works well. Conversely, for load over the entire span, a steeper arch with a ratio of 1:3 is the more optimal. For tied arch highway bridge structures where the dead load is more-or-less uniform over the length of the bridge, but the loaded length and position of the live load varies, the optimal ratio is usually considered to be in the range of 1:4 to 1:6. Designing within this range provides a reasonably efficient system in terms of the magnitude of the thrusts and moments to be carried in both the rib and the tie and the resulting amount of material required. The resulting geometry is also usually visually pleasing, providing an arch profile that is neither too high nor too flat.

**2.4.1 Arch Rib.** This compression member is typically a welded box girder erected in sections spliced together. For shorter spans it's not uncommon for the rib to be a curved rolled I-section or for concrete the rib is typically has a rectangular cross section.

**2.4.2 Tie-Girder.** This element connects the ends of the arch and is either a welded box girder or an I-section such as plate girder. Tied arch bridges can be categorized into two main categories depending on the action in the tie-girder. Structures with a relatively flexible tie-girder are termed a "bowstring" arch as the tie-girder carries mainly axial tension and has a small cross-section, hence the bowstring moniker. Tied arch bridges having a stiffer, larger tie-girder are defined as a Langer girder system. In this system, the tie-girder carries significant flexural demand. This has the benefit of nearly eliminating flexural demands on the arch rib so that it is very nearly in pure compression. This element is singularly most responsible for the tied arch being categorized as fracture critical. The composition of more contemporary tie-girders is discussed further in this proposal.

**2.4.3 Hangers.** There are three commonly used hanger systems for tied arch bridges. Vertical hangers are referred to as a "Langer" system. The "Nielson" system having inclined hangers and an improvement to that system which is denoted the "Network" system. The Network system was developed by Norwegian Per Tveit in the 1950s while the Nielson system was developed 30 years earlier. The Langer system is further characterized as a bridge arrangement that has a relatively small arch rib cross-section in contrast to the much larger cross-section for the arch tie-girder. The majority of the recent tied arch bridges are Langer tied arches. For this project, all bridges have vertical hangers with a Langer-girder arrangement. The hangers or vertical suspenders are typically located every 30 to 40 feet for long spans and are typically composed of bridge rope. The hanger spacing for Nielson or Network hangers is smaller and so reduces the flexural demand on the tie-girder while providing additional stiffness in-plane and out-of-plane. Not all hangers are rope hangers; in some variations on the tied arch such as the trussed tied arch, it's common for the hangers to be I-sections. Sets of four or two typically comprise the hanger when using bridge rope. It's common practice for the bridge rope to have a factor of safety of 4 as a minimum.

**2.4.4 Floor System.** Over time the deck or floor systems of tied arches (and trusses also) have evolved into transverse floor beam systems supporting longitudinal stringers, which in turn support a transversely spanning mild reinforced concrete deck slab. And while other deck systems are, of course, possible, the majority of truss and arch bridges use this basic arrangement. The floor beams are usually plate girders with a depth-to-span ratio of about 1:8. Panel lengths are in the range of 40 to 50 feet, which provides for efficient truss framing and reasonable arch hanger sizes. This panel length also works well with the use of rolled beams for stringers. The stringers may or may not be made composite with the deck slab they support, although a noncomposite design will usually be the most economical. This economy results since the stringer is sized for the noncomposite negative moment over the floorbeams and due to its short span length it is not typically economical to vary the stringer section in the positive moment area, so the same section is used throughout. Thus the stringer section alone is more than adequate to carry the positive moments and there is no reason to effect a composite connection.

Where structural depth is a concern the stringers may be framed into the floorbeams. Various stringer-to-floorbeam connection types have been used in this situation ranging from a full moment connection with upper splice plates to something more akin to a semi rigid connection. Alternatively, where structural depth is not a particular issue the stringers can be made continuous over the floorbeams, being supported on small bearings on the floorbeam top flange, Figure 2.10. The latter arrangement is usually the more economical of the two options.

Historically, designers have gone to great lengths to insure that the deck system does not participate with the main longitudinal support system, whether an arch or another type of system. This has been accomplished by placing transverse relief joints in the deck slab at about every fourth or fifth panel point and by using an appropriate mix of fixed and expansion bearings to support the stringers. These devices allow the deck to expand and contract independently of the arch both during construction (when the slab is placed) and in service when loaded by live load. The major drawback of such systems is the maintenance required by these relief joints themselves and the effect of the inevitable deck drainage that passes through them onto the steel below. On the Page Avenue (Rte 364) arches these deck relief joints were eliminated. And while still structurally separated from the arch itself the deck acts as one large continuous member instead of as a series of segmented slabs. In the system used the three center stringers have a fixed bearing at every floorbeam. The floorbeam top flanges are rather narrow and this fixity insures lateral buckling stability of these flanges. Given the length of the floorbeams (85 feet+) the resulting stresses in the top flange due to any resulting lateral bending are quite small. The center stringer is connected to the lower lateral system via a longitudinal truss at the center of the span that gathers all longitudinal forces to this point. All other stringers are supported on expansion bearings. It is important that stringers nearest the floorbeam-tie connection do not laterally restrain the floorbeam top flange. Such restraint can lead to fatigue cracking in the floorbeam top flange to web weld caused by differential longitudinal movement between the tie and the stringer system.

As an alternative to the traditional approach, some designers have structurally connected the floor system to the main longitudinal system (the tie girder in the case of a tied arch) to force the deck to participate with it. By so doing the overall stiffness of the system is increased and the size (depth) of the tie girder may be somewhat reduced as axial tension and, to a perhaps lesser extent, bending moments, are shared by the deck. These arrangements have been used in combination with orthotropic steel decks such as in the Port Mann, the Gorinchem and the Fremont tied arch bridges (Troitsky 1987; Chen and Duan 2000). In these cases the steel deck participates in carrying both dead and live load effects arising in the arch system. This structural connection between the deck and the tie girder has not typically been used with concrete decks although the new US 20 Bridge at Dubuque, Iowa has been designed in this way (Binns, 2004). For concrete decks, in order to limit the tension in the deck, it will be advantageous to make the deck connection to the tie using a closure pour after the majority of the deck has been placed. In this way the deck participates only in resisting the residually applied dead loads and the live load.

Figures 2.8 to 2.10 show various views of a contemporary tied arch.

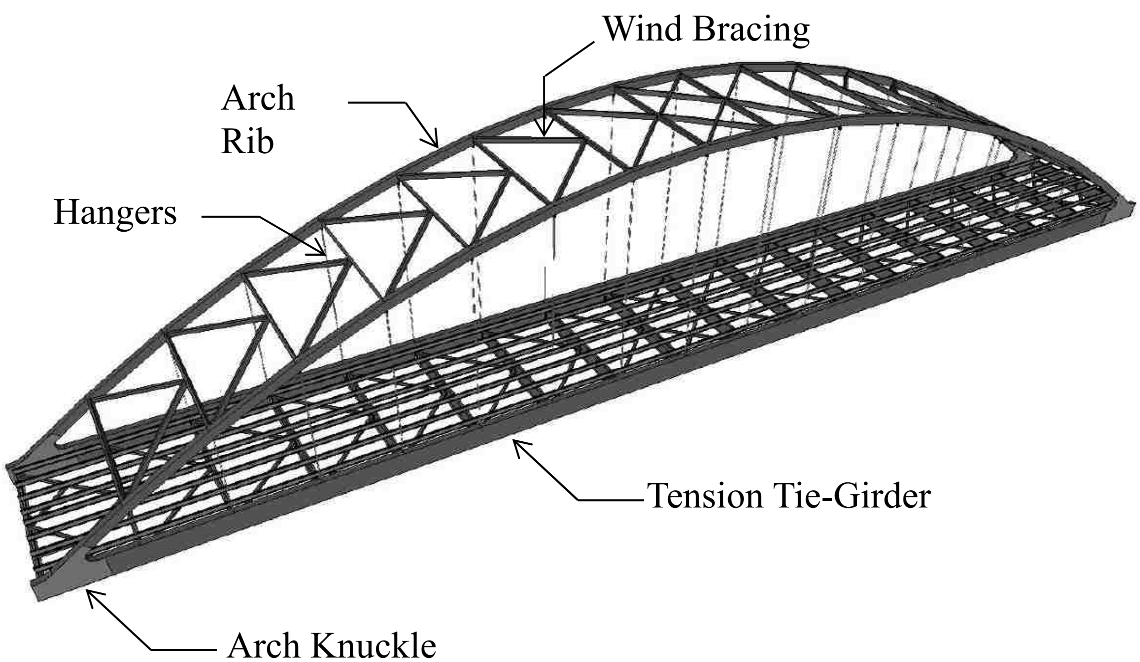



Figure 2.8. Tied Arch Bridge

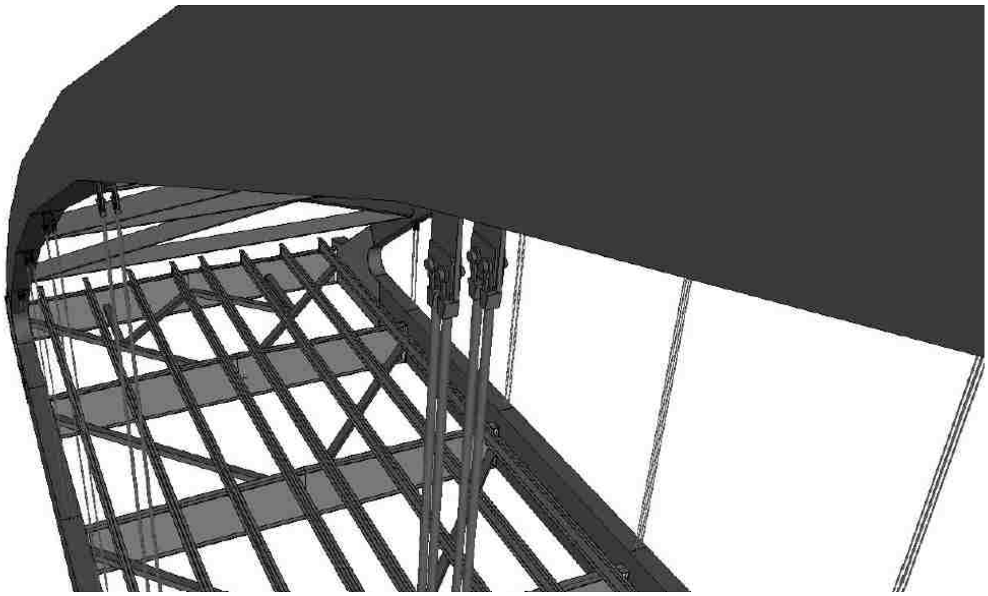


Figure 2.9. View of Tied Arch floorsystem: Stringers, Floorbeams, Lower laterals

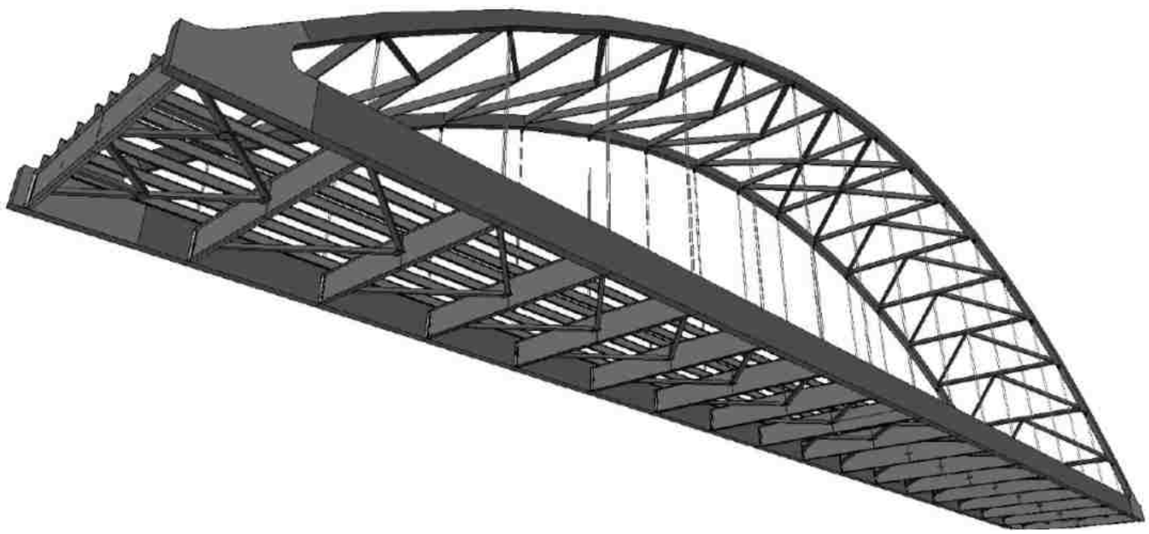


Figure 2.10. View of Floorsystem and Arch Tie-Girders

# 3. BRIDGE DESCRIPTIONS

## 3.1. JEFFERSON BARRACKS BRIDGE

The Jefferson Barracks bridges span eastbound and westbound I-255 over the Mississippi River from St. Louis County, Missouri to Blank County, Illinois about 11 miles south of St. Louis, Missouri. The bridges, built in 1984 and 1990, are about 4,000 feet from abutment to abutment and are mainly comprised of continuous, composite plate girder for the majority of the length. A 910 foot long tied arch spans the main navigation channel, near the St. Louis bank. The main span is comprised of the arch components, the roadway system and the arch bearings.

The tied arch rise, from the centerline of the rib to the centerline of the tie girder, is 182 feet. The hangers are comprised of four 2-1/8 inch diameter ASTM A586 multi-wire bridge strand and are spaced at 49 foot centers. The arch rib and tie girder are comprised of box sections and plate girders respectively. The box sections typically measure 6 foot 3 inches and the plate girders have a 12 foot web depth. The structural steel for the rib and tie is AASHTO M222. AASHTO M222 is similar to the ASTM A588 designation for high strength low alloy (HSLA) steel and includes structural steel applications with plate thicknesses 4 inches and under. For these plates, ASTM A588 structural steel has a minimum yield strength, $F_y$, of 50 ksi and a tensile strength, $F_u$, from 65-70 ksi. All structural steel for this bridge is specified as AASHTO M222 unless otherwise noted. High strength bolts are used throughout the structure and conform to AASHTO M164, Type 3, similar to ASTM A325, Type 3. The north and south arches of each bridge are spaced on 62 foot centers permitting a 54 foot wide bridge deck with two 19 inch safety barrier curbs. Wind bracing, upper and bottom laterals, is provided between the arch rib (upper) and tie girder (bottom). The bottom laterals are placed at angles to the floorbeam and tie girders (thusly called diagonals) work with the floorbeams to resist wind loading. The lower laterals are comprised of flanges (MC18) and a web plate. Upper laterals (box members) are provided between and normal to the arch ribs, only at the intersection of the arch rib and hangers, thereby forming a Vierendeel truss to resist wind loading and buckling of the arch rib. This simple upper bracing form is unusual in bridges, which typically contain diagonal members, but adds to the slender appearance of the bridges for aesthetics. The Jefferson Barracks Bridge is shown in Figure 3.1.

Figure 3.1. Jefferson Barracks Bridge. Photo from: http://bridgehunter.com/mo/st-louis/jefferson-barracks/

The roadway system is comprised of the bridge deck, a reinforced concrete, 28-day strength of 3,500 psi, 8 inches thick deck, supported by W30 stringers spaced at 8 foot centers. Diaphragms brace the stringers and are typically wide flange sections. The stringers are supported by the floorbeams spaced with the arch hangers at 49 feet centers. The floorbeams are comprised of welded plates, forming an “I” shape with two sets of web depths, 93 and 76 inches. The flanges are 2 inches thick with two sets of widths, 19 and 24 inches. Between the stringers and floorbeams, steel shim plates are used as bearings to distribute load. Typically two shim plates (1 ½ inches and a variable depth shim from 3/8 to 5/8 inch) are used per location and are beveled in the transverse direction to match the cross slope of the floorbeam. The plans show a four bolt connection between the stringer and floorbeam with a 1 inch diameter bolt in a 1 1/16 inch hole fully tightened.

The bearings for the main span are cast steel conforming to AASHTO M192 (ASTM A486). Components of the castings have specified heat treatment designations of Class 70, 90 and 120. Bearings of this era have upper and bottom shoes if designated as a fixed bearing whereas expansion bearings have an upper shoe but the bottom is replaced by a rocker or nest of rollers. The bearings are also designated as fixed or expansion. Fixed bearings constrain horizontal, longitudinal (bridge length) and transverse (bridge width) movement as well as vertical, downward, movement. Expansion bearings allow movement in the longitudinal direction while constraining movement in the transverse and vertical downward direction. Both fixed and expansion bearings permit longitudinal rotation (rotation about the transverse axis) through a pin. The steel pins for the Jefferson Barracks bridge are 9 inch diameter and conform to AASHTO M222 with an ANSI surface finish of 125. The main bearings provide a bearing area of about 7 feet square and are about 6 feet tall.

## 3.2. CITY ISLAND BRIDGE

The City Island Bridge, see Figure 3.2, is a single structure spanning US 61 over the Mississippi River at Dubuque, Iowa. The bridge was designed in the late 1970s with construction completed in the early 1980s. The total bridge length from abutment to abutment is approximately 2,827 feet. The bridge is comprised of two continuous, composite plate girder spans flanking the tied arch, a 670 feet span over the navigation channel. The main navigation channel is near the Wisconsin bank of the river. The main span components are described further below.

Figure 3.2. City Island Bridge, Dubuque, Iowa. Photo from: http://bridgehunter.com/ia/dubuque/604440/

The arch, span, 670 feet, has an arch rise, from centerline of tie girder to centerline of rib, of 132 feet. The arch rib and tie girder are both welded steel (ASTM A588) box members. The tie girder is approximately 9 feet 10 inches tall by 3 feet wide whereas the arch rib is 4 feet 3 inches tall by 3 feet wide. The arch has 15 hangers spaced at 41 feet 10.5 inches. The hangers are composed of four 2 inch diameter wire rope specified to ASTM

A603. The arches are spaced at 79 feet center to center and provide for a 75 feet 6 inch concrete bridge deck arranged for two 35 feet roadways, two 17 inch safety barrier curbs and a single 24 inch median barrier separating the eastbound and west bound traffic. The upper laterals, bracing the arch, are comprised of diagonals and struts (transverse members) are built-up box members typically having dimensions 16 x17 inches. The lower laterals between the tie girders and working with the floorbeams are also box members having dimensions 17 x 22 inches. All laterals for the City Island Bridge are specified to be ASTM A36 steel.

The bridge deck is nine inches thick and supported by nine stringers, W33x118, spaced at 8 feet 6 inches. C12 sections brace the stringers throughout their length at regular intervals. The stringers are supported by the floorbeams spaced with the arch hangers at 41 feet 10 ½ inch centers. The floorbeams are comprised of welded plates, forming an "I" shape with a web depths of 102 inches. Intermediate floorbeams have flanges that are 2 inches thick and 20 inches wide. End floorbeams have flanges with a 1 inch thickness and 18 inch width. The floorbeams are specified to be ASTM A588 steel. Bearing and floor system expansion between the stringers and floorbeams is accommodated by ½ inch by 12 inch tetrafluoroethylene (TFE) surfaces, guide blocks, beveled fill plates. Where fixed bearings are located they also have TFE surfaces with beveled fill plates. All stringer bearings have a four high strength bolt connection to finger tight with lock washers.

The bearings for the main span are cast steel conforming to ASTM A486, $f_y$ equal to 60,000 psi. Components of the castings have specified heat treatment designations of Class 90. The fixed bearing assembly has an upper shoe with a spherical surface while the lower show has a domed surface. These contact surfaces along with all remaining main bearing contact surfaces have a ANSI finish of 500. This spherical surface for the fixed bearing provides rotational capacity in the longitudinal and transverse directions. The expansion bearings have an upper shoe bearing on a nest of rollers which form a rack and pinion system with the lower bearing plate. The rollers provide longitudinal movement only and have a 14 inch diameter with two 16 inch guides each. Overall the bearings provide 5 feet on each side for the fixed bearing and 6 feet on each side for the expansion bearing. The bearing assemblies are approximately 4 feet tall.

The City Island Bridge has a unique feature in conjunction with the main bearings at each main pier. Two live load supports are positioned at the end floorbeam on each side of the centerline of bridge. These supports are each comprised of two 1 ¾ inch link plates connected via 2 ¾ inch pins to plates welded to the floorbeam bottom flange and an anchor plate atop the pier. This live load bearing link is used at both main piers limiting the displacement of the floorbeam under live load and distributing the live load reaction to four bearing devices at each pier. The purpose of the live load bearing links is to ensure the deflection of the end floorbeam, which indirectly supports the main expansion joints, is compatible with the multi-girder approach spans. Without the live load bearing links the end floorbeam would displace more than the approach span at the expansion joint thus causing a differential displacement (longitudinally) across the joint leading to premature wear and long term maintenance concerns.

### 3.3. PAGE AVENUE BRIDGE

The Page Avenue Bridges, see Figure 3.3, span eastbound and westbound Rte 364 over the Missouri River between St. Louis County and St. Charles County at St. Louis, MO. These bridges were design in the late 1990s. The total bridge length from abutment to abutment is 3, 238 feet. The bridge is composed of five units, two precast, prestressed I-girder units with lengths 305 feet and 942 feet and two composite steel plate girder units with lengths of 652 feet and 768 feet. The main span is positioned over the navigation channel near the St. Charles bank.

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Figure 3.3. Page Avenue Bridge (Rte 364), St. Louis, MO. Photo from: http://bridgehunter.com/mo/st-louis/page/

The tied arch span is 617 feet with an arch rise from the centerline of the tie girder to centerline arch rib is 124 feet -8 inches. The arch rib is a welded box member having dimensions, height 5.6 feet and width 3.2 feet. The tie girder is a bolted box member having dimensions, height 10 feet and width 3.4 feet. Both the arch rib and tie girder use ASTM A709 Grade 50W steel. Each arch has 15 hangers spaced at 38 feet 6.5 inches that are each composed of four 2 inch bridge (strand) rope. The arches are spaced at 90 feet 10.5 inches center to center providing for an 86 feet wide bridge deck having two 16 inch safety barrier curbs. The upper laterals, bracing the arch, are comprised of diagonals and struts (transverse members) are built-up box members typically having dimensions 15 x 30 inches. The lower laterals between the tie girders and working with the floorbeams are wide flanges, W14. All laterals for the Page Avenue Bridge are specified to be ASTM A36 steel.

The bridge deck has a thickness of 8.5 inches and is supported on W30x108 stringers spaced 9 feet 10.5 inch centers. Bent plates, 26 inches deep, brace the stringers throughout their length at regular intervals. The stringers are supported by the floorbeams spaced with the arch hangers at 38 feet 6 ½ inch centers. The floorbeams are comprised of welded plates, forming an "I" shape with a web depths of 127 inches. Intermediate floorbeams have flanges that are 2 inches thick and 20 inches wide. All floorbeams have flanges with a 2 3/8 inch thickness and 21 inch width. The floorbeams are specified to be ASTM A709 Grade 50 steel. Bearing and floor system expansion between the stringers and floorbeams is accommodated by laminated neoprene bearings with upper sole plates and polytetrafluoroethylene (PTFE) surfaces and stopper plates. Slotted holes are used in the sole plates with anchor bolts. Where fixed bearings are located they omit the TFE surfaces. All stringer bearings have a four high strength bolt connection to finger tight.

The bearings for the main span are POT bearings, a bridge bearing that evolved from older cast steel bearings to create a high load, multi-rotational bearing, having a low profile as well as less cost and production time. The POT bearing steel is specified to ASTM A709 Grade 50W. As with the other bridges, there are fixed and expansion POT bearings. Generally the POT bearings can be described as an assembly having an upper shoe and lower shoe (POT). The upper shoe provides for translation in the longitudinal direction (for expansion bearings) and is comprised of a single steel plate having a thin stainless steel plate affixed to the underside along with guide bars preventing translation in the transverse direction. The lower shoe is constructed of four main components, the lower expansion plate which is welded to a steel piston that sits in the bottom plate or POT (cylinder) atop a compressible material such as elastomer confined by the POT. The lower expansion plate has a PTFE affixed to the top that slides with the stainless steel plate above on the upper plate. The piston is welded to the lower expansion plate and provides a transition from the rectangular plate to the circular POT below. This piston acts as a rigid body as it compresses the confined elastomer in the POT thereby permitting rotation in the longitudinal and transverse directions. Such bearings are referred to as multi-rotational bearings. Fixed POT bearings are similar but eliminate the stainless steel, PTFE and lower expansion plate. These bearings provide approximately 7 feet on each side for the fixed and expansion bearing.

The Page Avenue shares a unique feature with the City Island Bridge. Both use a live load support in conjunction with the main bearings at each main pier. Page Avenue Bridge has only one live load support and it is located at the mid-span of the end floobeam. The Page live load support also differs dramatically from the complicated link used with the City Island Bridge. The Page live load support is comprised of elastomeric neoprene bearing pad sandwiched between an upper and lower sole plate. The upper sole plate for the fixed pier is bolted to the end floorbeam flange whereas the lower sole plate is bolted to a concrete pedestal atop the Pier 4 concrete bearing beam. Thus the overall height of the fixed live load bearing is just 5 inches. That is greatly reduced over the 3’-6” links on the City Island Bridge. The live load support for the expansion pier, Pier 5, is similar to the fixed bearing with the addition of a PTFE and stainless steel plate thus increasing the overall height to 5 3/8 inches.

### 3.4. TENNESSEE RIVER BRIDGE

Located in northwest Kentucky, not far from the confluence of the Tennessee River and the Ohio River are twin tied arch bridges spanning I-24 over the Tennessee River. These bridges are just east of Gilbertsville in Livingston County, Kentucky. These bridges were designed in the late 1960s. Construction of the bridges and project began in 1971 and ended in 1974. The total length of the bridge is 2,108 feet and 10 inches and is comprised of three units. These units include the main span and the approach spans on either side of the main span. The north and south approach spans are continuous, composite plate girders having spans totaling 782 feet each. The main span is situated over the navigation channel located in middle of the river.

The arch main span is 535 feet 4 inches and has an arch rise of 88 feet 10 5/8 inches from centerline of the tie girder to centerline of the arch rib. The tied arch has 13 hangers spaced at 38 feet 2 inches, each hanger is composed of four 1 5/8 inch diameter bridge rope specified to ASTM A586. The arch rib is welded box member having dimensions of 2 feet 1 inch width and 3 feet 5 inches height. The tie girder is also a welded box member with the webs offset inward to the interior of member. The overall dimensions are 3 feet 1 inch width and 9 feet height. All arch rib and tie girder material is A572 or A588 having a minimum yield stress, $F_y$, of 50 ksi. The arches are spaced at 46 feet providing for a bridge deck dimensioned at 43 feet. Between the arches and tie girder are the upper and bottom bracing (laterals) members. The upper laterals, bracing the arch, are comprised of diagonals and struts (transverse members) and are built-up "I" members having variable depth. The web of the diagonal and struts are deeper near the arch rib and shorter midpoint between the arches. The web varies from approximately from 3'-5" to 2'-3". The flanges are either 15 x ¾ inches or 15 x 7/8 inches depending on the location. The lower laterals between the tie girders and working with the floorbeams are wide flanges, BP14. Three types of BP14 laterals are used by pounds per foot, they are 102, 89, 73. All laterals for the Tennessee River Bridge are specified to be ASTM A36 steel. The I-24 Bridge is shown in Figure 3.4.

Figure 3.4. US 24 Bridge over the Tennessee River, near Paducah, KY. Photo from: http://bridgehunter.com/ky/marshall/tennessee-24/

The bridge deck is supported by five stringers, W30x116 or W30x99, spaced at 9 feet 3 ¾ inches bearing atop floorbeams. Channels are used to brace the stringers throughout their length at regular intervals. C15s are used at the floorbeam locations and C18s are used within the spans. The stringers are supported by the floorbeams spaced with the arch hangers at 38 feet 2 inch centers. The floorbeams are comprised of welded plates, forming an "I" shape with a web depths of 70 inches. Floorbeams have flanges that are vary from 7/8-1 7/8 inches thick and 16 inches wide. Bearings for the floor system consist of 12 x 10 ½ inch steel blocks of differing height between the stringer and floorbeam. Each connection has 4-high strength bolts tightened to finger tight and jam nuts. Expansion bearing have a 1/8" gap between the flange and the nut. Structural steel in the floor system including the floorbeams are specified to be ASTM A36 steel.

The bearings for the main span are very similar to the cast steel bearings noted for the Jefferson Barracks and City Island Bridges. However, despite the design and construction predating both of those bridges the bearings for the Tennessee River Bridge are not cast steel but fabricated structural steel specified to ASTM A36 and A588. The fixed bearing assembly has a small upper shoe that sits atop a 6 inch pin, which permits longitudinal rotation. The lower shoe is fabricated plate with a horizontal flat plate at the end. The expansion bearing is similar but at the bottom of the lower shoe is a roller plate permitting longitudinal movement. Both the fixed and expansion bearings sit atop a steel fabricated grillage of plates that are buried in the concrete bearing beam of the main piers. Overall the bearings provide 4’- 6” on each side for the fixed bearing and expansion bearing. The bearing assemblies are approximately 5’- 3” tall overall with only 3’ above the concrete bearing beam.

The characteristics of the aforementioned bridges are noted in Tables 3.1 and 3.2.

Table 3.1. Bridge Properties

| Bridge | Span (feet) | Rise (feet) | Panels | Rise/ Span | Rise to Span Ratio | $I_{tie}$ / $I_{rib}$ | Ratio $I_{tie}:I_{rib}$ | Ratio $A_{tie}:A_{rib}$ |
|---|---|---|---|---|---|---|---|---|
| Jefferson Barracks | 910 | 182 | 18 | 0.200 | 1:5 | 2,351,846 $in^4$ / 270,787 $in^4$ | 8.7 | 1.23 |
| City Island | 670 | 132 | 16 | 0.197 | 1:5.10 | 711,800 $in^4$ / 170,900 $in^4$ | 4.2 | 0.998 |
| Page Avenue | 617 | 124 | 16 | 0.201 | 1:4.97 | 762,985 $in^4$ / 277,074 $in^4$ | 2.8 | 0.923 |
| Tennessee River | 535 | 88.9 | 14 | 0.166 | 1:6 | 381,131 $in^4$ / 36,387 $in^4$ | 10.5 | 1.20 |

Table 3.2. Bridge Weights

| Bridge | Span (feet) | Width (feet) | Dead Load Plans (kips) | Weight (psf) | Dead Load SAP2000 (kips) | I/A |
|---|---|---|---|---|---|---|
| Jefferson Barracks | 910 | 62.0 | 17,568 | 311.0 | 17,136 | 769 |
| City Island | 670 | 79.0 | - | 244.0 | 12,924 | 464 |
| Page Avenue | 617 | 90.88 | 14,848 | 264.0 | 14,800 | 700 |
| Tennessee River | 535.33 | 46.00 | 6,256 | 254.0 | 6,016 | 218 |

## 3.5. BRIDGE MATERIALS

The desire to achieve a better product drives the innovation and subsequent change of construction materials for structures. To achieve a more durable product having reliable and robust stress-strain properties that is less prone to fatigue and fracture is the catalyst for change in the bridge metal industry. This is especially true of fatigue and fracture due to the dynamic nature of the loading on bridges versus the largely static loading for most buildings. The first metal bridge, for example, the Coalbrookdale bridge, built in 1776 (Cortright, 2003) in the United Kingdom is made of iron. Nearly one hundred years later construction of the Eads Bridge in St. Louis, Missouri, USA brings a new material, steel, to replace iron. At the time Eads realized that longer spans and heavier loads would push the limits of the then current practice for metal bridges of using a robust structural arrangement of members, wrought iron for tension members, and cast iron for compression members (Miller, 1999). Although limited in production in 1867 United States steel was capable of providing both the necessary tensile and compressive capacity in one materal (Miller 1999). Advances in production (Bessemer process) and the science of materials helped make structural steel the construction staple it is today. This section captures the various steel material and governing specifications used on the bridges in this study, presenting the benefits and drawbacks of each and culminates with the current state of the practice for structural steel in arch bridges in the USA.

**3.5.1 3AASHTO Material Specifications.** The American Association of State Highway Officials (AASHO) began in 1914 to address highway issues and to advocate for State priorities on the national level (Goguen, 2011). Certainly one landmark accomplishment of the organization, now the American Association of State Highway and Transportation Officials (AASHTO), was to develop standard specifications for the design, materials and construction involved in highway facilities, including bridges. Pushed forward by the industrial revolution, the American Society for Testing and Materials (ASTM) was founded in 1898 following attempts to standardize the composition of rail steel (http://www.astm.org/HISTORY/hist_chapter1.html). In 1901, with AASHO yet to form for another 13 years, ASTM published, as one of its first documents, "Structural Steel for Bridges". Today there continues to be much overlap between AASHTO and ASTM as both cover many of the same material specifications, in this case with respect to steel for bridges. As the material specifications remain technical the same with only minor administrative differences, AASHTO Material Specifications have incorporated the specific ASTM into the language of the former code noting the applicable differences for substitution. Common equivalent specifications for bridge materials are noted in Table 3.3.

Table 3.3. AASHTO and ASTM Material Specifications

| AASHTO | Subject Matter | ASTM |
|---|---|---|
| M164 | High Strength Bolts ($F_u \geq 120$ ksi, Dia. $\leq 1.0$ inch)<br>($F_u \geq 105$ ksi, 1.0 inch < Dia. $\leq 1.5$ inch) | A325 |

Table 3.3. AASHTO and ASTM Material Specifications (cont.)

| | | |
|---|---|---|
| M 222 | High Strength Low Alloy (up 50 ksi Minimum Yield Point) with Atmospheric Corrosion Resistance | A588 |
| M 223 | High Strength Low Alloy Steel | A572 |
| M 232M/M232 | Zinc Coating (Hot Dip) | A153 |
| M253 | High Strength Bolts ($F_u \geq 150$ ksi) | A490 |
| M270M/M270 | Structural Steel for Bridges (36 ksi $\leq F_y \leq 100$ ksi) | A709/A709M |
| M291 | Carbon/Alloy Steel Nuts | A563 |
| M292M/M292 | Carbon/Alloy Steel | A194 |
| M293M | Hardened Steel Washers | F436 |
| M298 | Zinc Coating (Mechanical) | B695 |

**3.5.2 Arch Bridge Steel Material Specifications.** Iron (Fe), Carbon (C) and Manganese (Mn) are the principal constituents of steel with alloys added to attain improved strength, ductility, as well as fatigue and fracture resistance. Carbon is primarily responsible for the strength of the early steels, referred to as Carbon controlled steels. These early steels had yield strengths between 36 and 42 ksi. However, while Carbon increases strength it also decreases ductility and weldability. Improvements to the Carbon controlled steels led to several new structural steel categories: High Strength, High Strength Low Alloy and Quenched and Tempered. High Strength and High Strength Low Alloy steel has yield strengths between 42 and 65 ksi with 50 ksi being the most common. To achieve this increase in strength small amounts of the elements Columbium (Cb) and Vanadium (V) are added to the Carbon-Manganese base. The additional of other elements, Copper (Cu), Chromium (Cr) and Nickel (Ni) significantly increase the atmospheric corrosion resistance nearly four times that of A36 steel (Wright, 2012). Finally there are the Quenched and Tempered, Q&T, steels which have yield strengths of 90-100 ksi. These strengths these steels reach is as much due to the thermal processes (normalizing or quenching/tempering) as the chemistry of the steel. Today, a Thermal-Mechanical Controlled Processing is used to high performance steels much more precisely thus eliminating sensitivity to narrow fields of deviation in composition. The various steel material specifications encountered in the design plans of the bridges in this study are covered below in the ASTM numerical order.

**3.5.3 ASTM A36**. A basic Carbon-Manganese steel having a minimum yield strength of 36 ksi. This specification was adopted in 1960 as the final evolution Carbon-Manganese steel (Wright, 2012). Throughout the 1960s, 1970s and into the 1980s, A36 steel is ubiquitous in steel construction everywhere, used in bridges at first for all steel but as secondary members in late 80s and early 90s. By the early 1990s as the steel industry changes and scrap steel is recycled more and more the resulting steel product contains more alloy elements thereby providing steel with yield strengths meeting Grade 50. So for roughly the same price a higher strength could be used. This change prompted the creation of ASTM A992, which provides for minimum yield strength of 50 ksi but addresses the wider variability in composition. A36 and A992 are included in AASHTO M270M.

**3.5.4 ASTM A572 (AASHTO M223).** A high strength low alloy steel having yield strengths from 42 ksi to 65 ksi though the most commonly produced grade is Grade 50 ($F_y$ = 50 ksi). This steel was introduced in 1966 in Grades 42, 50, 60 and 65. Grades 42 and 50 could be used for riveted, bolted and welded bridge applications. Grades 60 and 65 were limited to riveted and bolted bridge applications. Of course, riveted construction is rarely used in the current construction market. For ASTM A572, Grade 50 plate thickness is limited to less than or equal to 4 inches. A572 is a low alloy steel, where alloys are typically

Columbium (Cb) and Vanadium (V) that are included in small amounts, hence the moniker, low alloy. Vanadium, for example, is generally less than 0.12%, yet increases rupture strength, hardness and abrasion resistance. Columbium increases the yield strength. Though still available today, this steel material and the toughness requirements so necessary for bridge applications can be specified through ASTM A709/AASHTO M270M.

# 4. REVIEW OF LITERATURE

## 4.1. PUBLISHED LITERATURE

There are many objectives in completing a review of pertinent literature. Those objectives are varied and stretch from “gaining methodological insights” to “distinguishing what has been done from what needs to be done” (Randolph, 2009). The following literature review follows on the latter theme – demonstrating what literature is available for tied arch bridges, the categories which that information falls into, and finally a review of what is not available. The categories for the literature are: Analysis, Buckling, Design, Dynamics, Structural Health Monitoring and Construction. A brief discussion of the proprietary information concludes this section.

The literature selections are from the following journal and scientific database sources:

- Academic Search Complete
- American Society of Civil Engineers (ASCE) – Civil Engineering Database 1970-present
- ASCE - *Journal of Bridge Engineering*
- ASCE – *Journal of Engineering Mechanics*
- ASCE – *Practice Periodical on Structural Design and Construction*
- ASCE - *Journal of Structural Engineering*
- Elsevier’s *Journal of Constructional Steel Research*
- Elsevier’s *Engineering Structures*

## 4.2. ANALAYSIS OF TIED ARCH BRIDGES

For the purpose of this study, contemporary, describes authors and references in the computer age or in a period of widespread use of computers in structural analysis. Thus

Nettleton and Torkelson (1977), Beyer (1984), Hall and Lawin (1985), Xanthakos (1994), Brockenbrough and Merritt (1994), Fu and Wang (2015) all provide contemporary reference to the analysis of arches and in particular tied arches. Each reference provides limited information and the material discussed varies by topics associated with tied arches.

**4.2.1 Arch Bridges.** Nettleton and Torkelson (1977), of the Federal Highway Administration (FHWA), produced a reference to address topics of steel and concrete arch bridge design not previously examined. The work includes open spandrel arch bridges and through arch bridges. Specifically the document covers wind stress analysis and deflection, stress amplification due to deflection, rib shortening moments, plate stiffening, and calculations for preliminary design. Additional topics include construction of arch bridges. Planar, two dimensional analysis is used throughout the text and the design uses Allowable Stress methodology. Still the reference is valuable as it presents topics beyond arch analysis and can be consulted for analysis and design of arch members not covered elsewhere. Member details for static loading are easily developed; however, no information is presented on the overall dynamic characteristics of arch bridges. It does have a short section on wind induced vibration on specific members – tied arch hangers and open spandrel arch columns. The examples of bridges impacted by wind are dated though the analysis and outcomes are still in use today. The equation for vortex shedding induced vibration is noted below and remains in use to evaluate hangers (bridge rope), hangers (H members), cables, and truss members (H or I shapes).

$$f = \frac{VS}{D} \qquad \text{Equation 4.1}$$

$$V = \frac{fD}{S} \qquad \text{Equation 4.2}$$

Where:

V = wind speed, feet per second.

S = Strouhal Number

D = Characteristic Dimension, ft

Alternately, the member frequency is given as:

$$f = C\sqrt{\frac{EI}{ml^4}} \qquad \text{Equation 4.3}$$

And which has been expanded on by C.C. Ulstrup as noted in Brockenbrough and Merritt (1994) to include flexural and torsional components as well as axially loaded members.

$$f_n = \frac{a}{2\pi}\left(\frac{k_n L}{L}\right)^2\left[1 + \epsilon_p\left(\frac{KL}{\pi}\right)^2\right]^{1/2} \qquad \text{Equation 4.4}$$

Where:

$f$, $f_n$= natural frequency of a structural member, frequency for mode, n = 1, 2, 3….

$k_nL$= eigenvalue for each mode.

K = effective length factor

L = length of the member, inches

I = moment of inertia, in$^4$, of the member cross section.

a = Coefficient dependent on the physical properties of the member

= $\sqrt{EIg/\gamma A}$ For bending

$=\sqrt{EC_w g/\gamma I_p}$ For torsion

$\epsilon_p$ = Coefficient depending on the physical properties of the member

$=P/EI$ For bending

$=\frac{GJA+PI_p}{AEC_w}$ For torsion

E = Young's modulus of elasticity, psi

G = Shear modulus of elasticity, psi

$\gamma$ = weight density of member, lb/in$^3$

g = gravitational acceleration, in/s$^2$

P = axial force (tension positive), lb

A = Area of member cross section, in$^2$

$C_w$ = Warping constant

J = Torsional constant

$I_p$ = Polar Moment of Inertia, in$^4$

m = mass per unit length of the member

**4.2.2 Preliminary Analysis and Hanger Adjustment of Tied Arch Bridges.** Bryer's (1984) thesis is focused on the preliminary design of tied arch bridges and hanger adjustments. In this paper, Beyer provides a brief history of the tied arch bridge and goes on to present the effects of several parameters on tied arch behavior. The parameters include rise to span ratio; ratio of moments of inertia of rib to tie; ratio of areas of the rib and tie; and hanger spacing. Beyer's analysis included two arch bridges having a rise to span ratio of 1:5.9 and 1:5. The results of the parametric study are presented in terms of moment influence lines for both rib and tie; hanger forces, rib and tie deflection and the portion of the live load carried by the rib and by the tie. Breyer demonstrates through moment influence lines that when the arch rib cross-sectional area is 60% of the arch tie cross-sectional area and the moment of inertia of the arch rib area is 5% of the moment of inertia of the arch tie area then the moment in the arch tie is on an order of two times greater than the moment in the arch rib. As the ratio of cross sectional area and moments of inertia each approach unity, the positive moments for the arch rib remain smaller, though not significantly so, than the arch tie whereas the negative moments for arch rib and tie are nearly equal. For the case where the cross sectional area of the arch rib is three-halves greater than that of the arch tie and the moment of inertia for the arch rib area is 20 times greater than that of the arch tie, the arch rib carries a large portion of the moment whereas the arch tie carries a very small amount. For the abo ve analysis, the tied arch structure had 16 panels over the length. Beyer also demonstrates the hanger forces for the stiffer arch rib and slender arch tie carry most of the live load and loads diminish in magnitude toward the mid-span of the bridge. Conversely it is shown that for the case of slender arch rib and stiff arch tie, the live load is carried through the arch tie via flexure. In this case, the magnitude of the hanger forces increase toward the center of the bridge. He concludes the paper with a design example emphasizing the preliminary design process using the Allowable Stress Design methodology in compliance with the 1977 AASHTO. Breyer's work does not include dynamic analysis of tied arch bridges.

**4.2.3 Design of Steel Tied Arch Bridges: An Alternative.** In 1985 Hall and Lawin, of Bridge Software Development International (BDSI), published an innovative paper for the analysis and design of an alternate to steel tied arch bridges. They proposed and developed a tied arch bridge having a post-tensioned concrete arch tie girder.. The effort was partially funded by the American Institute of Steel Construction (AISC), an unusual partner for a partial concrete alternate. To this author's knowledge the publication remained in obscurity until possibly the mid 2000s when the concept of a post-tensioned, concrete arch tie girder was used for a tied arch spanning the Raccoon River at Des Moines, IA.

The impetus for the innovative approach by Hall and Lawin is the lack of overall redundancy inherent with the arch-tie girder system. As a non-redundant tension member the arch tie-girder is fracture critical. Thus should the arch-tie fracture and that fracture propagate through the arch-tie cross-section anywhere along its length the entire bridge is likely to fail catastrophically. These concerns follow the 1978 Federal Highway Administration (FHWA) Technical Advisory, T 5140.4, advising owner agencies of known defects in tie girders of existing tied arch bridges. Hall and Lawin state as their objective – "…use modern techniques to reduce or eliminate the non-redundant members, make the structure less expensive to construct, make more of the components work more efficiently, eliminate as many of the pieces of the structure as possible, reduce the field labor, particularly the elimination of falsework." The innovative cross section is shown in Figure 4.1.

The bridge proposed includes many of the same overall structural elements as a typical tied arch bridge: steel box arch rib, concrete arch tie, hangers between the rib and tie, steel floorbeams, and a concrete deck. Most notably absent are the longitudinal stringers and upper and lower bracing. Special features of the proposed arrangement are: external dead load post-tensioning; precast concrete superstructure units that include monolithically cast arch tie girders and bridge deck that, as a unit, is composite with steel floorbeams.

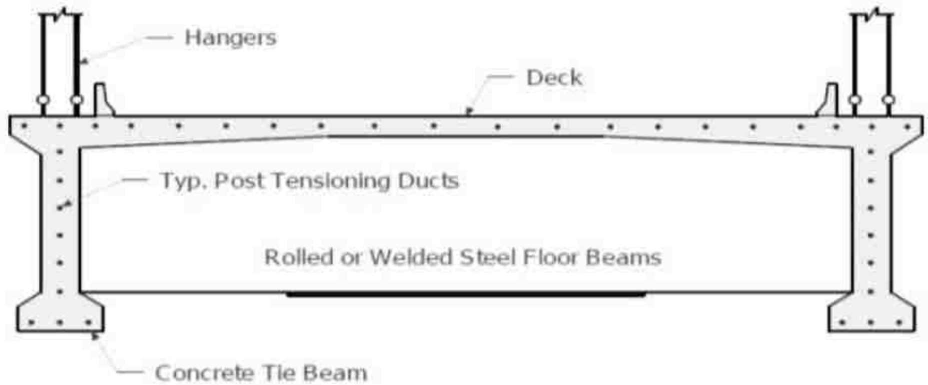



Figure 4.1. Alternate Cross Section from Hall and Lawin (1985)

The length of the precast units is about the same as a typical tied arch panel thereby having one hanger unit per arch for each precast section. While the concrete sections are heavier there is little to no increase in superstructure weight as stringers, bearings, and diaphragms usually associated steel bridge floor systems are eliminated. The precast units are match-cast and keyed for erection similar to precast, post-tension box girder bridges. Though the industry standard is for longitudinal external post-tensioning, this specific alternate uses longitudinal internal post tensioning uniformly spaced around the perimeter of the section. Based on experience in the industry challenges for this type of system will be inspection and maintenance of the post-tensioning. The dead load thrust of the arch ribs is taken by the post-tensioning set up as the arch rib and floor system is erected. These tensioning elements are located above the precast concrete deck units and outside of the roadway behind the roadway barriers. This is similar to how the lower anchorages of cables are protected on Cable Stayed Bridges. With the steel tie girder eliminated, all of the major splices are eliminated also and with the dual post-tensioning system, concrete section, and additional post-tensioning ducts provided for, the lack of redundancy is eliminated. Further advantages of this system include: reduction of stress joints, reduced structural steel weight, and more efficient structural performance. The alternate does have disadvantages, the most prolific include: construction requires tiebacks or falsework towers; post-tensioning generally requires a specialty subcontractor, and the owner has a deck which cannot be removed and replaced while the bridge remains in service. Hall and Lawin also point out that a relatively high concrete strength (28-day strength, f'c = 6 to 8ksi) is necessary for this new arrangement versus that typically used. While that certainly may have been true at the time the study was published, major bridges now routinely use precast concrete compressive strengths up to 10ksi.

Lastly, the bridge parameters used in the study for the alternate arrangement is well within the scope of this study. The tied arch has a span of 620.5 feet, a rise of 128 feet (rise to span ratio of 1:4.85) and a distance of 91 feet center of arch to center of arch. The bridge has 17 panels spaced at 36.5 feet. The analysis and design presented covers the traditional elements in details with an added focus on the post-tensioning. Hall and Lawin do not consider wind effects on the suspended superstructure or other dynamic input and subsequent bridge performance. Moreover, the stability of the arches, without lateral bracing, is also notably absent.

**4.2.4 Theory and Design of Bridges and Structural Steel Designers Handbook.** Xanthankos (1994) along with Brockenbrough and Merritt (1994) are detailed handbooks on bridge design and structural steel design respectively. Each reference has a chapter dedicated to arch bridges and include a variety of arch including two and three hinged arches, fixed arches, spandrel arches and through arches such as tied arches. Each reference demonstrates the use of Strain Energy Method to determine the bending moments, axial and shear forces at any section of the structure. Up to the point of analysis, the references are somewhat parallel then Xanthakos delves into a broader treatment of topics relevant to all arches. Those topics include but are not limited to temperature effects, elastic rib shortening, support displacements, buckling and geometrical imperfections, concrete arch topcis, fixed and hinged arches, multiple arches, bowstring arches, parametric and optimizations and finally design codes. In contrast, Brockenbrough and Merritt provide background on arch form, erection and parameters involved in the geometry and design of arches. They follow with a litany of arch bridge descriptions, providing detailed information for each entry. Finally a design example is presented for the major elements (arch rib, arch tie, floorsystem) for the Glenfield Bridge at Neville Island, Pennsylvania. Neither Xanthakos nor Brockenbrough and Merritt provide guidance on the dynamic behavior of arch bridges, particularly tied arch bridges.

**4.2.5 Computational Analysis and Design of Bridge Structures.** Fu and Wang's (2015) Computational Analysis and Design of Bridge Structures is one of the most recent additions to reference books on bridge engineering. The book is informative, timely, and as it pertains to computer modeling will be a well-used classic reference. The material is presented in three parts: general, bridge behavior and modeling, and special topics of bridges. In the general portion topics include an introduction of bridges and current analytical methods including numerical methods with subsections on finite elements, time dependent analysis and live loading via influence lines or surfaces. The second part, Bridge Behavior and Modeling, focuses on each of the current and relevant bridge types: reinforced concrete bridges, prestressed/post-tensioned concrete bridges, curved concrete bridges, straight and curved steel bridges, straight and curved steel box girder bridges, arch bridges, steel truss bridges, cable stayed bridges and suspension bridges. For each major bridge category the authors provide further information on the main elements of the bridge, special analytic topics germane to that bridge type, and an example to illustrate the topics developed.

Of particular interest for this study are structural computer modeling, design of arch bridges, and arch bridge construction which are summarized below.

Fu and Wang (2015) provide structural computer modeling techniques for many different bridge types and computer programs. The information provided combines into one location references from academia and industry on finite element modeling of bridges. Modeling techniques are provided for reinforced concrete slab bridges, segmental bridges, slab on girder bridges, arch bridges, cable stayed bridges and suspension bridges. Modeling topics include element types (beams, frames, plates, shells, and solids) as well as topics such as concrete cracking, composite behavior, torsion, shear lag, and bracing etc.

The chapter on arch bridges provides background information, ideal geometry for arches, and modeling of major arch elements: ribs, deck, hangers and discusses stability. Stability of arches is also discussed further in a chapter on advanced topics for bridges. The authors provide a small glimpse into the modeling and design of arches with case studies on bridges located in China thereby providing a new perspective to many readers. One of the bridges, a tied arch concrete fill steel tube (CFST), in Linyi, People's Republic of China is featured.

Fu and Wang (2015) provide details for vertical/horizontal construction using the Yajisha Bridge. The Yajisha Bridge is a continuous half-thru tied arch, over the Pearl River located in Guangzhou, Guangdong, China. Additional details are provided in Section 4.2.

Fu and Wang (2015) provide the reader with guidance on finite element modeling for buckling of the arch rib in the section on Stability. This guidance is enhanced using the Linyi arch bridge as an example. This bridge has a span of 289 feet and a rise of 57 feet. The bridge has minimal upper lateral wind and stability bracing.

Finally only the sections on dynamic analysis, cable stayed and suspension bridges mention wind induced or earthquake vibration information and formulas. No vibration information is presented in the sections on arches.

### 4.3. BUCKLING ANALYSIS OF TIED ARCH BRIDGES

The four bridges of this study are examined for elastic buckling. Arch bridges are characterized by relatively high compressive normal forces in the arch rib thereby making buckling a mode of failure of interest to the design engineer. Buckling of arch ribs may occur in-plane or out-of-plane of the arch. Yet, tied arch bridges also have common and simple features that lower the risk of buckling. Arch bridges typically are constructed with upper laterals or wind bracing between the arch ribs forcing the otherwise independent arches to act in tandem to resist or lower the risk of buckling failure. Additionally, the hangers, under load, are expected to provide a restoring force to any disturbance. Lastly, the vast majority of tied arch bridges designed and constructed since the 1950s have very stiff tied girders relative to the arch rib stiffness. This feature places the majority of the live load demand in the tension tie girder rather than the arch rib. Still, the buckling of tied arch bridges is investigated as part of this study to examine the relationship of instability to the stiffness relationship of the arch rib and tie. At this time there is a trend in bridge engineering to reduce and even eliminate the overall bracing between the arch ribs for aesthetic and cost saving reasons. Along with lighter or fewer bracing members, arch bridges are spanning longer distances. This combination results in concerns over arch rib buckling since longer spans result in greater rise for the arch which translates to more dead load, greater length of arch rib, increased buckling length and finally less horizontal thrust. Since the primary focus of this study is the dynamic performance of tied arch bridges the eigenvalue solution can be used to solve the elastic buckling problem too. Background for the analysis of tied arch buckling follows the references described hereinafter.

**4.3.1 Buckling and Vibration of Arches and Tied Arches.** Nair (1986) provides a practical method for establishing elastic buckling loads, natural frequencies and mode shapes for tied arches. The method suggested is based on the flexibility method and can include arches having a circular or parabolic shape, members with variable cross sections and second order effects, if appropriate. A number, *n*, unit displacement components, *d*, are applied to the tied arch planar model. The value of *n* need not be a large number but should be at least one half the actual number of hangers. The final eigenvalue equation is shown below:

$$\{d\} = H[F][G]\{d\} \qquad \text{Equation 4.5}$$

Where {d} is the displacement matrix

H is the horizontal force component of the arch rib compression

[F] is the flexibility matrix, determined by using a preliminary plane frame analysis program

[G] is a geometrical term used to modify H for secondary forces in the rib.

Equation 4.5 is solved for the horizontal thrust, H, and the corresponding buckling mode. Thus the critical load for buckling should be the lowest value of H. For a preliminary practical vibration analysis Nair (1986) provides a solution using a model where the lumped mass is applied where the displacements are sought, typically at every other hanger. For vibration the final eigenvalue equation is:

$$[d] = \omega^2[F][M]\{d\} \qquad \text{Equation 4.6}$$

Where {d} is the displacement matrix

ω is the natural frequency

[F] is the flexibility matrix, determined by using a preliminary plane frame analysis program

[M] is the mass matrix

Equation 4.6 is solved for the natural frequencies, ω, and the model shapes.

The author provides the reader with six example applications that include a fixed arch and tied arch. Different parameters are revised through six examples such as increase in number of displacement locations and increased in cross section area. The results are shown for all cases and the model shapes plotted. This information is useful as the planar arches are close, in dimensions, to real world applications. Particularly the tied arch has a span of 910 feet, a rise of 182 feet and 18 panels or 17 hangers. The span to rise ratio is 1:5. As a result this model is very close to the Jefferson Barracks Bridge of this study.

**4.3.2 Buckling Design of Steel Tied Arch Bridges.** Backer, Outtier, and Van Bogaert (2007) provide two practical methods for developing the out-of-plane critical buckling load for design of slender arch ribs in bridges. Specifically examine the Albert Canal Bridge, a tied arch structure, in Belgium near Antwerp. The bridge, a network tied arch, has a span of 377 feet and limited upper lateral bracing between the two arches. The first method proposes revisions to the existing Eurocode equations for buckling while the second method involves a simple finite element model. The authors assert there are no design aides for buckling analysis of arches as there are for straight steel members and so suggest revisions. Generally both methods follow Eurocode 3 and both methods involve a simple beam finite element model (FEM) to determine the maximum axial force in the arch prior to buckling. From the paper, the process for the Eurocode is as follows:

Determine the slenderness factor:

$$\bar{\lambda} = \sqrt{\frac{A * f_y}{N_{cr}}} \qquad \text{Equation 4.7}$$

Where the critical normal force acting on the arch, $N_{cr}$, can be calculated from:

$$N_{cr} = \left(\frac{\pi}{\beta l}\right)^2 EI_z \qquad \text{Equation 4.8}$$

Determine the reduction factor, $\chi$

$$\chi = \frac{1}{\varphi + \sqrt{\varphi^2 + \bar{\lambda}^2}}; \ \chi \leq 1 \qquad \text{Equation 4.9}$$

Where:

$$\varphi = 0.5\left(1 + \alpha\left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^2\right) \qquad \text{Equation 4.10}$$

And finally, the reduced buckling load is:

$$N_{b,RD} = \chi \frac{A * f_y}{\gamma_{M1}} \qquad \text{Equation 4.11}$$

Where:

$\alpha$ is a parameter, 0.34 for Buckling Curve “a” or 0.21 for Buckling Curve “b” in Eurocode 3.

A is the cross section area of the arch rib

$f_y$ is the yield strength of the steel

$\beta$ is the buckling length factor, Annex D of the Eurocode

l is the bridge span

$EI_z$ is the out-of-plane bending stiffness of the arch

$\gamma_{M1}$ is a safety factor from the Eurocode.

To expand the above calculations to tied arches, Outtier, et al (2007) developed the following similar procedure presented as Method 1:

By using a simple FEM, using only beam or frame elements, the critical normal load on the arch for Equation 4.7 is replaced by the linear elastic normal load on the arch rib before buckling denoted $N_{FE,el}$. Thus the new slenderness factor becomes:

$$\bar{\lambda}_{FE} = \sqrt{\frac{A * f_y}{N_{FE,el}}} \qquad \text{Equation 4.12}$$

Equations 4.9 and 4.10 remain the same though we instructed to use Buckling Curve "a" for which the authors have determined through many parametric permutations for several bridges have found to apply to tied arch bridges have spans from 164 feet (50 m) to 656 feet (200 m). Finally, the maximum permissible axial load in the arch is calculated using Equation 4.11.

The second method offered by Outtier et al (2007) modifies the buckling length factor, β, based on the thorough parametric analysis using a robust, high fidelity, FEM of the study bridges. The results of the parametric analysis showed that for a short range of arch rise to span ratio, 0.16 to 0.19 the buckling length factors also fell within a tight range of values, 0.39 to 0.42. The authors developed the following relationship for an alternate buckling length,

$$\beta_{alt} = \beta_A + I_z(\beta_B - l\beta_C) \qquad \text{Equation 4.13}$$

$\beta_A$ is taken as 0.255

$\beta_B$ is taken as 16.393 and

$\beta_C$ is taken as 0.114

The alternate buckling length factor is inserted into Equation 4.8 to determine the new slenderness factor $\bar{\lambda}_{alt}$, using Equation 4.7 and follow through with Equations 4.9-11 to determine the maximum permissible normal load for the arch rib.

Finally the authors compare results for the simplified method and a non-linear FEA for six different bridges and find the results to be within 10% with the non-linear methodology consistently producing lower values for the critical normal load. The authors emphasize the application is limited to tied arches with short to medium spans (160 to 650 feet) having no imperfections in the arch members.

The methods noted above should provide a practical means to estimate the buckling load for the arches and a comparison for the work performed in this study using a 3D FEM of the tied arch bridges.

### 4.4. TIED ARCH DESIGN

It is proposed that very few references offer design related information with even fewer having design examples. The literature review finds that Nettleton and Torkelson (1977), Beyer (1984), Hall and Lawin (1985), and Brockenbrough and Merritt (1994) provide varying depths of design information with examples. The latest of these references is Brockenbrough and Merritt (1994) which provides the Glenfield Bridge as a backdrop for their design example. The bridge, located at Neville Island, Pennsylvania, was originally designed using the 1965 AASHTO code and in the 1994 edition of the Structuarl Steel Designer's Handbook, Brockenbrough and Merritt update the design using the 1991 AASHTO 15th edition. Originally the design used was Allowable Stress Design (ASD) while

Load Factor Design (LFD) was used for the recent example. Breyer (1984) and Hall and Lawin (1985) both use Allowable Stress Design in their examples. This writer is unaware of any design example using the latest 2012 AASHTO 6$^{th}$ Edition for Load Factor and Resistance Design.

**4.4.1 Design of Steel Tied Arch Bridges: An Alternative.** Hall and Lawin (1985) present the analysis, design, and construction of an alternate tied arch bridge. The alternate comprises a steel arch rib with an integral, precast arch tie girder and bridge deck system. The design example is completed to the 1985 AASHTO 15$^{th}$ edition. No further discussion will be presented in this section as the reference is discussed in Section 4.2.

**4.4.2 Arch Bridges.** Nettleton and Torkelson (1977) discuss both steel and concrete arch design in their enduring reference, Arch Bridges. The steel and concrete design examples use the same bridge, an open spandrel, deck arch bridge having two hinges at the bridge supports. Consequently the example bridge does not fit the profile of the bridges contained in this study. However some of the elements and their design can provide insight into the overall design practice. Moreover, the reference does provide material relevant to tied arch bridges that highlight the nuances with these types of bridges.

**4.4.3 Structural Steel Designers Handbook.** Another longstanding reference, The Structural Steel Designer's Handbook, provides an informative example for the design of a tied arch bridge. The example bridge has the requisite profile of the bridges in this study and through several editions, Brockenbrough and Merritt (1994) have updated the example to conform to both ASD and LFD. Topics for design applicable to tied arch bridges are noted below with salient features noted.

**4.4.3.1 Rise to span ratio.** A tight range from 1:5 to 1:6 with a preference for the flatter rise for aesthetic reasons.

**4.4.3.2 Panel length.** This feature is governed by the geometry and flexural stress in the arch members. As the arch rib is typically constructed on chords, larger panel lengths lead to larger angle breaks from panel to panel that can be unsightly. The longer panel lengths also place a greater flexural demand on the chorded arch rib member. For these reasons panel lengths are general within 1/15$^{th}$ of the overall span.

**4.4.3.3 Depth to span ratio.** Arch rib depths for tied arches depth to span ratios range from 1:140 to 1:190.

**4.4.3.4 Arch rib cross section.** Box girders are typically used for arch ribs though for short spans, less than 200 feet, single web member can be considered.

**4.4.3.5 Dead load distribution.** For dead load distribution it is typical to use an arch axis conforming to the dead load thrust line. This combined with cambering the arch rib for dead load will eliminate flexural in the rib and tie. As a result, the rib and tie will experience pure compression and tension respectively.

**4.4.3.6 Live load distribution.** Uniform live load specified by codes and applied to the entire roadway generally creates relatively small flexural demand in the arch rib and tie. Partial (patch loading) uniform live loading tend to create much larger flexure demands in the rib and tie. For those bridges with very stiff arch tie girder compared to the arch rib stiffness, the live load demands will be much larger in the tie girder.

**4.4.3.7 Wind loading.** The effects of wind loading on bridges are a function of the arch spacing to overall span length. For relatively narrow spacing, more common in an era where fewer traffic lanes were required, the wind loading may control sections in many parts of a structure. However for wider structures, constructed to meet contemporary traffic demands, wind loading effects are not as severe. This is likely to be the case for arch spacing to span ratios less than 1:20.

**4.4.3.8 Thermal loading.** Thermal loading should be considered for arches, especially non-uniform thermal distribution due to the relative spatial difference between arch and tie.

**4.4.3.9 Deflections.** Deflections should conform to the applicable codes. As discussed earlier, for greater economy, the arch rib should be cambered for dead load. The results of secondary stresses due to live load deflections should be considered on a case by cases basis and will depend greatly on the overall rigidity of the bridge.

**4.4.3.10 Dead load to total load ratio.** The authors find that for many arches the dead load to total load falls within a range of 0.74 to 0.88, with a mode of 0.85. The weight of the arch ribs and tie girder to total load ranged from 0.20 to 0.30. The use of higher strength steels may nudge this ratio down to 0.18 or 0.19.

## 4.5. CONSTRUCTION OF TIED ARCH BRIDGES

Construction methods for arch bridges are briefly discussed in the following references: Nettleton and Torkelson (1977), Beyer (1984), Hall and Lawin (1985), Xanthakos (1994), Brockenbrough and Merritt (1994) and Fu and Wang (2015). Generally, construction methods are limited only by the constructor's imagination and engineering. In the past, these methods have been proprietary means and methods to the contractor. Design engineers are discouraged from developing a structure erected by limited means as it often means higher construction cost. Today there are new methods of procurement which combine contractors and engineers in contrast to separating them as done in the past. As a result there are new erection means and methods available to the industry. These methods are covered in the section on Tied Arch Construction.

## 4.6. STRUCTURAL HEALTH MONITORING

Structural health monitoring (SHM) encompasses a broad range of monitoring methods from technical based data gathering to comprehensive systems that capture bridge performance as well as the environmental data for the site. A survey of DOT information available on the internet show that comprehensive systems are rare and most instances of SHM are applications focusing on on-going performance matter such as fatigue and fracture crack assessment or performance of repair methods in response to the demands on a bridge but specifically the element repaired. Focused SHM is not new and has been going on for decades in university laboratories the world over. Despite the lack of real world applications, there is a wealth of information that documents structural or bridge performance variables, monitoring systems, data collection and processing. There are many reasons cited for the slow implementation of the available technology. The reasons range from concensus on what data to collected, when to collected it, how to transmit it, how to store it and once in the owners hands, what to do with the data. And funding isn't noted explicitly it certainly is implicit in many of the reasons especially collecting and processing. Addressing those challenges is beyond the scope of this document. Rather this review is developed to summarize the information and to identify how the results of this study may fit into a SHM for owners with tied arch bridges in their inventory.

Reid (2012) documents the application of two state-of-the-art SHM programs by the Univeristy of Michigan (UM) and North Carolina State University (NCSU) to capture the performance of three bridges. The UM program will involve the application of a "…sensing skin, a thin film, surrounded by electrodes…" to detect cracks and monitor for corrosion on steel girders. This application will be applied to a 40 year old concrete slab on steel girder structure. The film is comprised of carbon nanotubes and polymer and is about 16 square inches. One surprising advantage of this technology is the sensor is able to capture data from a broader area and in two-dimensions in contrast to the strain gauges predominantly in use today. The data generated will be transmitted wirelessly to a sun powered server at the site. The remaining two structures, a single span welded plate girder bridge in Maryland and a swing span bridge located in the Outer Banks area of North Carolina. The SHM system for these two bridges will use piezoelectric paint sensors with acoustic emissions sensors. This technology is also a thin film somewhat similar to the nanotube and polymer application by UM. For all three bridges there will be 4-6 locations where the sensors will be applied. The author notes this technology due to the advancement of technology and because piezoelectric sensors can also be used to detect accelerations and vibrations. Lastly it is noted that while data collected will be able to detect the formations of cracks 1mm in length (though other sources are working on materials will the capability to detect cracks of 1μm in length or width) it will still be necessary to visually inspect the structures upon detection.

Brownjohn (2006) presents a comprehensive overview of SHM of civil infrastructure including but not limited to bridges. Among the topics are present state-of-the-art, future developments, data mining and diagnosis of infrastructure health. Brownjohn list ten objectives of SHM which include:

- Monitoring effects by external loading,
- Assessment of long term movement or degradation
- Fatigue assessment, and
- Post earthquake assessment of structural integrity

He reminds us that the primary motivation of SHM is to produce consistent and reliable means of acquiring, managing, integrating, intreperting structural performance by removing or supplementing the qualitative, subjective and unrealiable human element. Moreover that any SHM system should be continuous "not only measuring vibrations but also quasi-static changes" in the structure which are compared to baseline characterization of structural performance, identifying those occasions where the actual performance contrast with the baseline predictions. An overview of the system, he notes, is to:

- Determine the parameters sought for collection and study
- Implement the System
- Detection and Data Collection
- Process and interpret the Data
- Intervention Analysis

Where the last item, intervention analysis, describes a phase of SHM where an anomaly exists between the recorded performance and baseline data. And additional work needs to be done to ascertain the anomaly is a performance event and steps need to be taken to improve the structure performance.

Brownjohn (2006) also acknowledges the lack of applications for SHM to bring real-time data from the field into the owner's realm. That vibration-based damage detection (VBDD) has only limited successes with real operational infrastructure. For successes he points to dams as a proto-typical civil infrastructure where mandates (in the United Kingdom following the Reservoir Reform Act of 1975) following tragic incidents call for instrumentation for structural parameters such as displacements, strains, pressure, and seepage. Environmental or meterological data is also collected and matched via timing to the aforementioned recordings.

Brownjohn notes the focus is currently shifting from dams to bridges. And as part of that transtion notes that the dynamic response monitoring is important to understanding the effect of earthquake motions on structures and estimates of dynamic characteristics using ambient (or forced vibrations) to track structural characteristics as indicator of structural health. Brownjohn points to the Golden Gate and Bay Bridges as two of the earliest attempts of structural characterization. The goal for those bridges was to understand the dynamic behavior (periods) of several components as the bridges were under construction in order to under their response to earthquakes. Maintaining a focus on dynamic behavior the focus shifted in the 1940s to aerodynamic behavior due to the Tacoma Narrows disaster. He argues that while major bridges garner attention and funding for instrumentation only small portions of the bridge are studied and that overall behavior as determined through a much denser, nearly cost prohibitive, array of sensors is necessary to have a true assessment. As a result Brownjohn belives it may be more advantageous to advance SHM systems on smaller bridges.

The paper presents case studies such as the Humber Suspension Bridge, built in the 1980s and having a main span of 4,625 feet. This bridge was first instrumented to determine the effects of spatial variations for earthquake ground motions between the towers. It reportedly has about 20 miles of instrumentation cable installed. The successful instrumentation of this bridge has been used to validate FEA work on other bridges such as the Bosporus Bridge and the yet to be constructed Bridge over the Straits of Messina. From the results, Brownjohn notes, that observation of global response such as deck accelerations is unlikely to indicate structural damage or deterioration to the major components of the deck but would aid with predictions for hangers and bearings. It's further observed that bridge deck vertical vibration modes are sensitive to the bearing behavior and condition such that overall fundamental vertical deck modes would be helpful in assessing bearing conditions. Another case study highlights the effects of bearing conditions on a routine bridge and the growing trend toward tangible proof of rehabilitation work. The bridge has a span of 59 feet comprised of adjacent, inverted t-beams that are tensioned transversely and CIP deck placed within and atop the beams. The superstructure is supported on pinned bearings. The focus of the rehabilitation was to fix the bearings and the improvements to structural performance were ascertained using frequency response functions (FRF). To complete this analysis, the response of the original and retrofitted bridge was monitored for a period of time. This allowed the engineers to capture a statistical relevant data set. The output, mode shapes and frequency plots, were used to update or refine the FEA models for the analysis. However, the frequency plots themselves showed increases in all of the lowest frequencies measured after the retrofit due to the increase in stiffness from fixing the bearings. Certainly there are other methods that may be used (load displacement relationships developed from specific vehicle weights, position and measuring the resultant displacements) the case study uses methods that are consistent with SHM and the possibility of working remote from the bridge site.

As a premise of this study is based on dynamic characteristics of tied arch bridges as predictors to the performance of the same, it's worth noting some of the challenges that Brownjohn believes face the civil industry for SHM. These include: system reliability, inappropriate instrumentation and sensor overload, data storage and data overload, communcations, environmental factors and noise, data mining and presentation, funding and vested interests and finally lack of collaboration. Brownjohn concludes with comments on the state-of-the-art and directions. In summary he notes that there is a concensus from a vast network of stakeholders that SHM needs to be implemented in the design phase identifying then the substructures of interest to the owner/analyst.

A State of the Practice of Modern Structural Health Monitoring for Bridges: A Comprehensive Review, Ahlborn et al (2010) covers in-situ sensors/networks, on-site techniques and remote sensor technologies with case studies for several bridges. This summary will cover those techniques that should be relevant to long span bridges and for which vibration or modal response are applicable or used in case studies.

According to Ahlborn et al (2010) as of 2005, about 40 bridges, having spans longer than 300 feet, have been instrumented. Such instrumentation is far from routine and according to the report includes "spatially distributed wirelessly powered, wirelessly networked, embedded sensing devices supporting frequent on-demand acquisition of real time information about loading and environmental effects, structural characteristics and responses." He goes on to note that modern global health monitoring relies on finding shifts in resonant frequencies or changes in structural mode shapes. There are difficulties he explains in differentiating real structural damage from environmental factors such as moisture and temperature. In their assessment on accelerometers and velociometers it is further explained that each instrument is specific with regard to signal noise and significantly poor performance at vibration frequencies lower than 0.2Hz which discount applicability to long span bridges. And for that reason accelerometers are used for high frequency applications which includes forced vibration testing however ambient vibration is also present at these frequency ranges making signal processing a challenge. Moreover, it is typically not feasible to eliminate traffic as a source of ambient vibration from major structures. Piezoelectric sensors used in Electromechanical Impedence (EMI) applications measure electrical impedence in the circuit which is directly related to the mechanical impedence of the bridge thereby providing a measure of fundamental bridge characteristic such as mass, stiffness and damping. Those quantities also form the basis of any dynamic system analysis and changes in those quantities may define structural damage. Other possible dynamic sensing schematics include Global Positioning Systems (GPS) coupled with triaxial accelerometers. This combination measures bridge deflection and with the GPS driving the accelerometer by time pulses the deflections and accelerometer are synchronized. Another method, not directly applicable to dynamics but able to detect structural damage in cables is the Magnetic Flux Leakage (MFL) test. These applications involve both expensive equipment and are labor intensive with rates up to a single cable per day.

The Ahlborn et al (2010) paper concludes with examples of bridges having SHM systems. Of four cases, three are of interest to this scope of work. The authors discuss the SHM used on the Golden Gate Bridge. There are 64 accelerometers having accuracy to measure ambient vibration to 30 μG and a programmed sampling rate of 1 kHz for a time window of 10 μs. Likewise the Tsing Ma suspension bridge in China is outfitted with 774 instrumented nodes comprised of accelerometers, strain gauges, displacement transducers, level sensors, GPS sensors, anemometers, and weigh-in-motiono sensors all connected to a data acquisition system. The last example is a routine bridge but the data processing component of this project demonstrates the eventual downstream application of structural health monitoring. The Vernon Avenue Bridge in Massachusetts is comprised of three continuous 150 feet plate girder spans and is instrumented with 100 strain gauges, 36 girder thermistors, 30 concrete thermistors, 4 biaxial tiltmeters and 16 biaxial accelerometers. Two models are developed using SAP2000, one for the as-designed state and the other for the as-performing state using the monitored data in an attempt to best reflect the actual performance. The design model uses non-factored loads to develop the baseline model. The two models can them be compared to see how well the predictions pan out. No data or comparisons were presented in the Ahlborn paper.

In their paper, Modal Analysis For Damage Detection in Structures, Hearn and Testa (1991) present a method for non-destructive testing for damage in structures based on fundamental properties of structural elements. Hearn and Testa, like others, postulate that fundamental characteristics such as mode shapes and natural frequencies are functions of mass, stiffness and damping. Thus damage in structures may manifest as change in the mode shape, natural frequency, or damping. They propose the perturbation method combined with a dynamic inspection method using a calibrated hammer to induce a dynamic load and multiple receivers to record the vibration response of the structure. The perturbation equation is:

$$[(K + \Delta K) + (\omega^2 + \Delta\omega^2)(M + \Delta M)](\varphi + \Delta\varphi) = 0 \quad \text{Equation 4.14}$$

Where:

K = is the global stiffnes matrix

M = is the global mass matrix

ω = is the natural frequency

φ = is the normalized mode shape

Wherein civil structures may not lose appreciable mass in a crack event, the term ΔM may be neglected as well as second order terms resulting in:

$$\Delta\omega_i^2 = \frac{\varphi_i^T \Delta K \varphi_i}{\varphi_i^T M \varphi_i} \qquad \text{Equation 4.15}$$

For a single vibration mode, i.

As the global stiffness matrix, K is comprised of the stiffness of the individual elements, the global stiffnes matrix may be expressed as:

$$\varphi_i^T K \varphi_i = \sum_N \varepsilon_i^T(\varphi_i) k_N \varepsilon_N(\varphi_i) \qquad \text{Equation 4.16}$$

Where N denotes the individual member

$\varepsilon_N$ = is the member deformation

$k_N$ = is the member stiffness

A similar equation can be developed for the change in stiffness, ΔK,

$$\varphi_i^T \Delta K \varphi_i = \sum_N \varepsilon_i^T(\varphi_i) \Delta k_N \varepsilon_N(\varphi_i) \qquad \text{Equation 4.17}$$

Substituting equation 4.17 into equation 4.15 yields a chage in natural frequency for a change in the individual member stiffness due to damage.

$$\Delta\omega_i^2 = \frac{\varepsilon_i^T(\varphi_i) \Delta k_N \varepsilon_N(\varphi_i)}{\varphi_i^T M \varphi_i} \qquad \text{Equation 4.18}$$

Hearn and Testa (1991) note that the change in frequency are influenced by the severity of the damage and member affected. Moreover, explaining that the location and severity of the deterioration event may affect some modes strongly and others weakly.

By describing damage to a member in terms of it's stiffness we introduce a fractional multiplier, $\alpha_N$, and write:

$$\Delta k_N = \alpha_N k_N \qquad \text{Equation 4.19}$$

Equation 4.19 can be substituted into Equation 4.18 to provide a change in natural frequency that is a function of damage severity ($\alpha_N$) and location, N.

$$\Delta\omega_i^2 = \frac{\alpha_N \varepsilon_i^T(\varphi_i) k_N \varepsilon_N(\varphi_i)}{\varphi_i^T M \varphi_i} \qquad \text{Equation 4.20}$$

However, by considering the ratio of change in natural frequencies, the dependence is only on the location, N. This follows from:

$$\frac{\Delta\omega_i^2}{\Delta\omega_j^2} = \frac{\frac{\varepsilon_i^T(\varphi_i)\Delta k_N \varepsilon_N(\varphi_i)}{\varphi_i^T M \varphi_i}}{\frac{\varepsilon_j^T(\varphi_j)\Delta k_N \varepsilon_N(\varphi_j)}{\varphi_j^T M \varphi_j}} \qquad \text{Equation 4.21}$$

The authors present a case study of a frame of welded, with known poor fatitue characteristics, members subject to time varying load. They compare the predicted frequencies to observed frequencies and upon using an objective methodology can identify the damaged member using the ratios of the observed natural frequencies.

The authors present one final case study that is of interest to this study, modal analysis damage detection of wire rope. Bridge rope or wire strand is used exclusively in tied arch applications and from our assessment of the bridges in this study are typically subjected to dead load magnitudes of 45 kips to 99 kips and live load magnitudes 11 to 23 kips. Hearn and Testa note that the natural frequency of the loaded wire rope is not a function of the stiffness as is the case with frame members. As a result, the aforementioned reduced member stiffness cannot be used to determine change in the natural frequency. The natural frequency for a tensioned wire rope is:

$$\omega^2 = \frac{\pi^2}{L^2}\frac{T}{\rho} \qquad \text{Equation 4.22}$$

Since damping is also a characteristic trait of a dynamic system and since intact, continuous and solid systems generally have poor attenuation, damage in structural members may manifest in higher damping values (as dynamic response is attenuated). The authors studied several cases for wire rope having different tension values and variable reduction in cross sectional area (damage) and reported on the value of observed damping with damage to original damping, ($\eta/\eta_o$). The results show distinct changes to identify the damaged rope.

The final paper selected for this section is particularly relevant in a number of ways. Ren, Zhao, and Harik's 2004 paper on Experimental and Analytical Modal Analysis of Steel Arch Bridge focuses on the US 24 Bridge over the Tennessee River in Kentucky which is also included in this study. The paper also demonstrates that real world application of experimental modal analysis to extract characteristic parameters (frequencies, damping ratios and mode shapes) can be accomplished outside the quiet laboratory environment. This is especially important for civil infrastructure as many civil structures cannot be shut down to set up an elaborate or dense receiver network in which to capture responses to dynamic testings.

Ren et al (2004) acknowledge the difficulty in recording dynamic output in a noisy environment and propose to use the ambient noise (traffic, wind, etc) as source of input. However, that input is not known and the experimental modal analysis becomes an exercise in output only modal identification. The authors use both peak picking method in the frequency domain and the stochastic subspace identification method in the time domain to accomplish their goal. Though these methods are outside the scope of this study, the results presented provide invaluable insight and a means of corroborating the results of this study for the US 24 Tied Arch Bridge. The results presented by Ren et al (2004) include arch displacements, natural frequencies and mode shapes.

## 4.7. PROPRIETARY INFORMATION

The majority of the information sought and used for this study is available in the public domain. However, some reference material (calculations and plans) are owned by Jacobs Engineering Group through acquisition of Sverdrup Civil which developed final plans, specifications and estimates for the US 24 bridge over the Tennessee River, Rte 61 over the Mississippi River and Rte 364 (Page Avenue) over the Missouri River. Calculations and plans for the Page Avenue Bridge were available for review; for the other structures only plans were available. It should be noted that the plans for these bridges are also available through the respective Departments of Transportation via the Freedom of Information Act.

# 5. BRIDGE DESIGN REQUIREMENTS

## 5.1. BACKGROUND

The analysis and design of Tied Arch bridges presented herein using the current 2012 AASHTO LRFD Bridge Design Specifications (AASHTO). AASHTO is developed with input and concurrence from all Departments of Transportations. Previously the analysis and design of Tied Arch bridges developed by Brockenbrough and Merritt and Nettleton and Torkelson (Brockenbrough et al, 1994 and Nettleton et al, 1977) demonstrate design of limited members using Load Factor Design (LFD) and Allowable Stress Design (ASD). This project presents the analysis and design of Tied Arches using the 2012 American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD). This methodology places a focus on meeting strength, service, fatigue, and extreme event limit states to provide a structure for a specified lifetime, usually 100 years for major bridges. The crux of this design methodology is the following inequality.

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r \qquad \text{Equation 5.1}$$

This inequality requires the summation of all factored force effects, $Q_i$, to be less than the factored resistance, $R_r$, for all components and connections. The load modifier, $\eta_i$, accounts for ductility, redundancy and operational classification. The ductility load modifier, $\eta_D$, for strength limit states, is assigned 1.05, 1.0 or 0.95, contingent on the detail under investigation having little inherent ductility, complies with the requirements in the AASHTO specifications, or is over and above the ductile requirements in the specifications. For the extreme event limit state, $\eta_D$, is assigned a value of 1.0. AASHTO encourages redundant structures, i.e., having multiple load paths and continuity, but provides for a redundancy modifier, $\eta_R$. The values of $\eta_R$ for the strength limit states is 1.05 for non-redundant members, 1.0 for members meeting the redundancy requirements of AASHTO, and 0.95 for exceptional levels of redundancy, for example multiple girder lines in the superstructure or multiple column bents for the substructure. For all other limits states, the redundancy modifier is taken to be 1.0. Finally AASHTO defines the operational importance modifier, $\eta_I$, to be applied to only the strength and extreme event limit states. For the strength limits states the importance modifier should be taken as 1.05 for important or essential bridges, 1.0 for typical bridges and 0.95 for less important bridges. The product of the aforementioned modifiers should equal or exceed 0.95 where the maximum values of the load factor, $\gamma_i$, are warranted. Where the minimum values of the load factor, $\gamma_i$, are desired the inverse of the product of the modifiers should not exceed 1.0.

The loads and load factors, limited to this project, are defined in the following sections. Load factors depend on the load effect, thereby accounting for the variability in some loads being well quantified while others are not. For this project the loads effects are both permanent and transient, they include loads such as: dead, live, impact, wind, temperature, braking, and earthquake. See Figure 5.1. Due to the limited nature of the scope of this study, both temperature and braking effects will be omitted.

## 5.2. LOAD EFFECTS AND FACTORS

Figure 5.1 shows the AASHTO loads specific to this project and from that figure we see that dead loads and transient loads are delineated into composite and non-composite loads. Composite loads are applied to a structure or structural member in which at least two dissimilar materials are bonded and or physically connected to form a single member having more robust section properties. Non-composite loads are characterized as loads, such as self-weight, that are applied prior to any two dissimilar materials forming a single member.

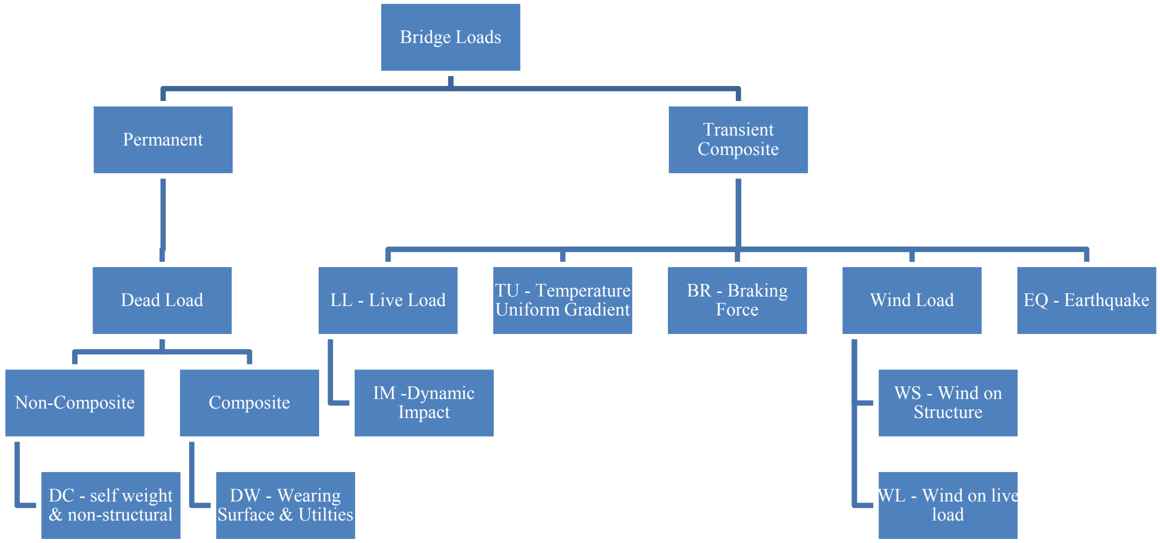



Figure 5.1. AASHTO Bridge Loads

The specific loads effects and factors are discussed in the sections below.

**5.2.1 Dead Load (DC).** The DC load is comprised of non-composite dead load which includes the self-weight of any and all structural members and any non-structural attachments that may be included in the bridge. There are two further delineations for this load: structural steel and reinforced concrete. The structural steel includes the following: arch rib, tension tie girder, floorbeams, roadway stringers and diaphragms. Also included are all connection steel as well as internal and external stiffeners and bearings. All structural steel has a density of 0.490 kcf. The reinforced concrete dead load is the *wet* weight of the concrete and reinforcing steel bridge deck. The density of the concrete is dependent on the 28-day strength, *f'*c and use of normal weight or lightweight concrete. For this project, a normal weight concrete deck with an industry standard of *f'*c = 4,000 psi is used. Thus the density of the reinforced concrete is 0.150 kcf per AASHTO Table 3.5.1-1 and commentary. Non-structural components may be inspection walkways and grab bars which are common appurtenances on major bridges. These walkways are typically steel but other materials are sometimes used when reduced weight or greater corrosion-resistance is desired. The load factor, $\gamma_p$, for DC loads for strength limit states I-V is 1.25 for maximum effects (or 0.90 for minimum effects) and for service limit states I-IV is 1.00. For the earthquake extreme event limit state, the load factor, $\gamma_p$, is 1.25.

**5.2.2 Dead Load (DW).** This category is comprised of composite dead loads, or loads applied after the concrete bridge deck, which is now bonded to the steel stringers and bonded around shear connections attached to the steel stringers. This dead load includes the wearing surface applied to the hardened concrete deck, the concrete safety barrier curbs or railings[1], roadway light posts, and utilities. Provisions are usually made to provide utility supports before the concrete deck is placed but the actual utility (water, gas, electric, fiber-optics, etc) are placed after the bridge is complete. Wearing surfaces vary from dense asphaltic concrete to special concrete mixes such as low slump, latex modified, and silica fume. These wearing surfaces are placed after the concrete deck has hardened and prior to allowing traffic on the bridge but more often these wearing surfaces are placed well after the bridge has opened to traffic. In the latter case, the design incorporates a *future* wearing surface. These wearing surface applications commonly result in an applied pressure of 0.035 ksf. The load factor, $\gamma_p$, for DW loads for strength limit states I-V is 1.50 for maximum effects (or 0.65 for minimum effects) and for service limit states I-IV is 1.00. For the earthquake extreme event limit state, the load factor, $\gamma_p$, is 1.50.

**5.2.3 Live Load (LL).** The LFRD live load model is markedly different than the model of the older, ASD and LFD AASHTO codes. Similarly the application of the live load

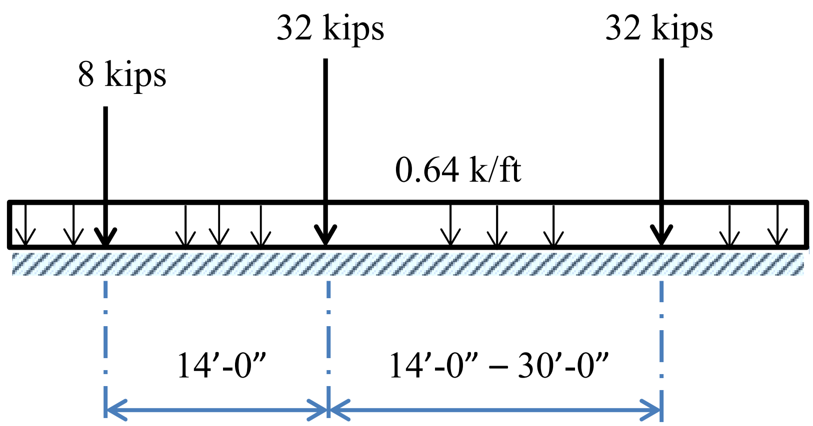
[1] Not all safety barrier curbs or railings are composed of concrete, metal railings in the shape of jersey barriers are available and a barrier/railing may be composed of both concrete and metal.

model has also changed as is evidenced by Strength Limit Case IV. Strength Limit Case is specifically for long span bridges where a high dead load to live load ratio is likely. The core of the live load model is the HL-93 model. HL-93 is a combination of truck and lane load. Wherein the past, the truck loading was applied separately from the lane load, the two loads are now applied concurrently. And the additional concentrated loads associated with the older lane load are no longer used. For completeness there is also a tandem axle, with axle spacing of 4 feet, and each axle having a magnitude of concentrated force of 25 kips. The tandem axle is not shown here. The truck loading is the same as the older HS-20-44, this arrangement is shown in Figure 5.2.

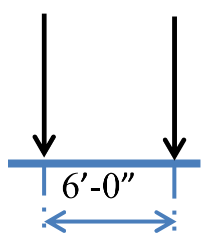
**5.2.4 Dynamic Impact Allowance (IM).** AASHTO provides for a static equivalent for a vehicle dynamic loading effect. This loading applies only to the vehicle, design truck or design tandem, and not the lane load. The value of the IM allowance is provided per AASHTO Table 3.6.2.1.1. and is 33% or expressed as a factor, 1.33, for strength and service limit states. In the past this value was computed from:

$$I = \frac{50}{L+125} \leq 0.33 \qquad \text{Equation 5.2}$$

Where for the equation above the variable L is the span length in feet. The value of I is expressed a percentage. The factor, I, had an upper limit of 0.33 with no lower limit. Assessing Equation 5.2 we see that for short spans, the value for impact will be 0.33 while for longer spans, such under consideration in this study, the value is small. This correlates well with the impact of single vehicles on long span bridges having no significant effect.




Truck and Lane Load Elevation




Truck End View

Figure 5.2. HL-93 Live Load Model

**5.2.5 Wind Load on Structure (WS).** AASHTO 3.8 covers the wind on structure loading and provides for calculation of the wind velocity and pressures for design wind, $V_{DZ}$ and $P_B$. A subsection, 3.8.1.2 allows for wind tunnel testing should wind become a major force and/or a more precise estimation of wind loading necessary. Lastly AASHTO Section 3.8.3 provides guidance, albeit sparse, on aeroelastic instability and phenomena.

The base wind speed may be taken as 100 mph, in lieu of more exacting meteorological work. For simplicity, AASHTO permits the basic wind velocity, $V_B$, to be taken as $V_{30}$, which is the velocity of wind at a height 30 feet from low ground or water surface. The following equation is used to determine the value of the wind speed at a height of interest for the bridge.

$$V_{DZ} = 2.5V_0\left(\frac{V_{30}}{V_B}\right)\ln\left(\frac{Z}{Z_0}\right) \qquad \text{Equation 5.3}$$

$V_0$ and $Z_0$ are meteorological terms for wind friction velocity and friction length of upstream fetch respectively. These terms are provided in AASHTO Table 3.8.1.1-1 and are dependent on local area characteristics. They vary by rural to city applications from 8.20 to 12.00 for $V_0$ and 0.23 to 8.20 for $Z_0$. By taking an example of a rural bridge site and the distance, z, from the water, which is about 60 feet to allow for navigation, to the mid-height of our bridges (approx. 0.5 times 120 feet = 60 feet), $V_{DZ}$ is 128 mph. The design pressure, $P_B$ is:

$$P_D = P_B\left(\frac{V_{DZ}}{V_B}\right)^2 \qquad \text{Equation 5.4}$$

So for our example, the windward design applied pressure at mid height of our bridge is calculated to be 0.082 ksf, with a base pressure, $P_B$, of 0.05 ksf. Whereas the leeward design applied pressure is 0.041 ksf. The pressure is applied to all exposed components of the bridge. The two loadings are applied simultaneously; however the total wind loading effect need not exceed 0.30 klf, windward, or 0.15 klf, leeward.

**5.2.6 Earthquake Load (EQ).** 2012 AASHTO philosophy for bridge structures, Section 3.10, stipulates the structure be "design to a low probability of collapse but may suffer significant damage and disruption to service when subject to earthquake ground motions that have a 7 percent probability of exceedance in 75 years". Such earthquake ground motions are noted as having a 1,000 year return period. The section further notes that higher levels of performance may be required by the owner. For major bridges such as those in this study, the current requirement is often to design a structure to remain elastic (no apparent damage) for the 1,000 year return period but permit limited inelastic behavior (damage) for the earthquake having 2 percent probability of exceedance in 50 years or a 2.500 year return period. To develop the earthquake ground motions for these seismic risk events, a site specific study is typically performed as allowed in AASHTO 3.10.2 and 3.10.2.2.

## 5.3. LOAD COMBINATIONS

For the design example presented in this work, the following AASHTO load cases will be used.

**5.3.1 Strength I**. The Strength I load case addresses the primary vertical loads affecting the bridge, dead and live load.

$$1.16[1.25DC + 1.5DW + 1.75(LL+IM)] \qquad \text{Equation 5.5}$$

**5.3.2 Strength III.** The Strength III load case includes wind loading in combination with the dead load. Live load is omitted from this load case.

$$1.16[1.25DC + 1.5DW + 1.4WS] \qquad \text{Equation 5.6}$$

**5.3.3 Extreme Event I.** The Extreme Event I load case includes the earthquake effects with all dead load. Live load is considered on a case by case basis for major bridges but is not typically included for routine bridges.

$$1.16[1.25DC + 1.5DW + 1.0EQ] \qquad \text{Equation 5.7}$$

**5.3.4 Service I.** Service I load case is typically used to investigate stresses, deformations and cracking under regular operating conditions. This load case includes all dead loads, live load and 30% of the wind loading.

$$1.16[1.0DC + 1.0DW + 1.3(LL+IM) + 0.3WS] \qquad \text{Equation 5.8}$$

**5.3.5 Service II.** The Service II load case is similar in nature to Service I for purpose, however it omits live load and increases the wind loading from 30% to 70%.

$$1.16[1.0DC + 1.0DW + + 0.7WS] \qquad \text{Equation 5.9}$$

## 5.4. LOAD ANALYSIS RESULTS

For the City Island Bridge, the resulting structural reactions are listed in Tables 5.1 and the section properties for the arch rib and tie girder in Table 5.2.

Table 5.1. City Island Bridge LRFD Member Reactions

| City Island Bridge | | Bridge Element | | |
|---|---|---|---|---|
| Load Case | Units | Arch Rib | Arch Tie | Hanger |
| Axial | | | | |
| DC | Kip | -3797 | 3680 | 312 |
| DW | Kip | -305 | 295 | 29 |
| LL+I | Kip | -802 | 868 | 89 |
| $M_{22}$ | | | | |
| DC | ft-kip | 0 | 0 | |
| DW | ft-kip | 0 | 0 | |
| LL+I | ft-kip | 0 | 0 | |
| Wind | ft-kip | 49 | 60 | |

Table 5.1. City Island Bridge LRFD Member Reactions (cont.)

| | | | | |
|---|---|---|---|---|
| $M_{33}$ | | | | |
| | DC | ft-kip | 1023 | 1500 |
| | DW | ft-kip | 100 | 235 |
| | LL+I | ft-kip | 2524 | 11860 |
| Wind | | ft-kip | 0 | 0 |

Table 5.2. City Island Arch Rib and Tie Girder Section Properties

| Section Property | Bridge Member Arch Rib | Arch Tie Girder |
|---|---|---|
| $A_g$, $in^2$ | 319.7 | 328.3 |
| $I_{xx}$, $in^4$ | 154,774 | 711,867 |
| $I_{yy}$, $in^4$ | 82,321 | 77,801 |
| $S_{xx}$, $in^3$ | 5,530 | 11,716 |
| $S_{yy}$, $in^3$ | 3,802 | 4,216 |

To determine a preliminary size for the arch and tie members, subject to either tension or compression and bi-axial flexure we will use the AASHTO LRFD interaction equation:

$$For\ \frac{P_u}{P_r} < 0.2;\ \frac{P_u}{2.0P_r} + \left(\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}}\right) \leq 1.0 \qquad \text{Equation 5.10}$$

$$For\ \frac{P_u}{P_r} \geq 0.2;\ \frac{P_u}{P_r} + \frac{8.0}{9.0}\left(\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}}\right) \leq 1.0 \qquad \text{Equation 5.11}$$

Where:

$P_r$ = factored tensile or compressive resistance, kips

$M_{rx}$ = factored flexural resistance about the x-axis, kip-inch.

$M_{ry}$ = factored flexural resistance about the y-axis, kip-inch

$M_{ux}$, $M_{uy}$ = moments about the x- and y-axes, respectively, resulting from factored loads.

$P_u$ = axial force effect resulting from factored loads, kip.

$\varphi_f$ = resistance factor for flexure

Based on the results from Table 5.1, $P_u$ is 7,808 kips. For the purpose of preliminary calculations, $P_r$ is determined using the gross area.

$$P_r = \varphi F_y A_g \qquad \text{Equation 5.12}$$

Where $\varphi$ = 1.0 and using the information from Table 5.2 and $F_y$ = 50 ksi, so that $P_r$ = 16,416 kips. This results in a demand to capacity ratio of 0.48 so that Equation 5.11 is used for the interaction equation. By inspection, the Strength I load case will control over Strength III which has wind load effects but no live load. The resulting interaction result is:

$$\frac{7{,}808kip}{16{,}416kip} + \frac{8}{9}\left(\frac{22{,}983ft-kip(12''/ft)}{(11{,}716in^3)(50\frac{kip}{sq.in})}\right) = 0.89 < 1.0 \qquad \text{Equation 5.13}$$

Thus the existing tie girder arrangement for the City Island Bridge is acceptable for the LRFD code for strength.

Similarly the arch rib is checked for the LRFD demand and the capacity based on Eqautoin 5.11 as the demand capacity ratio is 0.52.

$$\frac{7{,}577kip}{(0.9)(50ksi)(319sq.in)} + \frac{8}{9}\left(\frac{675.2ft{-}kip(12"/ft)}{(5530in^3)(50\frac{kip}{sq.in})}\right) = 0.78 < 1.0 \qquad \text{Equation 5.14}$$

The hanger is sized using service loads since the capacity of bridge rope or strand is reported in minimum breaking load. For ASTM A586 Grade 1, the minimum breaking strength for 2 inch diameter strand is 245 tons or 490 kip. Four strands are used such that the allowable load per strand is 122.5 kip or 123 kip. Using Table 5.1 and Equation 5.7 the demand is:

$$\frac{(312kip+29kip)+1.3(89kip)}{4} = 114kip \qquad \text{Equation 5.15}$$

And the demand to capacity ratio is:

$$\frac{Demand}{Capacity} = \frac{114kip}{123kip} = 0.93 \qquad \text{Equation 5.16}$$

# 6. FINITE ELEMENT MODEL DESCRIPTION

## 6.1. GENERAL

Three dimensional analytical models of the tied arch bridges for this study were developed to determine the static and dynamic characteristics of these bridge types. The models were constructed using SAP2000, V18.1.0, a computer finite element analysis program developed by Computers and Structures Inc (CSi) of Walnut Creek, California. The analysis is based on non-linear elastic behavior anticipated due to the small deformations and absence of geometric or material non-linear behavior. To represent the cables the model uses tension only frame members thus the reason for a non-linear model. Model development, limitations, calibration and results are presented in more detail in the following sections.

The models developed are based on available design plans and may not reflect the final constructed structure. The models do not include access facilities that are often placed on major river bridges. Access or inspection facilities typically have negligible mass compared to the structure as a whole and are planned and connected to the main structure in such a way to minimize influence on the structural bridge behavior. As a result, these ancillary structures do not add appreciably to the overall stiffness properties of the bridge.

The original analysis of the bridges were likely completed using 2-D methods commonly in use during the early 1970s and into the 1980s before personal computers and widely affordable structural analysis programs were available. The Page Avenue tied arch bridge analysis was completed in 2-D using STAAD software (Research Engineers International) and designed using spreadsheet programs. Table 6.1 shows the bridge, design firm, year of design and bridge owner.

Table 6.1. General Bridge Information

| Bridge | Design Firm | Design Year | Bridge Owner |
| --- | --- | --- | --- |
| Jefferson Barracks | Alfred Benesch & Company | Circa 1976 | Illinois DOT |
| City Island | Jacobs Engineering Group | Circa 1981 | Iowa DOT |
| Page Avenue | Jacobs Engineering Group | Circa 1998 | Missouri DOT |
| Tennessee River | Jacobs Engineering Group | Circa 1971 | Kentucky Transp. Cabinet |

## 6.2. BRIDGE MODELS

The bridges are comprised of the structural steel, concrete deck, bearings, and substructure. The finite element models capture these bridge members using different elements. Two node, frame, elements having three translational degrees of freedom (DOF) and three rotational DOF, are used for the majority of the structural steel. See Figure 6.1. The structural steel elements of the arch and arch roadway are all modeled using frame elements. The concrete deck is modeled using shell elements, having a four node formulation, where each node has 6 DOF. Figure 6.2 depicts the shell element axis orientations and element faces. Each of the joints, j1-j4, have the same DOF as one of the nodes of the frame element shown in Figure 6.1. The FEA models do not include a high level of detail in an attempt to produce satisfactory results by modeling members as single elements located on the centroid of the members. It is anticipated that more refined analysis will be used to capture the static and dynamic performance of bridge members should they warrant more in-depth investigation for fatigue and fracture. For those investigations each member or substructures of the overall model may be modelled in greater detail using 3D brick and plate elements with finer meshes as appropriate. The arch hangers, bearings and piers use frame elements with modifications and discussed in-depth below. The four FEA models are shown in Figure 6.3. Finite Element data for each model is shown in Table 6.2.

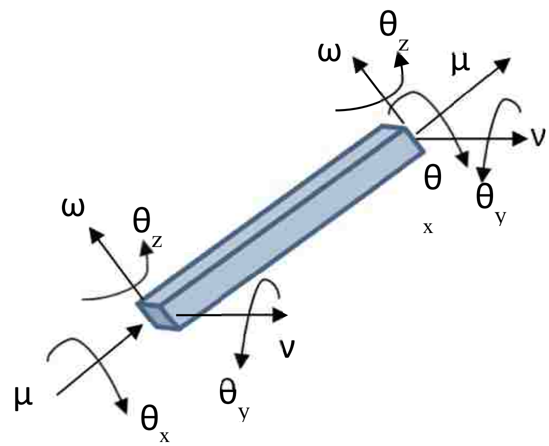



Figure 6.1. 3-D Frame Element with Degrees of Freedom. (Reproduced from Fu and Wang, 2015)

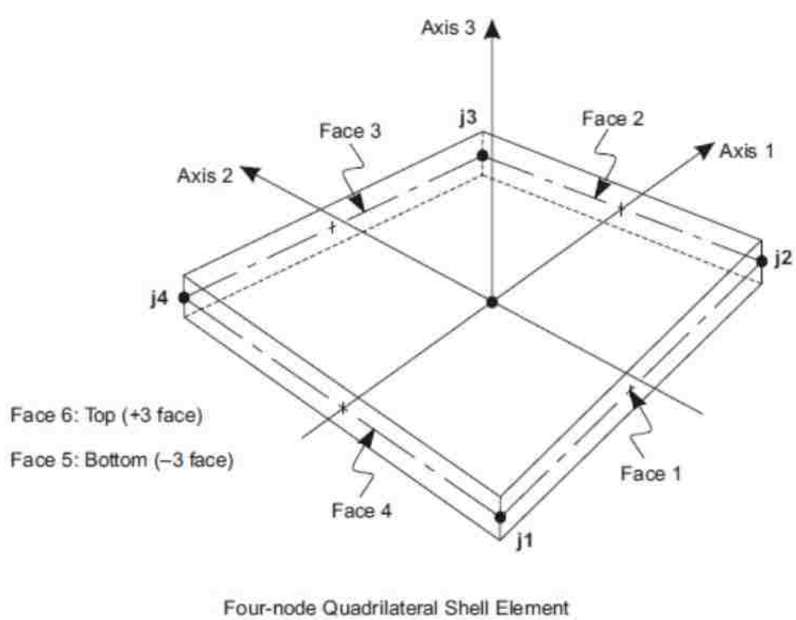



Figure 6.2. 3-D Shell Element. (Reproduced from CSI Analysis Reference Manual, 2015)

Table 6.2. Finite Element Model Data

| Bridge | DOF | Joints | Frame Elements | Shell Elements | Solid Elements | Links |
|---|---|---|---|---|---|---|
| Jeff. Barracks | 4,633 | 520 | 770 | 142 | 0 | 4 |
| City Island | 2,700 | 316 | 504 | 184 | 0 | 4 |
| Page Avenue | 1,680 | 342 | 600 | 132 | 0 | 4 |
| US 24 | 6,276 | 852 | 504 | 260 | 224 | 4 |

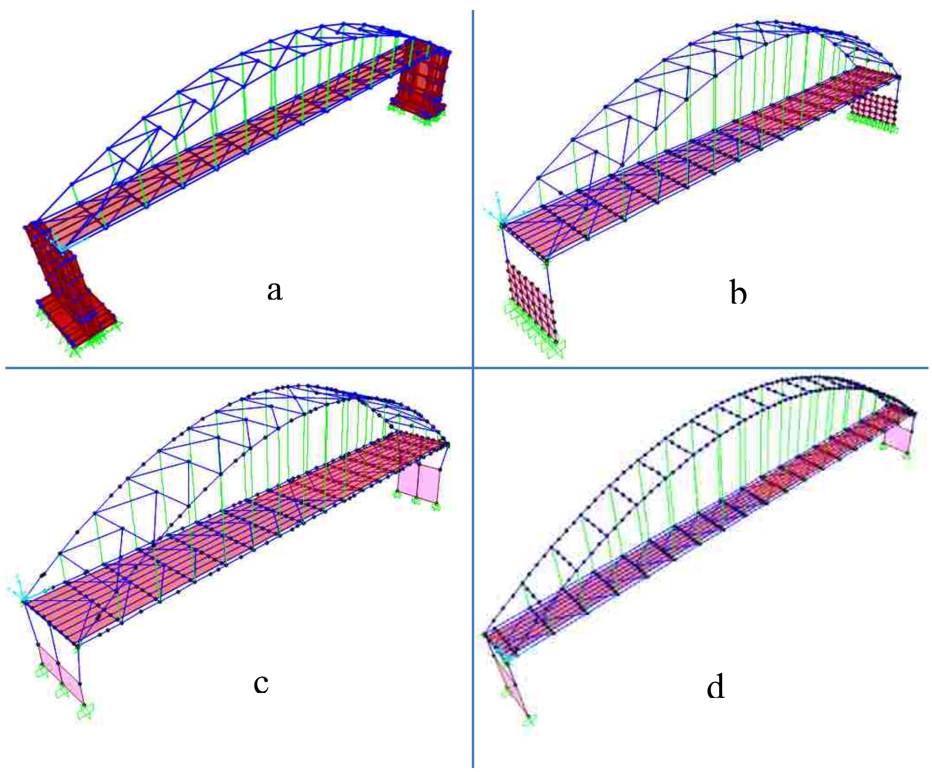



Figure 6.3. FEM Models a) US 24, b) City Island, c) Page Avenue, d) Jefferson Barracks

**6.2.1 Floorsystem.** The primary components of the tied arch floor system are the floorbeams, stringers and concrete deck. These elements can be seen in Figure 6.4 which shows the overall models. As noted in earlier sections, the floorbeams and stringers are modeled in SAP2000 using frame elements located at the centroid of the member while the deck is modeled using shell elements also located at the centroid of the deck. While various authors, Fu and Wang (2015), demonstrate the viability for modeling each of these elements in a more refined way, i.e., comprising stringers with frame elements for flanges and plate elements for webs, this level of refinement is unwarranted for this analysis and greatly increases the computational time. The floorsystem members are connected using offsets and massless rigid links within the SAP2000 software. These connections are shown in Figure 6.4. The offset and rigid links permit the model to capture the spatial relationship of the actual bridge floorsystem. Typically for major bridges designed and constructed in the 1960s and 1970s no composite behavior exists between the concrete bridge deck and stringers. As a result, the plate shear, f22, is zeroed for those applications without composite behavior for the floorsystem. The Page Avenue Bridge does have composite action between the concrete bridge deck and stringers via a series of shear connectors on the stringers.

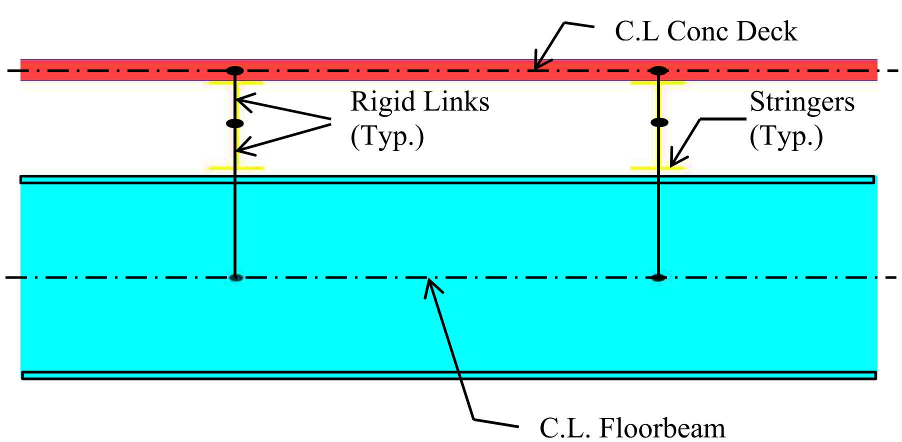



Figure 6.4. Rigid Link Connections for Floorsystem

**6.2.2 Hangers.** The hangers are bridge rope or strand and are tension-only elements. To capture this behavior, non-linear frame elements are used in the model. The frame element used for the hangers is similar to that of Figure 6.1 except that the rotational degrees of freedom, $\theta_y$ and $\theta_z$ are released. Tension-only restraints are placed on the axial degree of freedom along the element longitudinal axis, u. Compressive forces in the hangers are set to zero. CSI (2015) notes that any axial shortening below the compression limit will occur with zero axial stiffness. The frames for the hanger ropes are typically a single element. As the overall static and dynamic behavior of the bridges is at interest, the single element limits the results for the hanger elements. For a focus on the dynamic behavior of the hanger frame elements can be meshed into additional elements to provide a more accurate results of the dynamic behavior. Additional hanger elements in the overall model create a large number of modes pertaining to the hangers only thus obscuring the overall dynamic performance of the bridge.

**6.2.3 Bridge Piers.** The main piers are included in the model due to the influence of their stiffness on the longitudinal, transverse and rotational behavior of the main tied arch. The piers supporting the tied arches of the study vary in form. See Figure 6.3 for a general view of the pier models. Main piers for the tied arch bridges vary from simple wall piers to piers comprised of beams, columns and shafts (walls). The base of the shafts (walls) is founded on footings that are, in turn, founded on piling or rock. Several of the main piers have deep concrete seal courses below the footings where piling is present. This is largely due to methods of construction and these seal courses are typically well below the riverbed and any effects on the pier stiffness are assumed to be neglible. To simplify the analysis, the bridge piers are assumed to be fixed at the bottom of the shaft, unless noted otherwise. Wall piers are modeled using thick shell elements. These thick shell elements differ from the thin shell elements used to model the concrete deck. The deck shell elements are based on a Kirchoff formulation and do not have the transverse shear that the thicker shell element have, based on a Mendlin/Reissner formulation (CSI Analysis Reference Manual, 2015).

**6.2.4 Bridge Bearings.** The main bearings provide either fixity or movement in the longitudinal direction. Fixed bearings restrain translation in all coordinate directions but provide rotation about the transverse axes (in the longitudinal direction). Expansion bearings restrain translation in all but the longitudinal direction and also provide rotation about the transverse axis. Some bearings are multi-rotational and provide rotation about the transverse and longitudinal axes. Special elements within SAP2000 are used to model the bearing behavior. Link elements are used to span the distance from the main bridge to the substructure and emulate the behavior of the as-designed bearings. Two special link elements are developed for these bridges; a fixed link and an expansion link. A representation of the link element, for the longitudinal axis, (Gobal X), is shown in Figure 6.5. The fixed link in all of the bridges provides a link between the end joints of the tied arch to the substructure. The fixed links restrain translation in all direction but provide rotation in the longitudinal direction. Any translation that is experienced by the fixed end joints of the tied arch force these movements onto the main pier similar to how the bridge physically interacts with the main pier. From Figure 6.5 the fixed link element would not have a translational spring, $K_L$ but retains the rotational spring, $K_\theta$. Expansion links also connect the tied arch end joints to the substructure or main pier. The expansion links permit the tied arch expansion end to move independently with respect to the main pier below, again, just as the actual bridge and pier will. The expansion link also restrains movement in the vertical and transverse directions and provide for rotation in the longitudinal direction. Figure 6.5 depicts a link element showing only the longitudinal translational spring, $K_L$ along with the rotational spring, $K_\theta$. The rotational spring as shown provides rotational about the transverse bridge axis (Global Y) or link local axis 3. The remaining DOF and coordinate axes are similar. The vertical and transverse translation remains fixed for all bridge bearings as does the rotational DOF about the vertical axis and the longitudinal axis.

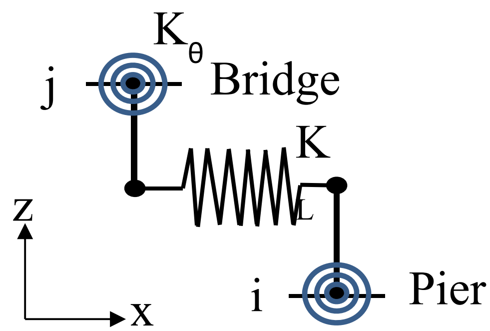



Figure 6.5. Visualized Link Element used for Bridge Bearings

**6.2.5 Approach Spans.** A dynamic analysis is a direct result of the system mass and stiffness as well as the system supporting the structure. This is true unless the structure is decoupled from the supporting system through some isolation system. For the four bridges in this study, there is no isolation system in place. As a result it's imperative that the mass and stiffness of the immediate main piers supporting the tied arch bridge be included in any analysis of the tied arch bridge itself. Moreover, it's important to recognize the impact of the approach structure stiffness has on the main structure. At the fixed pier, where the tied arch is coupled to the main pier and, in turn, the pier is coupled to the approach structure the approach superstructure and fixed substructure will influence the longitudinal and transverse stiffness. A similar situation occurs in the transverse direction for the expansion pier. The mass of the approach spans adjacent to the main span provide a direct influence, the remaining approach span mass may be negligible as it is distributed to substructure units well before influencing the main spans. This study omits the influence of the approach spans on the overall dynamic performance of the tied arch bridge itself. However additional studies should confirm this assumption. If the purpose of the dynamic analysis is seismic performance and results then the adjacent spans or their influence should be included in that analysis.

**6.2.6 Upper and Lower Bound Stiffness.** Meyer (1987) provides the FEA analyst with several best practices which should be incorporated in static and dynamic structural analysis. One such practice for dynamic analysis of structures is to bracket the structural response to upper and lower bound stiffness values. Determining what components and the values of stiffness for the same, of course, relies heavily on engineering judgement and familiarity with the structural arrangement. For example, Meyer suggests evaluating material properties which may be affected by age or condition due to years in service. It is recommended that the upper bound stiffness for concrete structures include uncracked section properties and a modulus of elasticity for concrete that reflects aged compressive strength of concrete rather than the usual design compressive strength of concrete. For the lower bound values, the effective moment of inertia and concrete design modulus of elasticity is used. Moreover, the dynamic behavior is influenced by the bridge support conditions (bearings). While the bearings typically remain in place for the life of the structure, the condition and performance change greatly over time. This is especially true for the expansion bearings. Generally, the expansion bearings mimic the design assumptions in the early years of service but over time their condition deteriorates to where the bearings are locked up thereby exhibiting the performance of fixed bearings. For this study the expansion bearing behavior (movement) is coupled with the uncracked concrete or upper bound stiffness. The locked expansion bearings are used with the cracked section properties or lower bound stiffness. Table 6.3 lists the upper and lower bounds for the models. The recommended values for the upper limit modulus of elasticity and effective moment of inertia is found in Priestley, Sieble, and Calvi (1996). Figure 4.9 of the Priestley, Sieble, and Calvi reference shows that for low axial load ratios ($P/f'_cA_g$) and low ratios of ρ the elastic stiffness ratio, $I_e/I_g$, approach a range from 0.25 to 0.30. This results in $I_e = 0.25\text{-}0.30(I_g)$. For this study a ratio of 0.25 is used since many of the structure have been in service for some time increasing the likelihood of cracked conditions.

Table 6.3. Stiffness Limits for Concrete Members

| | Modulus of Elasticity | | Moment of Inertia | |
|---|---|---|---|---|
| Element | Lower Limit | Upper Limit | Lower Limit | Upper Limit |
| Concrete Deck | $E_c$ | $\sqrt{1.3} * E_c$ | $I_e$ | $I_g$ |
| Concrete Column | $E_c$ | $\sqrt{1.3} * E_c$ | $I_e$ | $I_g$ |
| Concrete Shaft | $E_c$ | $\sqrt{1.3} * E_c$ | $I_e$ | $I_g$ |

## 6.3. BRIDGE MODEL CALIBRATION

The finite element method (FEM) is a numerical method based on mathematical modeling, assumptions and input to produce output matching observed physical behavior. For a structure, this input may include external loading while the mathematical model is a generalized equation describing the force-deformation ($f$-δ) relationship for an element, i, having stiffness, $K_i$. In the absence of actual observed output, the result of the FEM may be either satisfactory or unsatisfactory. Satisfactory results are those outcomes that match predicted or observed behaviors and follow correct modelling, assumptions, and input.

Wherein the outcomes are known a priori the FEM can be, and often is, calibrated or adjusted to match those outcomes provided they also result from appropriate and correct testing. For this study, the results of the four FEM were compared with engineered results in the design plans.

The FEM of the four tied arch bridges are based on the knowledge base developed over many, many years by researchers and practicing engineers that is captured, in part, by Meyers (1987) and Fu and Wang (2015). The results of the FEM were compared with the original engineering design plans for the dead load case for the bearing, hangers, tie girder and arch rib. Moreover, where available, the member deflections from the FEM were also compared with the engineering design plans. Initial results from the FEM indicated that overall structural steel weight was low by 10-20% depending on the bridge. Engineers often estimate the miscellaneous steel (stiffener plates, splice plates, and, in this case, internal diaphragms) as 10-15% of the overall weight of the member. External diaphragms were not added to the model as their contribution to the overall lateral stiffness is negligible compared to the large, inherent in-plane stiffness of the concrete bridge deck. As a result, the apparent weight deficit can be explained and adjusted by adding a percentage of weight for a specific steel element. The arch ribs were assigned the highest increase in weight due to the internal stiffeners, diaphragms and more robust splice plates. The floorbeams and stringers received the next highest adjustment followed by the tie girder. Once the concrete slab, barrier curb, future wearing surface and where applicable, median barriers were added a second adjustment was necessary to match the concrete dead load noted on the design plans. Again, this value differed by about 5-10% and is explained primarily by lack of concrete haunches in the FEM but that are typically situated between the stringer and nominal depth concrete deck. Since the stringers for major bridges are typically not cambered, the haunch concrete can be more than typically encountered in slab on stringer or plate girder bridges. Depending on the bridge, an increase in the concrete bridge deck by percentage of the overall weight is made. The final results of the full dead load for bridge members are listed in Table 6.4. The deflections of the Tennessee River Bridge are reported and compared in Table 6.5. This set of design plans is the only one of the four to directly report the deflections for dead load.

### 6.4. FINITE ELEMENT MODEL RESULTS

Presented in this section are the results of the static FEA for the four tied arch bridges. The results are presented in Table 6.4 and Table 6.6 for static axial loads resulting from dead load and live load. The live load includes both HS20 and HL93 for comparison to the original design plans and for comparison to the current AASHTO live load requirements. Impact is not included in these results. Tables 6.7 and 6.9 also include the major axis moment, $M_{33}$, for live load. Insight is provided into the dead load to live load force effect ratios. Deflection comparisons are made for the Tennessee River Bridge in Table 6.5 while Tables 6.8 and 6.9 compare reactions resulting from LRFD to the original design methods. Table 6.10 list the parametric study of the second moment of inertia for the rib and tie girder to the resulting moment in both elements.

Table 6.4. Bridge Model Force Comparisons

| Bridge | Axial Force (kips) – Dead Load[1] Only | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Arch Rib | | Tie Girder | | Hanger | | Bearing (each) | |
| | FEA | Plans | FEA | Plans | FEA | Plans | FEA | Plans |
| Jefferson Barracks | 5,640 | 5447 | 4325 | 5445 | 373 | 349 | 4557 | 4392 |
| City Island | 3959 | 3981 | 3886 | 3975 | 345 | 345 | 3234 | N/A |

Table 6.4. Bridge Model Force Comparisons (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Page Avenue | 4435 | 3987 | 3745 | 3983 | 388 | 398 | 3715 | 3712 |
| Tennessee River | 2653 | 2700 | 2105 | 2297 | 175 | 183 | 1506 | 1564 |

1 – Dead load is comprised of structural steel and concrete elements and includes future wearing surface weight.

Table 6.5. Bridge Model Deflections Comparison

| Tennessee River Bridge | Deflection (feet) – Dead Load Only | |
|---|---|---|
| | FEA | Plans |
| Panel Pt. 7 | 0.605 | 0.569 |
| Panel Pt. 6 | 0.585 | 0.556 |
| Panel Pt. 5 | 0.530 | 0.517 |
| Panel Pt. 4 | 0.448 | 0.453 |
| Panel Pt. 3 | 0.346 | 0.366 |
| Panel Pt. 2 | 0.233 | 0.259 |
| Panel Pt. 1 | 0.119 | 0.139 |

Table 6.6. Bridge Model Force Comparisons

| Bridge | Axial Force (kips) – Live Load[1] Only | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Arch Rib | | Tie Girder | | Hanger | | Bearing (each) | |
| | FEA | Plans | FEA | Plans | FEA | Plans | FEA | Plans |
| Jefferson Barracks | -715 | -652 | 532 | 651 | 68 | 58.1 | -436 | -543 |
| City Island | -576 | -498 | 428 | 351 | 51 | 47 | -384 | N/A |

Table 6.6. Bridge Model Force Comparisons (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Page Avenue 7lanes | -849 | -517 | 813 | 396.3 | 100 | 93.3 | -744 | -746 |
| Tennessee River | -488 | -468 | 375 | 414 | 44.8 | 45.2 | -308 | -284 |

1 – Live Load is comprised of the maximum of HS20-44 Truck, Lane Load or Alternate Military Loading. Page Avenue live load includes a 1.25 factor on the aforementioned live loads. No impact is included in this table.

2 – Negative values are compression, positive are tension

Table 6.7. Bridge Model Force Comparisons

| Bridge | Moment, $M_{3\text{-}3}$ (ft-kips) – HS20 Live Load[1] Only | | | |
|---|---|---|---|---|
| | Arch Rib | | Tie Girder | |
| | FEA | Plans | FEA | Plans |
| Jefferson Barracks | -1485 | -2009* | 12,076 | 16,371* |
| City Island | 770 | 737 | 6,371 | 7,124 |
| Page Avenue FEA 7-lanes | 3,300 | 3,192 | 11,617 | 11,173 |
| Tennessee River | -334 | -331 | 5,287 | 5,964 |

* – Live Load includes Impact

Table 6.8. Bridge Model Force Comparisons Unfactored Live Load LRFD and Pre-LRFD

| Bridge | Axial Force (kips) – Live Load[1] Only | | | |
|---|---|---|---|---|
| | Arch Rib | Tie Girder | Hanger | Bearing (each) |

Table 6.8. Bridge Model Force Comparisons Unfactored Live Load LRFD and Pre-LRFD (cont.)

| | HS20 | HL93 | HS20 | HL93 | HS20 | HL93 | HS20 | HL93 |
|---|---|---|---|---|---|---|---|---|
| Jefferson Barracks | -652 | -768 | 651 | 651 | 58 | 83 | -543 | -470 |
| City Island | -498 | -630 | 351 | 491 | 47 | 60 | -384 | -431 |
| Page Avenue | -517 | -578 | 396 | 530 | 93 | 63 | -746 | -619 |
| Tennessee River | -468 | -637 | 414 | 457 | 45 | 57 | -284 | -379 |

1 – Live Load is comprised of the maximum of HS20-44 Truck, Lane Load or Alternate Military Loading. Page Avenue live load includes a 1.25 factor on the aforementioned live loads. No impact is included in this table.

2 – Negative values are compression, positive are tension

Table 6.9. Bridge Model Force Comparisons Unfactored Live Load LRFD and Pre-LRFD

| Bridge | Moment, $M_{3-3}$ (ft-kips) – Live Load[1] Only | | | |
|---|---|---|---|---|
| | Arch Rib | | Tie Girder | |
| | HS20 | HL93 | HS20 | HL93 |
| Jefferson Barracks | 2009 | 2030 | 16,371 | 16,156 |
| City Island | 737 | 1,000 | 7,124 | 8,090 |
| Page Avenue | 3,192 | 2,576 | 11,173 | 9,158 |
| Tennessee River | -331 | -406 | 7,217 | 5,964 |

Table 6.10. Bridge Parametric Comparison, Rise to Span = 1:6; 14 Panels

| Tennessee River Bridge | Live Load (HS20-44) Only | | |
|---|---|---|---|
| | Arch Rib $M_{33}$ (ft-kips) | Arch Tie $M_{33}$ (ft-kips) | Arch Hanger Axial Load (kips) |
| $I_{tie}:I_{rib} = 0.084$ $A_{tie}:A_{rib} = 0.82$ | 349 | 5030 | 44.8 |
| $I_{tie}:I_{rib} = 0.1$ $A_{tie}:A_{rib} = 0.1$ | 458 | 5507 | 50 |
| $I_{tie}:I_{rib} = 0.5$ $A_{tie}:A_{rib} = 0.5$ | 1743 | 4155 | 59 |
| $I_{tie}:I_{rib} = 1.00$ $A_{tie}:A_{rib} = 1.0$ | 2723 | 3454 | 63 |
| $I_{tie}:I_{rib} = 10$ $A_{tie}:A_{rib} = 10$ | 6162 | 1399 | 69 |
| $I_{tie}:I_{rib} = 20$ $A_{tie}:A_{rib} = 20$ | 6905 | 1172 | 65 |
| $I_{tie}:I_{rib} = 40$ $A_{tie}:A_{rib} = 40$ | 7741 | 1102 | 65 |

# 7. BRIDGE DYNAMIC CHARACTERISTICS

## 7.1. GENERAL

Advanced knowledge of dynamic properties is important in ensuring improved performance of the bridge during wind, traffic, and earthquake induced vibrations. The resulting characteristics can assist researchers and engineers to plan successful field, ambient vibration testing and can be a foundation on which to build information of the bridge regarding structural health monitoring. To date a wealth of information is available on the dynamic characteristics of suspension bridges, cable stayed bridges and even smaller, more routine slab on girder bridges. Thus this section explores the dynamic characteristics and performance of medium to long span tied arch bridges.

## 7.2. DYNAMICS

The dynamic performance of the bridges of this study can be succinctly expressed using the equation of motion for an undamped multiple degree of freedom system.

$$[\mathbf{M}]\{\ddot{x}\} + [\mathbf{K}]\{x\} = 0 \qquad \text{Equation 7.1}$$

where [**M**] and [**K**] are the mass and stiffness matrices for the structural system respectively. and that couples the MDOFs. $\{x\}$ and $\{\ddot{x}\}$ are the displacement and acceleration vectors of the structure respectively. Equation 7. 1 is also known as an eigenvalue problem for which a characteristic equation is developed as noted in the SAP2000 reference manual (CSI, 2015):

$$[K - \Omega^2 M]\Phi = 0 \qquad \text{Equation 7.2}$$

the roots are eigenvalues or squared natural frequencies $\Omega^2$. For each eigenvalue there is a corresponding eigenvector or natural mode, Φ. These natural frequencies and modes are specific to the structure under investigation and are functions of the system mass, stiffness and displacement function which is dependent on boundary conditions imposed on the system such as pinned or fixed supports. The frequencies and modes are extracted from the SAP2000 model programs and evaluated based on a range of possible external excitation frequencies. Moreover, each of the modes will have a qualitative effective mass participation factor to assist in determining which modes are most likely to influence the dynamic performance. Those modes with small effective mass participation factors indicate little impact on dynamic performance or resonance. As a general rule, all modes having a mass participation factor above 0.01 will be included in the results.

AASHTO (2012) suggests natural frequencies, mode shapes, distributions of mass and stiffness, damping of a structure under investigation should be considered prior to starting a dynamic analysis. Moreover, frequency of the forcing function, duration and directionality of external effects on the structure should also be known a priori for best results. This is especially true for "irregular" bridges, a term AASHTO uses to describe structures with unusual distribution of mass, for example concrete and steel superstructures that share supporting substructure, abrupt changes in stiffness such as a bridge over a gorge having short and tall substructure, curved geometry, or non-linear elements. Tied arch bridges may be classified as irregular due to curved geometry of the arches, long, slender elements and abrupt stiffness changes at the tied arch knuckles, and tension only cables.

A discussion on the source of vibration, frequency range, duration and directionality follows.

## 7.3. EARTHQUAKE INFLUENCED BRIDGE DYNAMICS

Earthquakes are naturally occurring hazards present worldwide where events happen every day. Most such events are small and pose no threat to the built environment however each year the USGS (2016) records about 20,000 per year, the vast majority having magnitude 4.9 or less. See Figure 7.1. Still observations show that earthquakes having magnitude between 6 and 7.0 number into the thousands while those above 7 are less than 20 per year. Most of these earthquakes occur at specific locations such as tectonic plate boundaries. However the central United States, the region of interest to this study, has a unique intraplate feature forming a complex network of faults in the southern Missouri, Illinois, western Kentucky, Tennessee and northern Arkansas that remains active. Based on historical data the collection of faults in the aforementioned Central US region has the potential to produce large magnitude earthquakes having a high frequency content over a long duration and distance. This lack of attenuation is due largely to the make-up of the local geology.

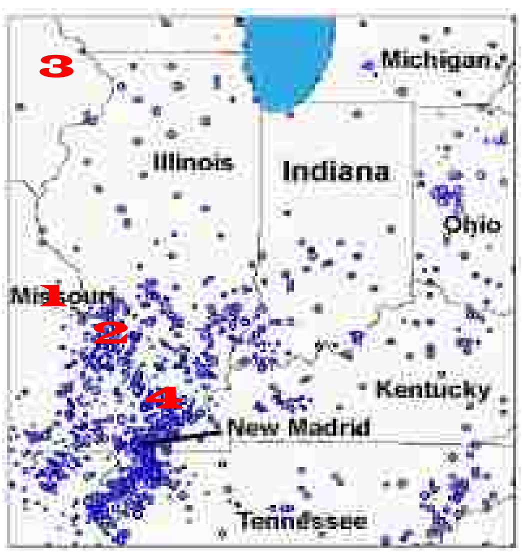



Figure 7.1. Central US Earthquakes from 1800 to 1995 in the New Madrid Seismic Zone and Wabash Valley Seismic Zone. Image from http://www.showme.net/~fkeller/quake/maps.htm Bridge Locations are also noted 1-4

The predominant period of strong ground motion is approximately in the range of 0.5s to 0.8s. This range coincides with the natural period for many routine bridges. Design earthquake spectra place limitations on the lower period range of the acceleration response spectra (ARS) to ensure an appropriate force level for structure response in the low period range. Outside this range, the ARS diminishes greatly per the design code. However, this isn't always the case and for many sites structures can be just as impacted by higher period, lower frequency regions of the ARS. An example of a site specific ARS for a site near Caruthersville, MO is show in Figure 7.2. This site is less than 100 miles from the US 24 bridge over the Tennessee River, see Figure 7.5. Figure 7.2 provides ARS for both longitudinal and transverse (to bridge centerline) for three return periods, 500-yr, 1000-yr, and 2500-yr. The 500-yr spectrum maintains a relatively flat decrease in acceleration from 2s to 6s. And the two upper level spectra have relatively large accelerations for longer period structures. Thus evaluating the natural period for major bridges over a period range of 0.5s to 5s would not be unreasonable. In addition to frequency content, duration of strong motion is an indicator of damage to structures. As noted earlier, the duration of ground shaking is generally accepted to be longer in the Central US due to the geology. Moreover, the dense soil deposits, particularly in the New Madrid Seismic Zone (NMSZ) can be expected to amplify the surface and structure response. Kramer (1996) presents a listing of bracketed durations for recorded earthquakes having epicentral distances of less than 10km. The bracketed durations are defined by the limits of first and last exceedance for a ±0.05g threshold. From that list we can expect durations for soil sites of 16s to 45s for magnitude 6 to 7.5 events respectively. Using a similar approach on the Caruthersville, MO time histories for the 500-yr and 2500-yr longitudinal components, see Figures 7.3 and 7.4, yields durations from 65s to 72s.

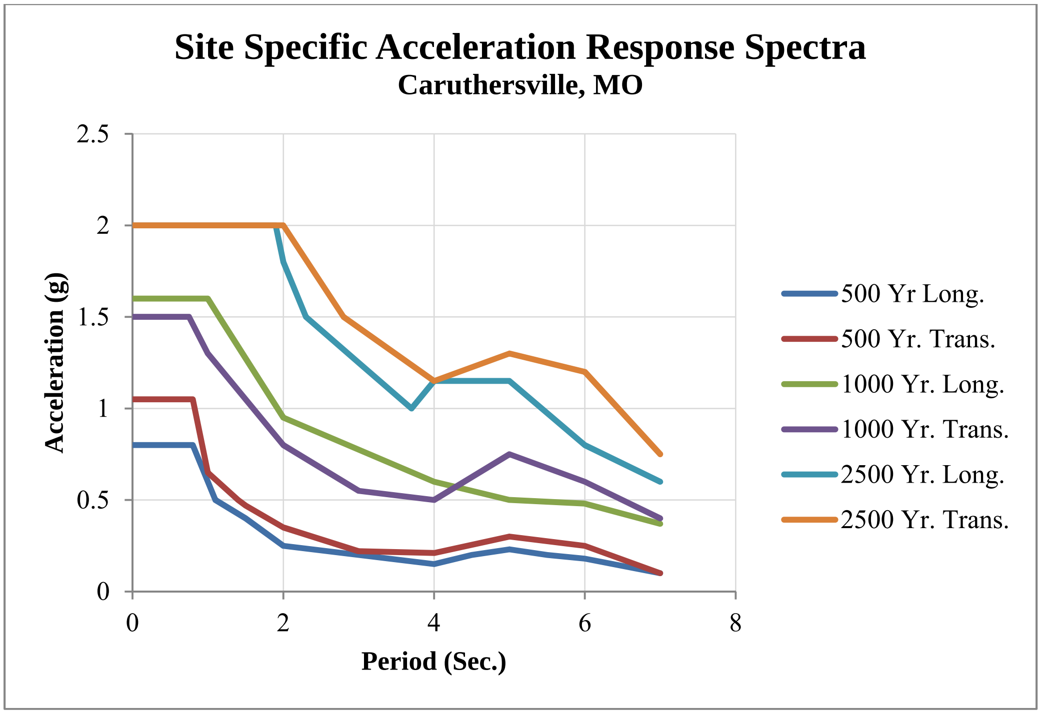



Figure 7.2. Site Specific Spectra for Caruthersville, MO. MoDOT/Jacobs April 2008

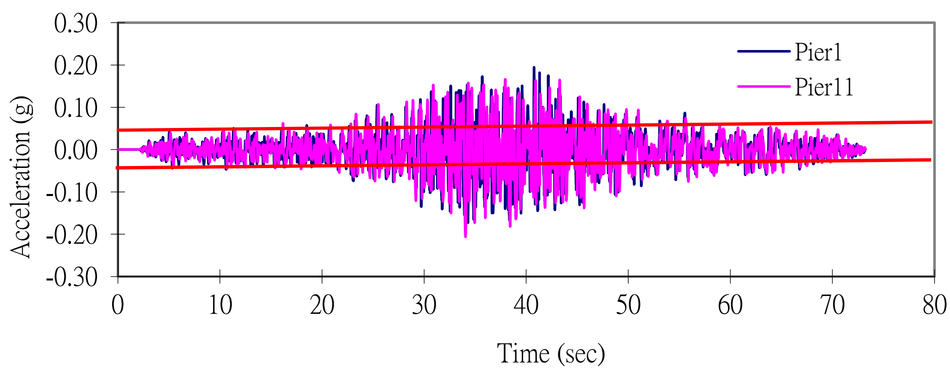



Figure 7.3. 500-Yr Longitudinal Time History at Caruthersville, MO site

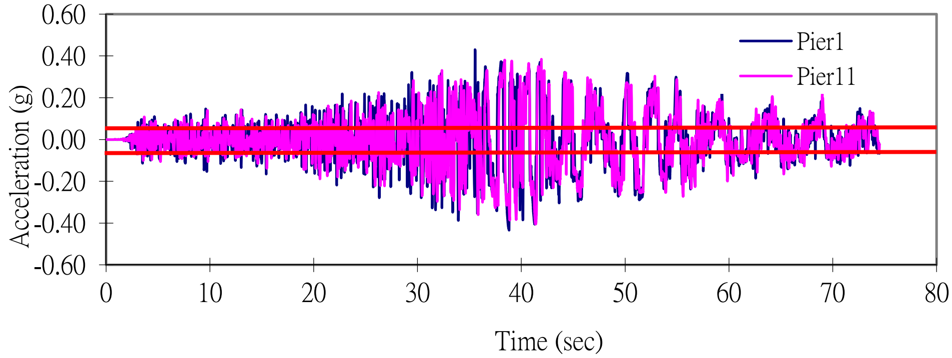



Figure 7.4. 2500-Yr Longitudinal Time History at Caruthersville, MO site


Figure 7.5. Caruthersville Site Location and Location of US 24 Bridge

Summarizing, the impact of earthquake induced ground motions on major bridges, such as the tied arch, can place great demands on the structure. This is particularly true as detrimental high frequency S-waves, dominate such a long duration, of the spectrum. On the lower end of the spectrum, longer period waves, surface waves, will impact less the resilience of the structure but pose concerns of greater displacements.

## 7.4. WIND INFLUENCED BRIDGE DYNAMICS

Svensson (2012) categorizes wind induced vibrations into three categories, turbulence induced, vortex induced and motion induced. He further summarizes the causes as random variations in wind speeds, shedding of vortices from the body, and rhythmic motion of the body in flow respectively. As with other dynamic effects, the structures natural frequencies and modes are indicators of performance to overall performance. In general, the longer the bridge the more flexible the bridge super and substructure are. Moreover, the more flexible a structure is the higher the natural period and conversely the lower the natural frequency. This, Svensson (2012), advises is an indication of susceptibility to wind related vibrations.

Though the analysis of wind induced vibrations is complex, multiple authors Brockenbrough and Merritt (1994), Podolny and Scalzi (1976) and Troitsky (1988) suggest a simple formula to check for resonance due to wind velocity. The relationship is based on vortex shedding and is presented below:

$$f = \frac{VS}{D} \qquad \text{Equation 7.3}$$

Where:

$f$ = the frequency of the pulsating pressure due to vortex shedding.

V = the wind speed

S = the Strouhal number

D = is the characteristic dimension, measured normal to the wind direction.

Rearranging the equation to solve for the wind speed for a specific set of structural frequencies:

$$V_{cr} = \frac{fD}{S} \qquad \text{Equation 7.4}$$

Generally, the lowest flexural and torsional frequencies will be of interest and by the direct relationship above will produce the lowest velocities expected to cause resonance. The variable, D, is taken as the depth of the superstructure and the Strouhal number can be determined from Brockenbrough and Merritt (1994) or Knisely (1990). For a rectangular cross section, the Strouhal value is provided for various aspect ratios (width to depth), b/d. Table 7.1 presents the results of the critical wind speed for each of the bridges, using the lower bound stiffness models.

Table 7.1. Critical Wind Speed based on Bridge Frequencies

| Bridge | Depth (ft) | Width (ft) | Aspect Ratio | St | $f_b$ Hz | $f_t$ Hz | $f_t / f_b$ | Vcr-b (mph) | Vcr-t (mph) |
|---|---|---|---|---|---|---|---|---|---|
| Jefferson Barracks | 12.0 | 62.0 | 5.2 | 0.10 | 1.10 | 1.13 | 1.03 | 90 | 93 |
| City Island | 9.8 | 70.0 | 8.0 | 0.07 | 0.39 | 1.25 | 3.18 | 38 | 120 |
| Page Avenue | 12.6 | 90.9 | 7.2 | 0.08 | 1.02 | 1.11 | 1.09 | 109 | 118 |
| US 24 | 9.0 | 46.0 | 5.1 | 0.10 | 1.48 | - | - | 91 | - |

St – is the Strouhal Number and flexural and torsional frequencies are noted $f_b$ and $f_t$.

The results of the table above are based on preliminary work and not the complex analysis necessary to thoroughly vet performance of wind induced vibrations. There are many variables to address prior to completing the wind analysis. The frequencies reported above are based on the lower bound stiffness, which assumes cracked section properties of the concrete deck and substructure. Additionally, the expansion bearings are assumed to be near perfect rollers permitting unhindered expansion and contraction. Still, the information still affords insight into the likely performance of the bridges with respect to vortex shedding.

1. The first observation is looking back through AASHTO for guidance on this phenomenon only to find no design criteria aimed at preventing vortex shedding. The Eurocode, however, requires the critical wind speed, $V_{cr}$, resulting from Equation 7.4 to be greater than $1.25v_m$, where $v_m$ is the 10-minute mean wind speed. An example of the magnitude for the 10 minute mean wind speed is about 65 mph for St. Louis, MO. The resulting values in the table would need to be above 82 mph to avoid shedding impacts per the Eurocode.

2. According to the results the City Island Bridge may be vulnerable to vortex shedding in the first vertical mode of vibration. There are a number of explanations for the lack of reported wind induced vibrations. As noted above, this analysis is based on arbitrary reduced stiffness and natural free vibration so that damping is not included. The structure will contain some damping effects and more so if the concrete is, in fact, cracked. The concrete may not be cracked to the extent of the assumptions made in this analysis. Additionally, while it's not uncommon to for an area to experience wind gusts of 38 mph it is unlikely to experience sustained wind speeds to permit the structure to respond in resonance.

3. Reviewing the City Island aspect ratio we see a relatively shallow superstructure depth for the overall width. This characteristic will influence the stiffness, resulting in a more flexible superstructure. This is confirmed by the low frequency for the first vertical mode of vibration, 0.39 Hz and a 2.5s period.

4. Upon evaluating the results, a more rigorous dynamic wind analysis may be planned to ascertain the performance for a bridge having such a low critical wind velocity.

5. The remaining bridges appear to perform beyond the range of vortex shedding.

## 7.5. TRAFFIC INFLUENCED BRIDGE DYNAMICS

Vehicles passing over bridges induce vibrations in a range of bridge members and can play a role in metal fatigue depending on the details, level of traffic and, of course, the potential for resonance of the passing frequency with the structural element natural frequency. In lieu of a rigorous vehicle-structure interaction model to assess vibration, the excitation frequency is determined from a vehicle passing over the series of floorbeams located at each panel point. Thus the excitation frequency can be determined from the equation:

$$\Omega(t) = \frac{V_v}{S} \qquad \text{Equation 7.5}$$

Where $\Omega(t)$ is the excitation frequency caused by the passing vehicle

$V_v$ = velocity of the vehicle in feet per second.

S= Panel spacing, feet.

All of the bridges are located on state highways or interstates and as a result have credible speed limits of 55-70 mph. Table 7.2 list the excitation for those two speeds for each bridge.

Table 7.2. Vehicle Excitation Frequency

| Bridge | Panel Spacing (ft) | $V_v$ = 55 mph | $V_v$ = 70 mph |
|---|---|---|---|
| Jefferson Barracks | 50.5 | 1.7 Hz | 2.0 Hz |

Table 7.2. Vehicle Excitation Frequency (cont.)

| | | | |
|---|---|---|---|
| City Island | 41.88 | 2.1 Hz | 2.5 Hz |
| Page Avenue | 38.5 | 2.3 Hz | 2.7 Hz |
| US 24 | 38.2 | 2.3 Hz | 2.7 Hz |

A review of the frequencies resulting from the modal analysis, Tables 7.4-9, shows that the forcing frequencies in Table 7.2 coincide with the higher modal frequencies of the bridges. This may very well explain the inherent and persistent vibration of the bridges felt by pedestrians or inspectors present on the bridges during traffic. It is unlikely that this vibration, while felt, is detrimental unless one or more of the individual structural members has a similar or near similar frequency. Several members will be modeled to determine their natural frequencies and compare with those from Table 7.2.

## 7.6. BRIDGE MODAL ANALYSIS RESULTS

The results of the dynamic analysis are tabulated below for each of the four bridges. Included in the tables are mode description, period, frequency, mode shape, and mass participation for the corresponding mode. Finally, presented below are the results of a simple parametric analysis demonstrating the influence of tie girder axial and flexural stiffness, rib flexural stiffness, hanger axial and flexural stiffness has on the overall bridge frequency.

Table 7.3 provides the total mass participation for each of the analysis per bridge. Tables 7.4 to 7.11 provide a summary of dynamic properties for each bridge with both upper and lower bound stiffness.

Table 7.3. Total Mass Participation for Dynamic Analysis

| Bridge | Global Axes Summary of Total Mass Participation (%) | | | | | |
|---|---|---|---|---|---|---|
| | Lower Bound Stiffness | | | Upper Bound Stiffness | | |
| | X | Y | Z | X | Y | Z |
| Jefferson Barracks | 92 | 77 | 43 | 89 | 46 | 42 |
| City Island | 89 | 62 | 45 | 68 | 59 | 42 |
| Page Avenue | 92 | 73 | 45 | 83 | 51 | 44 |
| US 24 | 56 | 55 | 18 | 51 | 20 | 17 |

Table 7.4. Tennessee I-24 Bridge - Dynamic Properties, Lower Bound Stiffness

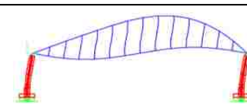
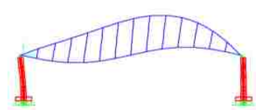
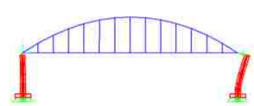
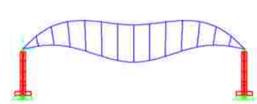
| Mode | Period Sec | Frequency Hz | Shape | Mass Participation |
|---|---|---|---|---|
| Longitudinal | 1.945 | 0.514 |  | 28% |
| 1st Transverse | 1.642 | 0.609 |  | 15% |
| 2nd Longitudinal | 1.608 | 0.622 |  | 9.4% |
| 2nd Transverse | 1.149 | 0.870 |  | 1% |
| 3rd Longitudinal (Pier) | 1.004 | 0.996 |  | 14% |
| 1st Vertical | 0.871 | 1.482 |  | 2.6% |

Table 7.4. Tennessee I-24 Bridge - Dynamic Properties, Lower Bound Stiffness (cont.)

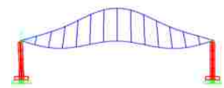
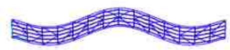
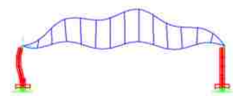
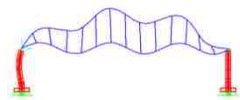
| | | | | |
|---|---|---|---|---|
| 2nd Vertical | 0.652 | 1.533 |  | 13.9% |
| 3rd Transverse | 0.352 | 2.837 |  | 7.4% |
| 4th Longitudinal (Pier) | 0.245 | 4.078 |  | 3.1% |
| 5th Longitudinal | 0.225 | 4.443 |  | 1.1% |

Table 7.5. Tennessee I-24 Bridge - Dynamic Properties, Upper Bound Stiffness

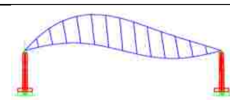
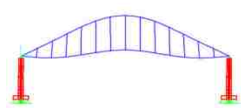
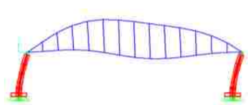
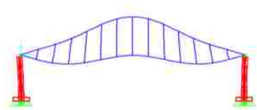
| Mode | Period Sec | Frequency Hz | Shape | Mass Participation |
|---|---|---|---|---|
| Longitudinal | 1.698 | 0.589 |  | 1.1% |
| Transverse | 1.489 | 0.672 |  | 13.4% |
| 2nd Transverse | 1.130 | 0.888 |  | 2% |
| Vertical | 0.871 | 1.148 |  | 2.2% |
| 2nd Longitudinal | 0.816 | 1.226 |  | 47.0% |
| 2nd Vertical | 0.639 | 1.565 |  | 13% |

Table 7.5. Tennessee I-24 Bridge Dynamic Properties, Upper Bound Stiffness (cont.)

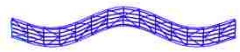
| | | | | |
|---|---|---|---|---|
| 3rd Transverse | 0.342 | 2.922 |  | 2.2% |

Table 7.6. City Island Bridge - Dynamic Properties, Lower Bound Stiffness

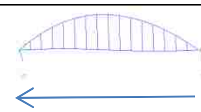
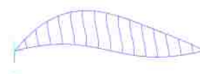
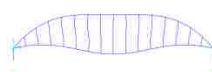
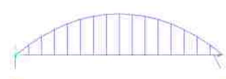
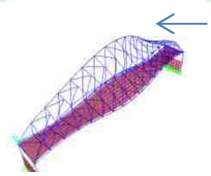
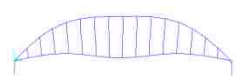
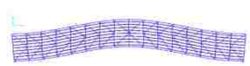
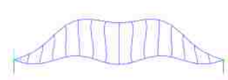
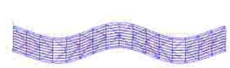
| Mode | Period Sec | Frequency Hz | Shape | Mass Participation |
|---|---|---|---|---|
| Longitudinal | 3.550 | 0.282 |  | 60% |
| 1st Vertical | 2.535 | 0.394 |  | 1.3% |
| Transverse | 2.042 | 0.490 |  | 49% |
| 2nd Vertical | 1.254 | 0.797 |  | 1% |
| Long. Pier | 1.206 | 0.829 |  | 8.7% |
| Torsional | 0.797 | 1.254 |  | 3.2% |
| 3rd Vertical | 0.779 | 1.283 |  | 41% |
| 2nd Transverse | 0.642 | 1.557 |  | 8.8% |
| 4th Vertical | 0.473 | 2.113 |  | 2.4% |
| 3rd Transverse | 0.358 | 2.797 |  | 1.0% |

Table 7.6. City Island Bridge - Dynamic Properties, Lower Bound Stiffness (cont.)

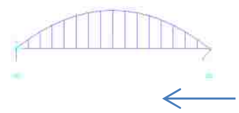
| | | | | |
|---|---|---|---|---|
| $2^{nd}$ Long. Pier | 0.275 | 3.632 |  | 9.5% |

Table 7.7. City Island Bridge - Dynamic Properties, Lower Bound Stiffness

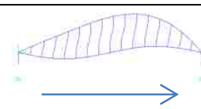
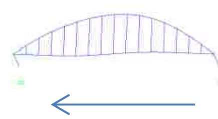
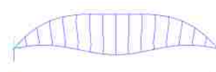
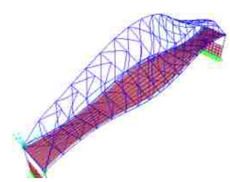
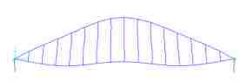
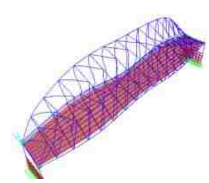
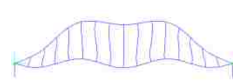
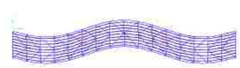
| Mode | Period<br>Sec | Frequency<br>Hz | Shape | Mass<br>Participation |
|---|---|---|---|---|
| Longitudinal | 2.578 | 0.388 |  | 1.6% |
| $1^{st}$ Transverse | 1.724 | 0.580 |  | 40% |
| $2^{nd}$ Longitudinal | 1.259 | 0.794 |  | 67% |
| $1^{st}$ Vertical | 1.249 | 0.800 |  | 1% |
| $1^{st}$ Torsional | 0.766 | 1.306 |  | 1% |
| $2^{nd}$ Vertical | 0.762 | 1.312 |  | 39% |
| $2^{nd}$ Torsional | 0.476 | 2.101 |  | 2.1% |
| $3^{rd}$ Vertical | 0.469 | 2.131 |  | 2.4% |
| $2^{nd}$ Transverse | 0.438 | 2.280 |  | 7% |

Table 7.7. City Island Bridge - Dynamic Properties, Upper Bound Stiffness (cont.)

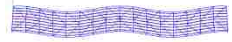
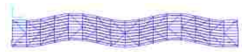
| | | | | |
|---|---|---|---|---|
| 3rd Transverse | 0.297 | 3.368 |  | 4.4% |
| 4th Transverse | 0.274 | 3.655 |  | 3.8% |

Table 7.8. Page Avenue Bridge - Dynamic Properties, Lower Bound Stiffness

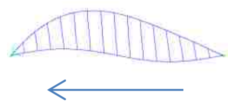
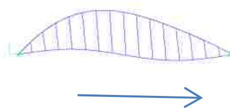
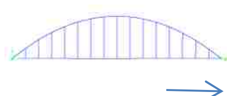
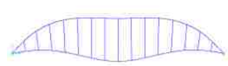
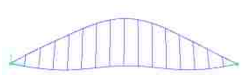
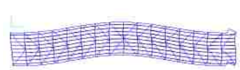
| Mode | Period<br>Sec | Frequency<br>Hz | Shape | Mass<br>Participation |
|---|---|---|---|---|
| Transverse | 3.605 | 0.277 |  | 9.5% |
| Longitudinal | 2.019 | 0.495 |  | 9.6% |
| 2nd Longitudinal | 1.591 | 0.628 |  | 54% |
| 2nd Transverse w/Torsion | 1.391 | 0.719 |  | 30% |
| 3rd Transverse w/Torsion | 1.161 | 0.861 |  | 8% |
| 3rd Longitudinal (Pier) | 1.024 | 0.976 |  | 21% |
| Vertical | 0.984 | 1.016 |  | 2.2% |
| 2nd Vertical | 0.714 | 1.401 |  | 40.6% |
| 4th Transverse | 0.431 | 2.322 |  | 22% |

Table 7.8. Page Avenue Bridge - Dynamic Properties, Lower Bound Stiffness (cont.)

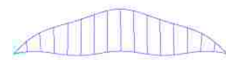
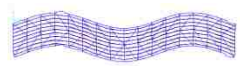
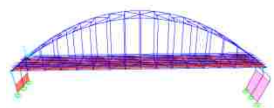
| | | | | |
|---|---|---|---|---|
| 3rd Vertical | 0.377 | 2.651 |  | 1.3% |
| 5th Transverse | 0.283 | 3.532 |  | 2.2% |
| 4th Longitudinal (Pier) | 0.275 | 3.66 |  | 6.6% |

Table 7.9. Page Avenue Bridge - Dynamic Properties, Upper Bound Stiffness

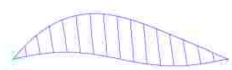
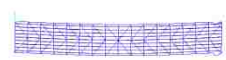
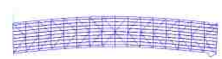
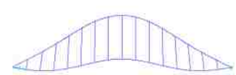
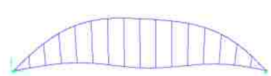
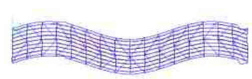
| Mode | Period Sec | Frequency Hz | Shape | Mass Participation |
|---|---|---|---|---|
| Transverse | 3.533 | 0.283 |  | 8.5% |
| Longitudinal | 1.977 | 0.506 |  | 1.7% |
| 2nd Transverse | 1.281 | 0.781 |  | 18.7% |
| 3rd Transverse | 1.117 | 0.895 |  | 14.2% |
| Vertical | 0.979 | 1.021 |  | 1.9% |
| 2nd Longitudinal | 0.751 | 1.331 |  | 64.9% |
| 2nd Vertical | 0.683 | 1.463 |  | 32.6% |
| 4th Transverse | 0.327 | 3.059 |  | 7.8% |

Table 7.10. Jefferson Barracks Bridge - Dynamic Properties, Lower Bound Stiffness

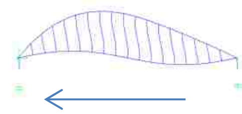
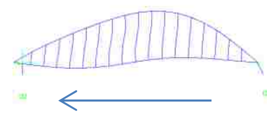
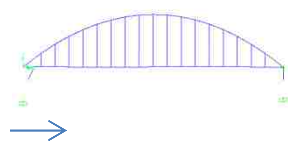
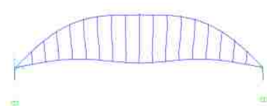
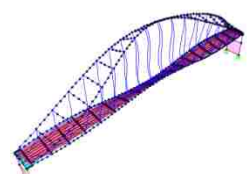
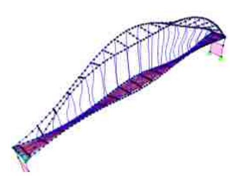
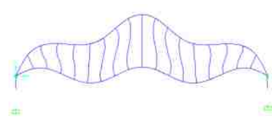
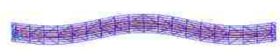
| Mode | Period Sec | Frequency Hz | Shape | Mass Participation |
|---|---|---|---|---|
| Longitudinal | 3.199 | 0.313 |  | 9% |
| 1st Transverse | 3.026 | 0.330 |  | 26% |
| 2nd Longitudinal | 1.924 | 0.520 |  | 59% |
| 2nd Transverse | 1.815 | 0.551 |  | 13% |
| 3rd Longitudinal (Pier) | 1.088 | 0.919 |  | 22% |
| 1st Vertical | 0.908 | 1.102 |  | 40% |
| 1st Torsion | 0.883 | 1.132 |  | 1.8% |
| 2nd Torsion | 0.585 | 1.708 |  | 1.4% |
| 2nd Vertical | 0.547 | 1.827 |  | 2.0% |
| 3rd Transverse | 0.429 | 2.328 |  | 9.8% |

Table 7.10. Jefferson Barracks Bridge - Dynamic Properties, Lower Bound Stiffness (cont.)

| | | | | |
|---|---|---|---|---|
| 4th Transverse | 0.405 | 2.468 |  | 2.3% |
| 5th Transverse | 0.294 | 3.403 |  | 21% |

Table 7.11. Jefferson Barracks Bridge - Dynamic Properties, Upper Bound Stiffness

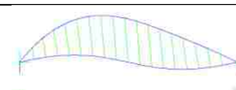
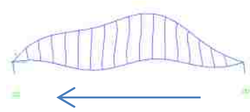
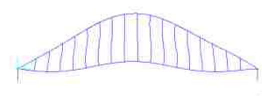
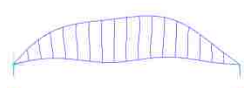
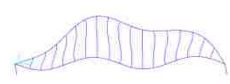
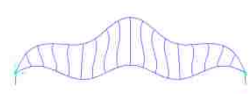
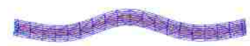
| Mode | Period Sec | Frequency Hz | Shape | Mass Participation |
|---|---|---|---|---|
| Longitudinal | 3.061 | 0.327 |  | 4% |
| 1st Transverse | 2.810 | 0.356 |  | 20% |
| 2nd Transverse | 1.592 | 0.628 |  | 17% |
| 2nd Longitudinal | 0.905 | 1.105 |  | 43% |
| 3rd Transverse | 0.876 | 1.142 |  | 1.4% |
| Vertical | 0.869 | 1.151 |  | 33% |
| 3rd Longitudinal | 0.756 | 1.323 |  | 37% |
| 2nd Vertical | 0.541 | 1.847 |  | 2.2% |

Table 7.11. Jefferson Barracks Bridge - Dynamic Properties, Upper Bound Stiffness (cont.)

| | | | | |
|---|---|---|---|---|
| 4th Transverse Torsion | 0.332 | 3.010 |  | 2.4% |
| 5th Transverse Torsion | 0.329 | 3.037 |  | 2.1% |

## 7.7. HANGER DYNAMIC CHARACTERISTICS

The hangers for each of the bridges were modeled as single frame elements. Those frame elements have the geometric properties of the actual bridge rope or strand. Moreover, the frames were modeled as tension only elements with pinned ends. To develop the best mass participation for the bridge models, the major members of the tied arch were discretized into at least four members. The exception to this was the hanger frame elements and ancillary bracing. The hanger frames were not discretized as the results would be overwhelming dominated by the individual hanger frames. This would result in the extraction of a much greater number of eigenvalues. So for the dynamic analysis the hanger frame elements, lower lateral, stringers and floorbeams were not discretized.

Moreover, the FE model, as developed, for each bridge uses the centerline arch and tie for the frame centerlines. The hanger frames are connected from the centerline of the arch to the centerline of the tie. This results in a longer than actual hanger length which may skew the results of an element sensitive to length and axial load for dynamic analysis.

This section develops the dynamic characteristics of the hangers using equations from Roark's Handbook of Stress and Strain. The formula for determining the lateral eigenvalues for a "string" under tensile axial load is given as:

$$f = \frac{K_n}{2\pi}\sqrt{\frac{Tg}{wl^2}} \quad \text{Equation 7.6}$$

Where

$f$ = is the frequency of the member for mode, n, in Hz.

$K_n$ = π, 2π, 3π for n = 1, 2, and 3 respectively

T = tensile load, kips

g = acceleration due to gravity, ft/s$^2$

*w*= self-weight of the "string", kips/ft

l = length of the member, ft

The resulting hanger frequency values (only a quarter are listed due to symmetry) are noted in the Tables 7.12 through 7.14 below for each bridge. Both the dead load and live load tension are included separately.

Table 7.12. Individual Hanger Frequency (Hz) – Mode 1

| Bridge | Individual Hanger Frequency (Hz) – Mode 1 | | |
|---|---|---|---|
| | Dead Load | Live Load | Total Load |
| Jefferson Barracks | 6 - 2 | 2 – 0.6 | 6 – 0.6 |
| City Island | 19 - 3 | 6 - 1 | 20 - 3 |
| Page Avenue | 23 - 4 | 7 – 4 | 24 - 4 |
| US 24 | 18 - 4 | 9 - 2 | 20 - 4 |

The frequencies listed are from the first hanger to the middle hanger.

Table 7.13. Individual Hanger Frequency (Hz) – Mode 2

| Bridge | Individual Hanger Frequency (Hz) – Mode 2 | | |
|---|---|---|---|
| | Dead Load | Live Load | Total Load |
| Jefferson Barracks | 12 - 3 | 4 – 1.3 | 12 - 3 |
| City Island | 37 - 6 | 12 - 2 | 39 - 7 |
| Page Avenue | 46 - 7 | 15 – 7 | 48 - 7 |
| US 24 | 37 - 7 | 18 - 3 | 41 - 8 |

The frequencies listed are from the first hanger to the middle hanger.

Table 7.14. Individual Hanger Frequency (Hz) – Mode 3

| Bridge | Individual Hanger Frequency (Hz) – Mode 3 | | |
|---|---|---|---|
| | Dead Load | Live Load | Total Load |
| Jefferson Barracks | 17 - 3 | 7 – 1.3 | 19 - 3 |
| City Island | 56 - 9 | 18 - 3 | 39 - 7 |
| Page Avenue | 68 - 11 | 22 – 11 | 72 - 11 |
| US 24 | 55 - 10 | 26 - 5 | 61 - 11 |

The frequencies listed are from the first hanger to the middle hanger.

SAP2000 was used to produce results for the dynamic analysis of the City Island Bridge hangers. Table 7.15 conveys the comparison and a third method from Kreyszig (1983). Figure 7.6 shows the mode shapes of the hangers.

To produce the values tabulated above, the individual bridge rope or strand is assumed to be load uniformly, that is all four ropes share the same axial load. From the design plans and our analysis we see that the hanger sets are loaded relatively uniform over the length of the bridge with less than 10% difference in the magnitude of the hanger forces.

Table 7.15. City Island Bridge Center Hanger Dynamics

| Frequency, mode Hz (#) | Hanger Length (ft) | Hanger Load[1] (kip) | Roark's Hz | Kreyszig Hz | SAP2000 Hz |
|---|---|---|---|---|---|
| $f_1$ | 121.6 | 86 | 2.432 | 2.614 | 2.622 |
| $f_2$ | 121.6 | 86 | 4.847 | 5.228 | 5.244 |
| $f_3$ | 121.6 | 86 | 7.270 | 7.841 | 7.844 |

1 – Hanger load includes DL only.

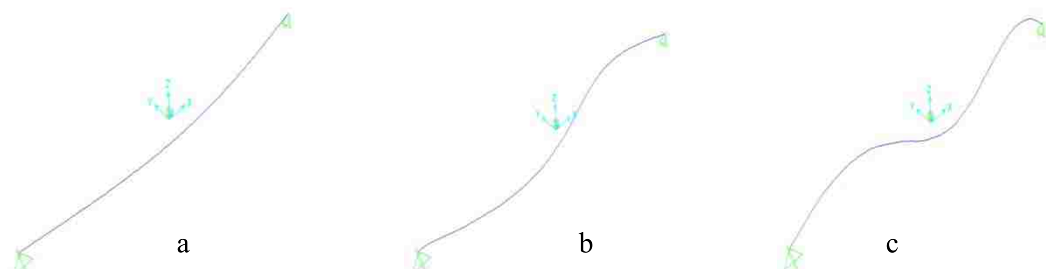



Figure 7.6. City Island Hanger Mode Shapes, a) first mode, b) second mode, c) third mode

The details typically provide for a spacer to ensure the individual hangers are positioned per design. However, this spacer has negligible effect on the stiffness and does not aid force the cables to act together. The following conclusions may be drawn from the tabulated individual hanger frequencies.

1. The longer, central hangers have lower frequencies for all three modes of lateral vibration.

2. There is a very small range of frequencies for the central hangers, though the range expands from the shortest to the longest hanger set.

3. Conversely to item 1 above, the shorter hangers have much higher frequencies. On the order of 5-6 times the smaller frequency.

4. The hanger frequency is dominated by the dead load.

5. The central hangers have low frequencies in mode 1 for most of the bridges and, for the longer span Jefferson Barracks Bridge, in modes 1 to 3 that match or will have a tendency to match those excitation frequencies for vehicles traveling across the bridge. As a result it would not be uncommon to see the individual ropes vibrate laterally under traffic on days with very low wind.

### 7.8. STRUCTURAL HEALTH MONITORING APPLICATIONS

The number of deficient bridges grows each year while the available funds to address those deficiencies continue to shrink each year. Moreover, the average age for bridges currently in service approaches the mid 40s for bridges designed during a time when service life was 50 to 75 years. Thus it is more important now than ever to investigate alternate approaches to replacement such as strengthening. Methods used for SHM can also be used to ascertain the level of the retrofit as well as the health of that retrofit. Where new structures are a must, plan for structures with extended periods of service life and an integrated system that informs the owner of distress before it becomes a crippling financial or life safety concern.

Based on the literature review we understand that much work has been done in this area with a focus on major civil infrastructure. The Golden Gate Bridge, the Humber Suspension Bridge and the Tsing Ma Suspension Bridge are examples of bridges having sophisticated structural and environmental monitoring systems (Brownjohn, 2006 and Ahlborn, 2010). Yet there are also applications for smaller bridges underway and there is a background of research and actual bridge studies to support modal analysis damage dection or structural health monitoring (Hearn and Testa, 1991 and Ren et al 2004). In addition to gaining early notification of structural element distress, the use of in-situ or remote sensoring can close the gap in Bridge Information Modeling (BrIM) for analysis models that can be updated to reflect and report on the actual performance of structures. For SHM to be viable it must continuously observe structural variables that are compared to baseline characterization of structural performance, identifying those occasions where the actual performance contrast with the baseline predictions. To accomplish this we need to ensure the baseline model, that is largely based on the original analysis model, is modeled on the structure's condition and current stiffness characteristics. The scope of this work precludes any field work associated with in-situ, on-site field surveying or remote monitoring for tied arch bridges. However the work completed by Ren et al (2004) provides an opportunity to corroborate the results of their field study on the US 24 Tied Arch Bridge over the Tennessee River in Kentucky with the dynamic study as part of this report. Moreover it permits us to also confidently examine the sensitivity of the dynamic results to changes in stiffness. Presented below in Figures 7.7 to 7.11 are the results of a sensitivity study for the natural frequencies as the the stiffness is varied for several members of the tied arch bridge.

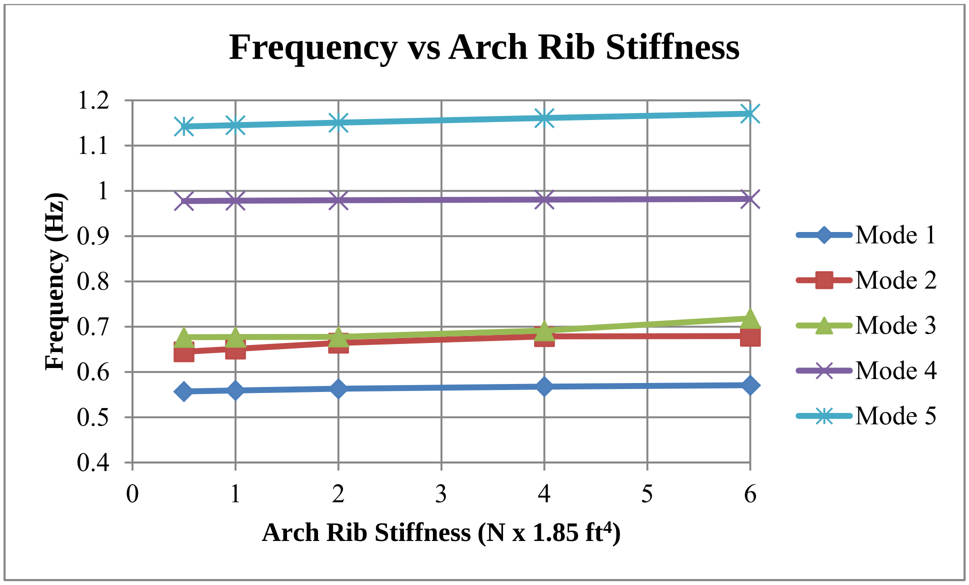



Figure 7.7. Variation of Frequency vs Arch Rib Stiffness, US 24 Bridge

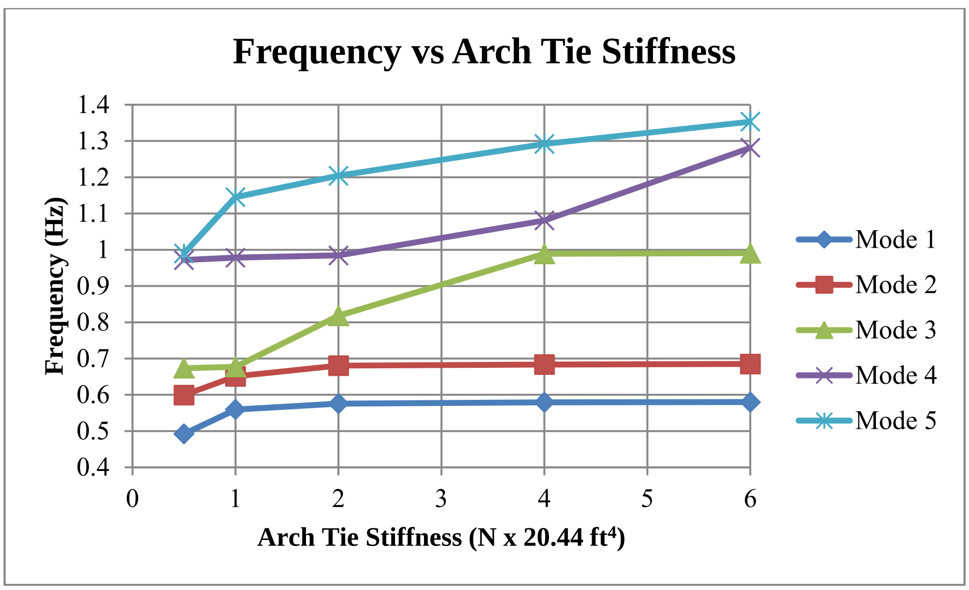



Figure 7.8. Variation of Frequencey vs Arch Tie Stiffness, US 24 Bridge

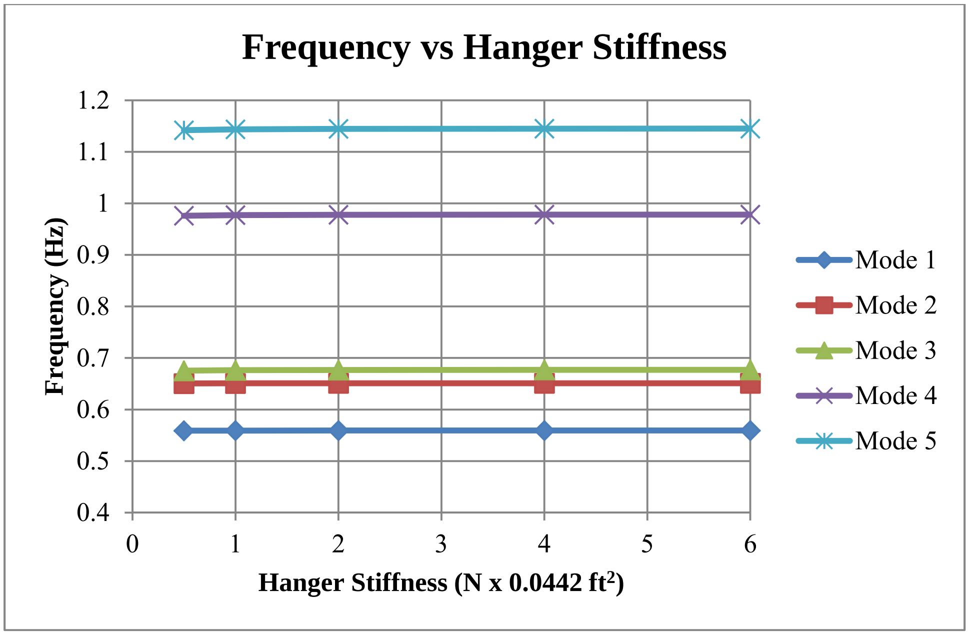



Figure 7.9. Variation of Frequency vs Hanger Stiffness, US 24 Bridge

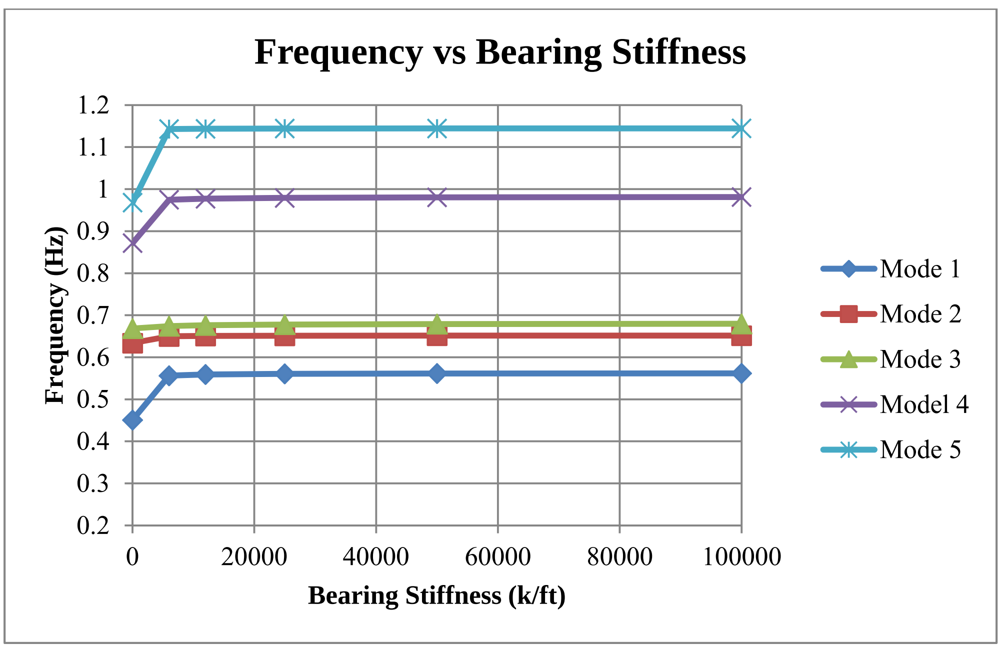



Figure 7.10. Variation of Frequency vs Bearing Stiffness, US 24 Bridge

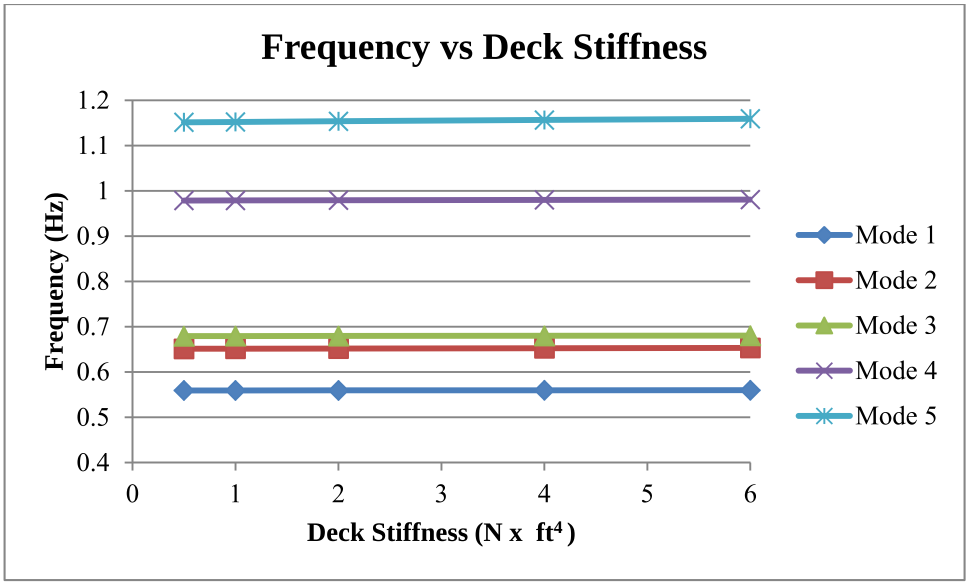



Figure 7.11. Variation of Frequency vs Deck Stiffness, US 24 Bridge

# 8. CONTEMPORARY TIED ARCH BRIDGES

## 8.1. GENERAL

Many of the tied arch bridges recently designed and built follow the adage that necessity is the mother of all invention. Where the need, in this case, is highlighted in the 1978 FHWA technical memorandum (FHWA, 1978) cautioning owners to consider alternate bridge types due cracks developing in the non-redundant and fracture-critical steel tie-girders constructed prior to 1978. To address this need, engineers have developed new tie-girder arrangements, new material for tie-girders and new hanger arrangements to produce a contemporary tied arch bridge that is unsusceptible to thru-fracture yet remains economical. However the ingenuity has not stopped there and today there are further advances in the design and construction of tied arch bridges to note. Other advances include: alternate hanger arrangements, inclined arch ribs (i.e. basket-handle), freestanding arches, concrete tie girders and composite superstructures.

## 8.2. INTERNAL REDUNDANCY

The crux of the FHWA (1978) technical advisory concerning Tied Arch Bridges is the statement "one of the most nonredundant structures relying entirely on the capacity of two tie girders to accommodate the total thrust imposed by the arch ribs". The remaining items noted in the advisory are addressed through improved hanger/tie girder connection details and improvements in the mill, rolling or welding process. Petzold (2005) Improvements have been made to the design and details of tied arch bridges over the years to address and remove these older, faulty design details. Hanger details are more robust and tie girders, perhaps the most non-redundant element of the bridge type, is designed with internal redundancy in a number of ways. Tie girders are typically composed of closed members such as box girders or open members such as I-girders. Over the years, in response to the

FHWA Technical Advisory, several derivatives of these arrangements have been suggested in order to address redundancy. This requires internal redundancy, load path and structural redundancy. These new developments are listed below.

**8.2.1 Internal Redundant Structural Steel.** Petzold (2005) groups the various alternates for the tie girders into closed and open arrangements. Figures 8.1 and 8.2 show the closed arrangements in items 1, 2, 3, 7 and items 8, 9, 10, 11 and 12 respectively. The remaining items of these Figures are the open arrangements, 4, 5, 6 and 13. The effectiveness of any one of the suggested arrangements is largely dependent on meeting as many of the prescribed constraints of the application. Drawing on the background of structural optimization, the constraints can be categorized as Fabrication, Design, and Codes for example. Figure 8.3 shows the categories with some items vying for priority in future tie-girder use. This figure will be used to briefly evaluate the advantages and disadvantages of the tie girders.

Figure 8.1. Alternate Tie Girder Arrangements. From Petzold (2005)

Figure 8.2. Alternate Tie Girder Arrangements. From Petzold (2005)

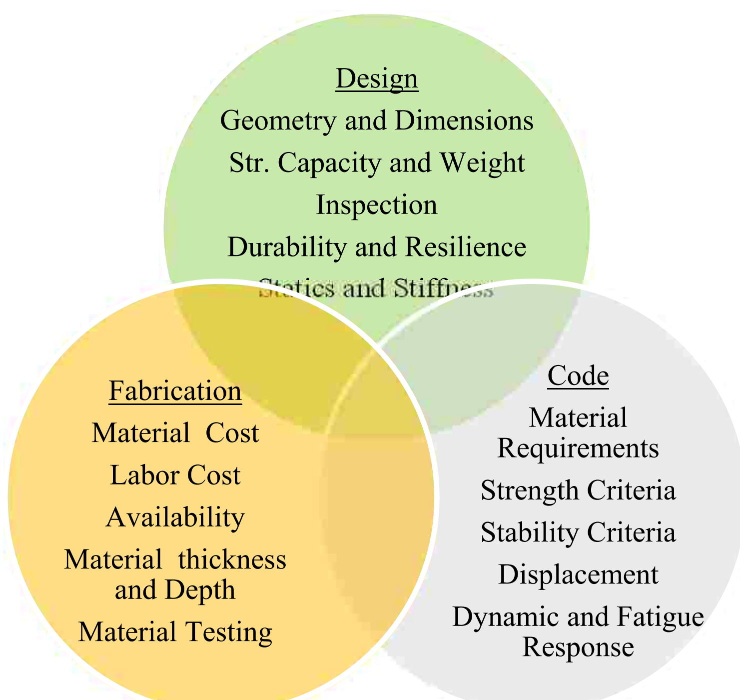



Figure 8.3. Tie Girder Constraint Sets

In Section 5, it was shown that the current tie girder arrangement for the City Island Bridge is acceptable for the 2012 AASHTO LRFD strength load case. This will serve as the basis for comparison to the aforementioned newer tie girder arrangements. The tie girder is shown in Figure 8.4. It is comprised entirely of ASTM A588 steel having $F_y = 50$ ksi.

From Figure 8.1 Arrangement 1 is the original, closed, welded plate box girder whereas Arrangement 2 is the closed, bolted plate box girder that is now more or less the norm for steel sections. The bolted plate box girder is used on the Page Avenue Bridge and has the benefit of providing the same strength, stability, inspection access and internal redundancy as far as limiting crack growth. With the bolted box girder, each plate is joined with angles or bent plates and bolted. As a result, there is no continuity for a crack to propagate from plate to another. In comparison to the welded box, the fabrication cost increased as did the durability and resilience, statics and stiffness. The ease of inspection remains the same. This comparison is tabulated in Table 8.1 for this and all arrangements.

Girder Arrangement 3 is a hybrid of the box and single web plate girder. Certainly the area and moment of inertia about the major axis remains the same but drawing in the web plates toward the centerline complicates fabrication and inspection.

Girder Arrangement 4 combines two welded plate girders using bolts. By inspection, one wonders if this arrangement provides the necessary level of redundancy. If the tie girder requires the full depth of both members to resist dead and live moments (with axial tension) and one member is compromised due to a crack through the flange, how can the remaining member provide the requisite capacity? Moreover, using the same plates as the City Island tie, the moment of inertia about the major axis is reduced by about 30% while the area stays about the same. Lastly, pack rust is a real concern for a built-up member with a parallel and horizontal joint exposed to the atmosphere. For these reasons arrangement 4 is not a very attractive solution.

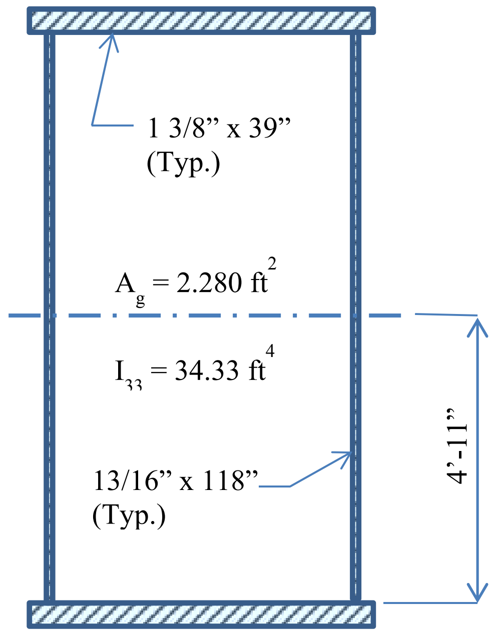



Figure 8.4. City Island Tie Girder Dimensions & Properties

Girder Arrangement 5 turns the solution of arrangement 4 ninety degrees and places single plate girders side by side with a diaphragm plate between them for compliance. This solution solves the lack of capacity in the event of a severe crack in one of the flanges. However it introduces another complexity. In the event of one the girders disabled, the resulting load path must account for the eccentricity in the now single plate girder. For durability this arrangement provides much open area for debris and moisture to collect and accelerate corrosion. Adding a cover plate on the top would solve this issue but add to the weight and overall fabrication cost.

Girder Arrangement 6 is a fallback to a bygone era when many of the structural shapes used in buildings and bridges were comprised of multiple plates and riveted together.

This single plate girder is very effective and efficient despite the added fabrication material and labor to bolt the sections together. A single plate girder tie has been in use on the two Jefferson Barracks Bridges, spanning over 900 feet. The open plate section is easy to inspect and maintain.

The last item in Figure 8.1 is a welded box girder with interior bolted web plates for redundancy. This arrangement employs, at the onset, an oft used retrofit to mitigate cracks or corrosion related section loss in plates. The web area is doubled up but the stiffness isn't increased greatly on the major axis. This aids in maintaining the intended balance of moment in the arch rib and tie. With the redundant plates added to the inside, pack-rust, so prevalent in built-up members, will not develop if the plates are properly bolted for sealing. In the event of a disabling crack, a section encompassing the crack may be removed and a new bolted section spliced in. The drawback is that the web plates have the greatest area and thus require an incredible number of bolts over the length. This quickly raises the fabrication costs.

Figure 8.2 begins with Alternate 8 which is plate girder within a box girder. The new arrangement is obviously redundant and increases the cost of the material and fabrication. The stiffness is increased by over 70% and the area by 60%. Thus this new redundant member will affect the distribution of moment between the tie and rib. It is likely the most expensive alternate shown due to the added material. It also poses limitations when inspecting the inside of the tie girder due to the resulting narrow openings.

Alternates 9, 10, 11 and 12 are all box girder arrangements. Alternate 9 is very similar to Alternate 4 and raises the same concerns and reservations. Item 10 pairs two independent boxes, joined and bolted by the web plates. The addition of the two interior web plates adds a level of redundancy but leaves a question. Will the flanges remain full effective if one of the exterior webs develops a severe, lengthy crack? It seems the best way to ensure the flanges remain compliant with the remaining plates is to have an interior cover plate bolting all flanges. If this were the case, then Alternate 10 would mostly resemble Alternate 8. Additionally, Alternate 10 has an extra web plate over that of Alternate 8. Both 8 and 10 share a lack of space for fabrication of internal diaphragms and inspection. Alternate 11 and 12 provide partial depth redundancy plates. These plates are provided in critical areas of the tie girder where tension stress exists for live load. This is a typical retrofit for existing two girder superstructure systems. Figure 8.5 shows a typical partial plate redundancy retrofit in the Central US.


Figure 8.5. Partial Plate Redundancy Retrofit

The last alternate, 13, shows a single welded plate girder option and supplementary web plates bolted to the central web plate. Again, this alternate derives from many retrofits that have been performed over the years. Like many of the other alternates, an increase in fabrication cost is necessary to provide the many bolt holes, install bolts, and test them for torque. Yet, this option is open, easy to inspect and with the edges of the additional plates tucked into the flanges, pack rust will be less of a concern.

Providing tie girder internal redundancy can be achieved but requires understanding the relationship of a myriad of factors, see Figure 8.3, to produce a cost effective option. Among those factors it's important to understand the role of tie girder flexural stiffness on the overall system to ensure the intended structural performance remains unabated. It is also worth noting that a completely redundant tie girder is not necessary. Given the requirements for bridge inspection, especially for fractural critical elements, cracks can be identified and monitored or repaired before a catastrophic event occurs. A completely severed tie girder is an unusual and unlikely event given the inspection programs and diligence afforded to our largest infrastructure. As a result it is possible that an arrangement providing partial redundancy is appropriate. Such an application would provide for high strength plates having partial depth, by design, to prevent complete propagation through the section but permit inspectors, owners and engineers to develop a retrofit for the localized area. Over the service life of the bridge this seems more economical than an initial, completely redundant element, which, in the end, may interfere with inspection and or retrofitting.

Table 8.1 shows the relative material or effort involved in fabrication, design and inspection of alternates to the welded box tie-girder. Obviously greater material and effort translate to increased cost. In some cases, the values in the table may be counter-intuitive at first glance. However after considering the process, such as fabrication, in its entirety the assessment is clear. As an example, several of the bolted options are noted has having lower labor effort. This may be counterintuitive since increasing the number of bolts, increases the number of holes to punch and ream and then draw-up with fit up bolts and finally finish bolt and proof with torque tests. This effort must be compared to the welded option which includes pre-heating, special welding processes, distortion control procedures, multiple pass welding, and in a confined space.

Table 8.1. Comparison of Tie Girder Alternates to Welded Box Tie Girder

| | Fabrication | | Design and Code | | | |
|---|---|---|---|---|---|---|
| Alt. Section | Matl Cost | Labor Cost | Durability and Resilience | Stiffness | Inspection | Statics |
| 2 | H | L | H | H | S | H |
| 3 | H | L | L | S | L | H |
| 4 | H | L | L | H | H | S |
| 5 | H | H | S | H | S | H |
| 6 | H | L | H | S | H | H |
| 7 | H | H | S | S | S | H |
| 8 | H | H | S | H | L | H |
| 9 | H | H | L | S | L | H |
| 10 | H | H | L | S | L | H |
| 11 | H | L | H | S | S | H |
| 12 | H | H | H | H | L | H |
| 13 | H | H | H | S | H | H |

H – Higher effort than original arrangement

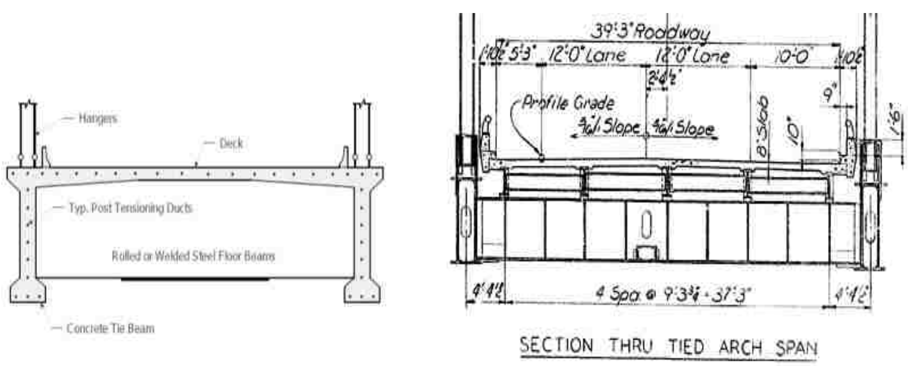
L – Lower effort than original arrangement

S – Same effort as original arrangement

**8.2.2 High Performance Steel**. Cassity, Serzan and McDonald (2003) demonstrates the benefits of high performance steel (HPS) when combined with internally tie girder arrangements. The authors present contemporary features of the new US 20 Bridge over the Mississippi River at Dubuque, Iowa. The bridge features a single span, 845 feet tied arch span with a rise of 105 feet and arches on 56 feet centers. The ratio of rise to span is 1:8. The arch rib is a welded box having dimensions four feet wide and seven feet deep. The bolted HPS box tie girder varies in cross section from 2.5 feet wide at mid-span, tapering to 4 feet wide at the end. The tie girder has a constant depth of 7 feet. HPS has the benefits of greater fracture toughness over conventional bridge steels and provides early onset brittle-ductile transitioning which provides ductility at extreme temperatures. Lastly, as the span to rise ratio is low, the result is higher arch thrust and thus higher tension in the tie girder. Use of the HPS 70W steel permitted engineers to maintain routine overall tie girder dimensions as well as plate thicknesses.

**8.2.3 Internal Redundant Concrete Tie Girder.** Perhaps one of the most significant developments in tie girder design is the use of a pre-stressed concrete tie girder for internal redundancy. Tie girders need not be comprised of structural steel; many tied arches have used concrete for both the arch rib and tie. For the most part those were bridges of a bygone era having short spans that have been replaced by more efficient and durable slab on girder bridges. Today concrete and post-tensioning has made their way in long span tied arch bridges. Many engineers believe that the concrete tie girders are internally redundant and that with the introduction of post-tensioning cracking in the concrete can be eliminated and additional ducts provided for future tendons as necessary.

The literature shows interest in long span tied arch bridges comprised of concrete elements. Hall and Lawin (1985) produced an illustrative design for a 625 feet tied arch comprised of a monolithic concrete superstructure. The width of the bridge, from centerline arch to centerline arch is 91 feet. In this alternate, the bridge deck is integral with the arch tie girders. The tension is developed through several post-tension tendons in the concrete tie-girder. The tie-girder for this alternate has a depth of 9 feet. The internal redundancy of the concrete tie-girder manifests in the number of post-tension ducts. Should one tendon fail the tension force is designed to be distributed to the remaining tendons. In many cases, additional empty ducts are provided should future tendons need to be added. The monolithic concrete section also provides some degree of load path redundancy. Because the superstructure in integral, the tie girders, deck and floorbeam, this unit shares load should one of the elements fail. Figure 8.6 shows the cross section from the Hall and Lawin (1985) study (a) and the cross section for the US 24 Bridge (b). From this figure we can see how the integral cross section (a) is connected and how the cross section acts as a unit to resist global tension of the tied arch. The US 24 cross section (b) shows, in contrast, that the tie girders are not connected to the deck.




a. b.

Figure 8.6. Alternate Bridge Cross Section from a. Hall and Lawin (1985). b. US 24 Cross Section

The recently constructed Hastings (Minnesota) Tied Arch Bridge carrying Trunk Highway 61 over the Mississippi River also employs a concrete tie girder. This bridge has a span of 545 feet, and from arch to arch, a width of 104 feet. The rise of the arch is 88 feet which gives a rise to span ratio of 1:6. The design criteria for the project contained several potential alternate tie girder arrangements. Figure 8.7 shows the concrete option with post tensioning. The tie girder measures 8 feet deep and 6.5 feet wide. For comparison, the flexural rigidity, EI, of the preliminary concrete (f'c = 4000 psi) tie girder, neglecting post-tension, is 1.44 x $10^8$ k-$ft^2$ whereas a comparable steel welded box girder, from the City Island Bridge, is 1.44 x $10^8$ k-$ft^2$. The majority of tied arch bridges, like the City Island Bridge and the remaining study bridges, are predicated on the stiff tie and slender arch. To ensure a similar level of moment distribution the concrete tie girder should have a similar flexural rigidity as the steel option. Figure 8.7 also shows that the tie girder acts independently of the superstructure, particularly the deck. As such the distribution of forces for the Hastings Tied Arch is dependent on the stiffness of the arch rib and tie. The preliminary design criteria and plan sheets were developed by the CH2M-Hill and Jacobs team. The final design, and ultimately construction, of the Hastings Bridge followed the work by the Design Build Team (DBT) Ames-Lunda with Parsons as the lead engineer. Gastroni (2011) documents this effort more in depth and describes the additional measures used to achieve redundancy.

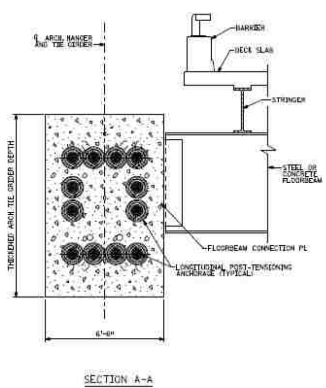



Figure 8.7. Concrete Tie Girder with Post Tensioning

Benefits that engineers and owners should consider for alternate tie-girders include: improvements to redundancy, maintain or improve force distribution, durability, level and ease of inspection, and improved construction parameters (shorter durations, lower costs, etc). Conventional structural steel requires long lead times for fabrication and runs the risk of fit-up or assembly issues on site. Conventional concrete forming is typically less costly provided falsework or form support is minimized. Adding post-tensioning usually adds a subcontractor, and maybe special inspection, to project which increases cost, however the increase may be minimized depending a host of factors or alternates considered. Engineers, owners and contractors, where permitted, should evaluate these methods and influencing factors together in a matrix where the alternates and factors can be weighted to attain the best alternate.

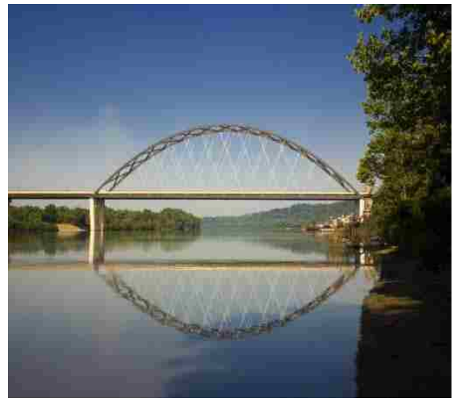
## 8.3. COMPOSITE TIE GIRDERS

In addition to the many possible tie girder arrangements the choice to make the tie girder composite with the bridge deck is another example of innovation that is becoming prevalent in the industry. The Hastings, MN Bridge (Gastoni, 2011) and the new Dubuque, IA (Cassity, Serzan, and McDonald, 2003) both use a composite tie girder. Over the years reasons for not making the tie girder composite with the bridge deck were mainly twofold. Engineers noted the additional and more complex analysis necessary for this composite action. Concrete bridge decks typically have a service life of 40 years with rehabilitation likely required at 20 years. As a result, for maintenance reasons, owners prefer the deck to remain independent so that it may be removed in part or in full without compromising the structures performance. Today advances in technology reduce both of those concerns. Engineers now engage in complex analysis routinely using structural analysis software and computational power unheard of by engineers 40 years ago. Similarly, bridges decks performance has increased thereby reducing concerns of completely removing major bridge decks. With concerns allayed new tied arch designs take advantage of the bridge deck resisting global tension and reducing the load on the tie girder. More importantly, including the deck in resisting the global tension provides an alternate load path for each of the tie girders as they are now connected by the deck.

When considering a composite tie-girder/bridge deck, engineers must consider that the concrete bridge deck must be continuous from end to end of the tied arch span. If relief joints are present, as with conventional design and construction, the benefit is lost. With the composite behavior, additional global live load stresses must be evaluated in the deck and measures taken to ensure the stresses remain below the required maximums. Alternately the deck can be post-tensioned to counter the tension stresses. Adding post-tensioning has the advantage of actively eliminating cracks or maintaining an acceptable crack width. A disadvantage is removing and replacing partial deck sections if necessary.

## 8.4. ALTERNATE CABLE ARRANGEMENTS

In Section 2, it was noted that there are three dominant hanger arrangements: the Langer System, comprised of vertical hangers, the Nielson System, using inclined hangers and the Network System, comprised of inclined hangers crossing multiple times. Further it was noted that many of the tied arches designed and constructed in North America in the 20$^{th}$ century are comprised of the Langer system with stiff tie-girders. Starting in northern Europe over 30 years ago the application of the Network Tied Arch Bridge became a viable alternate in the mid 2000s with the design and construction of the I-195 Bridge over the Providence River in Providence, Rhode Island followed by the Blennerhassett Bridge over the Ohio River in Blennerhassett, West Virginia. See Figure 8.8. Numerous other network tied arches followed in Kansas-Missouri border, north Texas and Little Rock, Arkansas.



a b

Figure 8.8. a. Providence River Bridge, b. Blennerhassett Bridge. Photos from Tveit (2006)

The original network tied arch, proposed by Per Tveit (2011) is based on the increased number of inclined hangers and connections such that flexure is minimized in the arch rib and tie girder, which then acts more like the bowstring arch bridges. Many of the early network tied arches designed and constructed in Norway and northern Europe have only minor structural steel in the tie girder and depend on concrete sections with partial or full post-tensioning. The concrete bridge deck, with post-tensioned concrete edge girders, becomes the primary tension element for the network tied arch. As a result Tveit (2011) is able to show a large reduction in structural steel weight compared with convention tied arches. Tveit (2006) demonstrates this through a case study for a redesign of the tied arch at Straubing, Germany (Langer System) using the network tied arch. Except for the Providence Bridge, the numerous network tied arches designed and built in the USA do not take full advantage of the shallow depth, concrete deck with edge girders, See Figure 8.9, as the sole tension tie. Rather, the network hanger system has become a tool to be used with other means to achieve a more redundant system.

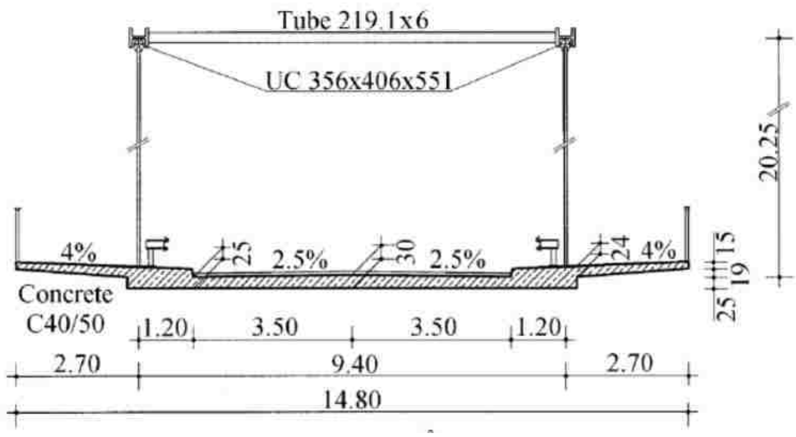



Figure 8.9. Network Tied Arch - Tie/Chord European Construction. Dimensions in cm for thickness and m for width/height, Figure taken from Tveit (2006)

Another characteristic of the original network tied arch is the circular or elliptical rib form. For vertical hangers, the parabola is the more optimal form.

The network hanger system does provide benefits over redundancy in the tie-girder. The combination of inclined hangers and overall increase in number of hanger reduces the flexural demand in the arch rib and provides inherent out-of-plane stiffness. This combined with the wind bracing typical of major through bridges increases the arch rib buckling capacity. These benefits combined could result in smaller arch rib members.

## 8.5. ARCH ARRANGEMENT

Along with the tie girder, the arch rib has also seen a variety of shapes and arrangements over the years. The arch ribs for bridges in this study are welded rectangular box members. Variations include pipes, H-sections (I shapes turned on their sides), trapezoidal welded box, welded plates to form a triangular section, and concrete filled pipe. China has been particularly active in research and application of the concrete filled steel tube (CFST) bridges. The Damen Avenue Bridge in Chicago, Illinois spans 308 feet over the

Chicago River used 4 feet diameter pipe for the arch ribs. The pipe has a one inch thickness throughout the length of the rib. The pipe was bent using heat induction techniques. The bridge Damen Street Bridge is a true arch bridge rather than a tied arch bridge. The Damen Street Bridge also employs free-standing arches – no wind bracing between the ribs. To help achieve this the lower 24 feet of the arch ribs are filled with concrete to provide the necessary lateral capacity.

Along with the Damen Street Bridge, the George Washington Carver Bridge over the Raccoon River in Des Moines, Iowa also uses free-standing arch ribs. The bridge is a tied arch with vertical hangers, a span of 280 feet and width of 110 feet and an arch rise of 56 feet. The rise to span ratio is 1:5. The arch ribs for this bridge are welded trapezoidal boxes and the tie girders are concrete with longitudinal post-tensioning. The concrete tie-girder and free standing arches are both shared by the Hastings, Minnesota TH 61 Tied Arch. This bridge described in Section 8.2.3 also has free-standing arches and the ribs are welded plate trapezoidal boxes as well. The span of the Hastings bridge is 265 feet longer than the Raccoon River Bridge. However, the Raccoon River bridge has vertical hangers while the Hastings Bridge has a network system of hangers.

# 9. CONSTRUCTION

The principle methods of constructing arch bridges are generally applicable to a number of structures, especially those with single spans. These methods include (1) Cantilever method, (2) Shored Construction, (3) Off-Site Construction and (4) Vertical-Horiztonal Construction. The contractor is responsible for the decision to use any one these methods and he must consider a myriad of risk factors to ensure the safe and economical erection. The design engineer responsible for the final arch arrangement works with the contractor and owner to ensure the means and methods of the contractor do not conflict with the structural design intent of any one element of the arch or the arch as a whole. The following sections discuss the general erection procedures.

## 9.1. CANTILEVER CONSTRUCTION

This method can be used in many locations and for differing types of arch bridges. It is characterized by the use of temporary towers referred to as "tie-back towers". As the arch rib construction progresses outward along the longitudinal bridge axis, cables are affixed to the erected arch rib segments to maintain the appropriate vertical profile. The cables supporting the segments are directed up and away from the arch rib back over the tie-back tower and fixed to a ground level support away from the bridge. As erection progresses new cables are added to the newer arch segments. See Figures 9.1 and 9.2. With the arch rib completed, the hangers can be erected and connected to the arch rib followed by the arch tie girder or just the deck if no tie girder is used. Hague and Blakemore (2004) and Blakemore and McCombs (2012) provide recent examples of an arch bridge constructed with cantilever construction. This method typically requires the use of a conventional water-base crane to erect the structural steel. In some case, spanning gorges for example, a high-line can be used to transport material from the end of the bridge to the beginning and vice versa.

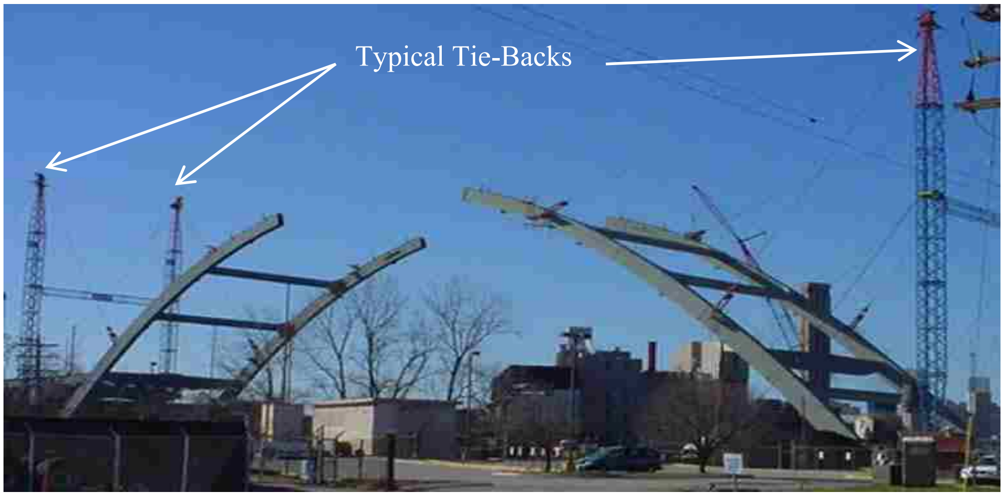



Figure 9.1. Example of Cantilevered Construction. Image from Hague and Blakemore (2004)


Figure 9.2. Tie-Backs used on Amelia Earhart Bridge. Image from Blakemore and McCombs (2012)

## 9.2. SHORED CONSTRUCTION

As the name implies this construction method is characterized by shoring towers strategically located within and under the span to support the bridge. The shoring towers may be set to support the tie girder or the arch rib or both. Use of this method is limited to sites where the height of the shoring towers is relatively short and do not impede navigation in a waterway, as may be required. It is also important to consider the locations for shoring. Where practical shoring should be placed under compression members but this is not always easy to work out pending the logistics of river traffic, subsurface conditions, erection, and access. In those cases where shoring must be placed under hangers, the hangers will need to be shored using temporary members. Niemietz and Bauer (1999), See Figure 9.3, describe a bridge over the Mississippi River erected with shored construction and subject restrictions due to navigation on the river. This method requires conventional water-based cranes to erect the structural steel for the bridge.

Figure 9.3. Single Span Construction using Shoring in the River. Image from Niemietz and Bauer (1999)

## 9.3. OFF-SITE CONSTRUCTION

Off-site construction refers to many things in the construction industry and the widely accepted meaning entails the fabrication and delivery of any necessary element to the actual site of the betterment. For the purpose of this study the term is broadened to include betterments fabricated, erected, or constructed merely off alignment. Where, in this case, alignment refers to the project or bridge centerline and where the majority of the construction activity takes place. In sense the work is likely to be close-by, in or out of the project right-of-way, just as long as it's off the alignment. There are two main categories of off-site construction, high level and low level. High level off-site construction refers to bridges that are essentially erected at or about the same elevation they will be in their final positions and then transported in that high-level condition. This is a considerable risk and requires much planning and bracing to ensure the stability of the bridge at height. The second category has considerably less risk and is termed low-level off-site construction. This method involves erecting the bridge off-site just above the ground and transported in this low position to the final location. Once at the final location, the bridge is lifted using high-strength strand-jacks to hoist the bridge into the final position. Off-site construction is gaining in popularity especially when combined with certain construction methods such as self-propelled-modular-travelers or SPMTs. SPMTs permit modular construction to take place off-site and be transported to their final location in the project. SPMT use is spectacularly highlighted in the article by Furrer and Hasbrouck (2011). The bridge presented by Furrer and Hasbrougk (2011) was erected on the bank of the Mississippi River at Hastings, MN, (low-level) transported onto barges via SPMTs and then floated upriver to final location where it was hoisted into place as single 545 feet unit. Ini contrast, the Rte 364 Bridge in West St. Louis County over the Missouri River is an example of high-level erection. It is also worth noting that many high- and low-level bridge transports are floated with the aid of tugboats. This is not the case for the Rte 364 Bridge. On Rte 364, the barges floating the bridge have large winch motors on their forward port and starboard positions. The winch lines are anchored to 10,000 pound Naval anchors that are placed well upstream of the bridge to provide ample room to winch the bridge into place. See Figure 9.6. In the best case, bridges are floated upstream for better control. Both methods are shown in the Figures 9.4 and 9.5 below.

Figure 9.4. Low-Level Transport. Hasting Bridge at the Mississippi River, Furrer and Hasbrouck (2011)

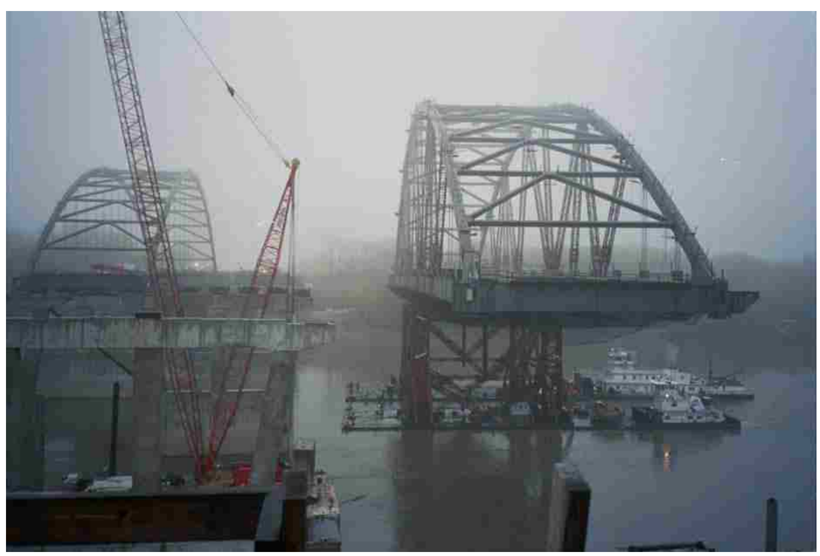
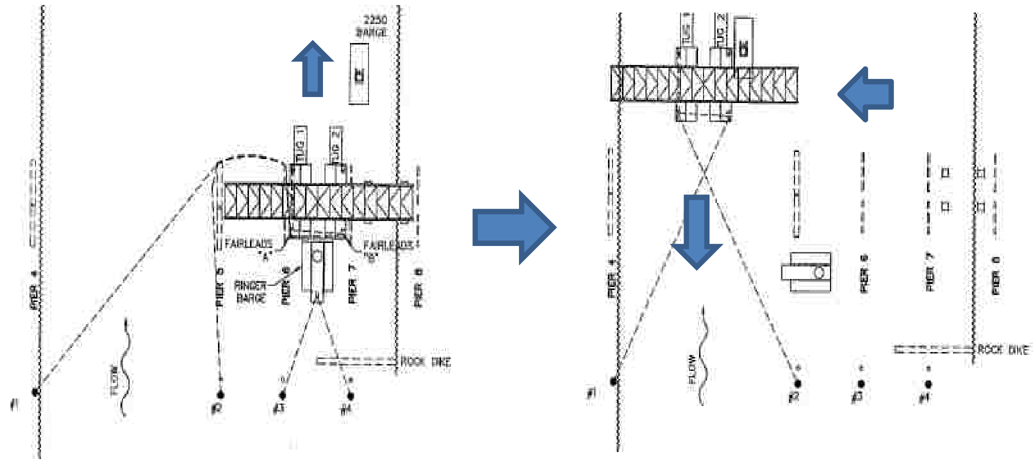


Figure 9.5. High-level Bridge Transport, Rte 364 at Missouri River. Photo Courtesy of Jacobs




a) b)

Figure 9.6. Schematic showing transport of Rte 364 Bridge. From temporary position a) to directly downstream of final position b). Note four anchor points in bottom of schematic. Barges and bridge were winched into place

## 9.4. VERTICAL-HORIZONTAL CONSTRUCTION

Fu and Wang (2015) present two interesting methods of arch construction, the vertical and horizontal rotation methods. These two methods are emphasized in the Yajisha Bridge, a continuous half-thru tied arch, over the Pearl River located in Guangzhou, Guangdong, China. The arch rib of a continuous, half thru arch will extend down below the roadway to a founding abutment before extending out away from the main span to form the under support for the exterior bridge. As a result, the contractor can elect to use the permanent foundation numerous ways to facilitate erecting the arch rib. The contractor may elect to erect the arch rib on the proposed bridge longitudinal alignment which means working in and over the waterway. Alternately the contractor may elect to erect the arch rib over land adjacent to the waterway and at an right angle to longitudinal bridge axis. The latter method allows the contractor use conventional, land-based equipment, while eliminating or reducing risks associated with working over water. In this example, the contractor built one half of the arch span over land on each bank, normal to the longitudinal axis of the waterway and much closer to the ground. The contractor constructed the foundation abutment first to support a temporary vertical tower, a tie-back, to re-direct erection cables forward and back of the tower to hold the arch in position. The key for the vertical rotation method is to found the tie-back tower on a pivot along with the bottom of the arch rib on a steel track/beam encircling the tie-back. Thus when the arch is constructed so that it will reach out over the waterway, it can be raised vertically (about a horizontal axis) and rotated, about the vertical axis of the tie-back tower, to align with the intended longitudinal axis of the bridge. Once the rotation is completed the mid-span connection can be made over water and from this point forward all bridge construction can proceed from the arch rib as a platform. Throughout the reference several photos of construction are provided to clarify the horizontal and vertical rotation methods and among these photos more routine methods of arch erection, such as with falsework towers, is also seen.

Fu and Wang (2015) provide details for vertical/horizontal construction using the Yajisha Bridge. See Figure 9.7. The Yajisha Bridge is a continuous half-thru tied arch, over the Pearl River located in Guangzhou, Guangdong, China.

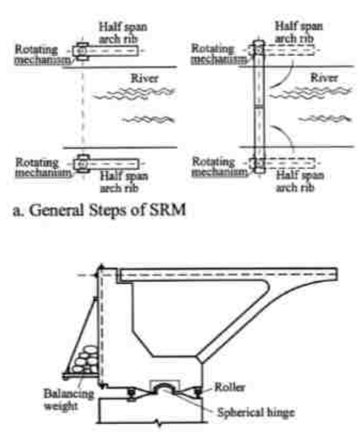



Figure 9.7. Superstructure Rotation Method. Image from Zhang, El-Diraby (2006)

# 10. RESULTS

## 10.1. STATIC RESULTS

Characteristics of the four tied arch structures examined as part of this study were developed and reported for application to preliminary design of future tied arches. The characteristic features include but are not limited to rise to span ratios, weight per square foot of bridge footprint, weight of structural steel, including the most salient components such as the arch rib and arch tie, relative to total dead load weight of the bridges, total live load relative to the total structure load, arch rib and arch tie girder dimensions. Hanger arrangement, spacing and loads, both dead and live load are examined as well. The results of this synthesis for tied arch bridge arrangement using ASD is presented as are the results of similar features designed using the latest LRFD code.

The tied arch characterisitics are captured in Tables 10.1 through 10.5.

Table 10.1. Bridge Rise to Span Properties

| Bridge | Span (feet) | Rise (feet) | Panels | Rise/Span | Rise to Span Ratio |
|---|---|---|---|---|---|
| Jefferson Barracks | 910 | 182 | 18 | 0.200 | 1:5 |
| City Island | 670 | 132 | 16 | 0.197 | 1:5.10 |
| Page Avenue | 617 | 124 | 16 | 0.201 | 1:4.97 |
| Tennessee River | 535.33 | 88.88 | 14 | 0.166 | 1:6 |

Based on our review of the literature we expect to see efficient and economical arches to be fairly shallow to ensure arching action thus producing more thrust at the arch knuckle and to minimize arch rib and hanger length. The bridges of this study fall within a rise to span ratio range of 1:5 to 1:6 as recommended meeting the aforementioned objectvies. The Page Avenue Bridge falls just outside this expectation, on the shallower side. Still the Page Avenue bridge rise to span remains very close to the anticipated range.

Table 10.2. Bridge Rib and Tie Properties

| Bridge | $I_{tie}$<br>$I_{rib}$ | Ratio $I_{tie}$:$I_{rib}$ | Ratio $A_{tie}$:$A_{rib}$ |
|---|---|---|---|
| Jefferson Barracks | 2,351,846 $in^4$<br>270,787 $in^4$ | 8.7 | 1.23 |
| City Island | 711,800 $in^4$<br>170,900 $in^4$ | 4.2 | 0.998 |
| Page Avenue | 762,985 $in^4$<br>277,074 $in^4$ | 2.8 | 0.923 |
| Tennessee River | 381,131 $in^4$<br>36,387 $in^4$ | 10.5 | 1.20 |

Table 10.2 demonstrates the strong tie girder concept for the Jefferseon Barracks and Tennessee River Bridges and though the City Island and Page Avenue Bridges have much smaller Itie to Irib ratios the tie girder, for these cases, will have about 3 to 5 times the moment of the rib. Moreover, though the arch tie girder is much deeper than the arch rib, to attain such a high second moment of interia, the areas for both the arch tie and arch rib remain very similar, within 20%.

Table 10.3 provides total dead load per bridge area, which is always of interest to the engineer for preliminary design of the arch, substructure and estimated construction cost. The steel and concrete are separated in later sections. Finally, the table shows the ratio of I/A for the arch rib relative to the bridge span.

Table 10.3. Bridge Weights

| Bridge | Span (feet) | Width (feet) | Dead Load Plans (kips) | Weight (psf) | Dead Load SAP2000 (kips) | I/A |
|---|---|---|---|---|---|---|
| Jefferson Barracks | 910 | 62.0 | 17,568 | 311.0 | 17,136 | 769 |
| City Island | 670 | 79.0 | - | 244.0 | 12,924 | 464 |
| Page Avenue | 617 | 90.88 | 14,848 | 264.0 | 14,800 | 700 |
| Tennessee River | 535.33 | 46.00 | 6,256 | 254.0 | 6,016 | 218 |

Table 10.4. Bridge Arch Member Weight to Total Weight

| Bridge | Span (feet) | Width (feet) | Weight (kips) | Total Dead Load (kips) | % |
|---|---|---|---|---|---|
| Jefferson Barracks | 910 | 62.0 | 2,661 | 17,136 | 16 |
| City Island | 670 | 79.0 | 1,605 | 12,924 | 12 |
| Page Avenue | 617 | 90.88 | 2,172 | 14,800 | 15 |
| Tennessee River | 535.33 | 46.00 | 696 | 6,016 | 12 |

Table 10.5. Bridge Tie Girder Weight to Total Weight

| Bridge | Span (feet) | Width (feet) | Weight (kips) | Total Dead Load (kips) | % |
|---|---|---|---|---|---|
| Jefferson Barracks | 910 | 62.0 | 3,134 | 17,136 | 18 |
| City Island | 670 | 79.0 | 1,400 | 12,924 | 11 |
| Page Avenue | 617 | 90.88 | 1,767 | 14,800 | 12 |
| Tennessee River | 535.33 | 46.00 | 807 | 6,016 | 13 |

Tables 10.4 and 10.5 show the weights for the arch rib and tie respectively for all of the study bridges. In each case, the arch rib ranges from 12% to 16% of the total dead load while the arch tie ranges from 11% to 18% of the total dead load. Combined, the arch and tie range from 23% to 34%. The concrete bridge deck typically accounts for 30% of the total dead load leaving a range of 36% to 47% for the floorsystem (floorbeams, stringers and stringer bracing) and all of the upper and lower wind bracing.

**10.1.1 Static Dead Load Results.** Figure 10.1 presents the normalized dead load (FEA to Plans) axial load for the major elements of the Tied Arch Bridge. Earlier it was explained that the FEA model was calibrated to the dead loads on the plans. To that end, the figure shows good correlation for all major components falling within ±5% of the plan dead load. As noted earlier this load does not include ancillary structures such as the inspection walkway or any changes in the design plans capture in the "as-built" plans.

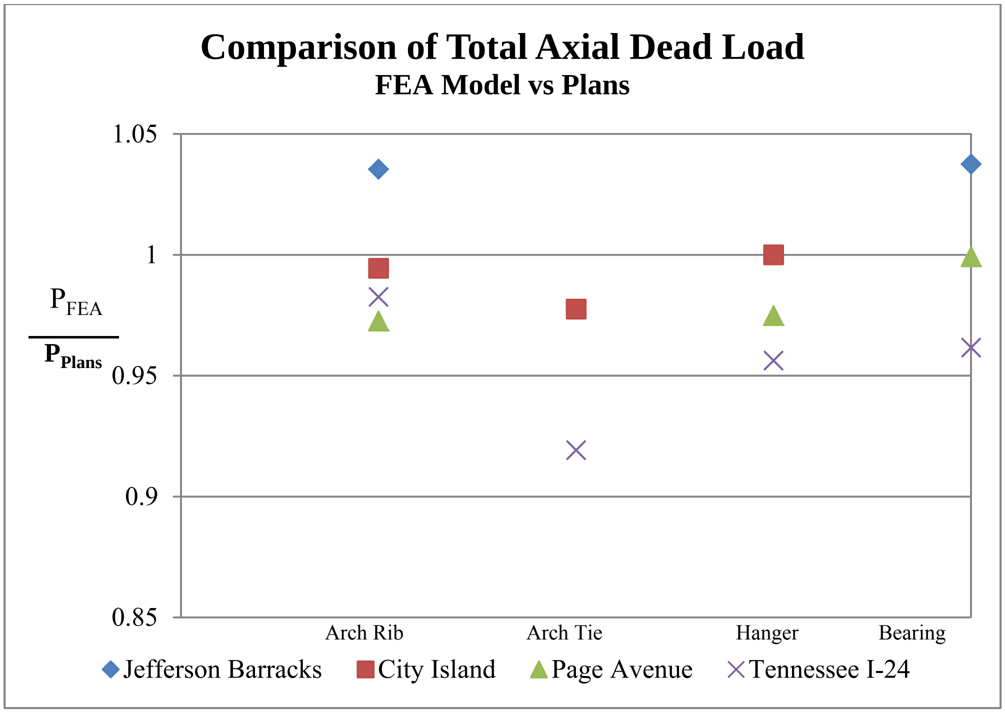



Figure 10.1. Normalized Axial Dead Load for all Study Bridges

Figure 10.2 demonstrates the relationship of the ratio of second moments of inertia for the rib to tie and the resulting moment demands for the rib to tie. This figure graphically demonstrates the data in Table 6.10. This figure confirms the performance of the rib to tie for a range of rigidities (assuming Young's modulus to be constant). For the case where the rib has many times the rigidity of the tie girder, the moment in the rib can be expected to be 4 to 8 times that of the tie girder. At this point, the rib behaves more as a true arch. Conversley, when the rib is many times stiffer than the rib, the tie girder behaves more as a beam and the arch becomes functionless.

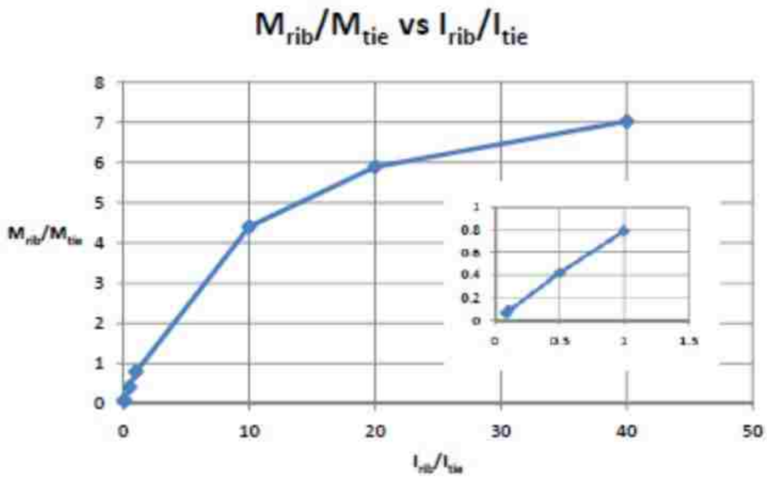



Figure 10.2. Relationship of Arch Rib Moment to Arch Tie Moment

**10.1.2 Static Live Load Results.** The following graph compares the live load for the FEA model to the information tablulated on the design plans; the pre-LRFD live load of the plan sets to that of the current live load in the AASHTO LRFD code. Figure 10.3 shows the normalized axial load (FEA to plan value) for each of the main Tied Arch Bridge element. A good correlation would have the values close to unity. However, there is much to note to provide a context in which to view these results. The application of live load is not as straight forward and consistent as one would like from engineer to engineer and office to office. That many of these plans are 40 years old adds generations to the mix as well. The AASHTO code, whether from 1965 to present, is clear on loading but provides some interpretation as to how many lanes are placed on a bridge. The code makes clear that lanes are to be 12 feet wide and within that distance a vehicle lane is 10 feet with the distance from wheel line to wheel line given at 6 feet. It further makes clear no partial lanes are to be used. However, when a fraction of a lane results it is the practice of some to round up and reduce the 12 feet lane. This obviously results in more live load on a structure than the code actually specifies. For long span structures, the lane load, full or patch, will typically control the main members such as the rib, tie girder, hangers, and bearings. This is a straight-forward analysis especially for the computer-aided analysis. Yet most of these bridges were analyzed and designed at a time when computers were few and of limited capacity in the office. So engineers calculated a distribution factor for each of the planar arches by placing as many vehicles as possible between the roadway barriers but offset to load one arch greater. Many times the number of vehicles in this analysis was more conservative. As a result this comparison captures a true three dimensional stiffness analysis using code defined vehicles and surface influence lines to a conservative and subjective two dimensional analysis. Another source for difference is in the multiple presence factor which accounts for the probability of vehicles being present at the same location in other lanes. The current LRFC code has smaller values for greater lanes loaded than the HS20 model uses. Other possible differences include accounting for construction tolerances and including eccentric connections or other secondary effects that will add to the moment effect. One difference is the combination of values reported. Not all maximums occur at the same time and so there is a question of whether or not the maximum axial load case also produced a maximum moment. Without the calculations it's difficult to know if all maximums are listed or not. Lastly, not all values reported the impact load separately making it difficult to know the exact value used. However, for bridges of the spans reported impact is generally as low as 5%.

With this in mind the values for the axial load show for each of the main members to be within ±25%. Figure 10.4 also shows a similar result for the moments in the arch rib and tie.

Figures 10.5 and 10.6 show a comparison between the normalized axial load and strong axis moment (HS20 to HL93).

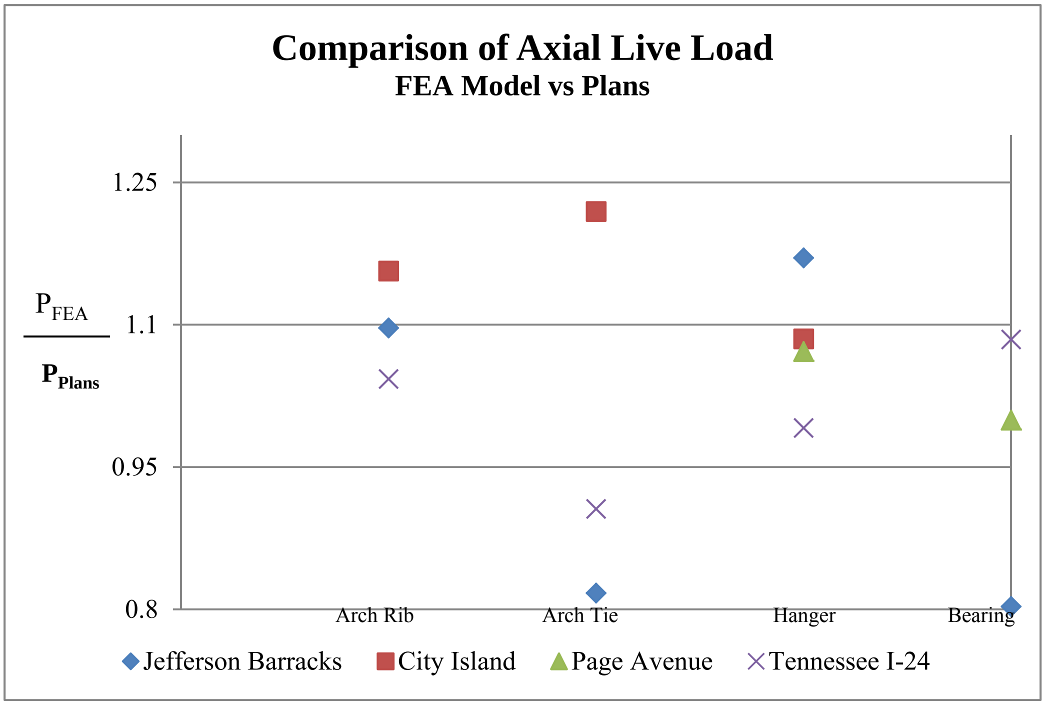



Figure 10.3. Normalized Axial Live Load for all Study Bridges

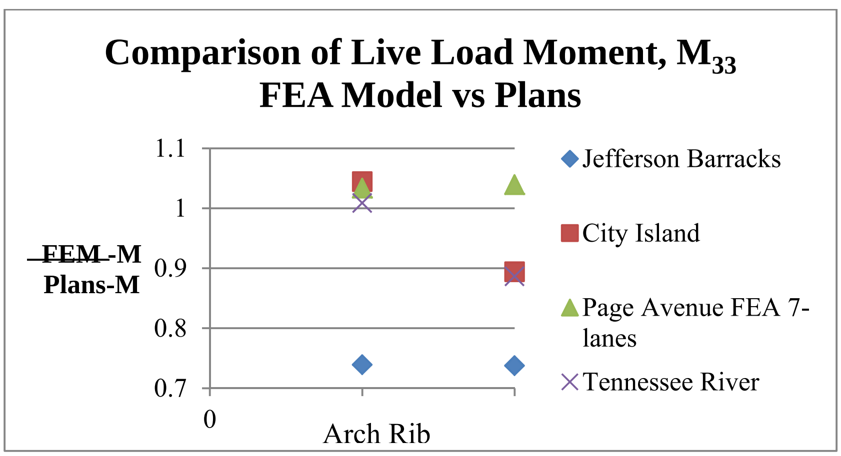



Figure 10.4. Normalized Live Load Moment for all Study Bridges

The HL 93 value is generated using the FEA models. Since the HL93 vehicle is a heavier load model than the older HS20 it was thought the HL93 would result in larger reactions (moments, shears and reactions). This is the case for much of the elements under axial load but not necessarily true for the moment in the arch rib and tie. The reader is reminded that the Page Avenue Bridge is designed using a modified HS20 vehicle model such that all magnitudes are increased by a factor of 1.25. It is also known that the Page Avenue did include additional moment to account for unintentional eccentricity due to construction.

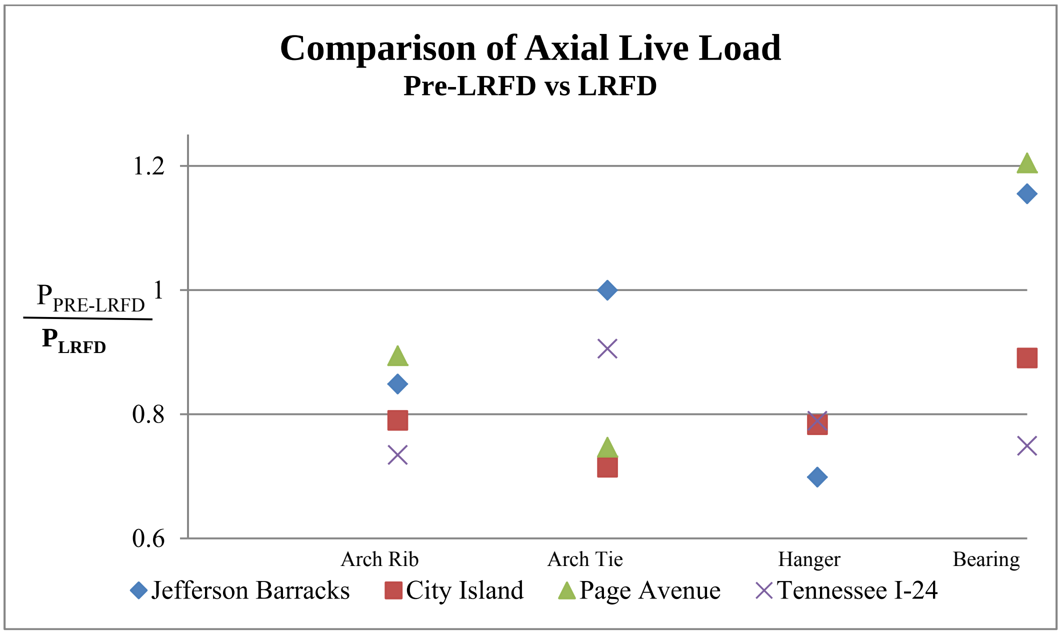



Figure 10.5. Normalized Axial Live Load (Plans) to FEA - LRFD

To summarize the static dead and live load portion, we see that there is sufficient support that all of the mass and stiffness is accounted for. The stiffness as compared via the deflections match those of the plans for the US 24 Bridge over the Tennessee River and the work done by Ren et al (2004). Though the live load differences are greater than preferred we know that today's computational is not only reasonable but free from much of the subjectiveness in the process generations ago.

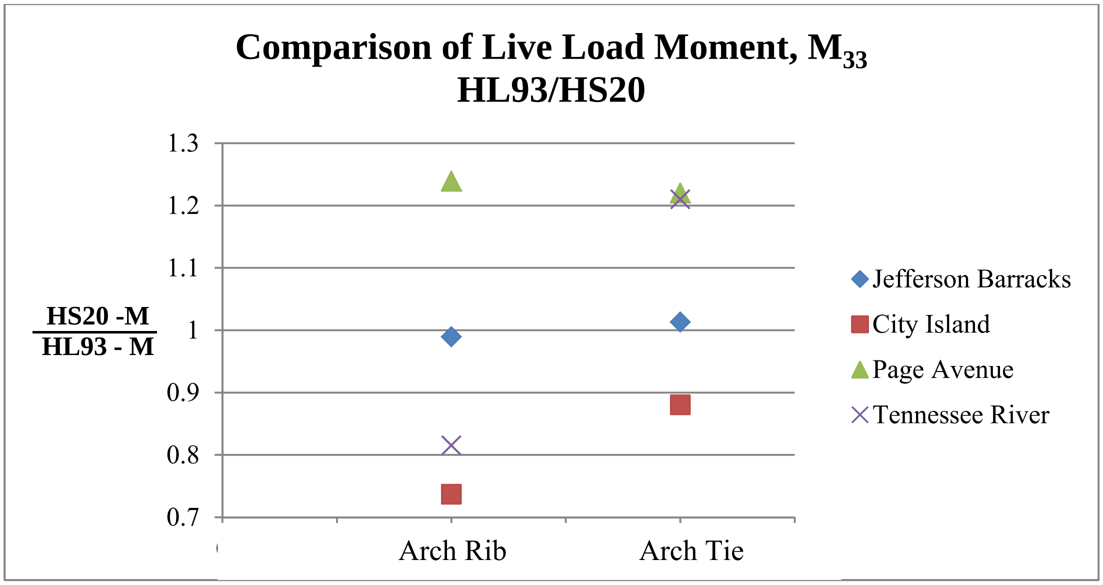



Figure 10.6. Normalized Live Load Moment, HS20 to HL93

Lastly, we see that using LRFD will not drive up cost with larger members. For the benefit of greater reliability and consistency in the LRFD the overall preliminary result is very similar to those from earlier codes.

## 10.2. DYNAMIC RESULTS

Dynamic characteristics of the four tied arch structures examined as part of this study were developed and reported for application to preliminary design and potential for structural health monitoring of future tied arches. Two models were developed, a lower bound stiffness model and an upper bound stiffness model. The mass remained the same for both models. The characteristic features include frequency and mode shapes.

Mass participation ranges from 43% to 92% for the lower bound models and for the upper bound stiffness model a range of 42% to 89% is noted.

Select frequencies, periods, and mode shapes for the four bridges, for both stiffness models, are developed. Thirty modes were assessed in the FEA models and an arbitrary cut off of 1% mass participation was used to collect the tabulated data. The data shows the tied arch bridges to be characterized by low, relatively close frequencies. The shorter bridge, US 24 over the Tennessee River, ranges from 0.514-4.94 Hz for the lower bound stiffness and 0.589-2.922 Hz for the upper bound stiffness. The City Island and Page Avenue Bridges, having similar features have frequencies of 0.277-3.66 Hz for the lower bound and 0.283-3.655 Hz for the upper bound stiffness. The longer bridge, Jefferson Barracks, has a lower bound range from 0.313-3.463 Hz and 0.327-3.037 Hz for the upper bound. The four bridges share similar mode shapes as shown in the aforementioned tables. However the first two mode shapes are typically asymmetric full sinuous for the first vertical/longitudinal mode or symmetric half sinuous for the first transverse mode.

Table 10.6 shows a comparison of the modal parameters for the I-24 Bridge over the Tennessee River from this study to that of Ren et al (2004).

Table 10.6. US 24 Bridge over the Tennessee River Modal Comparison

| Mode | FEA Model+ Hz | Ren et al (2004) Hz |
|---|---|---|
| First Vertical | 0.589 | 0.561 |
| Second Vertical | 1.148 | 1.149 |
| Third Vertical | 1.565 | 1.749 |
| First Transverse | 0.672 | 0.717 |
| Second Transverse | 0.888 | 1.557 |

+ - Upper Bound Stiffness

The hanger dynamic parameters are reported for modes 1 to 3 respectively. The range of frequencies for the hangers, from middle to end hanger is 0.6-24 Hz in mode 1. For mode 2, the range is 3-48 Hz and for mode 3, 3-72 Hz for the middle to end hanger respectively.

Sources of excitation include traffic, wind and earthquake. Traffic related vibrations are determined to range from 1.7-2.3 Hz for a velocity of 55 mph and a range from 2-2.7 Hz for a vehicle velocity of 70 mph. Wind induced vibrations may become problematic for vertical bending modes having a frequency less than 1 Hz. Lastly, it is shown that vibrations due to ground motions are a concern since most frequency content of ground motion is low frequency similar to the bridges. Typically this motion will not last long enough to set a major bridge into motion let alone resonance. However for the Central US it is shown that large magnitude events are capbable of providing longer duration strong (low frequency) ground motion which can have a more pronounced effect on the structure. As a result, the dynamic parameters of the tied arch bridge will prove valuable to bridge planners and designers.

**10.3. CONCLUSIONS**

Tied Arch Bridges are a cost effective, aesthetic long span solution for major river crossings and are experiencing resurgence in popularity with owners and communities. This is especially true as details that once plagued these bridges are eliminated and newer, more robust and redundant arrangments are developed. Understanding the complex dynamics of a structure begin with a good understanding of the static performance of the structure. With a better understanding of the base tied arch, variations may be added with greater confidence that dynamic effects of those variations can be understood as well. To that end this work demonstrates the characteristics of tied arch bridges for static and dynamic loads.

Four major tied arch bridges having different spans, widths, rise to span ratios, and wind bracing are examined to produce the most characteristic features. These features will aide bridge planners and designers to have an idea for the type and size of main bridge featuers and elements. These will also aide in more accurately assessing the anticipated construction costs.

Finite element models of the four bridges were developed and explained with the results shown demonstrating good correlation to both dead and live loads. The FEM were then used to develop the dynamic parameters for each of the bridges. Those parameters are tabulated and compared to various likely sources of vibration.

The four bridges of this study were originally designed using either Allowable Stress Design (ASD) or Load Factor Design (LFD). Preliminary design was developed for the current AASHTO code to compare the resulting cross-section with that of the original plans. It was determined that the current member type and sizes would provide a good start for final design. Thus, only minor changes to the overall bridge features and characteristics are expected over the original work.

The work demonstrates the most recent advances in tied arch bridge design, with a focus on making the tie girder less redundant while fulfilling the original design intent of a strong tie girder – slender arch rib concept. Bridge decks composite with the tie girder are examined as are the newest hanger arrangments, network hangers.

The report also discusses structural health monitoring with the possibility of using modal parameters for assessing the health of tied arch bridges.

While not all of these topics are discussed indepth, the topics covered do provide a strong foundation for additional or future work.

### 10.4. FUTURE WORK

Additional work to consider for the topic of Tied Arch Bridges is listed below:

Redundancy Study – With the arch tie-girder identified as a non-redundant, fracture critical member, a study to determine the behavior of the bridge as a whole post-fracture of a hanger or element of the tie girder. The structure is inherently indeterminate as are cable stayed bridges. Computational work on cable stayed bridges has shown certain elements such as the floorbeams not to be non-redundant and not fracture critical. This designation has broad impacts on inspection protocols and reducing such effort can permit allocating needed resources to other needs.

Structural Health Monitoring – With several tied arches in the central region, field data acquisition for these bridges could provide valuable information in providing physical evidence to compare with the dynamic data herein. In addition, more analytic work can be done to assess what the dynamic response of these structures is to fracture of a key element. The result of this study demonstrate the frequency range for the bridge overall and some elements. As a result we understand that an assessment method based on the flexibility method may be more appropriate and that methods used to capture the dynamic parameters will need to address ambient vibrations and perhaps use those vibrations to capture the necessary dynamic properties. The results of such a study could provide insight to the anticipated response of in service bridges.

Revised Member Details – The work performed can be extended to include the response of the study bridges to variable tie-girder cross sections. Such work would involve including more detailed substructured FEM of areas of interest using loading from the larger, less refined global model. This would provide the industry with insight to how well these, largely untried, details for redundancy will work.

Similar to this work, a study of the characteristics of the newer network tied arches is suggested and could include a comparison to the tied arches of this report to highlight the benefits of the newer, contemporary work.

## APPENDIX A

## ANALYSIS OUTPUT FOR CITY ISLAND BRIDGE

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**Static and Dynamic Characteristics of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: Rev 012 HS20 C2F LBK**
**City Island Bridge**

**26 June 2016**

Section 1 General Load Input Information

Dead Load

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 124 |
| PDELTA | Full Load | U1 | 124 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns |
|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | |
| PDELTA | 0.1 | 1.618 | | |

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | StageMinTD | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther |
|---|---|---|---|---|---|---|
| DEAD | | Yes | Yes | Yes | Yes | Yes |
| PDELTA | | Yes | Yes | Yes | Yes | Yes |

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TimeDepMat | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|---|
| DEAD | | 10 | 0.01 | 1. | No |
| PDELTA | | 10 | 0.01 | 1. | No |

Live Load

Table: Case - Moving Load 1 - Lane Assignments, Part 1 of 2

Table: Case - Moving Load 1 - Lane Assignments, Part 1 of 2

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded |
|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 1 | 4 |

Table: Case - Moving Load 1 - Lane Assignments, Part 2 of 2

Table: Case - Moving Load 1 - Lane Assignments, Part 2 of 2

| Case | AssignNum | NumLanes |
|---|---|---|
| LIVELOAD | 1 | 6 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | LTLANE1 |
| LIVELOAD | 1 | LTLANE1C |
| LIVELOAD | 1 | LTLANE2 |
| LIVELOAD | 1 | RGTLANE1 |
| LIVELOAD | 1 | RGTLANE1C |
| LIVELOAD | 1 | RGTLANE2 |

Table: Case - Moving Load 3 - MultiLane Factors

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1. |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.9 |
| LIVELOAD | 4 | 0.75 |
| LIVELOAD | 5 | 0.75 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |
| LIVELOAD | 10 | 0.75 |
| LIVELOAD | 11 | 0.75 |
| LIVELOAD | 12 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 13 | 0.75 |
| LIVELOAD | 14 | 0.75 |
| LIVELOAD | 15 | 0.75 |
| LIVELOAD | 16 | 0.75 |
| LIVELOAD | 17 | 0.75 |
| LIVELOAD | 18 | 0.75 |
| LIVELOAD | 19 | 0.75 |
| LIVELOAD | 20 | 0.75 |
| LIVELOAD | 21 | 0.75 |
| LIVELOAD | 22 | 0.75 |
| LIVELOAD | 23 | 0.75 |
| LIVELOAD | 24 | 0.75 |
| LIVELOAD | 25 | 0.75 |
| LIVELOAD | 26 | 0.75 |
| LIVELOAD | 27 | 0.75 |
| LIVELOAD | 28 | 0.75 |
| LIVELOAD | 29 | 0.75 |
| LIVELOAD | 30 | 0.75 |
| LIVELOAD | 31 | 0.75 |
| LIVELOAD | 32 | 0.75 |
| LIVELOAD | 33 | 0.75 |
| LIVELOAD | 34 | 0.75 |
| LIVELOAD | 35 | 0.75 |
| LIVELOAD | 36 | 0.75 |
| LIVELOAD | 37 | 0.75 |
| LIVELOAD | 38 | 0.75 |
| LIVELOAD | 39 | 0.75 |
| LIVELOAD | 40 | 0.75 |
| LIVELOAD | 41 | 0.75 |

Modal Analysis

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift Cyc/sec | EigenCutoff Cyc/sec | EigenTol |
|---|---|---|---|---|---|---|
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Structure Frame Member Imput

Table:  Frame Section Properties 01 - General, Part 1 of 7

Table:  Frame Section Properties 01 - General, Part 1 of 7

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| ARL0R3 | A992Fy50 | SD Section | | | |
| ARR3R5 | A992Fy50 | SD Section | | | |
| ARR5R11 | A992Fy50 | SD Section | | | |
| Cable | ASTM A586G | General | 1. | 1. | |
| ENDFB | A992Fy50 | I/Wide Flange | 8.8333 | 1.5 | 0.0833 |
| INTFB | A992Fy50 | I/Wide Flange | 9. | 1.6667 | 0.1667 |
| LBBL0L2 | A992Fy50 | SD Section | | | |
| LBBL2L7 | A992Fy50 | SD Section | | | |
| LBTALL | A992Fy50 | SD Section | | | |
| PBEAM | 3500psi | Rectangular | 9.5 | 7.5 | |
| PCOL | 3500psi | Rectangular | 8. | 14.2 | |
| Stringer | A36 | I/Wide Flange | 2.7417 | 0.9583 | 0.0617 |
| TGL0L2 | A992Fy50 | SD Section | | | |
| TGL2L4 | A992Fy50 | SD Section | | | |
| TGL4L12 | A992Fy50 | SD Section | | | |

Table:  Frame Section Properties 01 - General, Part 2 of 7

Table:  Frame Section Properties 01 - General, Part 2 of 7

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ARL0R3 | | | | 2.3646 | 7.750177 | 8.245495 |
| ARR3R5 | | | | 2.2222 | 7.390792 | 7.463477 |
| ARR5R11 | | | | 2.0799 | 6.985421 | 6.6953 |
| Cable | | | | 0.0667 | 0.000707 | 0.000354 |
| ENDFB | 0.0313 | 1.5 | 0.0833 | 0.5212 | 0.000646 | 6.481335 |
| INTFB | 0.0313 | 1.6667 | 0.1667 | 0.8269 | 0.004911 | 12.53867 |
| LBBL0L2 | | | | 0.2007 | 0.087758 | 0.062943 |
| LBBL2L7 | | | | 0.1721 | 0.074211 | 0.053658 |
| LBTALL | | | | 0.2413 | 0.141648 | 0.119759 |
| PBEAM | | | | 71.25 | 692.994044 | 535.859375 |
| PCOL | | | | 113.6 | 1570.527787 | 605.866667 |
| Stringer | 0.0458 | 0.9583 | 0.0617 | 0.2382 | 0.000227 | 0.280883 |
| TGL0L2 | | | | 2.0764 | 10.821517 | 29.156993 |
| TGL2L4 | | | | 2.2795 | 11.256056 | 34.330796 |
| TGL4L12 | | | | 2.0764 | 10.821517 | 29.156993 |

Table:  Frame Section Properties 01 - General, Part 3 of 7

Table:  Frame Section Properties 01 - General, Part 3 of 7

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARL0R3 | 3.892669 | 0. | 1.1533 | 1.1988 | 3.502511 | 2.278635 |
| ARR3R5 | 3.75418 | 0. | 1.1409 | 1.0683 | 3.198633 | 2.197569 |
| ARR5R11 | 3.615691 | 0. | 1.1281 | 0.9373 | 2.895265 | 2.116502 |
| Cable | 0.000354 | 0. | 0.06 | 0.06 | 1. | 1. |

Table: Frame Section Properties 01 - General, Part 3 of 7

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ENDFB | 0.046878 | 0. | 0.2765 | 0.2083 | 1.467478 | 0.062505 |
| INTFB | 0.128656 | 0. | 0.2817 | 0.4631 | 2.786371 | 0.154385 |
| LBBL0L2 | 0.058228 | 0. | 0.1008 | 0.0963 | 0.089515 | 0.082202 |
| LBBL2L7 | 0.049649 | 0. | 0.086 | 0.0822 | 0.076879 | 0.070091 |
| LBTALL | 0.081676 | 0. | 0.1529 | 0.0849 | 0.126339 | 0.115304 |
| PBEAM | 333.984375 | 0. | 59.375 | 59.375 | 112.8125 | 89.0625 |
| PCOL | 1908.858667 | 0. | 94.6667 | 94.6667 | 151.466667 | 268.853333 |
| Stringer | 0.009071 | 0. | 0.1256 | 0.0985 | 0.204897 | 0.018931 |
| TGL0L2 | 3.788958 | 0. | 1.3215 | 0.7163 | 5.795179 | 2.331666 |
| TGL2L4 | 3.96775 | 0. | 1.3387 | 0.909 | 6.781392 | 2.441692 |
| TGL4L12 | 3.788958 | 0. | 1.3215 | 0.7163 | 5.795179 | 2.331666 |

Table: Frame Section Properties 01 - General, Part 4 of 7

Table: Frame Section Properties 01 - General, Part 4 of 7

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARL0R3 | 4.06977 | 2.787109 | 1.86737 | 1.28306 | | No |
| ARR3R5 | 3.736111 | 2.665509 | 1.83264 | 1.29976 | | No |
| ARR5R11 | 3.405418 | 2.543909 | 1.79419 | 1.31849 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| ENDFB | 1.681061 | 0.095835 | 3.5265 | 0.29991 | | No |
| INTFB | 3.04197 | 0.23366 | 3.89393 | 0.39444 | | No |
| LBBL0L2 | 0.103275 | 0.099738 | 0.55994 | 0.53857 | | No |
| LBBL2L7 | 0.088331 | 0.085312 | 0.55829 | 0.53704 | | No |
| LBTALL | 0.152572 | 0.132416 | 0.70446 | 0.58177 | | No |
| PBEAM | 169.21875 | 133.59375 | 2.74241 | 2.16506 | | Yes |
| PCOL | 227.2 | 403.28 | 2.3094 | 4.09919 | | Yes |
| Stringer | 0.236956 | 0.029704 | 1.08597 | 0.19515 | | No |
| TGL0L2 | 6.978073 | 2.647625 | 3.74729 | 1.35085 | | No |
| TGL2L4 | 8.003219 | 2.812664 | 3.8808 | 1.31932 | | No |
| TGL4L12 | 6.978073 | 2.647625 | 3.74729 | 1.35085 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 7

Table: Frame Section Properties 01 - General, Part 5 of 7

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| ARL0R3 | No | Red | 796.339 | 21.52 | No | 1. |
| ARR3R5 | No | Cyan | 451.295 | 12.2 | No | 1. |
| ARR5R11 | No | Magenta | 597.07 | 16.14 | No | 1. |
| Cable | No | Yellow | 91.643 | 2.85 | No | 1. |
| ENDFB | No | Cyan | 46.401 | 1.25 | No | 1. |
| INTFB | No | Yellow | 600.205 | 14.92 | No | 1. |
| LBBL0L2 | No | Blue | 49.83 | 1.41 | No | 1. |
| LBBL2L7 | No | Cyan | 128.194 | 3.62 | No | 1. |
| LBTALL | No | Gray8Dark | 338.39 | 10.52 | No | 1. |
| PBEAM | No | Cyan | 1688.625 | 52.48 | No | 1. |
| PCOL | No | Magenta | 2686.867 | 83.51 | No | 1. |

Table: Frame Section Properties 01 - General, Part 5 of 7

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| Stringer | No | Green | 914.846 | 21.87 | No | 1. |
| TGL0L2 | No | Gray8Dark | 426.049 | 10.59 | No | 1. |
| TGL2L4 | No | Green | 467.728 | 11.63 | No | 1. |
| TGL4L12 | No | Red | 852.098 | 21.19 | No | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 7

Table: Frame Section Properties 01 - General, Part 6 of 7

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARL0R3 | 1. | 1. | 1. | 1. | 1. | 1. |
| ARR3R5 | 1. | 1. | 1. | 1. | 1. | 1. |
| ARR5R11 | 1. | 1. | 1. | 1. | 1. | 1. |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| ENDFB | 1. | 1. | 1. | 1. | 1. | 1. |
| INTFB | 1. | 1. | 1. | 1. | 1. | 1. |
| LBBL0L2 | 1. | 1. | 1. | 1. | 1. | 1. |
| LBBL2L7 | 1. | 1. | 1. | 1. | 1. | 1. |
| LBTALL | 1. | 1. | 1. | 1. | 1. | 1. |
| PBEAM | 1. | 1. | 1. | 1. | 1. | 1. |
| PCOL | 1. | 1. | 1. | 1. | 1. | 1. |
| Stringer | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL0L2 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL2L4 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL4L12 | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Frame Section Properties 01 - General, Part 7 of 7

Table: Frame Section Properties 01 - General, Part 7 of 7

| SectionName | WMod | GUID | Notes |
|---|---|---|---|
| ARL0R3 | 1.15 | | Added 2/6/2016 9:01:40 PM |
| ARR3R5 | 1.15 | | Added 2/6/2016 9:11:02 PM |
| ARR5R11 | 1.15 | | Added 2/6/2016 9:15:12 PM |
| Cable | 1. | | Added 5/30/2016 11:33:00 AM |
| ENDFB | 1.15 | | Added 2/15/2013 4:03:40 PM |
| INTFB | 1.25 | | Added 2/6/2016 9:37:56 PM |
| LBBL0L2 | 1.1 | | Added 2/6/2016 9:44:23 PM |
| LBBL2L7 | 1.1 | | Added 2/6/2016 9:53:50 PM |
| LBTALL | 1. | | Added 2/7/2016 9:45:39 AM |
| PBEAM | 1. | | Added 3/15/2016 7:43:57 AM |
| PCOL | 1. | | Added 3/15/2016 7:44:49 AM |
| Stringer | 1.3 | | Added 2/7/2016 9:56:42 AM |
| TGL0L2 | 1.25 | | Added 2/6/2016 9:20:01 PM |
| TGL2L4 | 1.25 | | Added 2/6/2016 9:27:49 PM |
| TGL4L12 | 1.25 | | Added 2/6/2016 9:31:35 PM |

Table:  Frame Section Properties 02 - Concrete Column, Part 1 of 3

Table:  Frame Section Properties 02 - Concrete Column, Part 1 of 3

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover | NumBars3Dir |
|---|---|---|---|---|---|---|
| | | | | | ft | |
| PBEAM | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 |
| PCOL | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 |

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 3

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 3

| SectionName | NumBars2Dir | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 |
|---|---|---|---|---|---|---|
| | | | | ft | | |
| PBEAM | 3 | #9 | #4 | 0.5 | 3 | 3 |
| PCOL | 3 | #9 | #4 | 0.5 | 3 | 3 |

Table:  Frame Section Properties 02 - Concrete Column, Part 3 of 3

Table:  Frame Section Properties 02 - Concrete Column, Part 3 of 3

| SectionName | ReinfType |
|---|---|
| PBEAM | Design |
| PCOL | Design |

Table:  Link Property Definitions 01 - General, Part 1 of 3

Table:  Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| P7FIX | Linear | 0. | 0. | 0. | 0. | 0. |
| P8EXP | Linear | 0. | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 2 of 3

Table:  Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| P7FIX | 1. | 1. | 0. | 0. | 0. | 0. |
| P8EXP | 1. | 1. | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 3 of 3

Table:  Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| P7FIX | Yellow | 93bb7642-45a2-4c68-abf3-1921cf26fc83 | Added 3/15/2016 7:52:21 AM |
| P8EXP | Yellow | 734d8af5-df4f-4170-9032-7960e247016f | Added 3/15/2016 7:52:21 AM |

Table: Link Property Definitions 02 - Linear, Part 1 of 2

Table: Link Property Definitions 02 - Linear, Part 1 of 2

| Link | DOF | Fixed | TransKE | RotKE | TransCE | RotCE |
|---|---|---|---|---|---|---|
| | | | Kip/ft | Kip-ft/rad | Kip-s/ft | Kip-ft-s/rad |
| P7FIX | U1 | No | 100000. | | 0. | |
| P7FIX | U2 | No | 100000. | | 0. | |
| P7FIX | U3 | No | 100000. | | 0. | |
| P7FIX | R1 | No | | 0. | | 0. |
| P7FIX | R2 | No | | 0. | | 0. |
| P7FIX | R3 | No | | 0. | | 0. |
| P8EXP | U1 | No | 100000. | | 0. | |
| P8EXP | U2 | No | 100. | | 0. | |
| P8EXP | U3 | No | 100000. | | 0. | |
| P8EXP | R1 | No | | 0. | | 0. |
| P8EXP | R2 | No | | 0. | | 0. |
| P8EXP | R3 | No | | 0. | | 0. |

Table: Link Property Definitions 02 - Linear, Part 2 of 2

Table: Link Property Definitions 02 - Linear, Part 2 of 2

| Link | DOF | DJ |
|---|---|---|
| | | ft |
| P7FIX | U1 | |
| P7FIX | U2 | 0. |
| P7FIX | U3 | 0. |
| P7FIX | R1 | |
| P7FIX | R2 | |
| P7FIX | R3 | |
| P8EXP | U1 | |
| P8EXP | U2 | 0. |
| P8EXP | U3 | 0. |
| P8EXP | R1 | |
| P8EXP | R2 | |
| P8EXP | R3 | |

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 3500psi | Concrete | Isotropic | No | Red | |
| 4000Psi | Concrete | Isotropic | No | Red | |
| A36 | Steel | Isotropic | No | Green | |
| A416Gr270 | Tendon | Uniaxial | No | Yellow | |
| A615Gr60 | Rebar | Uniaxial | No | Magenta | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586G | Steel | Isotropic | No | Green | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 3500psi | Normalweight f'c = 4 ksi added 2/15/2013 3:37:45 PM |
| 4000Psi | Normalweight f'c = 4 ksi added 2/15/2013 3:37:45 PM |
| A36 | United States ASTM A36 Grade 36 added 2/7/2016 9:56:18 AM |
| A416Gr270 | ASTM A416 Grade 270 2/6/2016 9:02:10 PM |
| A615Gr60 | ASTM A615 Grade 60 2/6/2016 9:02:10 PM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 2/15/2013 3:37:45 PM |
| ASTM A586G | Steel added 2/7/2016 10:10:14 AM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| 3500psi | 1.5000E-01 | 4.6621E-03 | 121298. | 50540.83 | 0.2 | 5.5000E-06 |
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 519119.5 | 216299.79 | 0.2 | 5.5000E-06 |
| A36 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| ASTM A586G | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy | Fu | EffFy | EffFu | SSCurveOpt | SSHysType |
|---|---|---|---|---|---|---|
| | Kip/ft2 | Kip/ft2 | Kip/ft2 | Kip/ft2 | | |
| A36 | 5184. | 8352. | 7776. | 9187.2 | Simple | Kinematic |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic |
| ASTM A586G | 21600. | 31680. | 21600. | 31680. | Simple | Kinematic |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SHard | SMax | SRup | FinalSlope |
|---|---|---|---|---|
| A36 | 0.02 | 0.14 | 0.2 | -0.1 |
| A992Fy50 | 0.015 | 0.11 | 0.17 | -0.1 |
| ASTM A586G | 0.015 | 0.11 | 0.17 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap |
|---|---|---|---|---|---|---|
| | Kip/ft2 | | | | | |
| 3500psi | 504. | No | Mander | Takeda | 0.002219 | 0.005 |
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FinalSlope | FAngle | DAngle |
|---|---|---|---|
| | | Degrees | Degrees |
| 3500psi | -0.1 | 0. | 0. |
| 4000Psi | -0.1 | 0. | 0. |

Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static | Dynamic |
|---|---|---|---|---|
| | | | Percent | Percent |
| MODAL | Acceleration | UX | 99.9687 | 89.4368 |
| MODAL | Acceleration | UY | 99.9055 | 62.4317 |
| MODAL | Acceleration | UZ | 98.4484 | 45.4058 |

Table: Modal Participating Mass Ratios, Part 1 of 4

Table: Modal Participating Mass Ratios, Part 1 of 4

| OutputCase | StepType | StepNum | Period | UX | UY | UZ |
|---|---|---|---|---|---|---|
| | | | Sec | | | |
| MODAL | | | 0. | 0. | 0.09509 | 7.034E-16 |

Table: Modal Participating Mass Ratios, Part 2 of 4

Table: Modal Participating Mass Ratios, Part 2 of 4

| OutputCase | StepType | StepNum | SumUX | SumUY | SumUZ | RX |
|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0.09509 | 7.034E-16 | 6.254E-08 |

Table: Modal Participating Mass Ratios, Part 3 of 4

Table: Modal Participating Mass Ratios, Part 3 of 4

| OutputCase | StepType | StepNum | RY | RZ | SumRX | SumRY |
|---|---|---|---|---|---|---|
| MODAL | | | 2.483E-14 | 0.00229 | 6.254E-08 | 2.483E-14 |

Table: Modal Participating Mass Ratios, Part 4 of 4

Table: Modal Participating Mass Ratios, Part 4 of 4

| OutputCase | StepType | StepNum | SumRZ |
|---|---|---|---|
| MODAL | | | 0.00229 |

Table: Modal Participation Factors, Part 1 of 3

Table: Modal Participation Factors, Part 1 of 3

| OutputCase | StepType | StepNum | Period | UX | UY | UZ |
|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft |
| MODAL | | | 0. | 0. | -7.908153 | 1.978E-09 |

Table: Modal Participation Factors, Part 2 of 3

Table: Modal Participation Factors, Part 2 of 3

| OutputCase | StepType | StepNum | RX | RY | RZ | ModalMass |
|---|---|---|---|---|---|---|
| | | | Kip-ft | Kip-ft | Kip-ft | Kip-ft-s2 |
| MODAL | | | 0.006413 | 0.000229 | 345.436956 | 0. |

Table: Modal Participation Factors, Part 3 of 3

Table: Modal Participation Factors, Part 3 of 3

| OutputCase | StepType | StepNum | ModalStiff |
|---|---|---|---|
| | | | Kip-ft |
| MODAL | | | 0. |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period | Frequency | CircFreq | Eigenvalue |
|---|---|---|---|---|---|---|
| | | | Sec | Cyc/sec | rad/sec | rad2/sec2 |
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

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**Static and Dynamic Characteristics of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: Rev 013 HS20 C2F UBK**
**City Island Bridge**

**26 June 2016**

Section 1 City Island Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 3500psi | Concrete | Isotropic | No | Red | |
| 4000Psi | Concrete | Isotropic | No | Red | |
| A36 | Steel | Isotropic | No | Green | |
| A416Gr270 | Tendon | Uniaxial | No | Yellow | |
| A615Gr60 | Rebar | Uniaxial | No | Magenta | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586G | Steel | Isotropic | No | Green | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 3500psi | Normalweight f'c = 4 ksi added 2/15/2013 3:37:45 PM |
| 4000Psi | Normalweight f'c = 4 ksi added 2/15/2013 3:37:45 PM |
| A36 | United States ASTM A36 Grade 36 added 2/7/2016 9:56:18 AM |
| A416Gr270 | ASTM A416 Grade 270 2/6/2016 9:02:10 PM |
| A615Gr60 | ASTM A615 Grade 60 2/6/2016 9:02:10 PM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 2/15/2013 3:37:45 PM |
| ASTM A586G | Steel added 2/7/2016 10:10:14 AM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| 3500psi | 1.5000E-01 | 4.6621E-03 | 631269. | 263028.75 | 0.2 | 5.5000E-06 |
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 519119.5 | 216299.79 | 0.2 | 5.5000E-06 |
| A36 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| ASTM A586G | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A36 | 5184. | 8352. | 7776. | 9187.2 | Simple | Kinematic | 0.02 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| ASTM A586G | 21600. | 31680. | 21600. | 31680. | Simple | Kinematic | 0.015 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A36 | 0.14 | 0.2 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A586G | 0.11 | 0.17 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 3500psi | 655. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 3500psi | 0. | 0. |
| 4000Psi | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 7

Table: Frame Section Properties 01 - General, Part 1 of 7

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| ARL0R3 | A992Fy50 | SD Section | | | |
| ARR3R5 | A992Fy50 | SD Section | | | |
| ARR5R11 | A992Fy50 | SD Section | | | |
| Cable | ASTM A586G | General | 1. | 1. | |
| ENDFB | A992Fy50 | I/Wide Flange | 8.8333 | 1.5 | 0.0833 |
| INTFB | A992Fy50 | I/Wide Flange | 9. | 1.6667 | 0.1667 |
| LBBL0L2 | A992Fy50 | SD Section | | | |
| LBBL2L7 | A992Fy50 | SD Section | | | |
| LBTALL | A992Fy50 | SD Section | | | |
| PBEAM | 3500psi | Rectangular | 9.5 | 7.5 | |
| PCOL | 3500psi | Rectangular | 8. | 14.2 | |

Table: Frame Section Properties 01 - General, Part 1 of 7

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| Stringer | A36 | I/Wide Flange | 2.7417 | 0.9583 | 0.0617 |
| TGL0L2 | A992Fy50 | SD Section | | | |
| TGL2L4 | A992Fy50 | SD Section | | | |
| TGL4L12 | A992Fy50 | SD Section | | | |

Table: Frame Section Properties 01 - General, Part 2 of 7

Table: Frame Section Properties 01 - General, Part 2 of 7

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ARL0R3 | | | | 2.3646 | 7.750177 | 8.245495 |
| ARR3R5 | | | | 2.2222 | 7.390792 | 7.463477 |
| ARR5R11 | | | | 2.0799 | 6.985421 | 6.6953 |
| Cable | | | | 0.0667 | 0.000707 | 0.000354 |
| ENDFB | 0.0313 | 1.5 | 0.0833 | 0.5212 | 0.000646 | 6.481335 |
| INTFB | 0.0313 | 1.6667 | 0.1667 | 0.8269 | 0.004911 | 12.53867 |
| LBBL0L2 | | | | 0.2007 | 0.087758 | 0.062943 |
| LBBL2L7 | | | | 0.1721 | 0.074211 | 0.053658 |
| LBTALL | | | | 0.2413 | 0.141648 | 0.119759 |
| PBEAM | | | | 71.25 | 692.994044 | 535.859375 |
| PCOL | | | | 113.6 | 1570.527787 | 605.866667 |
| Stringer | 0.0458 | 0.9583 | 0.0617 | 0.2382 | 0.000227 | 0.280883 |
| TGL0L2 | | | | 2.0764 | 10.821517 | 29.156993 |
| TGL2L4 | | | | 2.2795 | 11.256056 | 34.330796 |
| TGL4L12 | | | | 2.0764 | 10.821517 | 29.156993 |

Table: Frame Section Properties 01 - General, Part 3 of 7

Table: Frame Section Properties 01 - General, Part 3 of 7

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARL0R3 | 3.892669 | 0. | 1.1533 | 1.1988 | 3.502511 | 2.278635 |
| ARR3R5 | 3.75418 | 0. | 1.1409 | 1.0683 | 3.198633 | 2.197569 |
| ARR5R11 | 3.615691 | 0. | 1.1281 | 0.9373 | 2.895265 | 2.116502 |
| Cable | 0.000354 | 0. | 0.06 | 0.06 | 1. | 1. |
| ENDFB | 0.046878 | 0. | 0.2765 | 0.2083 | 1.467478 | 0.062505 |
| INTFB | 0.128656 | 0. | 0.2817 | 0.4631 | 2.786371 | 0.154385 |
| LBBL0L2 | 0.058228 | 0. | 0.1008 | 0.0963 | 0.089515 | 0.082202 |
| LBBL2L7 | 0.049649 | 0. | 0.086 | 0.0822 | 0.076879 | 0.070091 |
| LBTALL | 0.081676 | 0. | 0.1529 | 0.0849 | 0.126339 | 0.115304 |
| PBEAM | 333.984375 | 0. | 59.375 | 59.375 | 112.8125 | 89.0625 |
| PCOL | 1908.858667 | 0. | 94.6667 | 94.6667 | 151.466667 | 268.853333 |
| Stringer | 0.009071 | 0. | 0.1256 | 0.0985 | 0.204897 | 0.018931 |
| TGL0L2 | 3.788958 | 0. | 1.3215 | 0.7163 | 5.795179 | 2.331666 |
| TGL2L4 | 3.96775 | 0. | 1.3387 | 0.909 | 6.781392 | 2.441692 |
| TGL4L12 | 3.788958 | 0. | 1.3215 | 0.7163 | 5.795179 | 2.331666 |

Table: Frame Section Properties 01 - General, Part 4 of 7

Table: Frame Section Properties 01 - General, Part 4 of 7

| SectionName | Z33<br>ft3 | Z22<br>ft3 | R33<br>ft | R22<br>ft | EccV2<br>ft | ConcCol |
|---|---|---|---|---|---|---|
| ARL0R3 | 4.06977 | 2.787109 | 1.86737 | 1.28306 | | No |
| ARR3R5 | 3.736111 | 2.665509 | 1.83264 | 1.29976 | | No |
| ARR5R11 | 3.405418 | 2.543909 | 1.79419 | 1.31849 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| ENDFB | 1.681061 | 0.095835 | 3.5265 | 0.29991 | | No |
| INTFB | 3.04197 | 0.23366 | 3.89393 | 0.39444 | | No |
| LBBL0L2 | 0.103275 | 0.099738 | 0.55994 | 0.53857 | | No |
| LBBL2L7 | 0.088331 | 0.085312 | 0.55829 | 0.53704 | | No |
| LBTALL | 0.152572 | 0.132416 | 0.70446 | 0.58177 | | No |
| PBEAM | 169.21875 | 133.59375 | 2.74241 | 2.16506 | | Yes |
| PCOL | 227.2 | 403.28 | 2.3094 | 4.09919 | | Yes |
| Stringer | 0.236956 | 0.029704 | 1.08597 | 0.19515 | | No |
| TGL0L2 | 6.978073 | 2.647625 | 3.74729 | 1.35085 | | No |
| TGL2L4 | 8.003219 | 2.812664 | 3.8808 | 1.31932 | | No |
| TGL4L12 | 6.978073 | 2.647625 | 3.74729 | 1.35085 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 7

Table: Frame Section Properties 01 - General, Part 5 of 7

| SectionName | ConcBeam | Color | TotalWt<br>Kip | TotalMass<br>Kip-s2/ft | FromFile | AMod |
|---|---|---|---|---|---|---|
| ARL0R3 | No | Red | 796.339 | 21.52 | No | 1. |
| ARR3R5 | No | Cyan | 451.295 | 12.2 | No | 1. |
| ARR5R11 | No | Magenta | 597.07 | 16.14 | No | 1. |
| Cable | No | Yellow | 91.643 | 2.85 | No | 1. |
| ENDFB | No | Cyan | 46.401 | 1.25 | No | 1. |
| INTFB | No | Yellow | 600.205 | 14.92 | No | 1. |
| LBBL0L2 | No | Blue | 49.83 | 1.41 | No | 1. |
| LBBL2L7 | No | Cyan | 128.194 | 3.62 | No | 1. |
| LBTALL | No | Gray8Dark | 338.39 | 10.52 | No | 1. |
| PBEAM | No | Cyan | 1688.625 | 52.48 | No | 1. |
| PCOL | No | Magenta | 2686.867 | 83.51 | No | 1. |
| Stringer | No | Green | 914.846 | 21.87 | No | 1. |
| TGL0L2 | No | Gray8Dark | 426.049 | 10.59 | No | 1. |
| TGL2L4 | No | Green | 467.728 | 11.63 | No | 1. |
| TGL4L12 | No | Red | 852.098 | 21.19 | No | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 7

Table: Frame Section Properties 01 - General, Part 6 of 7

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARL0R3 | 1. | 1. | 1. | 1. | 1. | 1. |
| ARR3R5 | 1. | 1. | 1. | 1. | 1. | 1. |
| ARR5R11 | 1. | 1. | 1. | 1. | 1. | 1. |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| ENDFB | 1. | 1. | 1. | 1. | 1. | 1. |
| INTFB | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Frame Section Properties 01 - General, Part 6 of 7

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| LBBL0L2 | 1. | 1. | 1. | 1. | 1. | 1. |
| LBBL2L7 | 1. | 1. | 1. | 1. | 1. | 1. |
| LBTALL | 1. | 1. | 1. | 1. | 1. | 1. |
| PBEAM | 1. | 1. | 1. | 1. | 1. | 1. |
| PCOL | 1. | 1. | 1. | 1. | 1. | 1. |
| Stringer | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL0L2 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL2L4 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL4L12 | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Frame Section Properties 01 - General, Part 7 of 7

Table:  Frame Section Properties 01 - General, Part 7 of 7

| SectionName | WMod | GUID | Notes |
|---|---|---|---|
| ARL0R3 | 1.15 | | Added 2/6/2016 9:01:40 PM |
| ARR3R5 | 1.15 | | Added 2/6/2016 9:11:02 PM |
| ARR5R11 | 1.15 | | Added 2/6/2016 9:15:12 PM |
| Cable | 1. | | Added 5/30/2016 11:33:00 AM |
| ENDFB | 1.15 | | Added 2/15/2013 4:03:40 PM |
| INTFB | 1.25 | | Added 2/6/2016 9:37:56 PM |
| LBBL0L2 | 1.1 | | Added 2/6/2016 9:44:23 PM |
| LBBL2L7 | 1.1 | | Added 2/6/2016 9:53:50 PM |
| LBTALL | 1. | | Added 2/7/2016 9:45:39 AM |
| PBEAM | 1. | | Added 3/15/2016 7:43:57 AM |
| PCOL | 1. | | Added 3/15/2016 7:44:49 AM |
| Stringer | 1.3 | | Added 2/7/2016 9:56:42 AM |
| TGL0L2 | 1.25 | | Added 2/6/2016 9:20:01 PM |
| TGL2L4 | 1.25 | | Added 2/6/2016 9:27:49 PM |
| TGL4L12 | 1.25 | | Added 2/6/2016 9:31:35 PM |

Table:  Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table:  Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| | | | | | ft | | |
| PBEAM | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |
| PCOL | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| | | | ft | | | |
| PBEAM | #9 | #4 | 0.5 | 3 | 3 | Design |
| PCOL | #9 | #4 | 0.5 | 3 | 3 | Design |

Table:  Link Property Definitions 01 - General, Part 1 of 3

Table:  Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| P7FIX | Linear | 0. | 0. | 0. | 0. | 0. |
| P8EXP | Linear | 0. | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 2 of 3

Table:  Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| P7FIX | 1. | 1. | 0. | 0. | 0. | 0. |
| P8EXP | 1. | 1. | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 3 of 3

Table:  Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| P7FIX | Yellow | 93bb7642-45a2-4c68-abf3-1921cf26fc83 | Added 3/15/2016 7:52:21 AM |
| P8EXP | Yellow | 734d8af5-df4f-4170-9032-7960e247016f | Added 3/15/2016 7:52:21 AM |

Table:  Link Property Definitions 02 - Linear

Table:  Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE | RotKE | TransCE | RotCE | DJ |
|---|---|---|---|---|---|---|---|
| | | | Kip/ft | Kip-ft/rad | Kip-s/ft | Kip-ft-s/rad | ft |
| P7FIX | U1 | No | 100000. | | 0. | | |
| P7FIX | U2 | No | 100000. | | 0. | | 0. |
| P7FIX | U3 | No | 100000. | | 0. | | 0. |
| P7FIX | R1 | Yes | | | | | |
| P7FIX | R2 | Yes | | | | | |
| P7FIX | R3 | No | | 0. | | 0. | |
| P8EXP | U1 | No | 100000. | | 0. | | |
| P8EXP | U2 | No | 100000. | | 0. | | 0. |
| P8EXP | U3 | No | 100000. | | 0. | | 0. |
| P8EXP | R1 | Yes | | | | | |
| P8EXP | R2 | Yes | | | | | |
| P8EXP | R3 | No | | 0. | | 0. | |

Section 2 City Island Bridge Load Case Data

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | DEAD | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING _DEAD | LinBuckling | PDELTA | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | No | Not Run |
| BUCKLING _DEAD | DEAD | Prog Det | Other | None | No | Not Run |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| MODAL | | |
| LIVELOAD | | |
| PDELTA | | |
| BUCKLING _DEAD | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |

Table:  Case - Static 2 - Nonlinear Load Application

Table:  Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 124 |
| PDELTA | Full Load | U1 | 124 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |
| PDELTA | 10 | 0.01 | 1. | No |

Table: Case - Moving Load 1 - Lane Assignments

Table: Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 1 | 4 | 6 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | LTLANE1 |
| LIVELOAD | 1 | LTLANE1C |
| LIVELOAD | 1 | LTLANE2 |
| LIVELOAD | 1 | RGTLANE1 |
| LIVELOAD | 1 | RGTLANE1C |
| LIVELOAD | 1 | RGTLANE2 |

Table: Case - Moving Load 3 - MultiLane Factors

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1. |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.9 |
| LIVELOAD | 4 | 0.75 |
| LIVELOAD | 5 | 0.75 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |
| LIVELOAD | 10 | 0.75 |
| LIVELOAD | 11 | 0.75 |
| LIVELOAD | 12 | 0.75 |
| LIVELOAD | 13 | 0.75 |
| LIVELOAD | 14 | 0.75 |
| LIVELOAD | 15 | 0.75 |
| LIVELOAD | 16 | 0.75 |
| LIVELOAD | 17 | 0.75 |
| LIVELOAD | 18 | 0.75 |
| LIVELOAD | 19 | 0.75 |
| LIVELOAD | 20 | 0.75 |
| LIVELOAD | 21 | 0.75 |
| LIVELOAD | 22 | 0.75 |
| LIVELOAD | 23 | 0.75 |
| LIVELOAD | 24 | 0.75 |
| LIVELOAD | 25 | 0.75 |
| LIVELOAD | 26 | 0.75 |
| LIVELOAD | 27 | 0.75 |
| LIVELOAD | 28 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 29 | 0.75 |
| LIVELOAD | 30 | 0.75 |
| LIVELOAD | 31 | 0.75 |
| LIVELOAD | 32 | 0.75 |
| LIVELOAD | 33 | 0.75 |
| LIVELOAD | 34 | 0.75 |
| LIVELOAD | 35 | 0.75 |
| LIVELOAD | 36 | 0.75 |
| LIVELOAD | 37 | 0.75 |
| LIVELOAD | 38 | 0.75 |
| LIVELOAD | 39 | 0.75 |
| LIVELOAD | 40 | 0.75 |
| LIVELOAD | 41 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift Cyc/sec | EigenCutoff Cyc/sec | EigenTol |
|---|---|---|---|---|---|---|
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 City Island Bridge Modal Analysis Results

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.5336 | 68.8094 |
| MODAL | Acceleration | UY | 99.8264 | 59.1319 |
| MODAL | Acceleration | UZ | 99.3687 | 42.9168 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period Sec | UX Kip-ft | UY Kip-ft | UZ Kip-ft | RX Kip-ft |
|---|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0. | -0.1183 | 2.749E-06 | -0.006939 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY<br>Kip-ft | RZ<br>Kip-ft | ModalMass<br>Kip-ft-s2 | ModalStiff<br>Kip-ft |
|---|---|---|---|---|---|---|
| MODAL | | | -0.000089 | 193.059528 | 0. | 0. |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period<br>Sec | Frequency<br>Cyc/sec | CircFreq<br>rad/sec | Eigenvalue<br>rad2/sec2 |
|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

Table: Program Control, Part 1 of 2

Table: Program Control, Part 1 of 2

| ProgramName | Version | ProgLevel | LicenseNum | LicenseOS | LicenseSC | LicenseHT | CurrUnits |
|---|---|---|---|---|---|---|---|
| SAP2000 | 18.1.1 | Advanced | 2010*1GRWHLW4599V5FQ | No | No | No | Kip, ft, F |

Table: Program Control, Part 2 of 2

Table: Program Control, Part 2 of 2

| SteelCode | ConcCode | AlumCode | ColdCode | RegenHinge |
|---|---|---|---|---|
| AISC360-05/IBC2006 | ACI 318-08/IBC2009 | AA-ASD 2000 | AISI-ASD96 | Yes |

SAP2000®



**Static and Dynamic Characteristics of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: Rev 013 HL93 C2F LBK**
**City Island Bridge**

**26 June 2016**

Section 1 City Island Bridge Input Data

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 3500psi | Concrete | Isotropic | No | Red | |
| 4000Psi | Concrete | Isotropic | No | Red | |
| A36 | Steel | Isotropic | No | Green | |
| A416Gr270 | Tendon | Uniaxial | No | Yellow | |
| A615Gr60 | Rebar | Uniaxial | No | Magenta | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586G | Steel | Isotropic | No | Green | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 3500psi | Normalweight f'c = 4 ksi added 2/15/2013 3:37:45 PM |
| 4000Psi | Normalweight f'c = 4 ksi added 2/15/2013 3:37:45 PM |
| A36 | United States ASTM A36 Grade 36 added 2/7/2016 9:56:18 AM |
| A416Gr270 | ASTM A416 Grade 270 2/6/2016 9:02:10 PM |
| A615Gr60 | ASTM A615 Grade 60 2/6/2016 9:02:10 PM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 2/15/2013 3:37:45 PM |
| ASTM A586G | Steel added 2/7/2016 10:10:14 AM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| 3500psi | 1.5000E-01 | 4.6621E-03 | 121298. | 50540.83 | 0.2 | 5.5000E-06 |
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 519119.5 | 216299.79 | 0.2 | 5.5000E-06 |
| A36 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| ASTM A586G | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A36 | 5184. | 8352. | 7776. | 9187.2 | Simple | Kinematic | 0.02 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| ASTM A586G | 21600. | 31680. | 21600. | 31680. | Simple | Kinematic | 0.015 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A36 | 0.14 | 0.2 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A586G | 0.11 | 0.17 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 3500psi | 504. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 3500psi | 0. | 0. |
| 4000Psi | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 7

Table: Frame Section Properties 01 - General, Part 1 of 7

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| ARL0R3 | A992Fy50 | SD Section | | | |
| ARR3R5 | A992Fy50 | SD Section | | | |
| ARR5R11 | A992Fy50 | SD Section | | | |
| Cable | ASTM A586G | General | 1. | 1. | |
| ENDFB | A992Fy50 | I/Wide Flange | 8.8333 | 1.5 | 0.0833 |
| INTFB | A992Fy50 | I/Wide Flange | 9. | 1.6667 | 0.1667 |
| LBBL0L2 | A992Fy50 | SD Section | | | |
| LBBL2L7 | A992Fy50 | SD Section | | | |
| LBTALL | A992Fy50 | SD Section | | | |
| PBEAM | 3500psi | Rectangular | 9.5 | 7.5 | |

Table:  Frame Section Properties 01 - General, Part 1 of 7

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| PCOL | 3500psi | Rectangular | 8. | 14.2 | |
| Stringer | A36 | I/Wide Flange | 2.7417 | 0.9583 | 0.0617 |
| TGL0L2 | A992Fy50 | SD Section | | | |
| TGL2L4 | A992Fy50 | SD Section | | | |
| TGL4L12 | A992Fy50 | SD Section | | | |

Table:  Frame Section Properties 01 - General, Part 2 of 7

Table:  Frame Section Properties 01 - General, Part 2 of 7

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ARL0R3 | | | | 2.3646 | 7.750177 | 8.245495 |
| ARR3R5 | | | | 2.2222 | 7.390792 | 7.463477 |
| ARR5R11 | | | | 2.0799 | 6.985421 | 6.6953 |
| Cable | | | | 0.0667 | 0.000707 | 0.000354 |
| ENDFB | 0.0313 | 1.5 | 0.0833 | 0.5212 | 0.000646 | 6.481335 |
| INTFB | 0.0313 | 1.6667 | 0.1667 | 0.8269 | 0.004911 | 12.53867 |
| LBBL0L2 | | | | 0.2007 | 0.087758 | 0.062943 |
| LBBL2L7 | | | | 0.1721 | 0.074211 | 0.053658 |
| LBTALL | | | | 0.2413 | 0.141648 | 0.119759 |
| PBEAM | | | | 71.25 | 692.994044 | 535.859375 |
| PCOL | | | | 113.6 | 1570.527787 | 605.866667 |
| Stringer | 0.0458 | 0.9583 | 0.0617 | 0.2382 | 0.000227 | 0.280883 |
| TGL0L2 | | | | 2.0764 | 10.821517 | 29.156993 |
| TGL2L4 | | | | 2.2795 | 11.256056 | 34.330796 |
| TGL4L12 | | | | 2.0764 | 10.821517 | 29.156993 |

Table:  Frame Section Properties 01 - General, Part 3 of 7

Table:  Frame Section Properties 01 - General, Part 3 of 7

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARL0R3 | 3.892669 | 0. | 1.1533 | 1.1988 | 3.502511 | 2.278635 |
| ARR3R5 | 3.75418 | 0. | 1.1409 | 1.0683 | 3.198633 | 2.197569 |
| ARR5R11 | 3.615691 | 0. | 1.1281 | 0.9373 | 2.895265 | 2.116502 |
| Cable | 0.000354 | 0. | 0.06 | 0.06 | 1. | 1. |
| ENDFB | 0.046878 | 0. | 0.2765 | 0.2083 | 1.467478 | 0.062505 |
| INTFB | 0.128656 | 0. | 0.2817 | 0.4631 | 2.786371 | 0.154385 |
| LBBL0L2 | 0.058228 | 0. | 0.1008 | 0.0963 | 0.089515 | 0.082202 |
| LBBL2L7 | 0.049649 | 0. | 0.086 | 0.0822 | 0.076879 | 0.070091 |
| LBTALL | 0.081676 | 0. | 0.1529 | 0.0849 | 0.126339 | 0.115304 |
| PBEAM | 333.984375 | 0. | 59.375 | 59.375 | 112.8125 | 89.0625 |
| PCOL | 1908.858667 | 0. | 94.6667 | 94.6667 | 151.466667 | 268.853333 |
| Stringer | 0.009071 | 0. | 0.1256 | 0.0985 | 0.204897 | 0.018931 |
| TGL0L2 | 3.788958 | 0. | 1.3215 | 0.7163 | 5.795179 | 2.331666 |
| TGL2L4 | 3.96775 | 0. | 1.3387 | 0.909 | 6.781392 | 2.441692 |
| TGL4L12 | 3.788958 | 0. | 1.3215 | 0.7163 | 5.795179 | 2.331666 |

Table: Frame Section Properties 01 - General, Part 4 of 7

Table: Frame Section Properties 01 - General, Part 4 of 7

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARL0R3 | 4.06977 | 2.787109 | 1.86737 | 1.28306 | | No |
| ARR3R5 | 3.736111 | 2.665509 | 1.83264 | 1.29976 | | No |
| ARR5R11 | 3.405418 | 2.543909 | 1.79419 | 1.31849 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| ENDFB | 1.681061 | 0.095835 | 3.5265 | 0.29991 | | No |
| INTFB | 3.04197 | 0.23366 | 3.89393 | 0.39444 | | No |
| LBBL0L2 | 0.103275 | 0.099738 | 0.55994 | 0.53857 | | No |
| LBBL2L7 | 0.088331 | 0.085312 | 0.55829 | 0.53704 | | No |
| LBTALL | 0.152572 | 0.132416 | 0.70446 | 0.58177 | | No |
| PBEAM | 169.21875 | 133.59375 | 2.74241 | 2.16506 | | Yes |
| PCOL | 227.2 | 403.28 | 2.3094 | 4.09919 | | Yes |
| Stringer | 0.236956 | 0.029704 | 1.08597 | 0.19515 | | No |
| TGL0L2 | 6.978073 | 2.647625 | 3.74729 | 1.35085 | | No |
| TGL2L4 | 8.003219 | 2.812664 | 3.8808 | 1.31932 | | No |
| TGL4L12 | 6.978073 | 2.647625 | 3.74729 | 1.35085 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 7

Table: Frame Section Properties 01 - General, Part 5 of 7

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| ARL0R3 | No | Red | 796.339 | 21.52 | No | 1. |
| ARR3R5 | No | Cyan | 451.295 | 12.2 | No | 1. |
| ARR5R11 | No | Magenta | 597.07 | 16.14 | No | 1. |
| Cable | No | Yellow | 91.643 | 2.85 | No | 1. |
| ENDFB | No | Cyan | 46.401 | 1.25 | No | 1. |
| INTFB | No | Yellow | 600.205 | 14.92 | No | 1. |
| LBBL0L2 | No | Blue | 49.83 | 1.41 | No | 1. |
| LBBL2L7 | No | Cyan | 128.194 | 3.62 | No | 1. |
| LBTALL | No | Gray8Dark | 338.39 | 10.52 | No | 1. |
| PBEAM | No | Cyan | 1688.625 | 52.48 | No | 1. |
| PCOL | No | Magenta | 2686.867 | 83.51 | No | 1. |
| Stringer | No | Green | 914.846 | 21.87 | No | 1. |
| TGL0L2 | No | Gray8Dark | 426.049 | 10.59 | No | 1. |
| TGL2L4 | No | Green | 467.728 | 11.63 | No | 1. |
| TGL4L12 | No | Red | 852.098 | 21.19 | No | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 7

Table: Frame Section Properties 01 - General, Part 6 of 7

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARL0R3 | 1. | 1. | 1. | 1. | 1. | 1. |
| ARR3R5 | 1. | 1. | 1. | 1. | 1. | 1. |
| ARR5R11 | 1. | 1. | 1. | 1. | 1. | 1. |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| ENDFB | 1. | 1. | 1. | 1. | 1. | 1. |
| INTFB | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Frame Section Properties 01 - General, Part 6 of 7

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| LBBL0L2 | 1. | 1. | 1. | 1. | 1. | 1. |
| LBBL2L7 | 1. | 1. | 1. | 1. | 1. | 1. |
| LBTALL | 1. | 1. | 1. | 1. | 1. | 1. |
| PBEAM | 1. | 1. | 1. | 1. | 1. | 1. |
| PCOL | 1. | 1. | 1. | 1. | 1. | 1. |
| Stringer | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL0L2 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL2L4 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL4L12 | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Frame Section Properties 01 - General, Part 7 of 7

Table:  Frame Section Properties 01 - General, Part 7 of 7

| SectionName | WMod | GUID | Notes |
|---|---|---|---|
| ARL0R3 | 1.15 | | Added 2/6/2016 9:01:40 PM |
| ARR3R5 | 1.15 | | Added 2/6/2016 9:11:02 PM |
| ARR5R11 | 1.15 | | Added 2/6/2016 9:15:12 PM |
| Cable | 1. | | Added 5/30/2016 11:33:00 AM |
| ENDFB | 1.15 | | Added 2/15/2013 4:03:40 PM |
| INTFB | 1.25 | | Added 2/6/2016 9:37:56 PM |
| LBBL0L2 | 1.1 | | Added 2/6/2016 9:44:23 PM |
| LBBL2L7 | 1.1 | | Added 2/6/2016 9:53:50 PM |
| LBTALL | 1. | | Added 2/7/2016 9:45:39 AM |
| PBEAM | 1. | | Added 3/15/2016 7:43:57 AM |
| PCOL | 1. | | Added 3/15/2016 7:44:49 AM |
| Stringer | 1.3 | | Added 2/7/2016 9:56:42 AM |
| TGL0L2 | 1.25 | | Added 2/6/2016 9:20:01 PM |
| TGL2L4 | 1.25 | | Added 2/6/2016 9:27:49 PM |
| TGL4L12 | 1.25 | | Added 2/6/2016 9:31:35 PM |

Table:  Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table:  Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| | | | | | ft | | |
| PBEAM | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |
| PCOL | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| | | | ft | | | |
| PBEAM | #9 | #4 | 0.5 | 3 | 3 | Design |
| PCOL | #9 | #4 | 0.5 | 3 | 3 | Design |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass<br>Kip-s2/ft | Weight<br>Kip | RotInert1<br>Kip-ft-s2 | RotInert2<br>Kip-ft-s2 | RotInert3<br>Kip-ft-s2 |
|---|---|---|---|---|---|---|
| P7FIX | Linear | 0. | 0. | 0. | 0. | 0. |
| P8EXP | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength<br>ft | DefArea<br>ft2 | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| P7FIX | 1. | 1. | 0. | 0. | 0. | 0. |
| P8EXP | 1. | 1. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| P7FIX | Yellow | 93bb7642-45a2-4c68-abf3-1921cf26fc83 | Added 3/15/2016 7:52:21 AM |
| P8EXP | Yellow | 734d8af5-df4f-4170-9032-7960e247016f | Added 3/15/2016 7:52:21 AM |

Table: Link Property Definitions 02 - Linear

Table: Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE<br>Kip/ft | RotKE<br>Kip-ft/rad | TransCE<br>Kip-s/ft | RotCE<br>Kip-ft-s/rad | DJ<br>ft |
|---|---|---|---|---|---|---|---|
| P7FIX | U1 | No | 100000. | | 0. | | |
| P7FIX | U2 | No | 100000. | | 0. | | 0. |
| P7FIX | U3 | No | 100000. | | 0. | | 0. |
| P7FIX | R1 | No | | 0. | | 0. | |
| P7FIX | R2 | No | | 0. | | 0. | |
| P7FIX | R3 | No | | 0. | | 0. | |
| P8EXP | U1 | No | 100000. | | 0. | | |
| P8EXP | U2 | No | 100. | | 0. | | 0. |
| P8EXP | U3 | No | 100000. | | 0. | | 0. |
| P8EXP | R1 | No | | 0. | | 0. | |
| P8EXP | R2 | No | | 0. | | 0. | |
| P8EXP | R3 | No | | 0. | | 0. | |

Section 2 City Island Load Case Input

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | DEAD | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING_DEAD | LinBuckling | PDELTA | | | | Prog Det |
| WIND | LinStatic | PDELTA | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| BUCKLING_DEAD | DEAD | Prog Det | Other | None | No | Not Run |
| WIND | DEAD | Prog Det | Non-Composite | None | Yes | Finished |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| MODAL | | |
| LIVELOAD | | |
| PDELTA | | |
| BUCKLING_DEAD | | |
| WIND | | |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift | EigenCutoff | EigenTol |
|---|---|---|---|---|---|---|
| | | | | Cyc/sec | Cyc/sec | |
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |
| WIND | Load pattern | WIND | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 124 |
| PDELTA | Full Load | U1 | 124 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |
| PDELTA | 10 | 0.01 | 1. | No |

Table:  Case - Moving Load 1 - Lane Assignments

Table:  Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HL93_LL | 1. | 1 | 4 | 6 |

Table:  Case - Moving Load 2 - Lanes Loaded

Table:  Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | LTLANE1 |
| LIVELOAD | 1 | LTLANE1C |
| LIVELOAD | 1 | LTLANE2 |
| LIVELOAD | 1 | RGTLANE1 |
| LIVELOAD | 1 | RGTLANE1C |
| LIVELOAD | 1 | RGTLANE2 |

Table:  Case - Moving Load 3 - MultiLane Factors

Table:  Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1.2 |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.85 |
| LIVELOAD | 4 | 0.65 |
| LIVELOAD | 5 | 0.65 |
| LIVELOAD | 6 | 0.65 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |
| LIVELOAD | 10 | 0.75 |
| LIVELOAD | 11 | 0.75 |
| LIVELOAD | 12 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 13 | 0.75 |
| LIVELOAD | 14 | 0.75 |
| LIVELOAD | 15 | 0.75 |
| LIVELOAD | 16 | 0.75 |
| LIVELOAD | 17 | 0.75 |
| LIVELOAD | 18 | 0.75 |
| LIVELOAD | 19 | 0.75 |
| LIVELOAD | 20 | 0.75 |
| LIVELOAD | 21 | 0.75 |
| LIVELOAD | 22 | 0.75 |
| LIVELOAD | 23 | 0.75 |
| LIVELOAD | 24 | 0.75 |
| LIVELOAD | 25 | 0.75 |
| LIVELOAD | 26 | 0.75 |
| LIVELOAD | 27 | 0.75 |
| LIVELOAD | 28 | 0.75 |
| LIVELOAD | 29 | 0.75 |
| LIVELOAD | 30 | 0.75 |
| LIVELOAD | 31 | 0.75 |
| LIVELOAD | 32 | 0.75 |
| LIVELOAD | 33 | 0.75 |
| LIVELOAD | 34 | 0.75 |
| LIVELOAD | 35 | 0.75 |
| LIVELOAD | 36 | 0.75 |
| LIVELOAD | 37 | 0.75 |
| LIVELOAD | 38 | 0.75 |
| LIVELOAD | 39 | 0.75 |
| LIVELOAD | 40 | 0.75 |
| LIVELOAD | 41 | 0.75 |

Section 3 City Island Modal Analysis Results

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.9687 | 89.4368 |
| MODAL | Acceleration | UY | 99.9055 | 62.4317 |
| MODAL | Acceleration | UZ | 98.4484 | 45.4058 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period Sec | UX Kip-ft | UY Kip-ft | UZ Kip-ft | RX Kip-ft |
|---|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0. | -7.908153 | 1.978E-09 | 0.006413 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY<br>Kip-ft | RZ<br>Kip-ft | ModalMass<br>Kip-ft-s2 | ModalStiff<br>Kip-ft |
|---|---|---|---|---|---|---|
| MODAL | | | 0.000229 | 345.436956 | 0. | 0. |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period<br>Sec | Frequency<br>Cyc/sec | CircFreq<br>rad/sec | Eigenvalue<br>rad2/sec2 |
|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

Table: Program Control, Part 1 of 2

Table: Program Control, Part 1 of 2

| ProgramName | Version | ProgLevel | LicenseNum | LicenseOS | LicenseSC | LicenseHT | CurrUnits |
|---|---|---|---|---|---|---|---|
| SAP2000 | 18.1.1 | Advanced | 2010*1GRWHLW4599V5FQ | No | No | No | Kip, ft, F |

Table: Program Control, Part 2 of 2

Table: Program Control, Part 2 of 2

| SteelCode | ConcCode | AlumCode | ColdCode | RegenHinge |
|---|---|---|---|---|
| AISC360-05/IBC2006 | ACI 318-08/IBC2009 | AA-ASD 2000 | AISI-ASD96 | Yes |

**APPENDIX B**

**ANALYSIS OUTPUT FOR JEFFERSON BARRACKS BRIDGE**

License #2010*1GRWHLW4599V5FQ

**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160611 JBBridge Rev 012 HS20 C2F LBK.sdb**

**26 June 2016**

Section 1 Jefferson Barracks Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 35000psi | Concrete | Isotropic | No | Yellow | |
| 4000Psi | Concrete | Isotropic | No | Yellow | |
| A416Gr270 | Tendon | Uniaxial | No | Blue | |
| A572Gr50 | Steel | Isotropic | No | Blue | |
| A615Gr60 | Rebar | Uniaxial | No | Gray8Dark | |
| A992Fy50 | Steel | Isotropic | No | Magenta | |
| ASTM A58G | Steel | Isotropic | No | Blue | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 35000psi | Normalweight f'c = 4 ksi added 12/27/2013 5:33:58 PM |
| 4000Psi | Normalweight f'c = 4 ksi added 12/27/2013 5:33:58 PM |
| A416Gr270 | ASTM A416 Grade 270 2/6/2016 4:27:13 PM |
| A572Gr50 | ASTM A572 Grade 50 added 12/27/2013 9:18:45 PM |
| A615Gr60 | ASTM A615 Grade 60 added 12/28/2013 9:51:32 AM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 12/27/2013 5:33:58 PM |
| ASTM A58G | ASTM A36 added 12/28/2013 1:03:46 PM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| 35000psi | 1.5000E-01 | 4.6621E-03 | 145680. | 60700. | 0.2 | 5.5000E-06 |
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 155740. | 64891.67 | 0.2 | 5.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A572Gr50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| ASTM A58G | 4.9000E-01 | 1.5230E-02 | 3312000. | 1273846.15 | 0.3 | 6.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A572Gr50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| ASTM A58G | 21600. | 31680. | 21600. | 31680. | Simple | Kinematic | 0.02 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A572Gr50 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A58G | 0.14 | 0.2 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 35000psi | 504. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 35000psi | 0. | 0. |
| 4000Psi | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 8

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| ARIBL0U7 | A572Gr50 | SD Section | | | |
| ARIBU7U7P | A572Gr50 | SD Section | | | |
| Cable | ASTM A58G | General | 1. | 1. | |
| FLBML0 | A572Gr50 | I/Wide Flange | 7.7708 | 2. | 0.1667 |
| FLBML1 | A572Gr50 | Built Up I | 6.6875 | 2. | 0.16667 |
| FLBML2-L9 | A572Gr50 | Built Up I | 6.6875 | 1.58333 | 0.16667 |
| FSEC1 | A992Fy50 | I/Wide Flange | 1. | 0.41667 | 0.03167 |
| LLBR | A572Gr50 | SD Section | | | |
| PBEAM | 35000psi | Rectangular | 12. | 11.29 | |
| PCOLUMN | 35000psi | Rectangular | 13.375 | 19. | |
| STRGR | A572Gr50 | I/Wide Flange | 1. | 0.4167 | 0.0317 |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| TGDRL0L2 | A992Fy50 | I/Wide Flange | 12.4167 | 4. | 0.2083 |
| TGDRL2L3 | A992Fy50 | I/Wide Flange | 12.5 | 4. | 0.25 |
| TGDRL3L4 | A992Fy50 | I/Wide Flange | 12.5833 | 4. | 0.2917 |
| TGDRL4L6 | A992Fy50 | I/Wide Flange | 12.6667 | 4. | 0.3333 |
| TGDRL6L7 | A992Fy50 | I/Wide Flange | 12.5833 | 4. | 0.2917 |
| TGDRl7l7P | A992Fy50 | I/Wide Flange | 12.5 | 4. | 0.25 |
| ULBRU10 | A572Gr50 | SD Section | | | |
| ULBRU2 | A572Gr50 | SD Section | | | |
| ULBRU2P | A572Gr50 | SD Section | | | |
| ULBRU3 | A572Gr50 | SD Section | | | |
| ULBRU3P | A572Gr50 | SD Section | | | |
| ULBRU4 | A572Gr50 | SD Section | | | |
| ULBRU4P | A572Gr50 | SD Section | | | |
| ULBRU5 | A572Gr50 | SD Section | | | |
| ULBRU5P | A572Gr50 | SD Section | | | |
| ULBRU6 | A572Gr50 | SD Section | | | |
| ULBRU6P | A572Gr50 | SD Section | | | |
| ULBRU7 | A572Gr50 | SD Section | | | |
| ULBRU7P | A572Gr50 | SD Section | | | |
| ULBRU8 | A572Gr50 | SD Section | | | |
| ULBRU8P | A572Gr50 | SD Section | | | |
| ULBRU9 | A572Gr50 | SD Section | | | |
| ULBRU9P | A572Gr50 | SD Section | | | |
| W30X108 | A572Gr50 | I/Wide Flange | 2.48333 | 0.875 | 0.06333 |
| W30X116 | A572Gr50 | I/Wide Flange | 2.5 | 0.875 | 0.07083 |
| W30X124 | A572Gr50 | I/Wide Flange | 2.51667 | 0.875 | 0.0775 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ARIBL0U7 | | | | 2.9297 | 24.591521 | 15.632105 |
| ARIBU7U7P | | | | 2.4457 | 20.451794 | 13.058811 |
| Cable | | | | 0.0753 | 0.000902 | 0.000451 |
| FLBML0 | 0.0625 | 2. | 0.1667 | 1.1316 | 0.006454 | 11.783232 |
| FLBML1 | 0.0625 | 2. | 0.16667 | 1.0638 | 0.006363 | 8.424631 |
| FLBML2-L9 | 0.0625 | 1.58333 | 0.16667 | 0.9249 | 0.005077 | 6.947876 |
| FSEC1 | 0.02083 | 0.41667 | 0.03167 | 0.0459 | 0.000011 | 0.007615 |
| LLBR | | | | 0.2642 | 0.00022 | 0.094972 |
| PBEAM | | | | 135.48 | 2567.16248 | 1625.76 |
| PCOLUMN | | | | 254.125 | 8570.65956 | 3788.381673 |
| STRGR | 0.0208 | 0.4167 | 0.0317 | 0.0459 | 0.000011 | 0.007619 |
| TGDRL0L2 | 0.0833 | 4. | 0.2083 | 2.666 | 0.025612 | 74.093685 |
| TGDRL2L3 | 0.0833 | 4. | 0.25 | 2.9996 | 0.042328 | 87.036867 |
| TGDRL3L4 | 0.0833 | 4. | 0.2917 | 3.3332 | 0.065449 | 100.15352 |
| TGDRL4L6 | 0.0833 | 4. | 0.3333 | 3.666 | 0.095855 | 113.418547 |
| TGDRL6L7 | 0.0833 | 4. | 0.2917 | 3.3332 | 0.065449 | 100.15352 |
| TGDRl7l7P | 0.0833 | 4. | 0.25 | 2.9996 | 0.042328 | 87.036867 |

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ULBRU10 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU2 | | | | 2.2344 | 19.383695 | 12.011948 |
| ULBRU2P | | | | 2.2344 | 19.383695 | 12.011948 |
| ULBRU3 | | | | 2.1797 | 18.057961 | 11.584114 |
| ULBRU3P | | | | 2.1797 | 18.057961 | 11.584114 |
| ULBRU4 | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU4P | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU5 | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU5P | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU6 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU6P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU7 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU7P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU8 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU8P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU9 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU9P | | | | 2.0703 | 15.469086 | 10.728447 |
| W30X108 | 0.04542 | 0.875 | 0.06333 | 0.2201 | 0.000241 | 0.215567 |
| W30X116 | 0.04708 | 0.875 | 0.07083 | 0.2375 | 0.00031 | 0.237751 |
| W30X124 | 0.04875 | 0.875 | 0.0775 | 0.2535 | 0.000385 | 0.258488 |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARIBL0U7 | 17.392731 | 0. | 1.4093 | 1.5068 | 5.466966 | 5.565674 |
| ARIBU7U7P | 14.532555 | 0. | 1.1718 | 1.2533 | 4.583714 | 4.650418 |
| Cable | 0.000451 | 0. | 0.0678 | 0.0678 | 1. | 1. |
| FLBML0 | 0.222418 | 0. | 0.4857 | 0.5557 | 3.032695 | 0.222418 |
| FLBML1 | 0.222351 | 0. | 0.418 | 0.5556 | 2.519516 | 0.222351 |
| FLBML2-L9 | 0.110388 | 0. | 0.418 | 0.4398 | 2.07787 | 0.139438 |
| FSEC1 | 0.000382 | 0. | 0.0208 | 0.022 | 0.01523 | 0.001836 |
| LLBR | 0.060936 | 0. | 0.0693 | 0.1532 | 0.134619 | 0.081247 |
| PBEAM | 1439.069689 | 0. | 112.9 | 112.9 | 270.96 | 254.9282 |
| PCOLUMN | 7644.927083 | 0. | 211.7708 | 211.7708 | 566.486979 | 804.729167 |
| STRGR | 0.000383 | 0. | 0.0208 | 0.022 | 0.015238 | 0.001838 |
| TGDRL0L2 | 2.222445 | 0. | 1.0343 | 1.3887 | 11.934521 | 1.111222 |
| TGDRL2L3 | 2.667245 | 0. | 1.0413 | 1.6667 | 13.925899 | 1.333622 |
| TGDRL3L4 | 3.112045 | 0. | 1.0482 | 1.9447 | 15.918483 | 1.556022 |
| TGDRL4L6 | 3.555778 | 0. | 1.0551 | 2.222 | 17.908144 | 1.777889 |
| TGDRL6L7 | 3.112045 | 0. | 1.0482 | 1.9447 | 15.918483 | 1.556022 |
| TGDRl7l7P | 2.667245 | 0. | 1.0413 | 1.6667 | 13.925899 | 1.333622 |
| ULBRU10 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU2 | 14.099183 | 0. | 1.054 | 1.1658 | 4.223982 | 4.394551 |
| ULBRU2P | 14.099183 | 0. | 1.054 | 1.1658 | 4.223982 | 4.394551 |
| ULBRU3 | 12.648153 | 0. | 1.0529 | 1.1129 | 4.073535 | 4.130009 |
| ULBRU3P | 12.648153 | 0. | 1.0529 | 1.1129 | 4.073535 | 4.130009 |
| ULBRU4 | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |

Table:  Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ULBRU4P | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU5 | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU5P | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU6 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU6P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU7 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU7P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU8 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU8P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU9 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU9P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| W30X108 | 0.007041 | 0. | 0.1128 | 0.0924 | 0.173611 | 0.016093 |
| W30X116 | 0.007909 | 0. | 0.1177 | 0.1033 | 0.190201 | 0.018078 |
| W30X124 | 0.008729 | 0. | 0.1227 | 0.113 | 0.205421 | 0.019951 |

Table:  Frame Section Properties 01 - General, Part 4 of 8

Table:  Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARIBL0U7 | 6.239319 | 6.542969 | 2.30993 | 2.43654 | | No |
| ARIBU7U7P | 5.211323 | 5.465495 | 2.31071 | 2.43762 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| FLBML0 | 3.399503 | 0.340663 | 3.22685 | 0.44333 | | No |
| FLBML1 | 2.804477 | 0.339539 | 2.81414 | 0.45718 | | No |
| FLBML2-L9 | 2.351642 | 0.215117 | 2.74079 | 0.34547 | | No |
| FSEC1 | 0.017346 | 0.00285 | 0.4073 | 0.09128 | | No |
| LLBR | 0.152414 | 0.102704 | 0.59952 | 0.48022 | | No |
| PBEAM | 406.44 | 382.3923 | 3.4641 | 3.25914 | | Yes |
| PCOLUMN | 849.730469 | 1207.09375 | 3.86103 | 5.48483 | | Yes |
| STRGR | 0.017352 | 0.002853 | 0.40742 | 0.09134 | | No |
| TGDRL0L2 | 13.170889 | 1.687217 | 5.27181 | 0.91303 | | No |
| TGDRL2L3 | 15.2488 | 2.020817 | 5.38666 | 0.94297 | | No |
| TGDRL3L4 | 17.340589 | 2.354416 | 5.48154 | 0.96626 | | No |
| TGDRL4L6 | 19.441739 | 2.687217 | 5.56218 | 0.98485 | | No |
| TGDRL6L7 | 17.340589 | 2.354416 | 5.48154 | 0.96626 | | No |
| TGDRl7l7P | 15.2488 | 2.020817 | 5.38666 | 0.94297 | | No |
| ULBRU10 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU2 | 4.782959 | 5.136556 | 2.31862 | 2.512 | | No |
| ULBRU2P | 4.782959 | 5.136556 | 2.31862 | 2.512 | | No |
| ULBRU3 | 4.630005 | 4.814697 | 2.30534 | 2.40889 | | No |
| ULBRU3P | 4.630005 | 4.814697 | 2.30534 | 2.40889 | | No |
| ULBRU4 | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU4P | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU5 | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU5P | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU6 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU6P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU7 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 ft3 | Z22 ft3 | R33 ft | R22 ft | EccV2 ft | ConcCol |
|---|---|---|---|---|---|---|
| ULBRU7P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU8 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU8P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU9 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU9P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| W30X108 | 0.200231 | 0.025405 | 0.98956 | 0.17884 | | No |
| W30X116 | 0.21875 | 0.028472 | 1.00053 | 0.18249 | | No |
| W30X124 | 0.236111 | 0.03125 | 1.00984 | 0.18557 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 8

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt Kip | TotalMass Kip-s2/ft | FromFile | AMod |
|---|---|---|---|---|---|---|
| ARIBL0U7 | No | 8421631 | 2617.96 | 81.37 | No | 1. |
| ARIBU7U7P | No | 8421631 | 926.384 | 28.79 | No | 1. |
| Cable | No | Red | 165.378 | 5.14 | No | 1. |
| FLBML0 | No | Green | 89.386 | 2.78 | No | 1. |
| FLBML1 | No | Gray8Dark | 84.028 | 2.61 | No | 1. |
| FLBML2-L9 | No | Green | 620.985 | 19.3 | No | 1. |
| FSEC1 | No | Magenta | 0. | 0. | No | 1. |
| LLBR | No | 13619151 | 301.96 | 9.39 | No | 1. |
| PBEAM | No | Blue | 2519.928 | 78.32 | No | 1. |
| PCOLUMN | No | Cyan | 5997.345 | 186.4 | No | 1. |
| STRGR | No | 4210816 | 0. | 0. | No | 1. |
| TGDRL0L2 | No | Blue | 391.144 | 12.16 | No | 1. |
| TGDRL2L3 | No | Blue | 345.232 | 10.73 | No | 1. |
| TGDRL3L4 | No | Blue | 383.814 | 11.93 | No | 1. |
| TGDRL4L6 | No | Blue | 844.802 | 26.26 | No | 1. |
| TGDRL6L7 | No | Blue | 384.222 | 11.94 | No | 1. |
| TGDRl7l7P | No | Blue | 1037.552 | 32.25 | No | 1. |
| ULBRU10 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU2 | No | Red | 67.88 | 2.11 | No | 1. |
| ULBRU2P | No | Red | 67.88 | 2.11 | No | 1. |
| ULBRU3 | No | Red | 66.219 | 2.06 | No | 1. |
| ULBRU3P | No | Magenta | 66.219 | 2.06 | No | 1. |
| ULBRU4 | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU4P | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU5 | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU5P | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU6 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU6P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU7 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU7P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU8 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU8P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU9 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU9P | No | Red | 62.896 | 1.95 | No | 1. |
| W30X108 | No | 4210816 | 0. | 0. | Yes | 1. |

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt Kip | TotalMass Kip-s2/ft | FromFile | AMod |
|---|---|---|---|---|---|---|
| W30X116 | No | 4227327 | 950.019 | 29.53 | Yes | 1. |
| W30X124 | No | Orange | 0. | 0. | Yes | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARIBL0U7 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| ARIBU7U7P | 1. | 1. | 1. | 1. | 1. | 1.3 |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBML0 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FLBML1 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FLBML2-L9 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| LLBR | 1. | 1. | 1. | 1. | 1. | 1. |
| PBEAM | 1. | 1. | 1. | 1. | 1. | 1. |
| PCOLUMN | 1. | 1. | 1. | 1. | 1. | 1. |
| STRGR | 1. | 1. | 1. | 1. | 1. | 1.1 |
| TGDRL0L2 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL2L3 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL3L4 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL4L6 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL6L7 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRl7l7P | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ULBRU10 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU2 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU2P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU3 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU3P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU4 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU4P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU5 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU5P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU6 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU6P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU7 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU7P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU8 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU8P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU9 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU9P | 1. | 1. | 1. | 1. | 1. | 1. |
| W30X108 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| W30X116 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| W30X124 | 1. | 1. | 1. | 1. | 1. | 1.2 |

Table: Frame Section Properties 01 - General, Part 7 of 8

Table: Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| ARIBL0U7 | 1.3 | | | |
| ARIBU7U7P | 1.3 | | | |
| Cable | 1. | | | |
| FLBML0 | 1.3 | | | |
| FLBML1 | 1.3 | | | |
| FLBML2-L9 | 1.3 | | | |
| FSEC1 | 1. | | | |
| LLBR | 1. | | | |
| PBEAM | 1. | | | |
| PCOLUMN | 1. | | | |
| STRGR | 1.1 | | | |
| TGDRL0L2 | 1.2 | | | |
| TGDRL2L3 | 1.2 | | | |
| TGDRL3L4 | 1.2 | | | |
| TGDRL4L6 | 1.2 | | | |
| TGDRL6L7 | 1.2 | | | |
| TGDRl7l7P | 1.2 | | | |
| ULBRU10 | 1. | | | |
| ULBRU2 | 1. | | | |
| ULBRU2P | 1. | | | |
| ULBRU3 | 1. | | | |
| ULBRU3P | 1. | | | |
| ULBRU4 | 1. | | | |
| ULBRU4P | 1. | | | |
| ULBRU5 | 1. | | | |
| ULBRU5P | 1. | | | |
| ULBRU6 | 1. | | | |
| ULBRU6P | 1. | | | |
| ULBRU7 | 1. | | | |
| ULBRU7P | 1. | | | |
| ULBRU8 | 1. | | | |
| ULBRU8P | 1. | | | |
| ULBRU9 | 1. | | | |
| ULBRU9P | 1. | | | |
| W30X108 | 1.2 | W30X108 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |
| W30X116 | 1.3 | W30X116 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |
| W30X124 | 1.2 | W30X124 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |

Table: Frame Section Properties 01 - General, Part 8 of 8

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARIBL0U7 | Added 12/28/2013 5:08:03 PM |
| ARIBU7U7P | Added 12/28/2013 5:14:13 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| Cable | Added 5/30/2016 11:02:21 AM |
| FLBML0 | Added 12/27/2013 9:11:58 PM |
| FLBML1 | Added 12/27/2013 9:19:14 PM |
| FLBML2-L9 | Added 12/27/2013 9:20:57 PM |
| FSEC1 | Added 12/27/2013 7:24:42 PM |
| LLBR | Added 12/28/2013 9:50:48 AM |
| PBEAM | Added 4/24/2016 8:49:51 PM |
| PCOLUMN | Added 4/24/2016 8:55:48 PM |
| STRGR | Added 10/3/2014 4:09:14 PM |
| TGDRL0L2 | Added 12/28/2013 4:08:24 PM |
| TGDRL2L3 | Added 12/28/2013 4:22:30 PM |
| TGDRL3L4 | Added 12/28/2013 4:24:00 PM |
| TGDRL4L6 | Added 12/28/2013 4:50:43 PM |
| TGDRL6L7 | Added 12/28/2013 4:53:15 PM |
| TGDRl7l7P | Added 12/28/2013 4:54:43 PM |
| ULBRU10 | Added 12/28/2013 12:52:46 PM |
| ULBRU2 | Added 12/28/2013 10:46:07 AM |
| ULBRU2P | Added 12/28/2013 12:59:27 PM |
| ULBRU3 | Added 12/28/2013 12:02:41 PM |
| ULBRU3P | Added 12/28/2013 12:58:52 PM |
| ULBRU4 | Added 12/28/2013 12:11:04 PM |
| ULBRU4P | Added 12/28/2013 12:58:20 PM |
| ULBRU5 | Added 12/28/2013 12:30:59 PM |
| ULBRU5P | Added 12/28/2013 12:57:53 PM |
| ULBRU6 | Added 12/28/2013 12:43:28 PM |
| ULBRU6P | Added 12/28/2013 12:57:18 PM |
| ULBRU7 | Added 12/28/2013 12:47:49 PM |
| ULBRU7P | Added 12/28/2013 12:56:04 PM |
| ULBRU8 | Added 12/28/2013 12:49:16 PM |
| ULBRU8P | Added 12/28/2013 12:55:31 PM |
| ULBRU9 | Added 12/28/2013 12:50:54 PM |
| ULBRU9P | Added 12/28/2013 12:54:31 PM |
| W30X108 | Imported 10/4/2014 12:09:11 PM from AISC13.pro |
| W30X116 | Imported 10/4/2014 12:10:07 PM from AISC13.pro |
| W30X124 | Imported 10/4/2014 12:10:40 PM from AISC13.pro |

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover<br>ft | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| PBEAM | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |
| PCOLUMN | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC<br>ft | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| PBEAM | #9 | #4 | 0.5 | 3 | 3 | Design |
| PCOLUMN | #9 | #4 | 0.5 | 3 | 3 | Design |

Table:  Frame Section Properties 07 - Built Up I, Part 1 of 2

Table:  Frame Section Properties 07 - Built Up I, Part 1 of 2

| SectionName | ItemType | ISection | FyTF<br>Kip/ft2 | FyW<br>Kip/ft2 | FyBF<br>Kip/ft2 | Material |
|---|---|---|---|---|---|---|
| FLBML1 | Web | | | | | A572Gr50 |
| FLBML1 | Top Cover Plate | | | | | A572Gr50 |
| FLBML1 | Bottom Cover Plate | | | | | A572Gr50 |
| FLBML2-L9 | Web | | | | | A572Gr50 |
| FLBML2-L9 | Top Cover Plate | | | | | A572Gr50 |
| FLBML2-L9 | Bottom Cover Plate | | | | | A572Gr50 |

Table:  Frame Section Properties 07 - Built Up I, Part 2 of 2

Table:  Frame Section Properties 07 - Built Up I, Part 2 of 2

| SectionName | Width<br>ft | Thick<br>ft |
|---|---|---|
| FLBML1 | 6.35417 | 0.0625 |
| FLBML1 | 2. | 0.16667 |
| FLBML1 | 2. | 0.16667 |
| FLBML2-L9 | 6.35417 | 0.0625 |
| FLBML2-L9 | 1.58333 | 0.16667 |
| FLBML2-L9 | 1.58333 | 0.16667 |

Table:  Link Property Definitions 01 - General, Part 1 of 3

Table:  Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass<br>Kip-s2/ft | Weight<br>Kip | RotInert1<br>Kip-ft-s2 | RotInert2<br>Kip-ft-s2 | RotInert3<br>Kip-ft-s2 |
|---|---|---|---|---|---|---|
| P12EXP | Linear | 0. | 0. | 0. | 0. | 0. |
| P13FIX | Linear | 0. | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 2 of 3

Table:  Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength<br>ft | DefArea<br>ft2 | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| P12EXP | 1. | 1. | 0. | 0. | 0. | 0. |
| P13FIX | 1. | 1. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| P12EXP | Magenta | | Added 4/24/2016 9:09:32 PM |
| P13FIX | Magenta | | Added 4/24/2016 9:09:32 PM |

Table: Link Property Definitions 02 - Linear

Table: Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE Kip/ft | RotKE Kip-ft/rad | TransCE Kip-s/ft | RotCE Kip-ft-s/rad | DJ ft |
|---|---|---|---|---|---|---|---|
| P12EXP | U1 | No | 100000. | | 0. | | |
| P12EXP | U2 | No | 100. | | 0. | | 0. |
| P12EXP | U3 | No | 100000. | | 0. | | 0. |
| P12EXP | R1 | No | | 0. | | 0. | |
| P12EXP | R2 | No | | 0. | | 0. | |
| P12EXP | R3 | No | | 0. | | 0. | |
| P13FIX | U1 | No | 100000. | | 0. | | |
| P13FIX | U2 | No | 100000. | | 0. | | 0. |
| P13FIX | U3 | No | 100000. | | 0. | | 0. |
| P13FIX | R1 | No | | 0. | | 0. | |
| P13FIX | R2 | No | | 0. | | 0. | |
| P13FIX | R3 | No | | 0. | | 0. | |

Section 2 Jefferson Barracks Bridge Load Data

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | Zero | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING _DEAD | LinBuckling | PDELTA | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | No | Not Run |
| BUCKLING _DEAD | DEAD | Prog Det | Other | None | No | Not Run |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| MODAL | | |
| LIVELOAD | | |
| PDELTA | | |
| BUCKLING_DEAD | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 10 |
| PDELTA | Full Load | U1 | 10 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |
| PDELTA | 10 | 0.01 | 1. | No |

Table:  Case - Moving Load 1 - Lane Assignments

Table:  Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 0 | 4 | 9 |

Table:  Case - Moving Load 2 - Lanes Loaded

Table:  Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CENLANE1 |
| LIVELOAD | 1 | CENTLANE2 |
| LIVELOAD | 1 | LTLANE1 |
| LIVELOAD | 1 | LTLANE2 |
| LIVELOAD | 1 | LTLANE21 |
| LIVELOAD | 1 | RGTLANE21 |
| LIVELOAD | 1 | RGTLANE22 |
| LIVELOAD | 1 | RTLANE1 |
| LIVELOAD | 1 | RTLANE2 |

Table:  Case - Moving Load 3 - MultiLane Factors

Table:  Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1. |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.9 |
| LIVELOAD | 4 | 0.75 |
| LIVELOAD | 5 | 0.75 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift | EigenCutoff | EigenTol |
|---|---|---|---|---|---|---|
| | | | | Cyc/sec | Cyc/sec | |
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 Jefferson Barracks Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static | Dynamic |
|---|---|---|---|---|
| | | | Percent | Percent |
| MODAL | Acceleration | UX | 99.8176 | 92.331 |
| MODAL | Acceleration | UY | 99.8753 | 76.9187 |
| MODAL | Acceleration | UZ | 98.5532 | 42.9878 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| | | | Sec | | | | |
| MODAL | | | 0. | 0. | 2.290E-05 | 1.559E-13 | 0. |

Table: Modal Participating Mass Ratios, Part 2 of 3

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | | | 2.290E-05 | 1.559E-13 | 3.064E-05 | 8.288E-16 | 0.00862 |

Table: Modal Participating Mass Ratios, Part 3 of 3

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | | | 3.064E-05 | 8.288E-16 | 0.00862 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | RX |
|---|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft | Kip-ft |
| MODAL | | | 0. | 0. | 0.394208 | -0.000012 | -0.172041 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY | RZ | ModalMass | ModalStiff |
|---|---|---|---|---|---|---|
| | | | Kip-ft | Kip-ft | Kip-ft-s2 | Kip-ft |
| MODAL | | | 0.000057 | -1098.69344 | 0. | 0. |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period | Frequency | CircFreq | Eigenvalue |
|---|---|---|---|---|---|---|
| | | | Sec | Cyc/sec | rad/sec | rad2/sec2 |
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

Table: Program Control, Part 1 of 2

Table: Program Control, Part 1 of 2

| ProgramName | Version | ProgLevel | LicenseNum | LicenseOS | LicenseSC | LicenseHT | CurrUnits |
|---|---|---|---|---|---|---|---|
| SAP2000 | 18.1.1 | Advanced | 2010*1GR WHLW4599 V5FQ | No | No | No | Kip, ft, F |

Table: Program Control, Part 2 of 2

Table: Program Control, Part 2 of 2

| SteelCode | ConcCode | AlumCode | ColdCode | RegenHinge |
|---|---|---|---|---|
| AISC360-05/IBC2006 | ACI 318-08/IBC2009 | AA-ASD 2000 | AISI-ASD96 | Yes |

SAP2000®

License #2010*1GRWHLW4599V5FQ

**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160611 JBBridge Rev 013 HS20 C2F UBK.sdb**

**26 June 2016**

Section 1 Jefferson Barracks Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 3500psi | Concrete | Isotropic | No | Yellow | |
| 4000Psi | Concrete | Isotropic | No | Yellow | |
| A416Gr270 | Tendon | Uniaxial | No | Blue | |
| A572Gr50 | Steel | Isotropic | No | Blue | |
| A615Gr60 | Rebar | Uniaxial | No | Gray8Dark | |
| A992Fy50 | Steel | Isotropic | No | Magenta | |
| ASTM A58G | Steel | Isotropic | No | Blue | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 3500psi | Normalweight f'c = 4 ksi added 12/27/2013 5:33:58 PM |
| 4000Psi | Normalweight f'c = 4 ksi added 12/27/2013 5:33:58 PM |
| A416Gr270 | ASTM A416 Grade 270 2/6/2016 4:27:13 PM |
| A572Gr50 | ASTM A572 Grade 50 added 12/27/2013 9:18:45 PM |
| A615Gr60 | ASTM A615 Grade 60 added 12/28/2013 9:51:32 AM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 12/27/2013 5:33:58 PM |
| ASTM A58G | ASTM A36 added 12/28/2013 1:03:46 PM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight Kip/ft3 | UnitMass Kip-s2/ft4 | E1 Kip/ft2 | G12 Kip/ft2 | U12 | A1 1/F |
|---|---|---|---|---|---|---|
| 3500psi | 1.5000E-01 | 4.6621E-03 | 631270. | 263029.17 | 0.2 | 5.5000E-06 |
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 674855. | 281189.58 | 0.2 | 5.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A572Gr50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| ASTM A58G | 4.9000E-01 | 1.5230E-02 | 3312000. | 1273846.15 | 0.3 | 6.5000E-06 |

Table:  Material Properties 03a - Steel Data, Part 1 of 2

Table:  Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A572Gr50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| ASTM A58G | 21600. | 31680. | 21600. | 31680. | Simple | Kinematic | 0.02 |

Table:  Material Properties 03a - Steel Data, Part 2 of 2

Table:  Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A572Gr50 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A58G | 0.14 | 0.2 | -0.1 |

Table:  Material Properties 03b - Concrete Data, Part 1 of 2

Table:  Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 3500psi | 655. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| 4000Psi | 749. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table:  Material Properties 03b - Concrete Data, Part 2 of 2

Table:  Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 3500psi | 0. | 0. |
| 4000Psi | 0. | 0. |

Table:  Frame Section Properties 01 - General, Part 1 of 8

Table:  Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| ARIBL0U7 | A572Gr50 | SD Section | | | |
| ARIBU7U7P | A572Gr50 | SD Section | | | |
| Cable | ASTM A58G | General | 1. | 1. | |
| FLBML0 | A572Gr50 | I/Wide Flange | 7.7708 | 2. | 0.1667 |
| FLBML1 | A572Gr50 | Built Up I | 6.6875 | 2. | 0.16667 |
| FLBML2-L9 | A572Gr50 | Built Up I | 6.6875 | 1.58333 | 0.16667 |
| FSEC1 | A992Fy50 | I/Wide Flange | 1. | 0.41667 | 0.03167 |
| LLBR | A572Gr50 | SD Section | | | |
| PBEAM | 3500psi | Rectangular | 12. | 11.29 | |
| PCOLUMN | 3500psi | Rectangular | 13.375 | 19. | |
| STRGR | A572Gr50 | I/Wide Flange | 1. | 0.4167 | 0.0317 |

Table:  Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3<br>ft | t2<br>ft | tf<br>ft |
|---|---|---|---|---|---|
| TGDRL0L2 | A992Fy50 | I/Wide Flange | 12.4167 | 4. | 0.2083 |
| TGDRL2L3 | A992Fy50 | I/Wide Flange | 12.5 | 4. | 0.25 |
| TGDRL3L4 | A992Fy50 | I/Wide Flange | 12.5833 | 4. | 0.2917 |
| TGDRL4L6 | A992Fy50 | I/Wide Flange | 12.6667 | 4. | 0.3333 |
| TGDRL6L7 | A992Fy50 | I/Wide Flange | 12.5833 | 4. | 0.2917 |
| TGDRl7l7P | A992Fy50 | I/Wide Flange | 12.5 | 4. | 0.25 |
| ULBRU10 | A572Gr50 | SD Section | | | |
| ULBRU2 | A572Gr50 | SD Section | | | |
| ULBRU2P | A572Gr50 | SD Section | | | |
| ULBRU3 | A572Gr50 | SD Section | | | |
| ULBRU3P | A572Gr50 | SD Section | | | |
| ULBRU4 | A572Gr50 | SD Section | | | |
| ULBRU4P | A572Gr50 | SD Section | | | |
| ULBRU5 | A572Gr50 | SD Section | | | |
| ULBRU5P | A572Gr50 | SD Section | | | |
| ULBRU6 | A572Gr50 | SD Section | | | |
| ULBRU6P | A572Gr50 | SD Section | | | |
| ULBRU7 | A572Gr50 | SD Section | | | |
| ULBRU7P | A572Gr50 | SD Section | | | |
| ULBRU8 | A572Gr50 | SD Section | | | |
| ULBRU8P | A572Gr50 | SD Section | | | |
| ULBRU9 | A572Gr50 | SD Section | | | |
| ULBRU9P | A572Gr50 | SD Section | | | |
| W30X108 | A572Gr50 | I/Wide Flange | 2.48333 | 0.875 | 0.06333 |
| W30X116 | A572Gr50 | I/Wide Flange | 2.5 | 0.875 | 0.07083 |
| W30X124 | A572Gr50 | I/Wide Flange | 2.51667 | 0.875 | 0.0775 |

Table:  Frame Section Properties 01 - General, Part 2 of 8

Table:  Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw<br>ft | t2b<br>ft | tfb<br>ft | Area<br>ft2 | TorsConst<br>ft4 | I33<br>ft4 |
|---|---|---|---|---|---|---|
| ARIBL0U7 | | | | 2.9297 | 24.591521 | 15.632105 |
| ARIBU7U7P | | | | 2.4457 | 20.451794 | 13.058811 |
| Cable | | | | 0.0753 | 0.000902 | 0.000451 |
| FLBML0 | 0.0625 | 2. | 0.1667 | 1.1316 | 0.006454 | 11.783232 |
| FLBML1 | 0.0625 | 2. | 0.16667 | 1.0638 | 0.006363 | 8.424631 |
| FLBML2-L9 | 0.0625 | 1.58333 | 0.16667 | 0.9249 | 0.005077 | 6.947876 |
| FSEC1 | 0.02083 | 0.41667 | 0.03167 | 0.0459 | 0.000011 | 0.007615 |
| LLBR | | | | 0.2642 | 0.00022 | 0.094972 |
| PBEAM | | | | 135.48 | 2567.16248 | 1625.76 |
| PCOLUMN | | | | 254.125 | 8570.65956 | 3788.381673 |
| STRGR | 0.0208 | 0.4167 | 0.0317 | 0.0459 | 0.000011 | 0.007619 |
| TGDRL0L2 | 0.0833 | 4. | 0.2083 | 2.666 | 0.025612 | 74.093685 |
| TGDRL2L3 | 0.0833 | 4. | 0.25 | 2.9996 | 0.042328 | 87.036867 |
| TGDRL3L4 | 0.0833 | 4. | 0.2917 | 3.3332 | 0.065449 | 100.15352 |
| TGDRL4L6 | 0.0833 | 4. | 0.3333 | 3.666 | 0.095855 | 113.418547 |
| TGDRL6L7 | 0.0833 | 4. | 0.2917 | 3.3332 | 0.065449 | 100.15352 |
| TGDRl7l7P | 0.0833 | 4. | 0.25 | 2.9996 | 0.042328 | 87.036867 |

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ULBRU10 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU2 | | | | 2.2344 | 19.383695 | 12.011948 |
| ULBRU2P | | | | 2.2344 | 19.383695 | 12.011948 |
| ULBRU3 | | | | 2.1797 | 18.057961 | 11.584114 |
| ULBRU3P | | | | 2.1797 | 18.057961 | 11.584114 |
| ULBRU4 | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU4P | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU5 | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU5P | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU6 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU6P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU7 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU7P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU8 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU8P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU9 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU9P | | | | 2.0703 | 15.469086 | 10.728447 |
| W30X108 | 0.04542 | 0.875 | 0.06333 | 0.2201 | 0.000241 | 0.215567 |
| W30X116 | 0.04708 | 0.875 | 0.07083 | 0.2375 | 0.00031 | 0.237751 |
| W30X124 | 0.04875 | 0.875 | 0.0775 | 0.2535 | 0.000385 | 0.258488 |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARIBL0U7 | 17.392731 | 0. | 1.4093 | 1.5068 | 5.466966 | 5.565674 |
| ARIBU7U7P | 14.532555 | 0. | 1.1718 | 1.2533 | 4.583714 | 4.650418 |
| Cable | 0.000451 | 0. | 0.0678 | 0.0678 | 1. | 1. |
| FLBML0 | 0.222418 | 0. | 0.4857 | 0.5557 | 3.032695 | 0.222418 |
| FLBML1 | 0.222351 | 0. | 0.418 | 0.5556 | 2.519516 | 0.222351 |
| FLBML2-L9 | 0.110388 | 0. | 0.418 | 0.4398 | 2.07787 | 0.139438 |
| FSEC1 | 0.000382 | 0. | 0.0208 | 0.022 | 0.01523 | 0.001836 |
| LLBR | 0.060936 | 0. | 0.0693 | 0.1532 | 0.134619 | 0.081247 |
| PBEAM | 1439.069689 | 0. | 112.9 | 112.9 | 270.96 | 254.9282 |
| PCOLUMN | 7644.927083 | 0. | 211.7708 | 211.7708 | 566.486979 | 804.729167 |
| STRGR | 0.000383 | 0. | 0.0208 | 0.022 | 0.015238 | 0.001838 |
| TGDRL0L2 | 2.222445 | 0. | 1.0343 | 1.3887 | 11.934521 | 1.111222 |
| TGDRL2L3 | 2.667245 | 0. | 1.0413 | 1.6667 | 13.925899 | 1.333622 |
| TGDRL3L4 | 3.112045 | 0. | 1.0482 | 1.9447 | 15.918483 | 1.556022 |
| TGDRL4L6 | 3.555778 | 0. | 1.0551 | 2.222 | 17.908144 | 1.777889 |
| TGDRL6L7 | 3.112045 | 0. | 1.0482 | 1.9447 | 15.918483 | 1.556022 |
| TGDRl7l7P | 2.667245 | 0. | 1.0413 | 1.6667 | 13.925899 | 1.333622 |
| ULBRU10 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU2 | 14.099183 | 0. | 1.054 | 1.1658 | 4.223982 | 4.394551 |
| ULBRU2P | 14.099183 | 0. | 1.054 | 1.1658 | 4.223982 | 4.394551 |
| ULBRU3 | 12.648153 | 0. | 1.0529 | 1.1129 | 4.073535 | 4.130009 |
| ULBRU3P | 12.648153 | 0. | 1.0529 | 1.1129 | 4.073535 | 4.130009 |
| ULBRU4 | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ULBRU4P | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU5 | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU5P | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU6 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU6P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU7 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU7P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU8 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU8P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU9 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU9P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| W30X108 | 0.007041 | 0. | 0.1128 | 0.0924 | 0.173611 | 0.016093 |
| W30X116 | 0.007909 | 0. | 0.1177 | 0.1033 | 0.190201 | 0.018078 |
| W30X124 | 0.008729 | 0. | 0.1227 | 0.113 | 0.205421 | 0.019951 |

Table: Frame Section Properties 01 - General, Part 4 of 8

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARIBL0U7 | 6.239319 | 6.542969 | 2.30993 | 2.43654 | | No |
| ARIBU7U7P | 5.211323 | 5.465495 | 2.31071 | 2.43762 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| FLBML0 | 3.399503 | 0.340663 | 3.22685 | 0.44333 | | No |
| FLBML1 | 2.804477 | 0.339539 | 2.81414 | 0.45718 | | No |
| FLBML2-L9 | 2.351642 | 0.215117 | 2.74079 | 0.34547 | | No |
| FSEC1 | 0.017346 | 0.00285 | 0.4073 | 0.09128 | | No |
| LLBR | 0.152414 | 0.102704 | 0.59952 | 0.48022 | | No |
| PBEAM | 406.44 | 382.3923 | 3.4641 | 3.25914 | | Yes |
| PCOLUMN | 849.730469 | 1207.09375 | 3.86103 | 5.48483 | | Yes |
| STRGR | 0.017352 | 0.002853 | 0.40742 | 0.09134 | | No |
| TGDRL0L2 | 13.170889 | 1.687217 | 5.27181 | 0.91303 | | No |
| TGDRL2L3 | 15.2488 | 2.020817 | 5.38666 | 0.94297 | | No |
| TGDRL3L4 | 17.340589 | 2.354416 | 5.48154 | 0.96626 | | No |
| TGDRL4L6 | 19.441739 | 2.687217 | 5.56218 | 0.98485 | | No |
| TGDRL6L7 | 17.340589 | 2.354416 | 5.48154 | 0.96626 | | No |
| TGDRl7l7P | 15.2488 | 2.020817 | 5.38666 | 0.94297 | | No |
| ULBRU10 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU2 | 4.782959 | 5.136556 | 2.31862 | 2.512 | | No |
| ULBRU2P | 4.782959 | 5.136556 | 2.31862 | 2.512 | | No |
| ULBRU3 | 4.630005 | 4.814697 | 2.30534 | 2.40889 | | No |
| ULBRU3P | 4.630005 | 4.814697 | 2.30534 | 2.40889 | | No |
| ULBRU4 | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU4P | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU5 | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU5P | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU6 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU6P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU7 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ULBRU7P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU8 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU8P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU9 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU9P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| W30X108 | 0.200231 | 0.025405 | 0.98956 | 0.17884 | | No |
| W30X116 | 0.21875 | 0.028472 | 1.00053 | 0.18249 | | No |
| W30X124 | 0.236111 | 0.03125 | 1.00984 | 0.18557 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 8

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| ARIBL0U7 | No | 8421631 | 2617.96 | 81.37 | No | 1. |
| ARIBU7U7P | No | 8421631 | 926.384 | 28.79 | No | 1. |
| Cable | No | Red | 165.378 | 5.14 | No | 1. |
| FLBML0 | No | Green | 89.386 | 2.78 | No | 1. |
| FLBML1 | No | Gray8Dark | 84.028 | 2.61 | No | 1. |
| FLBML2-L9 | No | Green | 620.985 | 19.3 | No | 1. |
| FSEC1 | No | Magenta | 0. | 0. | No | 1. |
| LLBR | No | 13619151 | 301.96 | 9.39 | No | 1. |
| PBEAM | No | Blue | 2519.928 | 78.32 | No | 1. |
| PCOLUMN | No | Cyan | 5997.345 | 186.4 | No | 1. |
| STRGR | No | 4210816 | 0. | 0. | No | 1. |
| TGDRL0L2 | No | Blue | 391.144 | 12.16 | No | 1. |
| TGDRL2L3 | No | Blue | 345.232 | 10.73 | No | 1. |
| TGDRL3L4 | No | Blue | 383.814 | 11.93 | No | 1. |
| TGDRL4L6 | No | Blue | 844.802 | 26.26 | No | 1. |
| TGDRL6L7 | No | Blue | 384.222 | 11.94 | No | 1. |
| TGDRl7l7P | No | Blue | 1037.552 | 32.25 | No | 1. |
| ULBRU10 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU2 | No | Red | 67.88 | 2.11 | No | 1. |
| ULBRU2P | No | Red | 67.88 | 2.11 | No | 1. |
| ULBRU3 | No | Red | 66.219 | 2.06 | No | 1. |
| ULBRU3P | No | Magenta | 66.219 | 2.06 | No | 1. |
| ULBRU4 | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU4P | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU5 | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU5P | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU6 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU6P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU7 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU7P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU8 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU8P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU9 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU9P | No | Red | 62.896 | 1.95 | No | 1. |
| W30X108 | No | 4210816 | 0. | 0. | Yes | 1. |

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| W30X116 | No | 4227327 | 950.019 | 29.53 | Yes | 1. |
| W30X124 | No | Orange | 0. | 0. | Yes | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARIBL0U7 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| ARIBU7U7P | 1. | 1. | 1. | 1. | 1. | 1.3 |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBML0 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FLBML1 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FLBML2-L9 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| LLBR | 1. | 1. | 1. | 1. | 1. | 1. |
| PBEAM | 1. | 1. | 1. | 1. | 1. | 1. |
| PCOLUMN | 1. | 1. | 1. | 1. | 1. | 1. |
| STRGR | 1. | 1. | 1. | 1. | 1. | 1.1 |
| TGDRL0L2 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL2L3 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL3L4 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL4L6 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL6L7 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRl7l7P | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ULBRU10 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU2 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU2P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU3 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU3P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU4 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU4P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU5 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU5P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU6 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU6P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU7 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU7P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU8 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU8P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU9 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU9P | 1. | 1. | 1. | 1. | 1. | 1. |
| W30X108 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| W30X116 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| W30X124 | 1. | 1. | 1. | 1. | 1. | 1.2 |

Table:  Frame Section Properties 01 - General, Part 7 of 8

Table:  Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| ARIBL0U7 | 1.3 | | | |
| ARIBU7U7P | 1.3 | | | |
| Cable | 1. | | | |
| FLBML0 | 1.3 | | | |
| FLBML1 | 1.3 | | | |
| FLBML2-L9 | 1.3 | | | |
| FSEC1 | 1. | | | |
| LLBR | 1. | | | |
| PBEAM | 1. | | | |
| PCOLUMN | 1. | | | |
| STRGR | 1.1 | | | |
| TGDRL0L2 | 1.2 | | | |
| TGDRL2L3 | 1.2 | | | |
| TGDRL3L4 | 1.2 | | | |
| TGDRL4L6 | 1.2 | | | |
| TGDRL6L7 | 1.2 | | | |
| TGDRl7l7P | 1.2 | | | |
| ULBRU10 | 1. | | | |
| ULBRU2 | 1. | | | |
| ULBRU2P | 1. | | | |
| ULBRU3 | 1. | | | |
| ULBRU3P | 1. | | | |
| ULBRU4 | 1. | | | |
| ULBRU4P | 1. | | | |
| ULBRU5 | 1. | | | |
| ULBRU5P | 1. | | | |
| ULBRU6 | 1. | | | |
| ULBRU6P | 1. | | | |
| ULBRU7 | 1. | | | |
| ULBRU7P | 1. | | | |
| ULBRU8 | 1. | | | |
| ULBRU8P | 1. | | | |
| ULBRU9 | 1. | | | |
| ULBRU9P | 1. | | | |
| W30X108 | 1.2 | W30X108 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |
| W30X116 | 1.3 | W30X116 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |
| W30X124 | 1.2 | W30X124 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |

Table:  Frame Section Properties 01 - General, Part 8 of 8

Table:  Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARIBL0U7 | Added 12/28/2013 5:08:03 PM |
| ARIBU7U7P | Added 12/28/2013 5:14:13 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| Cable | Added 5/30/2016 11:02:21 AM |
| FLBML0 | Added 12/27/2013 9:11:58 PM |
| FLBML1 | Added 12/27/2013 9:19:14 PM |
| FLBML2-L9 | Added 12/27/2013 9:20:57 PM |
| FSEC1 | Added 12/27/2013 7:24:42 PM |
| LLBR | Added 12/28/2013 9:50:48 AM |
| PBEAM | Added 4/24/2016 8:49:51 PM |
| PCOLUMN | Added 4/24/2016 8:55:48 PM |
| STRGR | Added 10/3/2014 4:09:14 PM |
| TGDRL0L2 | Added 12/28/2013 4:08:24 PM |
| TGDRL2L3 | Added 12/28/2013 4:22:30 PM |
| TGDRL3L4 | Added 12/28/2013 4:24:00 PM |
| TGDRL4L6 | Added 12/28/2013 4:50:43 PM |
| TGDRL6L7 | Added 12/28/2013 4:53:15 PM |
| TGDRl7l7P | Added 12/28/2013 4:54:43 PM |
| ULBRU10 | Added 12/28/2013 12:52:46 PM |
| ULBRU2 | Added 12/28/2013 10:46:07 AM |
| ULBRU2P | Added 12/28/2013 12:59:27 PM |
| ULBRU3 | Added 12/28/2013 12:02:41 PM |
| ULBRU3P | Added 12/28/2013 12:58:52 PM |
| ULBRU4 | Added 12/28/2013 12:11:04 PM |
| ULBRU4P | Added 12/28/2013 12:58:20 PM |
| ULBRU5 | Added 12/28/2013 12:30:59 PM |
| ULBRU5P | Added 12/28/2013 12:57:53 PM |
| ULBRU6 | Added 12/28/2013 12:43:28 PM |
| ULBRU6P | Added 12/28/2013 12:57:18 PM |
| ULBRU7 | Added 12/28/2013 12:47:49 PM |
| ULBRU7P | Added 12/28/2013 12:56:04 PM |
| ULBRU8 | Added 12/28/2013 12:49:16 PM |
| ULBRU8P | Added 12/28/2013 12:55:31 PM |
| ULBRU9 | Added 12/28/2013 12:50:54 PM |
| ULBRU9P | Added 12/28/2013 12:54:31 PM |
| W30X108 | Imported 10/4/2014 12:09:11 PM from AISC13.pro |
| W30X116 | Imported 10/4/2014 12:10:07 PM from AISC13.pro |
| W30X124 | Imported 10/4/2014 12:10:40 PM from AISC13.pro |

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover ft | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| PBEAM | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |
| PCOLUMN | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| | | | ft | | | |
| PBEAM | #9 | #4 | 0.5 | 3 | 3 | Design |
| PCOLUMN | #9 | #4 | 0.5 | 3 | 3 | Design |

Table: Frame Section Properties 07 - Built Up I, Part 1 of 2

Table: Frame Section Properties 07 - Built Up I, Part 1 of 2

| SectionName | ItemType | ISection | FyTF | FyW | FyBF | Material |
|---|---|---|---|---|---|---|
| | | | Kip/ft2 | Kip/ft2 | Kip/ft2 | |
| FLBML1 | Web | | | | | A572Gr50 |
| FLBML1 | Top Cover Plate | | | | | A572Gr50 |
| FLBML1 | Bottom Cover Plate | | | | | A572Gr50 |
| FLBML2-L9 | Web | | | | | A572Gr50 |
| FLBML2-L9 | Top Cover Plate | | | | | A572Gr50 |
| FLBML2-L9 | Bottom Cover Plate | | | | | A572Gr50 |

Table: Frame Section Properties 07 - Built Up I, Part 2 of 2

Table: Frame Section Properties 07 - Built Up I, Part 2 of 2

| SectionName | Width | Thick |
|---|---|---|
| | ft | ft |
| FLBML1 | 6.35417 | 0.0625 |
| FLBML1 | 2. | 0.16667 |
| FLBML1 | 2. | 0.16667 |
| FLBML2-L9 | 6.35417 | 0.0625 |
| FLBML2-L9 | 1.58333 | 0.16667 |
| FLBML2-L9 | 1.58333 | 0.16667 |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| P12EXP | Linear | 0. | 0. | 0. | 0. | 0. |
| P13FIX | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| P12EXP | 1. | 1. | 0. | 0. | 0. | 0. |
| P13FIX | 1. | 1. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| P12EXP | Magenta | | Added 4/24/2016 9:09:32 PM |
| P13FIX | Magenta | | Added 4/24/2016 9:09:32 PM |

Table: Link Property Definitions 02 - Linear

Table: Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE | RotKE | TransCE | RotCE | DJ |
|---|---|---|---|---|---|---|---|
| | | | Kip/ft | Kip-ft/rad | Kip-s/ft | Kip-ft-s/rad | ft |
| P12EXP | U1 | No | 100000. | | 0. | | |
| P12EXP | U2 | No | 100000. | | 0. | | 0. |
| P12EXP | U3 | No | 100000. | | 0. | | 0. |
| P12EXP | R1 | No | | 0. | | 0. | |
| P12EXP | R2 | No | | 0. | | 0. | |
| P12EXP | R3 | No | | 0. | | 0. | |
| P13FIX | U1 | No | 100000. | | 0. | | |
| P13FIX | U2 | No | 100000. | | 0. | | 0. |
| P13FIX | U3 | No | 100000. | | 0. | | 0. |
| P13FIX | R1 | No | | 0. | | 0. | |
| P13FIX | R2 | No | | 0. | | 0. | |
| P13FIX | R3 | No | | 0. | | 0. | |

Table: Area Section Properties, Part 1 of 4

Table: Area Section Properties, Part 1 of 4

| Section | Material | MatAngle | AreaType | Type | DrillDOF | Thickness | BendThick |
|---|---|---|---|---|---|---|---|
| | | Degrees | | | | ft | ft |
| BRDECK | 4000Psi | 0. | Shell | Shell-Thin | Yes | 0.6667 | 0.6667 |
| P12SHAFT | 3500psi | 0. | Shell | Shell-Thick | Yes | 13.375 | 13.375 |

Table: Area Section Properties, Part 2 of 4

Table: Area Section Properties, Part 2 of 4

| Section | Arc | InComp | CoordSys | Color | TotalWt | TotalMass |
|---|---|---|---|---|---|---|
| | Degrees | | | | Kip | Kip-s2/ft |
| BRDECK | | | | Magenta | 4361.719 | 135.57 |
| P12SHAFT | | | | Cyan | 15921.6 | 494.86 |

Table: Area Section Properties, Part 3 of 4

Table: Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| BRDECK | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| P12SHAFT | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Area Section Properties, Part 4 of 4

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| BRDECK | 1. | 1. | 1. | | Added 3/9/2016 8:37:33 PM |
| P12SHAFT | 1. | 1. | 1. | | Added 4/24/2016 9:05:45 PM |

Section 2 Jefferson Barracks Bridge Load Cases

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | Zero | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING_DEAD | LinBuckling | PDELTA | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | No | Not Run |
| BUCKLING_DEAD | DEAD | Prog Det | Other | None | No | Not Run |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| MODAL | | |
| LIVELOAD | | |
| PDELTA | | |
| BUCKLING_DEAD | | |

Table:  Case - Static 1 - Load Assignments

Table:  Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |

Table:  Case - Static 2 - Nonlinear Load Application

Table:  Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 10 |
| PDELTA | Full Load | U1 | 10 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |
| PDELTA | 10 | 0.01 | 1. | No |

Table: Case - Moving Load 1 - Lane Assignments

Table: Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 0 | 4 | 9 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CENLANE1 |
| LIVELOAD | 1 | CENTLANE2 |
| LIVELOAD | 1 | LTLANE1 |
| LIVELOAD | 1 | LTLANE2 |
| LIVELOAD | 1 | LTLANE21 |
| LIVELOAD | 1 | RGTLANE21 |
| LIVELOAD | 1 | RGTLANE22 |
| LIVELOAD | 1 | RTLANE1 |
| LIVELOAD | 1 | RTLANE2 |

Table: Case - Moving Load 3 - MultiLane Factors

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1. |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.9 |
| LIVELOAD | 4 | 0.75 |
| LIVELOAD | 5 | 0.75 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |

Table:  Case - Modal 1 - General, Part 1 of 2

Table:  Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift Cyc/sec | EigenCutoff Cyc/sec | EigenTol |
|---|---|---|---|---|---|---|
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table:  Case - Modal 1 - General, Part 2 of 2

Table:  Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3  Jefferson Barracks Bridge Modal Analysis Output

Table:  Modal Load Participation Ratios

Table:  Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.5384 | 88.7069 |
| MODAL | Acceleration | UY | 99.5882 | 46.0817 |
| MODAL | Acceleration | UZ | 99.2667 | 41.9053 |

Table:  Modal Participating Mass Ratios, Part 1 of 3

Table:  Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period Sec | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0. | 9.614E-06 | 1.462E-13 | 0. |

Table:  Modal Participating Mass Ratios, Part 2 of 3

Table:  Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | | | 9.614E-06 | 1.462E-13 | 0.002 | 4.504E-14 | 0.0001 |

Table:  Modal Participating Mass Ratios, Part 3 of 3

Table:  Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | | | 0.002 | 4.504E-14 | 0.0001 |

Table:  Modal Participation Factors, Part 1 of 2

Table:  Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period Sec | UX Kip-ft | UY Kip-ft | UZ Kip-ft | RX Kip-ft |
|---|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0. | -0.113192 | 0.00001 | 1.389986 |

Table:  Modal Participation Factors, Part 2 of 2

Table:  Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY<br>Kip-ft | RZ<br>Kip-ft | ModalMass<br>Kip-ft-s2 | ModalStiff<br>Kip-ft |
|---|---|---|---|---|---|---|
| MODAL | | | -0.000415 | 120.847864 | 0. | 0. |

Table:  Modal Periods And Frequencies

Table:  Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period<br>Sec | Frequency<br>Cyc/sec | CircFreq<br>rad/sec | Eigenvalue<br>rad2/sec2 |
|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

Table:  Program Control, Part 1 of 2

Table:  Program Control, Part 1 of 2

| ProgramNa<br>me | Version | ProgLevel | LicenseNum | LicenseOS | LicenseSC | LicenseHT | CurrU<br>nits |
|---|---|---|---|---|---|---|---|
| SAP2000 | 18.1.1 | Advanced | 2010*1GR<br>WHLW4599<br>V5FQ | No | No | No | Kip, ft,<br>F |

Table:  Program Control, Part 2 of 2

Table:  Program Control, Part 2 of 2

| SteelCode | ConcCode | AlumCode | ColdCode | RegenHi<br>nge |
|---|---|---|---|---|
| AISC360-05/IBC2006 | ACI 318-08/IBC2009 | AA-ASD 2000 | AISI-ASD96 | Yes |

SAP2000®

License #2010*1GRWHLW4599V5FQ

**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160611 JBBridge Rev 015 HL93 C2F LBK.sdb**

**26 June 2016**

Section 1 Jefferson Barracks Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 35000psi | Concrete | Isotropic | No | Yellow | |
| 4000Psi | Concrete | Isotropic | No | Yellow | |
| A416Gr270 | Tendon | Uniaxial | No | Blue | |
| A572Gr50 | Steel | Isotropic | No | Blue | |
| A615Gr60 | Rebar | Uniaxial | No | Gray8Dark | |
| A992Fy50 | Steel | Isotropic | No | Magenta | |
| ASTM A58G | Steel | Isotropic | No | Blue | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 35000psi | Normalweight f'c = 4 ksi added 12/27/2013 5:33:58 PM |
| 4000Psi | Normalweight f'c = 4 ksi added 12/27/2013 5:33:58 PM |
| A416Gr270 | ASTM A416 Grade 270 2/6/2016 4:27:13 PM |
| A572Gr50 | ASTM A572 Grade 50 added 12/27/2013 9:18:45 PM |
| A615Gr60 | ASTM A615 Grade 60 added 12/28/2013 9:51:32 AM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 12/27/2013 5:33:58 PM |
| ASTM A58G | ASTM A36 added 12/28/2013 1:03:46 PM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| 35000psi | 1.5000E-01 | 4.6621E-03 | 145680. | 60700. | 0.2 | 5.5000E-06 |
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 155740. | 64891.67 | 0.2 | 5.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A572Gr50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| ASTM A58G | 4.9000E-01 | 1.5230E-02 | 3312000. | 1273846.15 | 0.3 | 6.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A572Gr50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| ASTM A58G | 21600. | 31680. | 21600. | 31680. | Simple | Kinematic | 0.02 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A572Gr50 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A58G | 0.14 | 0.2 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 35000psi | 504. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 35000psi | 0. | 0. |
| 4000Psi | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 8

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| ARIBL0U7 | A572Gr50 | SD Section | | | |
| ARIBU7U7P | A572Gr50 | SD Section | | | |
| Cable | ASTM A58G | General | 1. | 1. | |
| FLBML0 | A572Gr50 | I/Wide Flange | 7.7708 | 2. | 0.1667 |
| FLBML1 | A572Gr50 | Built Up I | 6.6875 | 2. | 0.16667 |
| FLBML2-L9 | A572Gr50 | Built Up I | 6.6875 | 1.58333 | 0.16667 |
| FSEC1 | A992Fy50 | I/Wide Flange | 1. | 0.41667 | 0.03167 |
| LLBR | A572Gr50 | SD Section | | | |
| PBEAM | 35000psi | Rectangular | 12. | 11.29 | |
| PCOLUMN | 35000psi | Rectangular | 13.375 | 19. | |
| STRGR | A572Gr50 | I/Wide Flange | 1. | 0.4167 | 0.0317 |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| TGDRL0L2 | A992Fy50 | I/Wide Flange | 12.4167 | 4. | 0.2083 |
| TGDRL2L3 | A992Fy50 | I/Wide Flange | 12.5 | 4. | 0.25 |
| TGDRL3L4 | A992Fy50 | I/Wide Flange | 12.5833 | 4. | 0.2917 |
| TGDRL4L6 | A992Fy50 | I/Wide Flange | 12.6667 | 4. | 0.3333 |
| TGDRL6L7 | A992Fy50 | I/Wide Flange | 12.5833 | 4. | 0.2917 |
| TGDRl7l7P | A992Fy50 | I/Wide Flange | 12.5 | 4. | 0.25 |
| ULBRU10 | A572Gr50 | SD Section | | | |
| ULBRU2 | A572Gr50 | SD Section | | | |
| ULBRU2P | A572Gr50 | SD Section | | | |
| ULBRU3 | A572Gr50 | SD Section | | | |
| ULBRU3P | A572Gr50 | SD Section | | | |
| ULBRU4 | A572Gr50 | SD Section | | | |
| ULBRU4P | A572Gr50 | SD Section | | | |
| ULBRU5 | A572Gr50 | SD Section | | | |
| ULBRU5P | A572Gr50 | SD Section | | | |
| ULBRU6 | A572Gr50 | SD Section | | | |
| ULBRU6P | A572Gr50 | SD Section | | | |
| ULBRU7 | A572Gr50 | SD Section | | | |
| ULBRU7P | A572Gr50 | SD Section | | | |
| ULBRU8 | A572Gr50 | SD Section | | | |
| ULBRU8P | A572Gr50 | SD Section | | | |
| ULBRU9 | A572Gr50 | SD Section | | | |
| ULBRU9P | A572Gr50 | SD Section | | | |
| W30X108 | A572Gr50 | I/Wide Flange | 2.48333 | 0.875 | 0.06333 |
| W30X116 | A572Gr50 | I/Wide Flange | 2.5 | 0.875 | 0.07083 |
| W30X124 | A572Gr50 | I/Wide Flange | 2.51667 | 0.875 | 0.0775 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ARIBL0U7 | | | | 2.9297 | 24.591521 | 15.632105 |
| ARIBU7U7P | | | | 2.4457 | 20.451794 | 13.058811 |
| Cable | | | | 0.0753 | 0.000902 | 0.000451 |
| FLBML0 | 0.0625 | 2. | 0.1667 | 1.1316 | 0.006454 | 11.783232 |
| FLBML1 | 0.0625 | 2. | 0.16667 | 1.0638 | 0.006363 | 8.424631 |
| FLBML2-L9 | 0.0625 | 1.58333 | 0.16667 | 0.9249 | 0.005077 | 6.947876 |
| FSEC1 | 0.02083 | 0.41667 | 0.03167 | 0.0459 | 0.000011 | 0.007615 |
| LLBR | | | | 0.2642 | 0.00022 | 0.094972 |
| PBEAM | | | | 135.48 | 2567.16248 | 1625.76 |
| PCOLUMN | | | | 254.125 | 8570.65956 | 3788.381673 |
| STRGR | 0.0208 | 0.4167 | 0.0317 | 0.0459 | 0.000011 | 0.007619 |
| TGDRL0L2 | 0.0833 | 4. | 0.2083 | 2.666 | 0.025612 | 74.093685 |
| TGDRL2L3 | 0.0833 | 4. | 0.25 | 2.9996 | 0.042328 | 87.036867 |
| TGDRL3L4 | 0.0833 | 4. | 0.2917 | 3.3332 | 0.065449 | 100.15352 |
| TGDRL4L6 | 0.0833 | 4. | 0.3333 | 3.666 | 0.095855 | 113.418547 |
| TGDRL6L7 | 0.0833 | 4. | 0.2917 | 3.3332 | 0.065449 | 100.15352 |
| TGDRl7l7P | 0.0833 | 4. | 0.25 | 2.9996 | 0.042328 | 87.036867 |

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| ULBRU10 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU2 | | | | 2.2344 | 19.383695 | 12.011948 |
| ULBRU2P | | | | 2.2344 | 19.383695 | 12.011948 |
| ULBRU3 | | | | 2.1797 | 18.057961 | 11.584114 |
| ULBRU3P | | | | 2.1797 | 18.057961 | 11.584114 |
| ULBRU4 | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU4P | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU5 | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU5P | | | | 2.125 | 16.752549 | 11.156281 |
| ULBRU6 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU6P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU7 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU7P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU8 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU8P | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU9 | | | | 2.0703 | 15.469086 | 10.728447 |
| ULBRU9P | | | | 2.0703 | 15.469086 | 10.728447 |
| W30X108 | 0.04542 | 0.875 | 0.06333 | 0.2201 | 0.000241 | 0.215567 |
| W30X116 | 0.04708 | 0.875 | 0.07083 | 0.2375 | 0.00031 | 0.237751 |
| W30X124 | 0.04875 | 0.875 | 0.0775 | 0.2535 | 0.000385 | 0.258488 |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARIBL0U7 | 17.392731 | 0. | 1.4093 | 1.5068 | 5.466966 | 5.565674 |
| ARIBU7U7P | 14.532555 | 0. | 1.1718 | 1.2533 | 4.583714 | 4.650418 |
| Cable | 0.000451 | 0. | 0.0678 | 0.0678 | 1. | 1. |
| FLBML0 | 0.222418 | 0. | 0.4857 | 0.5557 | 3.032695 | 0.222418 |
| FLBML1 | 0.222351 | 0. | 0.418 | 0.5556 | 2.519516 | 0.222351 |
| FLBML2-L9 | 0.110388 | 0. | 0.418 | 0.4398 | 2.07787 | 0.139438 |
| FSEC1 | 0.000382 | 0. | 0.0208 | 0.022 | 0.01523 | 0.001836 |
| LLBR | 0.060936 | 0. | 0.0693 | 0.1532 | 0.134619 | 0.081247 |
| PBEAM | 1439.069689 | 0. | 112.9 | 112.9 | 270.96 | 254.9282 |
| PCOLUMN | 7644.927083 | 0. | 211.7708 | 211.7708 | 566.486979 | 804.729167 |
| STRGR | 0.000383 | 0. | 0.0208 | 0.022 | 0.015238 | 0.001838 |
| TGDRL0L2 | 2.222445 | 0. | 1.0343 | 1.3887 | 11.934521 | 1.111222 |
| TGDRL2L3 | 2.667245 | 0. | 1.0413 | 1.6667 | 13.925899 | 1.333622 |
| TGDRL3L4 | 3.112045 | 0. | 1.0482 | 1.9447 | 15.918483 | 1.556022 |
| TGDRL4L6 | 3.555778 | 0. | 1.0551 | 2.222 | 17.908144 | 1.777889 |
| TGDRL6L7 | 3.112045 | 0. | 1.0482 | 1.9447 | 15.918483 | 1.556022 |
| TGDRl7l7P | 2.667245 | 0. | 1.0413 | 1.6667 | 13.925899 | 1.333622 |
| ULBRU10 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU2 | 14.099183 | 0. | 1.054 | 1.1658 | 4.223982 | 4.394551 |
| ULBRU2P | 14.099183 | 0. | 1.054 | 1.1658 | 4.223982 | 4.394551 |
| ULBRU3 | 12.648153 | 0. | 1.0529 | 1.1129 | 4.073535 | 4.130009 |
| ULBRU3P | 12.648153 | 0. | 1.0529 | 1.1129 | 4.073535 | 4.130009 |
| ULBRU4 | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ULBRU4P | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU5 | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU5P | 11.289834 | 0. | 1.0518 | 1.06 | 3.923088 | 3.8708 |
| ULBRU6 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU6P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU7 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU7P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU8 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU8P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU9 | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| ULBRU9P | 10.021903 | 0. | 1.0505 | 1.0069 | 3.772641 | 3.616927 |
| W30X108 | 0.007041 | 0. | 0.1128 | 0.0924 | 0.173611 | 0.016093 |
| W30X116 | 0.007909 | 0. | 0.1177 | 0.1033 | 0.190201 | 0.018078 |
| W30X124 | 0.008729 | 0. | 0.1227 | 0.113 | 0.205421 | 0.019951 |

Table: Frame Section Properties 01 - General, Part 4 of 8

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARIBL0U7 | 6.239319 | 6.542969 | 2.30993 | 2.43654 | | No |
| ARIBU7U7P | 5.211323 | 5.465495 | 2.31071 | 2.43762 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| FLBML0 | 3.399503 | 0.340663 | 3.22685 | 0.44333 | | No |
| FLBML1 | 2.804477 | 0.339539 | 2.81414 | 0.45718 | | No |
| FLBML2-L9 | 2.351642 | 0.215117 | 2.74079 | 0.34547 | | No |
| FSEC1 | 0.017346 | 0.00285 | 0.4073 | 0.09128 | | No |
| LLBR | 0.152414 | 0.102704 | 0.59952 | 0.48022 | | No |
| PBEAM | 406.44 | 382.3923 | 3.4641 | 3.25914 | | Yes |
| PCOLUMN | 849.730469 | 1207.09375 | 3.86103 | 5.48483 | | Yes |
| STRGR | 0.017352 | 0.002853 | 0.40742 | 0.09134 | | No |
| TGDRL0L2 | 13.170889 | 1.687217 | 5.27181 | 0.91303 | | No |
| TGDRL2L3 | 15.2488 | 2.020817 | 5.38666 | 0.94297 | | No |
| TGDRL3L4 | 17.340589 | 2.354416 | 5.48154 | 0.96626 | | No |
| TGDRL4L6 | 19.441739 | 2.687217 | 5.56218 | 0.98485 | | No |
| TGDRL6L7 | 17.340589 | 2.354416 | 5.48154 | 0.96626 | | No |
| TGDRl7l7P | 15.2488 | 2.020817 | 5.38666 | 0.94297 | | No |
| ULBRU10 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU2 | 4.782959 | 5.136556 | 2.31862 | 2.512 | | No |
| ULBRU2P | 4.782959 | 5.136556 | 2.31862 | 2.512 | | No |
| ULBRU3 | 4.630005 | 4.814697 | 2.30534 | 2.40889 | | No |
| ULBRU3P | 4.630005 | 4.814697 | 2.30534 | 2.40889 | | No |
| ULBRU4 | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU4P | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU5 | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU5P | 4.477051 | 4.500814 | 2.29129 | 2.30496 | | No |
| ULBRU6 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU6P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU7 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |

Table:  Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33<br>ft3 | Z22<br>ft3 | R33<br>ft | R22<br>ft | EccV2<br>ft | ConcCol |
|---|---|---|---|---|---|---|
| ULBRU7P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU8 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU8P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU9 | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| ULBRU9P | 4.324097 | 4.194906 | 2.27641 | 2.20017 | | No |
| W30X108 | 0.200231 | 0.025405 | 0.98956 | 0.17884 | | No |
| W30X116 | 0.21875 | 0.028472 | 1.00053 | 0.18249 | | No |
| W30X124 | 0.236111 | 0.03125 | 1.00984 | 0.18557 | | No |

Table:  Frame Section Properties 01 - General, Part 5 of 8

Table:  Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt<br>Kip | TotalMass<br>Kip-s2/ft | FromFile | AMod |
|---|---|---|---|---|---|---|
| ARIBL0U7 | No | 8421631 | 2617.96 | 81.37 | No | 1. |
| ARIBU7U7P | No | 8421631 | 926.384 | 28.79 | No | 1. |
| Cable | No | Red | 165.378 | 5.14 | No | 1. |
| FLBML0 | No | Green | 89.386 | 2.78 | No | 1. |
| FLBML1 | No | Gray8Dark | 84.028 | 2.61 | No | 1. |
| FLBML2-L9 | No | Green | 620.985 | 19.3 | No | 1. |
| FSEC1 | No | Magenta | 0. | 0. | No | 1. |
| LLBR | No | 13619151 | 301.96 | 9.39 | No | 1. |
| PBEAM | No | Blue | 2519.928 | 78.32 | No | 1. |
| PCOLUMN | No | Cyan | 5997.345 | 186.4 | No | 1. |
| STRGR | No | 4210816 | 0. | 0. | No | 1. |
| TGDRL0L2 | No | Blue | 391.144 | 12.16 | No | 1. |
| TGDRL2L3 | No | Blue | 345.232 | 10.73 | No | 1. |
| TGDRL3L4 | No | Blue | 383.814 | 11.93 | No | 1. |
| TGDRL4L6 | No | Blue | 844.802 | 26.26 | No | 1. |
| TGDRL6L7 | No | Blue | 384.222 | 11.94 | No | 1. |
| TGDRl7l7P | No | Blue | 1037.552 | 32.25 | No | 1. |
| ULBRU10 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU2 | No | Red | 67.88 | 2.11 | No | 1. |
| ULBRU2P | No | Red | 67.88 | 2.11 | No | 1. |
| ULBRU3 | No | Red | 66.219 | 2.06 | No | 1. |
| ULBRU3P | No | Magenta | 66.219 | 2.06 | No | 1. |
| ULBRU4 | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU4P | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU5 | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU5P | No | Red | 64.558 | 2.01 | No | 1. |
| ULBRU6 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU6P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU7 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU7P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU8 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU8P | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU9 | No | Red | 62.896 | 1.95 | No | 1. |
| ULBRU9P | No | Red | 62.896 | 1.95 | No | 1. |
| W30X108 | No | 4210816 | 0. | 0. | Yes | 1. |

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| W30X116 | No | 4227327 | 950.019 | 29.53 | Yes | 1. |
| W30X124 | No | Orange | 0. | 0. | Yes | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARIBL0U7 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| ARIBU7U7P | 1. | 1. | 1. | 1. | 1. | 1.3 |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBML0 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FLBML1 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FLBML2-L9 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| FSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| LLBR | 1. | 1. | 1. | 1. | 1. | 1. |
| PBEAM | 1. | 1. | 1. | 1. | 1. | 1. |
| PCOLUMN | 1. | 1. | 1. | 1. | 1. | 1. |
| STRGR | 1. | 1. | 1. | 1. | 1. | 1.1 |
| TGDRL0L2 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL2L3 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL3L4 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL4L6 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRL6L7 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| TGDRl7l7P | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ULBRU10 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU2 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU2P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU3 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU3P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU4 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU4P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU5 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU5P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU6 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU6P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU7 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU7P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU8 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU8P | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU9 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULBRU9P | 1. | 1. | 1. | 1. | 1. | 1. |
| W30X108 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| W30X116 | 1. | 1. | 1. | 1. | 1. | 1.3 |
| W30X124 | 1. | 1. | 1. | 1. | 1. | 1.2 |

Table:  Frame Section Properties 01 - General, Part 7 of 8

Table:  Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| ARIBL0U7 | 1.3 | | | |
| ARIBU7U7P | 1.3 | | | |
| Cable | 1. | | | |
| FLBML0 | 1.3 | | | |
| FLBML1 | 1.3 | | | |
| FLBML2-L9 | 1.3 | | | |
| FSEC1 | 1. | | | |
| LLBR | 1. | | | |
| PBEAM | 1. | | | |
| PCOLUMN | 1. | | | |
| STRGR | 1.1 | | | |
| TGDRL0L2 | 1.2 | | | |
| TGDRL2L3 | 1.2 | | | |
| TGDRL3L4 | 1.2 | | | |
| TGDRL4L6 | 1.2 | | | |
| TGDRL6L7 | 1.2 | | | |
| TGDRl7l7P | 1.2 | | | |
| ULBRU10 | 1. | | | |
| ULBRU2 | 1. | | | |
| ULBRU2P | 1. | | | |
| ULBRU3 | 1. | | | |
| ULBRU3P | 1. | | | |
| ULBRU4 | 1. | | | |
| ULBRU4P | 1. | | | |
| ULBRU5 | 1. | | | |
| ULBRU5P | 1. | | | |
| ULBRU6 | 1. | | | |
| ULBRU6P | 1. | | | |
| ULBRU7 | 1. | | | |
| ULBRU7P | 1. | | | |
| ULBRU8 | 1. | | | |
| ULBRU8P | 1. | | | |
| ULBRU9 | 1. | | | |
| ULBRU9P | 1. | | | |
| W30X108 | 1.2 | W30X108 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |
| W30X116 | 1.3 | W30X116 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |
| W30X124 | 1.2 | W30X124 | c:\program files (x86)\computers and structures\sap2000 16\aisc13.pro | |

Table:  Frame Section Properties 01 - General, Part 8 of 8

Table:  Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARIBL0U7 | Added 12/28/2013 5:08:03 PM |
| ARIBU7U7P | Added 12/28/2013 5:14:13 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| Cable | Added 5/30/2016 11:02:21 AM |
| FLBML0 | Added 12/27/2013 9:11:58 PM |
| FLBML1 | Added 12/27/2013 9:19:14 PM |
| FLBML2-L9 | Added 12/27/2013 9:20:57 PM |
| FSEC1 | Added 12/27/2013 7:24:42 PM |
| LLBR | Added 12/28/2013 9:50:48 AM |
| PBEAM | Added 4/24/2016 8:49:51 PM |
| PCOLUMN | Added 4/24/2016 8:55:48 PM |
| STRGR | Added 10/3/2014 4:09:14 PM |
| TGDRL0L2 | Added 12/28/2013 4:08:24 PM |
| TGDRL2L3 | Added 12/28/2013 4:22:30 PM |
| TGDRL3L4 | Added 12/28/2013 4:24:00 PM |
| TGDRL4L6 | Added 12/28/2013 4:50:43 PM |
| TGDRL6L7 | Added 12/28/2013 4:53:15 PM |
| TGDRl7l7P | Added 12/28/2013 4:54:43 PM |
| ULBRU10 | Added 12/28/2013 12:52:46 PM |
| ULBRU2 | Added 12/28/2013 10:46:07 AM |
| ULBRU2P | Added 12/28/2013 12:59:27 PM |
| ULBRU3 | Added 12/28/2013 12:02:41 PM |
| ULBRU3P | Added 12/28/2013 12:58:52 PM |
| ULBRU4 | Added 12/28/2013 12:11:04 PM |
| ULBRU4P | Added 12/28/2013 12:58:20 PM |
| ULBRU5 | Added 12/28/2013 12:30:59 PM |
| ULBRU5P | Added 12/28/2013 12:57:53 PM |
| ULBRU6 | Added 12/28/2013 12:43:28 PM |
| ULBRU6P | Added 12/28/2013 12:57:18 PM |
| ULBRU7 | Added 12/28/2013 12:47:49 PM |
| ULBRU7P | Added 12/28/2013 12:56:04 PM |
| ULBRU8 | Added 12/28/2013 12:49:16 PM |
| ULBRU8P | Added 12/28/2013 12:55:31 PM |
| ULBRU9 | Added 12/28/2013 12:50:54 PM |
| ULBRU9P | Added 12/28/2013 12:54:31 PM |
| W30X108 | Imported 10/4/2014 12:09:11 PM from AISC13.pro |
| W30X116 | Imported 10/4/2014 12:10:07 PM from AISC13.pro |
| W30X124 | Imported 10/4/2014 12:10:40 PM from AISC13.pro |

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover ft | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| PBEAM | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |
| PCOLUMN | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.125 | 3 | 3 |

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| | | | ft | | | |
| PBEAM | #9 | #4 | 0.5 | 3 | 3 | Design |
| PCOLUMN | #9 | #4 | 0.5 | 3 | 3 | Design |

Table: Frame Section Properties 07 - Built Up I, Part 1 of 2

Table: Frame Section Properties 07 - Built Up I, Part 1 of 2

| SectionName | ItemType | ISection | FyTF | FyW | FyBF | Material |
|---|---|---|---|---|---|---|
| | | | Kip/ft2 | Kip/ft2 | Kip/ft2 | |
| FLBML1 | Web | | | | | A572Gr50 |
| FLBML1 | Top Cover Plate | | | | | A572Gr50 |
| FLBML1 | Bottom Cover Plate | | | | | A572Gr50 |
| FLBML2-L9 | Web | | | | | A572Gr50 |
| FLBML2-L9 | Top Cover Plate | | | | | A572Gr50 |
| FLBML2-L9 | Bottom Cover Plate | | | | | A572Gr50 |

Table: Frame Section Properties 07 - Built Up I, Part 2 of 2

Table: Frame Section Properties 07 - Built Up I, Part 2 of 2

| SectionName | Width | Thick |
|---|---|---|
| | ft | ft |
| FLBML1 | 6.35417 | 0.0625 |
| FLBML1 | 2. | 0.16667 |
| FLBML1 | 2. | 0.16667 |
| FLBML2-L9 | 6.35417 | 0.0625 |
| FLBML2-L9 | 1.58333 | 0.16667 |
| FLBML2-L9 | 1.58333 | 0.16667 |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| P12EXP | Linear | 0. | 0. | 0. | 0. | 0. |
| P13FIX | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| P12EXP | 1. | 1. | 0. | 0. | 0. | 0. |
| P13FIX | 1. | 1. | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 3 of 3

Table:  Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| P12EXP | Magenta | | Added 4/24/2016 9:09:32 PM |
| P13FIX | Magenta | | Added 4/24/2016 9:09:32 PM |

Table:  Link Property Definitions 02 - Linear

Table:  Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE Kip/ft | RotKE Kip-ft/rad | TransCE Kip-s/ft | RotCE Kip-ft-s/rad | DJ ft |
|---|---|---|---|---|---|---|---|
| P12EXP | U1 | No | 100000. | | 0. | | |
| P12EXP | U2 | No | 100. | | 0. | | 0. |
| P12EXP | U3 | No | 100000. | | 0. | | 0. |
| P12EXP | R1 | No | | 0. | | 0. | |
| P12EXP | R2 | No | | 0. | | 0. | |
| P12EXP | R3 | No | | 0. | | 0. | |
| P13FIX | U1 | No | 100000. | | 0. | | |
| P13FIX | U2 | No | 100000. | | 0. | | 0. |
| P13FIX | U3 | No | 100000. | | 0. | | 0. |
| P13FIX | R1 | No | | 0. | | 0. | |
| P13FIX | R2 | No | | 0. | | 0. | |
| P13FIX | R3 | No | | 0. | | 0. | |

Section 2  Jefferson Barracks Bridge Load Data

Table:  Load Case Definitions, Part 1 of 3

Table:  Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | DEAD | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING _DEAD | LinBuckling | PDELTA | | | | Prog Det |

Table:  Load Case Definitions, Part 2 of 3

Table:  Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | No | Not Run |
| BUCKLING _DEAD | DEAD | Prog Det | Other | None | No | Not Run |

Table:  Load Case Definitions, Part 3 of 3

Table:  Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| MODAL | | |
| LIVELOAD | | |
| PDELTA | | |
| BUCKLING_DEAD | | |

Table:  Case - Static 1 - Load Assignments

Table:  Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |

Table:  Case - Static 2 - Nonlinear Load Application

Table:  Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 10 |
| PDELTA | Full Load | U1 | 10 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |
| PDELTA | 10 | 0.01 | 1. | No |

Table:  Case - Moving Load 1 - Lane Assignments

Table:  Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HL93_ALL | 1. | 0 | 4 | 9 |

Table:  Case - Moving Load 2 - Lanes Loaded

Table:  Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CENLANE1 |
| LIVELOAD | 1 | CENTLANE2 |
| LIVELOAD | 1 | LTLANE1 |
| LIVELOAD | 1 | LTLANE2 |
| LIVELOAD | 1 | LTLANE21 |
| LIVELOAD | 1 | RGTLANE21 |
| LIVELOAD | 1 | RGTLANE22 |
| LIVELOAD | 1 | RTLANE1 |
| LIVELOAD | 1 | RTLANE2 |

Table:  Case - Moving Load 3 - MultiLane Factors

Table:  Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1.2 |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.85 |
| LIVELOAD | 4 | 0.65 |
| LIVELOAD | 5 | 0.65 |
| LIVELOAD | 6 | 0.65 |
| LIVELOAD | 7 | 0.65 |
| LIVELOAD | 8 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 9 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift | EigenCutoff | EigenTol |
|---|---|---|---|---|---|---|
| | | | | Cyc/sec | Cyc/sec | |
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 Jefferson Barracks Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.8176 | 92.331 |
| MODAL | Acceleration | UY | 99.8753 | 76.9187 |
| MODAL | Acceleration | UZ | 98.5532 | 42.9878 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| | | | Sec | | | | |
| MODAL | | | 0. | 0. | 2.290E-05 | 1.559E-13 | 0. |

Table: Modal Participating Mass Ratios, Part 2 of 3

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | | | 2.290E-05 | 1.559E-13 | 3.064E-05 | 8.288E-16 | 0.00862 |

Table: Modal Participating Mass Ratios, Part 3 of 3

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | | | 3.064E-05 | 8.288E-16 | 0.00862 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period<br>Sec | UX<br>Kip-ft | UY<br>Kip-ft | UZ<br>Kip-ft | RX<br>Kip-ft |
|---|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0. | 0.394208 | -0.000012 | -0.172041 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY<br>Kip-ft | RZ<br>Kip-ft | ModalMass<br>Kip-ft-s2 | ModalStiff<br>Kip-ft |
|---|---|---|---|---|---|---|
| MODAL | | | 0.000057 | -1098.69344 | 0. | 0. |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period<br>Sec | Frequency<br>Cyc/sec | CircFreq<br>rad/sec | Eigenvalue<br>rad2/sec2 |
|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

Table: Program Control, Part 1 of 2

Table: Program Control, Part 1 of 2

| ProgramName | Version | ProgLevel | LicenseNum | LicenseOS | LicenseSC | License HT | CurrUnits |
|---|---|---|---|---|---|---|---|
| SAP2000 | 18.1.1 | Advanced | 2010*1GR WHLW4599 V5FQ | No | No | No | Kip, ft, F |

Table: Program Control, Part 2 of 2

Table: Program Control, Part 2 of 2

| SteelCode | ConcCode | AlumCode | ColdCode | RegenHinge |
|---|---|---|---|---|
| AISC360-05/IBC2006 | ACI 318-08/IBC2009 | AA-ASD 2000 | AISI-ASD96 | Yes |

**APPENDIX C**

**ANALYSIS OUTPUT FOR PAGE AVENUE BRIDGE**

License #2010*1GRWHLW4599V5FQ

**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160610 Page Avenue Rev 012 HS20 C2F LBK.sdb**

**26 June 2016**

Section 1  Page Avenue Bridge Analysis Input

Table:  Material Properties 01 - General, Part 1 of 2

Table:  Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 4000Psi | Concrete | Isotropic | No | Red | |
| A416Gr270 | Tendon | Uniaxial | No | Magenta | |
| A572Gr50 | Steel | Isotropic | No | Blue | |
| A615Gr60 | Rebar | Uniaxial | No | Gray8Dark | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586 | Steel | Isotropic | No | Blue | |
| STAAD1 | Steel | Isotropic | No | Yellow | D7D209AA-88D2-4D08-A6D1-DC069FD57107 |
| STAAD2 | Other | Isotropic | No | Blue | 02574C1E-4D75-4112-B3BD-9AF3D1778D8A |

Table:  Material Properties 01 - General, Part 2 of 2

Table:  Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 4000Psi | Normalweight f'c = 4 ksi added 12/30/2013 8:14:18 PM |
| A416Gr270 | ASTM A416 Grade 270 3/5/2016 7:31:46 PM |
| A572Gr50 | ASTM A572 Grade 50 added 1/5/2014 1:54:23 PM |
| A615Gr60 | ASTM A615 Grade 60 added 1/5/2014 1:54:38 PM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 12/30/2013 8:14:18 PM |
| ASTM A586 | ASTM A36 added 1/5/2014 9:29:36 PM |
| STAAD1 | ASTM A36 added 12/30/2013 8:14:18 PM |
| STAAD2 | ASTM A36 added 12/30/2013 8:14:18 PM |

Table:  Material Properties 02 - Basic Mechanical Properties

Table:  Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| 4000Psi | 2.5920E+02 | 9.6674E+01 | 18688320. | 7786800. | 0.2 | 5.5000E-06 |
| A416Gr270 | 8.4672E+02 | 3.1580E+02 | 590976000. | | | 6.5000E-06 |
| A572Gr50 | 8.4672E+02 | 3.1580E+02 | 601344000. | 231286153.8 | 0.3 | 6.5000E-06 |
| A615Gr60 | 8.4672E+02 | 3.1580E+02 | 601344000. | | | 6.5000E-06 |
| A992Fy50 | 8.4672E+02 | 3.1580E+02 | 601344000. | 231286153.8 | 0.3 | 6.5000E-06 |
| ASTM A586 | 8.4672E+02 | 3.1580E+02 | 476928000. | 183433846.2 | 0.3 | 6.5000E-06 |
| STAAD1 | 8.4503E+02 | 3.1517E+02 | 601344000. | 231286153.8 | 0.3 | 0.0000E+00 |
| STAAD2 | 8.4503E+02 | 3.1517E+02 | 476928000. | 183433846.2 | 0.3 | 0.0000E+00 |

Table:  Material Properties 03a - Steel Data, Part 1 of 2

Table:  Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A572Gr50 | 1036800. | 1347840. | 1140480. | 1482624. | Simple | Kinematic | 0.015 |
| A992Fy50 | 1036800. | 1347840. | 1140480. | 1482624. | Simple | Kinematic | 0.015 |
| ASTM A586 | 3110400. | 4561920. | 3110400. | 4561920. | Simple | Kinematic | 0.02 |
| STAAD1 | 746496. | 1202688. | 1119744. | 1322956.8 | Simple | Kinematic | 0.02 |

Table:  Material Properties 03a - Steel Data, Part 2 of 2

Table:  Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A572Gr50 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A586 | 0.14 | 0.2 | -0.1 |
| STAAD1 | 0.14 | 0.2 | -0.1 |

Table:  Material Properties 03b - Concrete Data, Part 1 of 2

Table:  Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 4000Psi | 82944. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table:  Material Properties 03b - Concrete Data, Part 2 of 2

Table:  Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 4000Psi | 0. | 0. |

Table:  Frame Section Properties 01 - General, Part 1 of 8

Table:  Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| Cable | ASTM A586 | General | 0.08333 | 0.08333 | |
| FLBMS | A572Gr50 | I/Wide Flange | 0.91722 | 0.14757 | 0.01639 |
| LLATERALS | A572Gr50 | I/Wide Flange | 0.10264 | 0.10764 | 0.00757 |
| P4Beam | 4000Psi | Rectangular | 0.80381 | 1.17563 | |
| P4Col | 4000Psi | Rectangular | 0.81667 | 0.81667 | |
| Pier5Beam | 4000Psi | Rectangular | 0.80381 | 1.17563 | |
| Pier5Col | 4000Psi | Rectangular | 0.81667 | 0.81667 | |
| R1-2 R14-15 | A572Gr50 | SD Section | | | |
| R1LATERAL | A572Gr50 | SD Section | | | |
| R3-4 R12-13 | A572Gr50 | SD Section | | | |
| R5-7 R9-11 | A572Gr50 | SD Section | | | |
| R8 | A572Gr50 | SD Section | | | |
| STDSEC1 | STAAD1 | General | 0.14415 | 0.14415 | |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| STDSEC10 | STAAD1 | General | 0.13823 | 0.13823 | |
| STDSEC11 | STAAD1 | General | 0.14348 | 0.14348 | |
| STDSEC12 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC13 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC14 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC15 | STAAD1 | General | 0.07336 | 0.07336 | |
| STDSEC16 | STAAD1 | General | 0.07336 | 0.07336 | |
| STDSEC17 | STAAD1 | General | 0.06682 | 0.06682 | |
| STDSEC18 | STAAD1 | General | 0.06682 | 0.06682 | |
| STDSEC19 | STAAD2 | General | 0.02282 | 0.02282 | |
| STDSEC2 | STAAD1 | General | 0.14415 | 0.14415 | |
| STDSEC3 | STAAD1 | General | 0.13282 | 0.13282 | |
| STDSEC4 | STAAD1 | General | 0.14415 | 0.14415 | |
| STDSEC5 | STAAD1 | General | 0.14415 | 0.14415 | |
| STDSEC6 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC7 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC8 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC9 | STAAD1 | General | 0.14348 | 0.14348 | |
| TGDRT1-T3 T13-T15 | A572Gr50 | SD Section | | | |
| TGDRT4-6 T10-12 | A572Gr50 | SD Section | | | |
| TGDRT7-9 | A572Gr50 | SD Section | | | |
| ULATERALS | A572Gr50 | SD Section | | | |
| W30X108 | A992Fy50 | I/Wide Flange | 0.20715 | 0.07274 | 0.00528 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| Cable | | | | 5.229E-04 | 4.349E-08 | 2.174E-08 |
| FLBMS | 0.00521 | 0.14757 | 0.01639 | 0.0094 | 4.443E-07 | 0.001282 |
| LLATERALS | 0.00472 | 0.10764 | 0.00757 | 0.002 | 3.271E-08 | 3.953E-06 |
| P4Beam | | | | 0.945 | 0.117451 | 0.05088 |
| P4Col | | | | 0.6669 | 0.062645 | 0.037068 |
| Pier5Beam | | | | 0.945 | 0.117451 | 0.05088 |
| Pier5Col | | | | 0.6669 | 0.062645 | 0.037068 |
| R1-2 R14-15 | | | | 0.0219 | 0.000711 | 0.000759 |
| R1LATERAL | | | | 0.0029 | 0.000012 | 0.000015 |
| R3-4 R12-13 | | | | 0.0219 | 0.000711 | 0.000759 |
| R5-7 R9-11 | | | | 0.0206 | 0.000657 | 0.000734 |
| R8 | | | | 0.0191 | 0.000616 | 0.000645 |
| STDSEC1 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC10 | | | | 0.0191 | 0. | 0.000644 |
| STDSEC11 | | | | 0.0206 | 0. | 0.000735 |
| STDSEC12 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC13 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC14 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC15 | | | | 0.0054 | 0. | 0.000027 |

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| STDSEC16 | | | | 0.0054 | 0. | 0.000027 |
| STDSEC17 | | | | 0.0045 | 0. | 0.00004 |
| STDSEC18 | | | | 0.0045 | 0. | 0.00004 |
| STDSEC19 | | | | 5.208E-04 | 0. | 1.891E-06 |
| STDSEC2 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC3 | | | | 0.0176 | 0. | 0.001774 |
| STDSEC4 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC5 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC6 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC7 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC8 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC9 | | | | 0.0206 | 0. | 0.000735 |
| TGDRT1-T3 T13-T15 | | | | 0.0208 | 9.917E-07 | 0.002421 |
| TGDRT4-6 T10-12 | | | | 0.0208 | 9.917E-07 | 0.002421 |
| TGDRT7-9 | | | | 0.0176 | 4.193E-07 | 0.001771 |
| ULATERALS | | | | 0.0029 | 0.000012 | 0.000015 |
| W30X108 | 0.00378 | 0.07274 | 0.00528 | 0.0015 | 1.161E-08 | 0.00001 |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| Cable | 2.174E-08 | 0. | 4.822E-05 | 4.822E-05 | 3.349E-07 | 3.349E-07 |
| FLBMS | 8.788E-06 | 0. | 0.0048 | 0.004 | 0.002795 | 0.000119 |
| LLATERALS | 1.574E-06 | 0. | 4.847E-04 | 0.0014 | 0.000077 | 0.000029 |
| P4Beam | 0.10884 | 0. | 0.7875 | 0.7875 | 0.126598 | 0.185159 |
| P4Col | 0.037068 | 0. | 0.5558 | 0.5558 | 0.090779 | 0.090779 |
| Pier5Beam | 0.10884 | 0. | 0.7875 | 0.7875 | 0.126598 | 0.185159 |
| Pier5Col | 0.037068 | 0. | 0.5558 | 0.5558 | 0.090779 | 0.090779 |
| R1-2 R14-15 | 0.000317 | 0. | 0.0131 | 0.0096 | 0.003051 | 0.00213 |
| R1LATERAL | 6.007E-06 | 0. | 0.0021 | 6.828E-04 | 0.000142 | 0.00011 |
| R3-4 R12-13 | 0.000317 | 0. | 0.0131 | 0.0096 | 0.003051 | 0.00213 |
| R5-7 R9-11 | 0.000288 | 0. | 0.0119 | 0.0095 | 0.002951 | 0.001954 |
| R8 | 0.000279 | 0. | 0.0117 | 0.008 | 0.002619 | 0.001893 |
| STDSEC1 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC10 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC11 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC12 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC13 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC14 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC15 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC16 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC17 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC18 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC19 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC2 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC3 | 0. | 0. | 0. | 0. | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 ft4 | I23 ft4 | AS2 ft2 | AS3 ft2 | S33 ft3 | S22 ft3 |
|---|---|---|---|---|---|---|
| STDSEC4 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC5 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC6 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC7 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC8 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC9 | 0. | 0. | 0. | 0. | 0. | 0. |
| TGDRT1-T3 T13-T15 | 0.00031 | 0. | 0.0119 | 0.0097 | 0.005483 | 0.002062 |
| TGDRT4-6 T10-12 | 0.00031 | 0. | 0.0119 | 0.0097 | 0.005483 | 0.002062 |
| TGDRT7-9 | 0.000288 | 0. | 0.0113 | 0.0065 | 0.004139 | 0.001918 |
| ULATERALS | 6.007E-06 | 0. | 0.0021 | 6.828E-04 | 0.000142 | 0.00011 |
| W30X108 | 3.395E-07 | 0. | 7.840E-04 | 6.399E-04 | 0.0001 | 9.336E-06 |

Table: Frame Section Properties 01 - General, Part 4 of 8

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 ft3 | Z22 ft3 | R33 ft | R22 ft | EccV2 ft | ConcCol |
|---|---|---|---|---|---|---|
| Cable | 3.349E-07 | 3.349E-07 | 0.00694 | 0.00694 | 0. | No |
| FLBMS | 0.003197 | 0.000184 | 0.36841 | 0.03051 | | No |
| LLATERALS | 0.000086 | 0.000044 | 0.04399 | 0.02776 | | No |
| P4Beam | 0.189896 | 0.277739 | 0.23204 | 0.33938 | | Yes |
| P4Col | 0.136168 | 0.136168 | 0.23575 | 0.23575 | | Yes |
| Pier5Beam | 0.189896 | 0.277739 | 0.23204 | 0.33938 | | Yes |
| Pier5Col | 0.136168 | 0.136168 | 0.23575 | 0.23575 | | Yes |
| R1-2 R14-15 | 0.003682 | 0.002451 | 0.18623 | 0.12043 | | No |
| R1LATERAL | 0.000182 | 0.000127 | 0.07102 | 0.04551 | | No |
| R3-4 R12-13 | 0.003682 | 0.002451 | 0.18623 | 0.12043 | | No |
| R5-7 R9-11 | 0.003525 | 0.002255 | 0.18894 | 0.11842 | | No |
| R8 | 0.003163 | 0.002156 | 0.1837 | 0.12096 | | No |
| STDSEC1 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC10 | 0. | 0. | 0.18365 | 0. | 0. | No |
| STDSEC11 | 0. | 0. | 0.18895 | 0. | 0. | No |
| STDSEC12 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC13 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC14 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC15 | 0. | 0. | 0.07103 | 0. | 0. | No |
| STDSEC16 | 0. | 0. | 0.07103 | 0. | 0. | No |
| STDSEC17 | 0. | 0. | 0.0947 | 0. | 0. | No |
| STDSEC18 | 0. | 0. | 0.0947 | 0. | 0. | No |
| STDSEC19 | 0. | 0. | 0.06025 | 0. | 0. | No |
| STDSEC2 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC3 | 0. | 0. | 0.31716 | 0. | 0. | No |
| STDSEC4 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC5 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC6 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC7 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC8 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC9 | 0. | 0. | 0.18895 | 0. | 0. | No |

Table:  Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| TGDRT1-T3 T13-T15 | 0.006438 | 0.002345 | 0.34141 | 0.12217 | | No |
| TGDRT4-6 T10-12 | 0.006438 | 0.002345 | 0.34141 | 0.12217 | | No |
| TGDRT7-9 | 0.005005 | 0.002119 | 0.31701 | 0.12793 | | No |
| ULATERALS | 0.000182 | 0.000127 | 0.07102 | 0.04551 | | No |
| W30X108 | 0.000116 | 0.000015 | 0.08246 | 0.0149 | | No |

Table:  Frame Section Properties 01 - General, Part 5 of 8

Table:  Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| Cable | No | Cyan | 96.385 | 35.95 | No | 1. |
| FLBMS | No | White | 1029.448 | 383.95 | No | 1. |
| LLATERALS | No | White | 285.956 | 106.65 | No | 1. |
| P4Beam | No | Gray8Dark | 1854.997 | 691.86 | No | 1. |
| P4Col | No | Green | 1757.783 | 655.6 | No | 1. |
| Pier5Beam | No | Magenta | 1854.997 | 691.86 | No | 1. |
| Pier5Col | No | Gray8Dark | 1754.872 | 654.52 | No | 1. |
| R1-2 R14-15 | No | White | 775.511 | 289.24 | No | 1. |
| R1LATERAL | No | White | 37.195 | 13.87 | No | 1. |
| R3-4 R12-13 | No | White | 519.074 | 193.6 | No | 1. |
| R5-7 R9-11 | No | White | 574.544 | 214.29 | No | 1. |
| R8 | No | White | 154.893 | 57.77 | No | 1. |
| STDSEC1 | No | Cyan | 27.606 | 10.3 | No | 1. |
| STDSEC10 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC11 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC12 | No | Gray8Dark | 0. | 0. | No | 1. |
| STDSEC13 | No | Blue | 0. | 0. | No | 1. |
| STDSEC14 | No | Green | 0. | 0. | No | 1. |
| STDSEC15 | No | Cyan | 0. | 0. | No | 1. |
| STDSEC16 | No | Red | 0. | 0. | No | 1. |
| STDSEC17 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC18 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC19 | No | Gray8Dark | 0. | 0. | No | 1. |
| STDSEC2 | No | Red | 0. | 0. | No | 1. |
| STDSEC3 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC4 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC5 | No | Gray8Dark | 20.404 | 7.61 | No | 1. |
| STDSEC6 | No | Blue | 7.905 | 2.95 | No | 1. |
| STDSEC7 | No | Green | 0. | 0. | No | 1. |
| STDSEC8 | No | Cyan | 0. | 0. | No | 1. |
| STDSEC9 | No | Red | 0. | 0. | No | 1. |
| TGDRT1-T3 T13-T15 | No | White | 657.549 | 245.25 | No | 1. |
| TGDRT4-6 T10-12 | No | White | 818.63 | 305.33 | No | 1. |
| TGDRT7-9 | No | White | 240.673 | 89.76 | No | 1. |
| ULATERALS | No | White | 594.731 | 221.82 | No | 1. |
| W30X108 | No | Green | 590.479 | 220.23 | Yes | 1. |

Table:  Frame Section Properties 01 - General, Part 6 of 8

Table:  Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBMS | 1. | 1. | 1. | 1. | 1. | 1. |
| LLATERALS | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Beam | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Col | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Beam | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Col | 1. | 1. | 1. | 1. | 1. | 1. |
| R1-2 R14-15 | 1. | 1. | 1. | 1. | 1. | 1. |
| R1LATERAL | 1. | 1. | 1. | 1. | 1. | 1. |
| R3-4 R12-13 | 1. | 1. | 1. | 1. | 1. | 1. |
| R5-7 R9-11 | 1. | 1. | 1. | 1. | 1. | 1. |
| R8 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC10 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC11 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC12 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC13 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC14 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC15 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC16 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC17 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC18 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC19 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC2 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC3 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC4 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC5 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC6 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC7 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC8 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC9 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT1-T3 T13-T15 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT4-6 T10-12 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT7-9 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULATERALS | 1. | 1. | 1. | 1. | 1. | 1. |
| W30X108 | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Frame Section Properties 01 - General, Part 7 of 8

Table:  Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| Cable | 1. | | | |
| FLBMS | 1. | | | |
| LLATERALS | 1. | | | |
| P4Beam | 1. | | | |
| P4Col | 1. | | | |

Table:  Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| Pier5Beam | 1. | | | |
| Pier5Col | 1. | | | |
| R1-2 R14-15 | 1. | | | |
| R1LATERAL | 1. | | | |
| R3-4 R12-13 | 1. | | | |
| R5-7 R9-11 | 1. | | | |
| R8 | 1. | | | |
| STDSEC1 | 1. | | | |
| STDSEC10 | 1. | | | |
| STDSEC11 | 1. | | | |
| STDSEC12 | 1. | | | |
| STDSEC13 | 1. | | | |
| STDSEC14 | 1. | | | |
| STDSEC15 | 1. | | | |
| STDSEC16 | 1. | | | |
| STDSEC17 | 1. | | | |
| STDSEC18 | 1. | | | |
| STDSEC19 | 1. | | | |
| STDSEC2 | 1. | | | |
| STDSEC3 | 1. | | | |
| STDSEC4 | 1. | | | |
| STDSEC5 | 1. | | | |
| STDSEC6 | 1. | | | |
| STDSEC7 | 1. | | | |
| STDSEC8 | 1. | | | |
| STDSEC9 | 1. | | | |
| TGDRT1-T3 T13-T15 | 1. | | | |
| TGDRT4-6 T10-12 | 1. | | | |
| TGDRT7-9 | 1. | | | |
| ULATERALS | 1. | | | |
| W30X108 | 1. | W30X108 | c:\program files\computers and structures\sap2000 18\sections.pro | |

Table:  Frame Section Properties 01 - General, Part 8 of 8

Table:  Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| Cable | Added 5/30/2016 10:27:21 AM |
| FLBMS | Added 1/6/2014 5:03:09 PM |
| LLATERALS | Added 1/6/2014 4:44:00 PM |
| P4Beam | Added 3/5/2016 8:05:10 PM |
| P4Col | Added 3/5/2016 8:10:25 PM |
| Pier5Beam | Added 3/5/2016 8:23:10 PM |
| Pier5Col | Added 3/5/2016 8:23:33 PM |
| R1-2 R14-15 | Added 1/5/2014 9:01:13 PM |
| R1LATERAL | Added 1/13/2014 11:02:26 PM |
| R3-4 R12-13 | Added 1/5/2014 9:09:56 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| R5-7 R9-11 | Added 1/5/2014 9:13:37 PM |
| R8 | Added 1/5/2014 9:18:02 PM |
| STDSEC1 | Added 12/30/2013 8:15:26 PM |
| STDSEC10 | Added 12/30/2013 8:15:26 PM |
| STDSEC11 | Added 12/30/2013 8:15:26 PM |
| STDSEC12 | Added 12/30/2013 8:15:26 PM |
| STDSEC13 | Added 12/30/2013 8:15:26 PM |
| STDSEC14 | Added 12/30/2013 8:15:26 PM |
| STDSEC15 | Added 12/30/2013 8:15:26 PM |
| STDSEC16 | Added 12/30/2013 8:15:26 PM |
| STDSEC17 | Added 12/30/2013 8:15:26 PM |
| STDSEC18 | Added 12/30/2013 8:15:26 PM |
| STDSEC19 | Added 12/30/2013 8:15:26 PM |
| STDSEC2 | Added 12/30/2013 8:15:26 PM |
| STDSEC3 | Added 12/30/2013 8:15:26 PM |
| STDSEC4 | Added 12/30/2013 8:15:26 PM |
| STDSEC5 | Added 12/30/2013 8:15:26 PM |
| STDSEC6 | Added 12/30/2013 8:15:26 PM |
| STDSEC7 | Added 12/30/2013 8:15:26 PM |
| STDSEC8 | Added 12/30/2013 8:15:26 PM |
| STDSEC9 | Added 12/30/2013 8:15:26 PM |
| TGDRT1-T3 T13-T15 | Added 1/5/2014 1:51:50 PM |
| TGDRT4-6 T10-12 | Added 1/5/2014 8:34:10 PM |
| TGDRT7-9 | Added 1/5/2014 8:43:17 PM |
| ULATERALS | Added 1/12/2014 9:20:26 PM |
| W30X108 | Imported 3/10/2016 2:49:32 PM from SECTIONS.PRO |

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover<br>ft | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| P4Beam | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |
| P4Col | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |
| Pier5Beam | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |
| Pier5Col | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC<br>ft | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| P4Beam | #9 | #4 | 0.04167 | 3 | 3 | Design |
| P4Col | #9 | #4 | 0.04167 | 3 | 3 | Design |
| Pier5Beam | #9 | #4 | 0.04167 | 3 | 3 | Design |

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| | | | ft | | | |
| Pier5Col | #9 | #4 | 0.04167 | 3 | 3 | Design |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| Pier4F | Linear | 0. | 0. | 0. | 0. | 0. |
| Pier5E | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| Pier4F | 0.08333 | 0.0069 | 0. | 0. | 0. | 0. |
| Pier5E | 0.08333 | 0.0069 | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| Pier4F | Cyan | 30d405fd-730f-41e3-bbea-244cda3e9650 | Added 3/5/2016 8:18:58 PM |
| Pier5E | Cyan | a2bde322-04e3-446c-ba4c-3fb7596045e1 | Added 3/5/2016 8:18:58 PM |

Table: Link Property Definitions 02 - Linear

Table: Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE | RotKE | TransCE | RotCE | DJ |
|---|---|---|---|---|---|---|---|
| | | | Kip/ft | Kip-ft/rad | Kip-s/ft | Kip-ft-s/rad | ft |
| Pier4F | U1 | No | 1200000. | | 0. | | |
| Pier4F | U2 | No | 1200000. | | 0. | | 0. |
| Pier4F | U3 | No | 1200000. | | 0. | | 0. |
| Pier4F | R1 | No | | 0. | | 0. | |
| Pier4F | R2 | No | | 0. | | 0. | |
| Pier4F | R3 | No | | 0. | | 0. | |
| Pier5E | U1 | No | 1200000. | | 0. | | |
| Pier5E | U2 | No | 1200. | | 0. | | 0. |
| Pier5E | U3 | No | 1200000. | | 0. | | 0. |
| Pier5E | R1 | No | | 0. | | 0. | |
| Pier5E | R2 | No | | 0. | | 0. | |
| Pier5E | R3 | No | | 0. | | 0. | |

Table: Area Section Properties, Part 1 of 4

| Section | Material | MatAngle | AreaType | Type | DrillDOF | Thickness | BendThick |
|---|---|---|---|---|---|---|---|
| | | Degrees | | | | ft | ft |
| CONCDECK | 4000Psi | 0. | Shell | Shell-Thin | Yes | 0.06015 | 0.06015 |
| P4Shaft | 4000Psi | 0. | Shell | Shell-Thick | Yes | 0.94583 | 0.94583 |
| Pier5Shaft | 4000Psi | 0. | Shell | Shell-Thick | Yes | 1.01 | 1.01 |

Table: Area Section Properties, Part 2 of 4

| Section | Arc | InComp | CoordSys | Color | TotalWt | TotalMass |
|---|---|---|---|---|---|---|
| | Degrees | | | | Kip | Kip-s2/ft |
| CONCDECK | | | | Red | 6047.367 | 1961.3 |
| P4Shaft | | | | Green | 2726.724 | 1016.99 |
| Pier5Shaft | | | | Green | 7775.441 | 2900.02 |

Table: Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| CONCDECK | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Shaft | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Shaft | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| CONCDECK | 1. | 1. | 1.15 | 758d35c5-1090-4412-961e-a55c3a7a8dcf | Added 3/13/2016 4:57:39 PM |
| P4Shaft | 1. | 1. | 1. | e23ce15c-c909-437f-a64a-f4b7fa56ca94 | Added 3/5/2016 8:14:07 PM |
| Pier5Shaft | 1. | 1. | 1. | 53f15048-2c5b-4fcb-a24a-21a06b537a20 | Added 3/5/2016 8:30:26 PM |

Table: Section Designer Properties 01 - General, Part 1 of 5

| SectionName | DesignType | DsgnOrChck | BaseMat | IncludeVStr | nTotalShp |
|---|---|---|---|---|---|
| R1-2 R14-15 | No Check/Design | Check | A572Gr50 | No | 4 |
| R1LATERAL | No Check/Design | Check | A572Gr50 | No | 4 |
| R3-4 R12-13 | No Check/Design | Check | A572Gr50 | No | 4 |
| R5-7 R9-11 | No Check/Design | Check | A572Gr50 | No | 4 |
| R8 | No Check/Design | Check | A572Gr50 | No | 4 |

Table: Section Designer Properties 01 - General, Part 1 of 5

| SectionName | DesignType | DsgnOrChck | BaseMat | IncludeVStr | nTotalShp |
|---|---|---|---|---|---|
| TGDRT1-T3 T13-T15 | No Check/Design | Check | A572Gr50 | No | 4 |
| TGDRT4-6 T10-12 | No Check/Design | Check | A572Gr50 | No | 4 |
| TGDRT7-9 | No Check/Design | Check | A572Gr50 | No | 4 |
| ULATERALS | No Check/Design | Check | A572Gr50 | No | 4 |

Table: Section Designer Properties 01 - General, Part 2 of 5

Table: Section Designer Properties 01 - General, Part 2 of 5

| SectionName | nIWideFlng | nChannel | nTee | nAngle | nDblAngle | nBoxTube |
|---|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 0 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 0 | 0 | 0 | 0 |
| R3-4 R12-13 | 0 | 0 | 0 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 0 | 0 | 0 | 0 |
| R8 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT1-T3 T13-T15 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 0 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 0 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 3 of 5

Table: Section Designer Properties 01 - General, Part 3 of 5

| SectionName | nPipe | nPlate | nSolidRect | nSolidCirc | nSolidSeg | nSolidSect |
|---|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 4 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 4 | 0 | 0 | 0 |
| R3-4 R12-13 | 0 | 0 | 4 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 4 | 0 | 0 | 0 |
| R8 | 0 | 0 | 4 | 0 | 0 | 0 |
| TGDRT1-T3 T13-T15 | 0 | 0 | 4 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 4 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 4 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 4 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 4 of 5

Table: Section Designer Properties 01 - General, Part 4 of 5

| SectionName | nPolygon | nReinfSing | nReinfLine | nReinfRect | nReinfCirc | nRefLine |
|---|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 0 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 0 | 0 | 0 | 0 |
| R3-4 R12-13 | 0 | 0 | 0 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 0 | 0 | 0 | 0 |
| R8 | 0 | 0 | 0 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 4 of 5

| SectionName | nPolygon | nReinfSing | nReinfLine | nReinfRect | nReinfCirc | nRefLine |
|---|---|---|---|---|---|---|
| TGDRT1-T3 T13-T15 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 0 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 0 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 5 of 5

Table: Section Designer Properties 01 - General, Part 5 of 5

| SectionName | nRefCirc | nCaltransSq | nCaltransCr | nCaltransHx | nCaltransOc |
|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 0 | 0 | 0 |
| R3-4 R12-13 | 0 | 0 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 0 | 0 | 0 |
| R8 | 0 | 0 | 0 | 0 | 0 |
| TGDRT1-T3 T13-T15 | 0 | 0 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 0 | 0 | 0 |

Section 2 Page Avenue Bridge Load Cases

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | DEAD | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| MODAL | | |
| LIVELOAD | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 59 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |

Table: Case - Moving Load 1 - Lane Assignments

Table: Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 1 | 7 | 7 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CTRLANE2 |
| LIVELOAD | 1 | LTLANE21 |
| LIVELOAD | 1 | LTLANE22 |
| LIVELOAD | 1 | LTLANE23 |
| LIVELOAD | 1 | RTLANE21 |
| LIVELOAD | 1 | RTLANE22 |
| LIVELOAD | 1 | RTLANE23 |

Table: Case - Moving Load 3 - MultiLane Factors

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1. |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.9 |
| LIVELOAD | 4 | 0.75 |
| LIVELOAD | 5 | 0.75 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |
| LIVELOAD | 10 | 0.75 |
| LIVELOAD | 11 | 0.75 |
| LIVELOAD | 12 | 0.75 |
| LIVELOAD | 13 | 0.75 |
| LIVELOAD | 14 | 0.75 |
| LIVELOAD | 15 | 0.75 |
| LIVELOAD | 16 | 0.75 |
| LIVELOAD | 17 | 0.75 |
| LIVELOAD | 18 | 0.75 |
| LIVELOAD | 19 | 0.75 |
| LIVELOAD | 20 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 21 | 0.75 |
| LIVELOAD | 22 | 0.75 |
| LIVELOAD | 23 | 0.75 |
| LIVELOAD | 24 | 0.75 |
| LIVELOAD | 25 | 0.75 |
| LIVELOAD | 26 | 0.75 |
| LIVELOAD | 27 | 0.75 |
| LIVELOAD | 28 | 0.75 |
| LIVELOAD | 29 | 0.75 |
| LIVELOAD | 30 | 0.75 |
| LIVELOAD | 31 | 0.75 |
| LIVELOAD | 32 | 0.75 |
| LIVELOAD | 33 | 0.75 |
| LIVELOAD | 34 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift Cyc/sec | EigenCutoff Cyc/sec | EigenTol |
|---|---|---|---|---|---|---|
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 Page Avenue Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.8425 | 92.3113 |
| MODAL | Acceleration | UY | 99.9012 | 73.4875 |
| MODAL | Acceleration | UZ | 98.2203 | 44.9992 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period Sec | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0. | 7.161E-06 | 6.611E-13 | 0. |

Table:  Modal Participating Mass Ratios, Part 2 of 3

Table:  Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | | | 7.161E-06 | 6.611E-13 | 3.712E-05 | 2.092E-11 | 0.00024 |

Table:  Modal Participating Mass Ratios, Part 3 of 3

Table:  Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | | | 3.712E-05 | 2.092E-11 | 0.00024 |

Table:  Modal Participation Factors, Part 1 of 2

Table:  Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period<br>Sec | UX<br>Kip-ft | UY<br>Kip-ft | UZ<br>Kip-ft | RX<br>Kip-ft |
|---|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0. | -0.00017 | 6.981E-09 | 0.000335 |

Table:  Modal Participation Factors, Part 2 of 2

Table:  Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY<br>Kip-ft | RZ<br>Kip-ft | ModalMass<br>Kip-ft-s2 | ModalStiff<br>Kip-ft |
|---|---|---|---|---|---|---|
| MODAL | | | 0.000143 | 2.634423 | 0. | 0. |

Table:  Modal Periods And Frequencies

Table:  Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period<br>Sec | Frequency<br>Cyc/sec | CircFreq<br>rad/sec | Eigenvalue<br>rad2/sec2 |
|---|---|---|---|---|---|---|
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

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**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160610 Page Avenue Rev 013 HS20 C2F UBK.sdb**
**Page Avenue Bridge**

**26 June 2016**

Section 1 Page Avenue Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 4000Psi | Concrete | Isotropic | No | Red | |
| A416Gr270 | Tendon | Uniaxial | No | Magenta | |
| A572Gr50 | Steel | Isotropic | No | Blue | |
| A615Gr60 | Rebar | Uniaxial | No | Gray8Dark | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586 | Steel | Isotropic | No | Blue | |
| STAAD1 | Steel | Isotropic | No | Yellow | D7D209AA-88D2-4D08-A6D1-DC069FD57107 |
| STAAD2 | Other | Isotropic | No | Blue | 02574C1E-4D75-4112-B3BD-9AF3D1778D8A |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 4000Psi | Normalweight f'c = 4 ksi added 12/30/2013 8:14:18 PM |
| A416Gr270 | ASTM A416 Grade 270 3/5/2016 7:31:46 PM |
| A572Gr50 | ASTM A572 Grade 50 added 1/5/2014 1:54:23 PM |
| A615Gr60 | ASTM A615 Grade 60 added 1/5/2014 1:54:38 PM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 12/30/2013 8:14:18 PM |
| ASTM A586 | ASTM A36 added 1/5/2014 9:29:36 PM |
| STAAD1 | ASTM A36 added 12/30/2013 8:14:18 PM |
| STAAD2 | ASTM A36 added 12/30/2013 8:14:18 PM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight Kip/in3 | UnitMass Kip-s2/in4 | E1 Kip/in2 | G12 Kip/in2 | U12 | A1 1/F |
|---|---|---|---|---|---|---|
| 4000Psi | 8.6806E-05 | 2.2483E-07 | 4110.347 | 1712.645 | 0.2 | 5.5000E-06 |
| A416Gr270 | 2.8356E-04 | 7.3446E-07 | 28500. | | | 6.5000E-06 |
| A572Gr50 | 2.8356E-04 | 7.3446E-07 | 29000. | 11153.846 | 0.3 | 6.5000E-06 |
| A615Gr60 | 2.8356E-04 | 7.3446E-07 | 29000. | | | 6.5000E-06 |
| A992Fy50 | 2.8356E-04 | 7.3446E-07 | 29000. | 11153.846 | 0.3 | 6.5000E-06 |
| ASTM A586 | 2.8356E-04 | 7.3446E-07 | 23000. | 8846.154 | 0.3 | 6.5000E-06 |
| STAAD1 | 2.8300E-04 | 7.3299E-07 | 29000. | 11153.846 | 0.3 | 0.0000E+00 |
| STAAD2 | 2.8300E-04 | 7.3299E-07 | 23000. | 8846.154 | 0.3 | 0.0000E+00 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/in2 | Fu Kip/in2 | EffFy Kip/in2 | EffFu Kip/in2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A572Gr50 | 50. | 65. | 55. | 71.5 | Simple | Kinematic | 0.015 |
| A992Fy50 | 50. | 65. | 55. | 71.5 | Simple | Kinematic | 0.015 |
| ASTM A586 | 150. | 220. | 150. | 220. | Simple | Kinematic | 0.02 |
| STAAD1 | 36. | 58. | 54. | 63.8 | Simple | Kinematic | 0.02 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A572Gr50 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A586 | 0.14 | 0.2 | -0.1 |
| STAAD1 | 0.14 | 0.2 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/in2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 4000Psi | 5.201 | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 4000Psi | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 8

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 in | t2 in | tf in |
|---|---|---|---|---|---|
| Cable | ASTM A586 | General | 12. | 12. | |
| FLBMS | A572Gr50 | I/Wide Flange | 132.08 | 21.25 | 2.36 |
| LLATERALS | A572Gr50 | I/Wide Flange | 14.78 | 15.5 | 1.09 |
| P4Beam | 4000Psi | Rectangular | 115.7484 | 169.2912 | |
| P4Col | 4000Psi | Rectangular | 117.6 | 117.6 | |
| Pier5Beam | 4000Psi | Rectangular | 115.7484 | 169.2912 | |
| Pier5Col | 4000Psi | Rectangular | 117.6 | 117.6 | |
| R1-2 R14-15 | A572Gr50 | SD Section | | | |
| R1LATERAL | A572Gr50 | SD Section | | | |
| R3-4 R12-13 | A572Gr50 | SD Section | | | |
| R5-7 R9-11 | A572Gr50 | SD Section | | | |
| R8 | A572Gr50 | SD Section | | | |
| STDSEC1 | STAAD1 | General | 20.7581 | 20.7581 | |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3<br>in | t2<br>in | tf<br>in |
|---|---|---|---|---|---|
| STDSEC10 | STAAD1 | General | 19.9048 | 19.9048 | |
| STDSEC11 | STAAD1 | General | 20.6616 | 20.6616 | |
| STDSEC12 | STAAD1 | General | 21.3026 | 21.3026 | |
| STDSEC13 | STAAD1 | General | 21.3026 | 21.3026 | |
| STDSEC14 | STAAD1 | General | 21.3026 | 21.3026 | |
| STDSEC15 | STAAD1 | General | 10.5641 | 10.5641 | |
| STDSEC16 | STAAD1 | General | 10.5641 | 10.5641 | |
| STDSEC17 | STAAD1 | General | 9.6224 | 9.6224 | |
| STDSEC18 | STAAD1 | General | 9.6224 | 9.6224 | |
| STDSEC19 | STAAD2 | General | 3.2863 | 3.2863 | |
| STDSEC2 | STAAD1 | General | 20.7581 | 20.7581 | |
| STDSEC3 | STAAD1 | General | 19.1259 | 19.1259 | |
| STDSEC4 | STAAD1 | General | 20.7581 | 20.7581 | |
| STDSEC5 | STAAD1 | General | 20.7581 | 20.7581 | |
| STDSEC6 | STAAD1 | General | 21.3026 | 21.3026 | |
| STDSEC7 | STAAD1 | General | 21.3026 | 21.3026 | |
| STDSEC8 | STAAD1 | General | 21.3026 | 21.3026 | |
| STDSEC9 | STAAD1 | General | 20.6616 | 20.6616 | |
| TGDRT1-T3 T13-T15 | A572Gr50 | SD Section | | | |
| TGDRT4-6 T10-12 | A572Gr50 | SD Section | | | |
| TGDRT7-9 | A572Gr50 | SD Section | | | |
| ULATERALS | A572Gr50 | SD Section | | | |
| W30X108 | A992Fy50 | I/Wide Flange | 29.83 | 10.475 | 0.76 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw<br>in | t2b<br>in | tfb<br>in | Area<br>in2 | TorsConst<br>in4 | I33<br>in4 |
|---|---|---|---|---|---|---|
| Cable | | | | 10.84 | 18.7 | 9.35 |
| FLBMS | 0.75 | 21.25 | 2.36 | 195.82 | 191.03 | 551106.29 |
| LLATERALS | 0.68 | 15.5 | 1.09 | 42.36 | 14.06 | 1699.9 |
| P4Beam | | | | 19595.19 | 50501943.52 | 21877521.87 |
| P4Col | | | | 13829.76 | 26936101.85 | 15938521.8 |
| Pier5Beam | | | | 19595.19 | 50501943.52 | 21877521.87 |
| Pier5Col | | | | 13829.76 | 26936101.85 | 15938521.8 |
| R1-2 R14-15 | | | | 453.87 | 305721.39 | 326410.59 |
| R1LATERAL | | | | 60.14 | 5208.8 | 6290.04 |
| R3-4 R12-13 | | | | 453.87 | 305721.39 | 326410.59 |
| R5-7 R9-11 | | | | 426.47 | 282345.1 | 315696.62 |
| R8 | | | | 396.07 | 264856.45 | 277132.38 |
| STDSEC1 | | | | 430.9 | 0. | 1013310. |
| STDSEC10 | | | | 396.2 | 0. | 277076. |
| STDSEC11 | | | | 426.9 | 0. | 316037. |
| STDSEC12 | | | | 453.8 | 0. | 326584. |
| STDSEC13 | | | | 453.8 | 0. | 326584. |
| STDSEC14 | | | | 453.8 | 0. | 326584. |
| STDSEC15 | | | | 111.6 | 0. | 11675. |

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | in | in | in | in2 | in4 | in4 |
| STDSEC16 | | | | 111.6 | 0. | 11675. |
| STDSEC17 | | | | 92.59 | 0. | 17219. |
| STDSEC18 | | | | 92.59 | 0. | 17219. |
| STDSEC19 | | | | 10.8 | 0. | 813. |
| STDSEC2 | | | | 430.9 | 0. | 1013310. |
| STDSEC3 | | | | 365.8 | 0. | 762994. |
| STDSEC4 | | | | 430.9 | 0. | 1013310. |
| STDSEC5 | | | | 430.9 | 0. | 1013310. |
| STDSEC6 | | | | 453.8 | 0. | 326584. |
| STDSEC7 | | | | 453.8 | 0. | 326584. |
| STDSEC8 | | | | 453.8 | 0. | 326584. |
| STDSEC9 | | | | 426.9 | 0. | 316037. |
| TGDRT1-T3 T13-T15 | | | | 430.71 | 426.42 | 1041044.8 |
| TGDRT4-6 T10-12 | | | | 430.71 | 426.42 | 1041044.8 |
| TGDRT7-9 | | | | 365.39 | 180.3 | 761409.98 |
| ULATERALS | | | | 60.14 | 5208.8 | 6290.04 |
| W30X108 | 0.545 | 10.475 | 0.76 | 31.7 | 4.99 | 4470. |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | in4 | in4 | in2 | in2 | in3 | in3 |
| Cable | 9.35 | 0. | 1. | 1. | 1. | 1. |
| FLBMS | 3778.79 | 0. | 99.06 | 83.58 | 8345.04 | 355.65 |
| LLATERALS | 676.83 | 0. | 10.05 | 28.16 | 230.03 | 87.33 |
| P4Beam | 46799035.3 | 0. | 16329.32 | 16329.32 | 378018.56 | 552882.08 |
| P4Col | 15938521.8 | 0. | 11524.8 | 11524.8 | 271063.3 | 271063.3 |
| Pier5Beam | 46799035.3 | 0. | 16329.32 | 16329.32 | 378018.56 | 552882.08 |
| Pier5Col | 15938521.8 | 0. | 11524.8 | 11524.8 | 271063.3 | 271063.3 |
| R1-2 R14-15 | 136506.3 | 0. | 272.46 | 199.26 | 9111.59 | 6361.5 |
| R1LATERAL | 2582.86 | 0. | 44.03 | 14.16 | 423.79 | 327.98 |
| R3-4 R12-13 | 136506.3 | 0. | 272.46 | 199.26 | 9111.59 | 6361.5 |
| R5-7 R9-11 | 124007.08 | 0. | 245.82 | 197.1 | 8812.53 | 5833.38 |
| R8 | 120157.28 | 0. | 242.25 | 165.26 | 7820.87 | 5652.28 |
| STDSEC1 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC10 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC11 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC12 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC13 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC14 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC15 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC16 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC17 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC18 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC19 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC2 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC3 | 0. | 0. | 0. | 0. | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | in4 | in4 | in2 | in2 | in3 | in3 |
| STDSEC4 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC5 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC6 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC7 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC8 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC9 | 0. | 0. | 0. | 0. | 0. | 0. |
| TGDRT1-T3 T13-T15 | 133303.4 | 0. | 247.76 | 201.69 | 16373.37 | 6156.17 |
| TGDRT4-6 T10-12 | 133303.4 | 0. | 247.76 | 201.69 | 16373.37 | 6156.17 |
| TGDRT7-9 | 124001.16 | 0. | 235.13 | 135.15 | 12358.67 | 5726.58 |
| ULATERALS | 2582.86 | 0. | 44.03 | 14.16 | 423.79 | 327.98 |
| W30X108 | 146. | 0. | 16.26 | 13.27 | 299.7 | 27.88 |

Table: Frame Section Properties 01 - General, Part 4 of 8

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | in3 | in3 | in | in | in | |
| Cable | 1. | 1. | 0.9996 | 0.9996 | 0. | No |
| FLBMS | 9546.81 | 550.75 | 53.0505 | 4.3929 | | No |
| LLATERALS | 258.28 | 132.39 | 6.335 | 3.9974 | | No |
| P4Beam | 567027.84 | 829323.12 | 33.4137 | 48.8702 | | Yes |
| P4Col | 406594.94 | 406594.94 | 33.9482 | 33.9482 | | Yes |
| Pier5Beam | 567027.84 | 829323.12 | 33.4137 | 48.8702 | | Yes |
| Pier5Col | 406594.94 | 406594.94 | 33.9482 | 33.9482 | | Yes |
| R1-2 R14-15 | 10995.36 | 7318.34 | 26.8174 | 17.3425 | | No |
| R1LATERAL | 542.53 | 379.33 | 10.2269 | 6.5534 | | No |
| R3-4 R12-13 | 10995.36 | 7318.34 | 26.8174 | 17.3425 | | No |
| R5-7 R9-11 | 10526.13 | 6733.13 | 27.2076 | 17.0521 | | No |
| R8 | 9443.32 | 6436.84 | 26.4521 | 17.4177 | | No |
| STDSEC1 | 0. | 0. | 48.4934 | 0. | 0. | No |
| STDSEC10 | 0. | 0. | 26.4449 | 0. | 0. | No |
| STDSEC11 | 0. | 0. | 27.2086 | 0. | 0. | No |
| STDSEC12 | 0. | 0. | 26.8266 | 0. | 0. | No |
| STDSEC13 | 0. | 0. | 26.8266 | 0. | 0. | No |
| STDSEC14 | 0. | 0. | 26.8266 | 0. | 0. | No |
| STDSEC15 | 0. | 0. | 10.2281 | 0. | 0. | No |
| STDSEC16 | 0. | 0. | 10.2281 | 0. | 0. | No |
| STDSEC17 | 0. | 0. | 13.6371 | 0. | 0. | No |
| STDSEC18 | 0. | 0. | 13.6371 | 0. | 0. | No |
| STDSEC19 | 0. | 0. | 8.6763 | 0. | 0. | No |
| STDSEC2 | 0. | 0. | 48.4934 | 0. | 0. | No |
| STDSEC3 | 0. | 0. | 45.6708 | 0. | 0. | No |
| STDSEC4 | 0. | 0. | 48.4934 | 0. | 0. | No |
| STDSEC5 | 0. | 0. | 48.4934 | 0. | 0. | No |
| STDSEC6 | 0. | 0. | 26.8266 | 0. | 0. | No |
| STDSEC7 | 0. | 0. | 26.8266 | 0. | 0. | No |
| STDSEC8 | 0. | 0. | 26.8266 | 0. | 0. | No |
| STDSEC9 | 0. | 0. | 27.2086 | 0. | 0. | No |

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | in3 | in3 | in | in | in | |
| TGDRT1-T3 T13-T15 | 19224.14 | 7001.88 | 49.1636 | 17.5926 | | No |
| TGDRT4-6 T10-12 | 19224.14 | 7001.88 | 49.1636 | 17.5926 | | No |
| TGDRT7-9 | 14943.5 | 6326.83 | 45.649 | 18.4219 | | No |
| ULATERALS | 542.53 | 379.33 | 10.2269 | 6.5534 | | No |
| W30X108 | 346. | 43.9 | 11.8747 | 2.1461 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 8

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/in | | |
| Cable | No | Cyan | 96.385 | 0.2496 | No | 1. |
| FLBMS | No | White | 1029.448 | 2.6664 | No | 1. |
| LLATERALS | No | White | 285.956 | 0.7406 | No | 1. |
| P4Beam | No | Gray8Dark | 1854.997 | 4.8046 | No | 1. |
| P4Col | No | Green | 1757.783 | 4.5528 | No | 1. |
| Pier5Beam | No | Magenta | 1854.997 | 4.8046 | No | 1. |
| Pier5Col | No | Gray8Dark | 1754.872 | 4.5453 | No | 1. |
| R1-2 R14-15 | No | White | 775.511 | 2.0086 | No | 1. |
| R1LATERAL | No | White | 37.195 | 0.0963 | No | 1. |
| R3-4 R12-13 | No | White | 519.074 | 1.3444 | No | 1. |
| R5-7 R9-11 | No | White | 574.544 | 1.4881 | No | 1. |
| R8 | No | White | 154.893 | 0.4012 | No | 1. |
| STDSEC1 | No | Cyan | 27.606 | 0.0715 | No | 1. |
| STDSEC10 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC11 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC12 | No | Gray8Dark | 0. | 0. | No | 1. |
| STDSEC13 | No | Blue | 0. | 0. | No | 1. |
| STDSEC14 | No | Green | 0. | 0. | No | 1. |
| STDSEC15 | No | Cyan | 0. | 0. | No | 1. |
| STDSEC16 | No | Red | 0. | 0. | No | 1. |
| STDSEC17 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC18 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC19 | No | Gray8Dark | 0. | 0. | No | 1. |
| STDSEC2 | No | Red | 0. | 0. | No | 1. |
| STDSEC3 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC4 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC5 | No | Gray8Dark | 20.404 | 0.0528 | No | 1. |
| STDSEC6 | No | Blue | 7.905 | 0.0205 | No | 1. |
| STDSEC7 | No | Green | 0. | 0. | No | 1. |
| STDSEC8 | No | Cyan | 0. | 0. | No | 1. |
| STDSEC9 | No | Red | 0. | 0. | No | 1. |
| TGDRT1-T3 T13-T15 | No | White | 657.549 | 1.7031 | No | 1. |
| TGDRT4-6 T10-12 | No | White | 818.63 | 2.1203 | No | 1. |
| TGDRT7-9 | No | White | 240.673 | 0.6234 | No | 1. |
| ULATERALS | No | White | 594.731 | 1.5404 | No | 1. |
| W30X108 | No | Green | 590.479 | 1.5294 | Yes | 1. |

Table:  Frame Section Properties 01 - General, Part 6 of 8

Table:  Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBMS | 1. | 1. | 1. | 1. | 1. | 1. |
| LLATERALS | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Beam | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Col | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Beam | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Col | 1. | 1. | 1. | 1. | 1. | 1. |
| R1-2 R14-15 | 1. | 1. | 1. | 1. | 1. | 1. |
| R1LATERAL | 1. | 1. | 1. | 1. | 1. | 1. |
| R3-4 R12-13 | 1. | 1. | 1. | 1. | 1. | 1. |
| R5-7 R9-11 | 1. | 1. | 1. | 1. | 1. | 1. |
| R8 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC10 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC11 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC12 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC13 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC14 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC15 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC16 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC17 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC18 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC19 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC2 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC3 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC4 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC5 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC6 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC7 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC8 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC9 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT1-T3 T13-T15 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT4-6 T10-12 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT7-9 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULATERALS | 1. | 1. | 1. | 1. | 1. | 1. |
| W30X108 | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Frame Section Properties 01 - General, Part 7 of 8

Table:  Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| Cable | 1. | | | |
| FLBMS | 1. | | | |
| LLATERALS | 1. | | | |
| P4Beam | 1. | | | |
| P4Col | 1. | | | |

Table: Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| Pier5Beam | 1. | | | |
| Pier5Col | 1. | | | |
| R1-2 R14-15 | 1. | | | |
| R1LATERAL | 1. | | | |
| R3-4 R12-13 | 1. | | | |
| R5-7 R9-11 | 1. | | | |
| R8 | 1. | | | |
| STDSEC1 | 1. | | | |
| STDSEC10 | 1. | | | |
| STDSEC11 | 1. | | | |
| STDSEC12 | 1. | | | |
| STDSEC13 | 1. | | | |
| STDSEC14 | 1. | | | |
| STDSEC15 | 1. | | | |
| STDSEC16 | 1. | | | |
| STDSEC17 | 1. | | | |
| STDSEC18 | 1. | | | |
| STDSEC19 | 1. | | | |
| STDSEC2 | 1. | | | |
| STDSEC3 | 1. | | | |
| STDSEC4 | 1. | | | |
| STDSEC5 | 1. | | | |
| STDSEC6 | 1. | | | |
| STDSEC7 | 1. | | | |
| STDSEC8 | 1. | | | |
| STDSEC9 | 1. | | | |
| TGDRT1-T3 T13-T15 | 1. | | | |
| TGDRT4-6 T10-12 | 1. | | | |
| TGDRT7-9 | 1. | | | |
| ULATERALS | 1. | | | |
| W30X108 | 1. | W30X108 | c:\program files\computers and structures\sap2000 18\sections.pro | |

Table: Frame Section Properties 01 - General, Part 8 of 8

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| Cable | Added 5/30/2016 10:27:21 AM |
| FLBMS | Added 1/6/2014 5:03:09 PM |
| LLATERALS | Added 1/6/2014 4:44:00 PM |
| P4Beam | Added 3/5/2016 8:05:10 PM |
| P4Col | Added 3/5/2016 8:10:25 PM |
| Pier5Beam | Added 3/5/2016 8:23:10 PM |
| Pier5Col | Added 3/5/2016 8:23:33 PM |
| R1-2 R14-15 | Added 1/5/2014 9:01:13 PM |
| R1LATERAL | Added 1/13/2014 11:02:26 PM |
| R3-4 R12-13 | Added 1/5/2014 9:09:56 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| R5-7 R9-11 | Added 1/5/2014 9:13:37 PM |
| R8 | Added 1/5/2014 9:18:02 PM |
| STDSEC1 | Added 12/30/2013 8:15:26 PM |
| STDSEC10 | Added 12/30/2013 8:15:26 PM |
| STDSEC11 | Added 12/30/2013 8:15:26 PM |
| STDSEC12 | Added 12/30/2013 8:15:26 PM |
| STDSEC13 | Added 12/30/2013 8:15:26 PM |
| STDSEC14 | Added 12/30/2013 8:15:26 PM |
| STDSEC15 | Added 12/30/2013 8:15:26 PM |
| STDSEC16 | Added 12/30/2013 8:15:26 PM |
| STDSEC17 | Added 12/30/2013 8:15:26 PM |
| STDSEC18 | Added 12/30/2013 8:15:26 PM |
| STDSEC19 | Added 12/30/2013 8:15:26 PM |
| STDSEC2 | Added 12/30/2013 8:15:26 PM |
| STDSEC3 | Added 12/30/2013 8:15:26 PM |
| STDSEC4 | Added 12/30/2013 8:15:26 PM |
| STDSEC5 | Added 12/30/2013 8:15:26 PM |
| STDSEC6 | Added 12/30/2013 8:15:26 PM |
| STDSEC7 | Added 12/30/2013 8:15:26 PM |
| STDSEC8 | Added 12/30/2013 8:15:26 PM |
| STDSEC9 | Added 12/30/2013 8:15:26 PM |
| TGDRT1-T3 T13-T15 | Added 1/5/2014 1:51:50 PM |
| TGDRT4-6 T10-12 | Added 1/5/2014 8:34:10 PM |
| TGDRT7-9 | Added 1/5/2014 8:43:17 PM |
| ULATERALS | Added 1/12/2014 9:20:26 PM |
| W30X108 | Imported 3/10/2016 2:49:32 PM from SECTIONS.PRO |

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover in | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| P4Beam | A615Gr60 | A615Gr60 | Rectangular | Ties | 1.5 | 3 | 3 |
| P4Col | A615Gr60 | A615Gr60 | Rectangular | Ties | 1.5 | 3 | 3 |
| Pier5Beam | A615Gr60 | A615Gr60 | Rectangular | Ties | 1.5 | 3 | 3 |
| Pier5Col | A615Gr60 | A615Gr60 | Rectangular | Ties | 1.5 | 3 | 3 |

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC in | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| P4Beam | #9 | #4 | 6. | 3 | 3 | Design |
| P4Col | #9 | #4 | 6. | 3 | 3 | Design |
| Pier5Beam | #9 | #4 | 6. | 3 | 3 | Design |

Table: Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| | | | in | | | |
| Pier5Col | #9 | #4 | 6. | 3 | 3 | Design |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/in | Kip | Kip-in-s2 | Kip-in-s2 | Kip-in-s2 |
| Pier4F | Linear | 0. | 0. | 0. | 0. | 0. |
| Pier5E | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | in | in2 | | | | |
| Pier4F | 12. | 144. | 0. | 0. | 0. | 0. |
| Pier5E | 12. | 144. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| Pier4F | Cyan | 30d405fd-730f-41e3-bbea-244cda3e9650 | Added 3/5/2016 8:18:58 PM |
| Pier5E | Cyan | a2bde322-04e3-446c-ba4c-3fb7596045e1 | Added 3/5/2016 8:18:58 PM |

Table: Link Property Definitions 02 - Linear

Table: Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE | RotKE | TransCE | RotCE | DJ |
|---|---|---|---|---|---|---|---|
| | | | Kip/in | Kip-in/rad | Kip-s/in | Kip-in-s/rad | in |
| Pier4F | U1 | No | 8333.3333 | | 0. | | |
| Pier4F | U2 | No | 8333.3333 | | 0. | | 0. |
| Pier4F | U3 | No | 8333.3333 | | 0. | | 0. |
| Pier4F | R1 | No | | 0. | | 0. | |
| Pier4F | R2 | No | | 0. | | 0. | |
| Pier4F | R3 | No | | 0. | | 0. | |
| Pier5E | U1 | No | 8333.3333 | | 0. | | |
| Pier5E | U2 | No | 8333.3333 | | 0. | | 0. |
| Pier5E | U3 | No | 8333.3333 | | 0. | | 0. |
| Pier5E | R1 | No | | 0. | | 0. | |
| Pier5E | R2 | No | | 0. | | 0. | |
| Pier5E | R3 | No | | 0. | | 0. | |

Table: Area Section Properties, Part 1 of 4

Table: Area Section Properties, Part 1 of 4

| Section | Material | MatAngle<br>Degrees | AreaType | Type | DrillDOF | Thickness<br>in | BendThick<br>in |
|---|---|---|---|---|---|---|---|
| CONCDECK | 4000Psi | 0. | Shell | Shell-Thin | Yes | 8.6616 | 8.6616 |
| P4Shaft | 4000Psi | 0. | Shell | Shell-Thick | Yes | 136.2 | 136.2 |
| Pier5Shaft | 4000Psi | 0. | Shell | Shell-Thick | Yes | 145.44 | 145.44 |

Table: Area Section Properties, Part 2 of 4

Table: Area Section Properties, Part 2 of 4

| Section | Arc<br>Degrees | InComp | CoordSys | Color | TotalWt<br>Kip | TotalMass<br>Kip-s2/in |
|---|---|---|---|---|---|---|
| CONCDECK | | | | Red | 6047.367 | 13.6201 |
| P4Shaft | | | | Green | 2726.724 | 7.0624 |
| Pier5Shaft | | | | Green | 7775.441 | 20.139 |

Table: Area Section Properties, Part 3 of 4

Table: Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| CONCDECK | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Shaft | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Shaft | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Area Section Properties, Part 4 of 4

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| CONCDECK | 1. | 1. | 1.15 | 758d35c5-1090-4412-961e-a55c3a7a8dcf | Added 3/13/2016 4:57:39 PM |
| P4Shaft | 1. | 1. | 1. | e23ce15c-c909-437f-a64a-f4b7fa56ca94 | Added 3/5/2016 8:14:07 PM |
| Pier5Shaft | 1. | 1. | 1. | 53f15048-2c5b-4fcb-a24a-21a06b537a20 | Added 3/5/2016 8:30:26 PM |

Section 2 Page Avenue Bridge Load Cases

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | DEAD | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| MODAL | | |
| LIVELOAD | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 59 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |

Table:  Case - Moving Load 1 - Lane Assignments

Table:  Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 1 | 7 | 14 |

Table:  Case - Moving Load 2 - Lanes Loaded

Table:  Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CTRLANE2 |
| LIVELOAD | 1 | LTLANE21 |
| LIVELOAD | 1 | LTLANE22 |
| LIVELOAD | 1 | LTLANE23 |
| LIVELOAD | 1 | M1 |
| LIVELOAD | 1 | M2 |
| LIVELOAD | 1 | M3 |
| LIVELOAD | 1 | M4 |
| LIVELOAD | 1 | M5 |
| LIVELOAD | 1 | M6 |
| LIVELOAD | 1 | M7 |

Table:  Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | RTLANE21 |
| LIVELOAD | 1 | RTLANE22 |
| LIVELOAD | 1 | RTLANE23 |

Table:  Case - Moving Load 3 - MultiLane Factors

Table:  Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1. |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.9 |
| LIVELOAD | 4 | 0.75 |
| LIVELOAD | 5 | 0.75 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |
| LIVELOAD | 10 | 0.75 |
| LIVELOAD | 11 | 0.75 |
| LIVELOAD | 12 | 0.75 |
| LIVELOAD | 13 | 0.75 |
| LIVELOAD | 14 | 0.75 |
| LIVELOAD | 15 | 0.75 |
| LIVELOAD | 16 | 0.75 |
| LIVELOAD | 17 | 0.75 |
| LIVELOAD | 18 | 0.75 |
| LIVELOAD | 19 | 0.75 |
| LIVELOAD | 20 | 0.75 |
| LIVELOAD | 21 | 0.75 |
| LIVELOAD | 22 | 0.75 |
| LIVELOAD | 23 | 0.75 |
| LIVELOAD | 24 | 0.75 |
| LIVELOAD | 25 | 0.75 |
| LIVELOAD | 26 | 0.75 |
| LIVELOAD | 27 | 0.75 |
| LIVELOAD | 28 | 0.75 |
| LIVELOAD | 29 | 0.75 |
| LIVELOAD | 30 | 0.75 |
| LIVELOAD | 31 | 0.75 |
| LIVELOAD | 32 | 0.75 |
| LIVELOAD | 33 | 0.75 |
| LIVELOAD | 34 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift Cyc/sec | EigenCutoff Cyc/sec | EigenTol |
|---|---|---|---|---|---|---|
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 Page Avenue Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.1302 | 83.6279 |
| MODAL | Acceleration | UY | 99.4415 | 50.6298 |
| MODAL | Acceleration | UZ | 99.1698 | 43.8486 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period Sec | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 3.533745 | 6.629E-12 | 0.0849 | 9.083E-12 | 6.629E-12 |
| MODAL | Mode | 2. | 1.976926 | 0.0168 | 2.077E-10 | 2.280E-04 | 0.0168 |
| MODAL | Mode | 3. | 1.280837 | 4.395E-10 | 0.1865 | 1.186E-11 | 0.0168 |
| MODAL | Mode | 4. | 1.116848 | 4.501E-10 | 0.1422 | 1.779E-10 | 0.0168 |
| MODAL | Mode | 5. | 0.979255 | 0.0017 | 9.242E-11 | 0.0187 | 0.0186 |
| MODAL | Mode | 6. | 0.75136 | 0.6486 | 5.189E-10 | 0.07 | 0.6671 |
| MODAL | Mode | 7. | 0.71314 | 3.411E-08 | 0.0054 | 3.538E-08 | 0.6671 |
| MODAL | Mode | 8. | 0.683397 | 0.1361 | 5.161E-11 | 0.3258 | 0.8033 |
| MODAL | Mode | 9. | 0.534033 | 0.0036 | 7.179E-11 | 0.0011 | 0.8068 |
| MODAL | Mode | 10. | 0.513421 | 1.711E-09 | 0.0011 | 1.646E-11 | 0.8068 |
| MODAL | Mode | 11. | 0.490411 | 9.205E-12 | 4.486E-04 | 1.621E-13 | 0.8068 |
| MODAL | Mode | 12. | 0.455059 | 8.579E-11 | 0.0054 | 1.467E-10 | 0.8068 |
| MODAL | Mode | 13. | 0.443201 | 4.146E-06 | 1.126E-10 | 2.570E-04 | 0.8068 |
| MODAL | Mode | 14. | 0.380253 | 2.566E-09 | 3.083E-05 | 9.668E-09 | 0.8068 |
| MODAL | Mode | 15. | 0.37541 | 6.070E-05 | 8.772E-15 | 0.0128 | 0.8069 |
| MODAL | Mode | 16. | 0.363979 | 1.603E-04 | 4.290E-11 | 0.0025 | 0.807 |
| MODAL | Mode | 17. | 0.361869 | 2.118E-08 | 3.445E-04 | 1.161E-08 | 0.807 |
| MODAL | Mode | 18. | 0.32687 | 1.314E-09 | 0.0778 | 3.649E-11 | 0.807 |
| MODAL | Mode | 19. | 0.309272 | 1.259E-05 | 1.051E-10 | 0.0016 | 0.807 |
| MODAL | Mode | 20. | 0.29573 | 6.030E-06 | 1.246E-10 | 1.062E-04 | 0.8071 |
| MODAL | Mode | 21. | 0.282586 | 4.867E-05 | 4.560E-11 | 7.825E-07 | 0.8071 |

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period Sec | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 22. | 0.27095 | 6.719E-06 | 1.130E-11 | 1.907E-04 | 0.8071 |
| MODAL | Mode | 23. | 0.265724 | 3.022E-11 | 0.0022 | 3.794E-13 | 0.8071 |
| MODAL | Mode | 24. | 0.263862 | 7.765E-05 | 1.920E-11 | 2.533E-05 | 0.8072 |
| MODAL | Mode | 25. | 0.261846 | 1.529E-04 | 2.095E-11 | 1.154E-04 | 0.8073 |
| MODAL | Mode | 26. | 0.256773 | 6.151E-04 | 7.526E-11 | 1.614E-05 | 0.808 |
| MODAL | Mode | 27. | 0.255175 | 4.231E-04 | 5.611E-11 | 0.003 | 0.8084 |
| MODAL | Mode | 28. | 0.254806 | 1.238E-08 | 1.326E-05 | 2.614E-09 | 0.8084 |
| MODAL | Mode | 29. | 0.248466 | 0.0207 | 5.417E-10 | 0.0016 | 0.829 |
| MODAL | Mode | 30. | 0.24688 | 0.0073 | 5.517E-10 | 5.800E-04 | 0.8363 |

Table: Modal Participating Mass Ratios, Part 2 of 3

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 0.0849 | 9.083E-12 | 0.3295 | 1.228E-10 | 0.0242 |
| MODAL | Mode | 2. | 0.0849 | 2.280E-04 | 1.115E-09 | 0.0913 | 4.367E-13 |
| MODAL | Mode | 3. | 0.2714 | 2.280E-04 | 0.2184 | 5.541E-11 | 0.0017 |
| MODAL | Mode | 4. | 0.4136 | 2.280E-04 | 8.867E-04 | 2.791E-11 | 0.0245 |
| MODAL | Mode | 5. | 0.4136 | 0.0189 | 1.126E-10 | 7.482E-04 | 1.241E-10 |
| MODAL | Mode | 6. | 0.4136 | 0.0889 | 2.029E-11 | 0.0047 | 4.772E-12 |
| MODAL | Mode | 7. | 0.419 | 0.0889 | 3.223E-04 | 9.621E-11 | 6.515E-06 |
| MODAL | Mode | 8. | 0.419 | 0.4147 | 1.095E-10 | 0.0294 | 4.517E-12 |
| MODAL | Mode | 9. | 0.419 | 0.4159 | 2.593E-10 | 0.0294 | 4.228E-10 |
| MODAL | Mode | 10. | 0.4201 | 0.4159 | 0.0058 | 2.367E-09 | 0.0141 |
| MODAL | Mode | 11. | 0.4205 | 0.4159 | 0.0014 | 1.129E-11 | 0.172 |
| MODAL | Mode | 12. | 0.4259 | 0.4159 | 0.1466 | 1.110E-11 | 3.910E-05 |
| MODAL | Mode | 13. | 0.4259 | 0.4161 | 3.413E-09 | 9.655E-04 | 1.961E-13 |
| MODAL | Mode | 14. | 0.4259 | 0.4161 | 0.0015 | 4.269E-10 | 9.127E-04 |
| MODAL | Mode | 15. | 0.4259 | 0.4289 | 1.809E-09 | 1.117E-04 | 7.358E-10 |
| MODAL | Mode | 16. | 0.4259 | 0.4313 | 5.092E-11 | 0.0026 | 1.660E-12 |
| MODAL | Mode | 17. | 0.4263 | 0.4313 | 2.974E-04 | 9.714E-09 | 2.151E-05 |
| MODAL | Mode | 18. | 0.5041 | 0.4313 | 0.0082 | 3.058E-10 | 0.003 |
| MODAL | Mode | 19. | 0.5041 | 0.4329 | 1.696E-11 | 2.360E-04 | 2.940E-13 |
| MODAL | Mode | 20. | 0.5041 | 0.433 | 4.274E-12 | 0.0092 | 4.755E-12 |
| MODAL | Mode | 21. | 0.5041 | 0.433 | 3.432E-13 | 0.0015 | 1.750E-11 |
| MODAL | Mode | 22. | 0.5041 | 0.4332 | 1.703E-12 | 1.468E-05 | 3.361E-11 |
| MODAL | Mode | 23. | 0.5063 | 0.4332 | 7.855E-04 | 9.303E-12 | 0.0023 |
| MODAL | Mode | 24. | 0.5063 | 0.4333 | 1.188E-11 | 3.426E-04 | 1.031E-10 |
| MODAL | Mode | 25. | 0.5063 | 0.4334 | 1.155E-10 | 3.762E-05 | 2.217E-10 |
| MODAL | Mode | 26. | 0.5063 | 0.4334 | 4.015E-09 | 1.670E-04 | 1.997E-09 |
| MODAL | Mode | 27. | 0.5063 | 0.4363 | 2.563E-08 | 3.160E-04 | 1.743E-09 |
| MODAL | Mode | 28. | 0.5063 | 0.4363 | 0.0149 | 3.868E-09 | 6.879E-04 |
| MODAL | Mode | 29. | 0.5063 | 0.4379 | 1.513E-08 | 0.0072 | 2.513E-07 |
| MODAL | Mode | 30. | 0.5063 | 0.4385 | 5.875E-09 | 0.0019 | 4.623E-07 |

Table: Modal Participating Mass Ratios, Part 3 of 3

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | Mode | 1. | 0.3295 | 1.228E-10 | 0.0242 |
| MODAL | Mode | 2. | 0.3295 | 0.0913 | 0.0242 |
| MODAL | Mode | 3. | 0.5479 | 0.0913 | 0.0258 |
| MODAL | Mode | 4. | 0.5488 | 0.0913 | 0.0504 |
| MODAL | Mode | 5. | 0.5488 | 0.0921 | 0.0504 |
| MODAL | Mode | 6. | 0.5488 | 0.0968 | 0.0504 |
| MODAL | Mode | 7. | 0.5491 | 0.0968 | 0.0504 |
| MODAL | Mode | 8. | 0.5491 | 0.1262 | 0.0504 |
| MODAL | Mode | 9. | 0.5491 | 0.1556 | 0.0504 |
| MODAL | Mode | 10. | 0.5549 | 0.1556 | 0.0645 |
| MODAL | Mode | 11. | 0.5563 | 0.1556 | 0.2365 |
| MODAL | Mode | 12. | 0.7029 | 0.1556 | 0.2365 |
| MODAL | Mode | 13. | 0.7029 | 0.1566 | 0.2365 |
| MODAL | Mode | 14. | 0.7044 | 0.1566 | 0.2375 |
| MODAL | Mode | 15. | 0.7044 | 0.1567 | 0.2375 |
| MODAL | Mode | 16. | 0.7044 | 0.1593 | 0.2375 |
| MODAL | Mode | 17. | 0.7047 | 0.1593 | 0.2375 |
| MODAL | Mode | 18. | 0.7129 | 0.1593 | 0.2405 |
| MODAL | Mode | 19. | 0.7129 | 0.1595 | 0.2405 |
| MODAL | Mode | 20. | 0.7129 | 0.1687 | 0.2405 |
| MODAL | Mode | 21. | 0.7129 | 0.1702 | 0.2405 |
| MODAL | Mode | 22. | 0.7129 | 0.1703 | 0.2405 |
| MODAL | Mode | 23. | 0.7136 | 0.1703 | 0.2428 |
| MODAL | Mode | 24. | 0.7136 | 0.1706 | 0.2428 |
| MODAL | Mode | 25. | 0.7136 | 0.1706 | 0.2428 |
| MODAL | Mode | 26. | 0.7136 | 0.1708 | 0.2428 |
| MODAL | Mode | 27. | 0.7136 | 0.1711 | 0.2428 |
| MODAL | Mode | 28. | 0.7286 | 0.1711 | 0.2435 |
| MODAL | Mode | 29. | 0.7286 | 0.1783 | 0.2435 |
| MODAL | Mode | 30. | 0.7286 | 0.1802 | 0.2435 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period<br>Sec | UX<br>Kip-in | UY<br>Kip-in | UZ<br>Kip-in | RX<br>Kip-in |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 3.533745 | -0.000021 | -2.307861 | 0.000024 | 2810.353501 |
| MODAL | Mode | 2. | 1.976926 | 1.026159 | 0.000116 | 0.119445 | -0.16394 |
| MODAL | Mode | 3. | 1.280837 | -0.000166 | 3.490172 | 0.000027 | -2305.35551 |
| MODAL | Mode | 4. | 1.116848 | -0.000168 | -3.034922 | 0.000106 | 158.079736 |
| MODAL | Mode | 5. | 0.979255 | 0.328707 | -0.000078 | -1.081401 | -0.051526 |
| MODAL | Mode | 6. | 0.75136 | -6.371025 | -0.000162 | 2.093239 | 0.017718 |
| MODAL | Mode | 7. | 0.71314 | -0.001461 | 0.51043 | 0.001488 | 105.106651 |
| MODAL | Mode | 8. | 0.683397 | -2.9175 | 0.000055 | -4.515669 | -0.050749 |
| MODAL | Mode | 9. | 0.534033 | -0.475384 | -0.000069 | -0.264031 | 0.079317 |
| MODAL | Mode | 10. | 0.513421 | 0.000328 | -0.269804 | 0.000032 | 373.9699 |
| MODAL | Mode | 11. | 0.490411 | -0.000024 | -0.173407 | -3.185E-06 | 184.810063 |
| MODAL | Mode | 12. | 0.455059 | -0.000072 | -0.031173 | -0.000096 | 2019.910259 |

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period<br>Sec | UX<br>Kip-in | UY<br>Kip-in | UZ<br>Kip-in | RX<br>Kip-in |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 13. | 0.443201 | -0.011073 | 0.000015 | 0.126817 | -0.309579 |
| MODAL | Mode | 14. | 0.380253 | 0.000398 | -0.025102 | -0.000778 | 207.814565 |
| MODAL | Mode | 15. | 0.37541 | 0.064543 | -0.000046 | 0.893642 | 0.219001 |
| MODAL | Mode | 16. | 0.363979 | -0.110055 | -0.000052 | 0.393045 | 0.034855 |
| MODAL | Mode | 17. | 0.361869 | 0.001149 | 0.137741 | 0.000852 | -82.241247 |
| MODAL | Mode | 18. | 0.32687 | 0.000286 | -2.181944 | 0.000048 | 436.566749 |
| MODAL | Mode | 19. | 0.309272 | -0.036812 | 0.000079 | -0.315586 | -0.019626 |
| MODAL | Mode | 20. | 0.29573 | -0.006431 | -0.000087 | 0.081543 | 0.009827 |
| MODAL | Mode | 21. | 0.282586 | 0.060323 | 0.000055 | 0.006998 | -0.003236 |
| MODAL | Mode | 22. | 0.27095 | 0.013321 | 0.000043 | 0.109248 | -0.010384 |
| MODAL | Mode | 23. | 0.265724 | -0.000044 | 0.576754 | -4.873E-06 | 88.382205 |
| MODAL | Mode | 24. | 0.263862 | -0.067145 | -0.000032 | -0.039814 | -0.017611 |
| MODAL | Mode | 25. | 0.261846 | -0.099125 | -0.000048 | -0.084984 | -0.04972 |
| MODAL | Mode | 26. | 0.256773 | -0.202671 | -0.000054 | -0.031786 | -0.313682 |
| MODAL | Mode | 27. | 0.255175 | -0.168682 | -0.000023 | -0.430212 | -0.792122 |
| MODAL | Mode | 28. | 0.254806 | 0.000884 | -0.003492 | -0.000404 | 605.492482 |
| MODAL | Mode | 29. | 0.248466 | 1.15683 | 0.000219 | 0.312479 | -0.610379 |
| MODAL | Mode | 30. | 0.24688 | -0.67921 | -0.000194 | 0.190517 | 0.377104 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY<br>Kip-in | RZ<br>Kip-in | ModalMass<br>Kip-in-s2 | ModalStiff<br>Kip-in |
|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | -0.269969 | 4062.685631 | 1. | 3.1615 |
| MODAL | Mode | 2. | -7362.2374 | -0.007719 | 1. | 10.1013 |
| MODAL | Mode | 3. | 0.181281 | 1437.708146 | 1. | 24.0642 |
| MODAL | Mode | 4. | 0.128649 | 4145.154282 | 1. | 31.6499 |
| MODAL | Mode | 5. | -666.212709 | 0.311856 | 1. | 41.1688 |
| MODAL | Mode | 6. | -1668.58695 | -0.018657 | 1. | 69.9299 |
| MODAL | Mode | 7. | 0.239022 | 166.434273 | 1. | 77.6265 |
| MODAL | Mode | 8. | -4177.1387 | 0.08472 | 1. | 84.5306 |
| MODAL | Mode | 9. | -4177.5233 | 0.621437 | 1. | 138.4277 |
| MODAL | Mode | 10. | 1.185181 | 3408.11093 | 1. | 149.766 |
| MODAL | Mode | 11. | 0.081882 | -9652.8256 | 1. | 164.1493 |
| MODAL | Mode | 12. | -0.080946 | 474.668957 | 1. | 190.6444 |
| MODAL | Mode | 13. | 758.106385 | -0.067403 | 1. | 200.9825 |
| MODAL | Mode | 14. | 0.502576 | -157.598644 | 1. | 273.0331 |
| MODAL | Mode | 15. | 258.188574 | 0.042046 | 1. | 280.1229 |
| MODAL | Mode | 16. | 1236.737159 | 0.083719 | 1. | 297.9936 |
| MODAL | Mode | 17. | 2.400297 | -352.754096 | 1. | 301.4785 |
| MODAL | Mode | 18. | 0.425885 | 1296.694034 | 1. | 369.4968 |
| MODAL | Mode | 19. | 372.109756 | -0.012365 | 1. | 412.7406 |
| MODAL | Mode | 20. | 2340.922998 | -0.070397 | 1. | 451.409 |
| MODAL | Mode | 21. | -953.211497 | 0.114573 | 1. | 494.3773 |
| MODAL | Mode | 22. | 91.605574 | 0.12449 | 1. | 537.7528 |
| MODAL | Mode | 23. | -0.074419 | 1012.947242 | 1. | 559.1123 |
| MODAL | Mode | 24. | -450.238548 | -0.257248 | 1. | 567.0317 |
| MODAL | Mode | 25. | -149.706913 | -0.351924 | 1. | 575.7971 |

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY | RZ | ModalMass | ModalStiff |
|---|---|---|---|---|---|---|
| | | | Kip-in | Kip-in | Kip-in-s2 | Kip-in |
| MODAL | Mode | 26. | -316.334478 | -1.101688 | 1. | 598.7701 |
| MODAL | Mode | 27. | -434.412754 | -1.054492 | 1. | 606.2942 |
| MODAL | Mode | 28. | 1.515834 | 668.38277 | 1. | 608.0492 |
| MODAL | Mode | 29. | 2069.969389 | 12.159519 | 1. | 639.4774 |
| MODAL | Mode | 30. | -1069.38874 | -16.531124 | 1. | 647.7196 |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period | Frequency | CircFreq | Eigenvalue |
|---|---|---|---|---|---|---|
| | | | Sec | Cyc/sec | rad/sec | rad2/sec2 |
| MODAL | Mode | 1. | 3.533745 | 2.8299E-01 | 1.7781E+00 | 3.1615E+00 |
| MODAL | Mode | 2. | 1.976926 | 5.0584E-01 | 3.1783E+00 | 1.0101E+01 |
| MODAL | Mode | 3. | 1.280837 | 7.8074E-01 | 4.9055E+00 | 2.4064E+01 |
| MODAL | Mode | 4. | 1.116848 | 8.9538E-01 | 5.6258E+00 | 3.1650E+01 |
| MODAL | Mode | 5. | 0.979255 | 1.0212E+00 | 6.4163E+00 | 4.1169E+01 |
| MODAL | Mode | 6. | 0.75136 | 1.3309E+00 | 8.3624E+00 | 6.9930E+01 |
| MODAL | Mode | 7. | 0.71314 | 1.4022E+00 | 8.8106E+00 | 7.7627E+01 |
| MODAL | Mode | 8. | 0.683397 | 1.4633E+00 | 9.1941E+00 | 8.4531E+01 |
| MODAL | Mode | 9. | 0.534033 | 1.8725E+00 | 1.1766E+01 | 1.3843E+02 |
| MODAL | Mode | 10. | 0.513421 | 1.9477E+00 | 1.2238E+01 | 1.4977E+02 |
| MODAL | Mode | 11. | 0.490411 | 2.0391E+00 | 1.2812E+01 | 1.6415E+02 |
| MODAL | Mode | 12. | 0.455059 | 2.1975E+00 | 1.3807E+01 | 1.9064E+02 |
| MODAL | Mode | 13. | 0.443201 | 2.2563E+00 | 1.4177E+01 | 2.0098E+02 |
| MODAL | Mode | 14. | 0.380253 | 2.6298E+00 | 1.6524E+01 | 2.7303E+02 |
| MODAL | Mode | 15. | 0.37541 | 2.6638E+00 | 1.6737E+01 | 2.8012E+02 |
| MODAL | Mode | 16. | 0.363979 | 2.7474E+00 | 1.7262E+01 | 2.9799E+02 |
| MODAL | Mode | 17. | 0.361869 | 2.7634E+00 | 1.7363E+01 | 3.0148E+02 |
| MODAL | Mode | 18. | 0.32687 | 3.0593E+00 | 1.9222E+01 | 3.6950E+02 |
| MODAL | Mode | 19. | 0.309272 | 3.2334E+00 | 2.0316E+01 | 4.1274E+02 |
| MODAL | Mode | 20. | 0.29573 | 3.3815E+00 | 2.1246E+01 | 4.5141E+02 |
| MODAL | Mode | 21. | 0.282586 | 3.5387E+00 | 2.2235E+01 | 4.9438E+02 |
| MODAL | Mode | 22. | 0.27095 | 3.6907E+00 | 2.3189E+01 | 5.3775E+02 |
| MODAL | Mode | 23. | 0.265724 | 3.7633E+00 | 2.3646E+01 | 5.5911E+02 |
| MODAL | Mode | 24. | 0.263862 | 3.7899E+00 | 2.3812E+01 | 5.6703E+02 |
| MODAL | Mode | 25. | 0.261846 | 3.8190E+00 | 2.3996E+01 | 5.7580E+02 |
| MODAL | Mode | 26. | 0.256773 | 3.8945E+00 | 2.4470E+01 | 5.9877E+02 |
| MODAL | Mode | 27. | 0.255175 | 3.9189E+00 | 2.4623E+01 | 6.0629E+02 |
| MODAL | Mode | 28. | 0.254806 | 3.9245E+00 | 2.4659E+01 | 6.0805E+02 |
| MODAL | Mode | 29. | 0.248466 | 4.0247E+00 | 2.5288E+01 | 6.3948E+02 |
| MODAL | Mode | 30. | 0.24688 | 4.0505E+00 | 2.5450E+01 | 6.4772E+02 |

Table: Program Control, Part 1 of 2

Table: Program Control, Part 1 of 2

| ProgramName | Version | ProgLevel | LicenseNum | LicenseOS | LicenseSC | LicenseHT | CurrUnits |
|---|---|---|---|---|---|---|---|
| SAP2000 | 18.1.1 | Advanced | 2010*1GRWHLW4599V5FQ | No | No | No | Kip, in, F |

Table: Program Control, Part 2 of 2

Table: Program Control, Part 2 of 2

| SteelCode | ConcCode | AlumCode | ColdCode | RegenHinge |
|---|---|---|---|---|
| AISC360-05/IBC2006 | ACI 318-08/IBC2009 | AA-ASD 2000 | AISI-ASD96 | Yes |

**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160610 Page Avenue Rev 012 HL93 C2F LBK.sdb**
**Page Avenue Bridge**

**26 June 2016**

Section 1  Page Avenue Bridge Analysis Input

Table:  Material Properties 01 - General, Part 1 of 2

Table:  Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 4000Psi | Concrete | Isotropic | No | Red | |
| A416Gr270 | Tendon | Uniaxial | No | Magenta | |
| A572Gr50 | Steel | Isotropic | No | Blue | |
| A615Gr60 | Rebar | Uniaxial | No | Gray8Dark | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586 | Steel | Isotropic | No | Blue | |
| STAAD1 | Steel | Isotropic | No | Yellow | D7D209AA-88D2-4D08-A6D1-DC069FD57107 |
| STAAD2 | Other | Isotropic | No | Blue | 02574C1E-4D75-4112-B3BD-9AF3D1778D8A |

Table:  Material Properties 01 - General, Part 2 of 2

Table:  Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 4000Psi | Normalweight f'c = 4 ksi added 12/30/2013 8:14:18 PM |
| A416Gr270 | ASTM A416 Grade 270 3/5/2016 7:31:46 PM |
| A572Gr50 | ASTM A572 Grade 50 added 1/5/2014 1:54:23 PM |
| A615Gr60 | ASTM A615 Grade 60 added 1/5/2014 1:54:38 PM |
| A992Fy50 | ASTM A992 Fy=50 ksi added 12/30/2013 8:14:18 PM |
| ASTM A586 | ASTM A36 added 1/5/2014 9:29:36 PM |
| STAAD1 | ASTM A36 added 12/30/2013 8:14:18 PM |
| STAAD2 | ASTM A36 added 12/30/2013 8:14:18 PM |

Table:  Material Properties 02 - Basic Mechanical Properties

Table:  Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| 4000Psi | 2.5920E+02 | 9.6674E+01 | 18688320. | 7786800. | 0.2 | 5.5000E-06 |
| A416Gr270 | 8.4672E+02 | 3.1580E+02 | 590976000. | | | 6.5000E-06 |
| A572Gr50 | 8.4672E+02 | 3.1580E+02 | 601344000. | 231286153.8 | 0.3 | 6.5000E-06 |
| A615Gr60 | 8.4672E+02 | 3.1580E+02 | 601344000. | | | 6.5000E-06 |
| A992Fy50 | 8.4672E+02 | 3.1580E+02 | 601344000. | 231286153.8 | 0.3 | 6.5000E-06 |
| ASTM A586 | 8.4672E+02 | 3.1580E+02 | 476928000. | 183433846.2 | 0.3 | 6.5000E-06 |
| STAAD1 | 8.4503E+02 | 3.1517E+02 | 601344000. | 231286153.8 | 0.3 | 0.0000E+00 |
| STAAD2 | 8.4503E+02 | 3.1517E+02 | 476928000. | 183433846.2 | 0.3 | 0.0000E+00 |

Table:  Material Properties 03a - Steel Data, Part 1 of 2

Table:  Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A572Gr50 | 1036800. | 1347840. | 1140480. | 1482624. | Simple | Kinematic | 0.015 |
| A992Fy50 | 1036800. | 1347840. | 1140480. | 1482624. | Simple | Kinematic | 0.015 |
| ASTM A586 | 3110400. | 4561920. | 3110400. | 4561920. | Simple | Kinematic | 0.02 |
| STAAD1 | 746496. | 1202688. | 1119744. | 1322956.8 | Simple | Kinematic | 0.02 |

Table:  Material Properties 03a - Steel Data, Part 2 of 2

Table:  Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A572Gr50 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |
| ASTM A586 | 0.14 | 0.2 | -0.1 |
| STAAD1 | 0.14 | 0.2 | -0.1 |

Table:  Material Properties 03b - Concrete Data, Part 1 of 2

Table:  Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 4000Psi | 82944. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table:  Material Properties 03b - Concrete Data, Part 2 of 2

Table:  Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 4000Psi | 0. | 0. |

Table:  Frame Section Properties 01 - General, Part 1 of 8

Table:  Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| Cable | ASTM A586 | General | 0.08333 | 0.08333 | |
| FLBMS | A572Gr50 | I/Wide Flange | 0.91722 | 0.14757 | 0.01639 |
| LLATERALS | A572Gr50 | I/Wide Flange | 0.10264 | 0.10764 | 0.00757 |
| P4Beam | 4000Psi | Rectangular | 0.80381 | 1.17563 | |
| P4Col | 4000Psi | Rectangular | 0.81667 | 0.81667 | |
| Pier5Beam | 4000Psi | Rectangular | 0.80381 | 1.17563 | |
| Pier5Col | 4000Psi | Rectangular | 0.81667 | 0.81667 | |
| R1-2 R14-15 | A572Gr50 | SD Section | | | |
| R1LATERAL | A572Gr50 | SD Section | | | |
| R3-4 R12-13 | A572Gr50 | SD Section | | | |
| R5-7 R9-11 | A572Gr50 | SD Section | | | |
| R8 | A572Gr50 | SD Section | | | |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| STDSEC1 | STAAD1 | General | 0.14415 | 0.14415 | |
| STDSEC10 | STAAD1 | General | 0.13823 | 0.13823 | |
| STDSEC11 | STAAD1 | General | 0.14348 | 0.14348 | |
| STDSEC12 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC13 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC14 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC15 | STAAD1 | General | 0.07336 | 0.07336 | |
| STDSEC16 | STAAD1 | General | 0.07336 | 0.07336 | |
| STDSEC17 | STAAD1 | General | 0.06682 | 0.06682 | |
| STDSEC18 | STAAD1 | General | 0.06682 | 0.06682 | |
| STDSEC19 | STAAD2 | General | 0.02282 | 0.02282 | |
| STDSEC2 | STAAD1 | General | 0.14415 | 0.14415 | |
| STDSEC3 | STAAD1 | General | 0.13282 | 0.13282 | |
| STDSEC4 | STAAD1 | General | 0.14415 | 0.14415 | |
| STDSEC5 | STAAD1 | General | 0.14415 | 0.14415 | |
| STDSEC6 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC7 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC8 | STAAD1 | General | 0.14793 | 0.14793 | |
| STDSEC9 | STAAD1 | General | 0.14348 | 0.14348 | |
| TGDRT1-T3 T13-T15 | A572Gr50 | SD Section | | | |
| TGDRT4-6 T10-12 | A572Gr50 | SD Section | | | |
| TGDRT7-9 | A572Gr50 | SD Section | | | |
| ULATERALS | A572Gr50 | SD Section | | | |
| W30X108 | A992Fy50 | I/Wide Flange | 0.20715 | 0.07274 | 0.00528 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| Cable | | | | 5.229E-04 | 4.349E-08 | 2.174E-08 |
| FLBMS | 0.00521 | 0.14757 | 0.01639 | 0.0094 | 4.443E-07 | 0.001282 |
| LLATERALS | 0.00472 | 0.10764 | 0.00757 | 0.002 | 3.271E-08 | 3.953E-06 |
| P4Beam | | | | 0.945 | 0.117451 | 0.05088 |
| P4Col | | | | 0.6669 | 0.062645 | 0.037068 |
| Pier5Beam | | | | 0.945 | 0.117451 | 0.05088 |
| Pier5Col | | | | 0.6669 | 0.062645 | 0.037068 |
| R1-2 R14-15 | | | | 0.0219 | 0.000711 | 0.000759 |
| R1LATERAL | | | | 0.0029 | 0.000012 | 0.000015 |
| R3-4 R12-13 | | | | 0.0219 | 0.000711 | 0.000759 |
| R5-7 R9-11 | | | | 0.0206 | 0.000657 | 0.000734 |
| R8 | | | | 0.0191 | 0.000616 | 0.000645 |
| STDSEC1 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC10 | | | | 0.0191 | 0. | 0.000644 |
| STDSEC11 | | | | 0.0206 | 0. | 0.000735 |
| STDSEC12 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC13 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC14 | | | | 0.0219 | 0. | 0.00076 |

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw | t2b | tfb | Area | TorsConst | I33 |
|---|---|---|---|---|---|---|
| | ft | ft | ft | ft2 | ft4 | ft4 |
| STDSEC15 | | | | 0.0054 | 0. | 0.000027 |
| STDSEC16 | | | | 0.0054 | 0. | 0.000027 |
| STDSEC17 | | | | 0.0045 | 0. | 0.00004 |
| STDSEC18 | | | | 0.0045 | 0. | 0.00004 |
| STDSEC19 | | | | 5.208E-04 | 0. | 1.891E-06 |
| STDSEC2 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC3 | | | | 0.0176 | 0. | 0.001774 |
| STDSEC4 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC5 | | | | 0.0208 | 0. | 0.002357 |
| STDSEC6 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC7 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC8 | | | | 0.0219 | 0. | 0.00076 |
| STDSEC9 | | | | 0.0206 | 0. | 0.000735 |
| TGDRT1-T3 T13-T15 | | | | 0.0208 | 9.917E-07 | 0.002421 |
| TGDRT4-6 T10-12 | | | | 0.0208 | 9.917E-07 | 0.002421 |
| TGDRT7-9 | | | | 0.0176 | 4.193E-07 | 0.001771 |
| ULATERALS | | | | 0.0029 | 0.000012 | 0.000015 |
| W30X108 | 0.00378 | 0.07274 | 0.00528 | 0.0015 | 1.161E-08 | 0.00001 |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| Cable | 2.174E-08 | 0. | 4.822E-05 | 4.822E-05 | 3.349E-07 | 3.349E-07 |
| FLBMS | 8.788E-06 | 0. | 0.0048 | 0.004 | 0.002795 | 0.000119 |
| LLATERALS | 1.574E-06 | 0. | 4.847E-04 | 0.0014 | 0.000077 | 0.000029 |
| P4Beam | 0.10884 | 0. | 0.7875 | 0.7875 | 0.126598 | 0.185159 |
| P4Col | 0.037068 | 0. | 0.5558 | 0.5558 | 0.090779 | 0.090779 |
| Pier5Beam | 0.10884 | 0. | 0.7875 | 0.7875 | 0.126598 | 0.185159 |
| Pier5Col | 0.037068 | 0. | 0.5558 | 0.5558 | 0.090779 | 0.090779 |
| R1-2 R14-15 | 0.000317 | 0. | 0.0131 | 0.0096 | 0.003051 | 0.00213 |
| R1LATERAL | 6.007E-06 | 0. | 0.0021 | 6.828E-04 | 0.000142 | 0.00011 |
| R3-4 R12-13 | 0.000317 | 0. | 0.0131 | 0.0096 | 0.003051 | 0.00213 |
| R5-7 R9-11 | 0.000288 | 0. | 0.0119 | 0.0095 | 0.002951 | 0.001954 |
| R8 | 0.000279 | 0. | 0.0117 | 0.008 | 0.002619 | 0.001893 |
| STDSEC1 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC10 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC11 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC12 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC13 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC14 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC15 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC16 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC17 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC18 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC19 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC2 | 0. | 0. | 0. | 0. | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 ft4 | I23 ft4 | AS2 ft2 | AS3 ft2 | S33 ft3 | S22 ft3 |
|---|---|---|---|---|---|---|
| STDSEC3 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC4 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC5 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC6 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC7 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC8 | 0. | 0. | 0. | 0. | 0. | 0. |
| STDSEC9 | 0. | 0. | 0. | 0. | 0. | 0. |
| TGDRT1-T3 T13-T15 | 0.00031 | 0. | 0.0119 | 0.0097 | 0.005483 | 0.002062 |
| TGDRT4-6 T10-12 | 0.00031 | 0. | 0.0119 | 0.0097 | 0.005483 | 0.002062 |
| TGDRT7-9 | 0.000288 | 0. | 0.0113 | 0.0065 | 0.004139 | 0.001918 |
| ULATERALS | 6.007E-06 | 0. | 0.0021 | 6.828E-04 | 0.000142 | 0.00011 |
| W30X108 | 3.395E-07 | 0. | 7.840E-04 | 6.399E-04 | 0.0001 | 9.336E-06 |

Table: Frame Section Properties 01 - General, Part 4 of 8

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 ft3 | Z22 ft3 | R33 ft | R22 ft | EccV2 ft | ConcCol |
|---|---|---|---|---|---|---|
| Cable | 3.349E-07 | 3.349E-07 | 0.00694 | 0.00694 | 0. | No |
| FLBMS | 0.003197 | 0.000184 | 0.36841 | 0.03051 | | No |
| LLATERALS | 0.000086 | 0.000044 | 0.04399 | 0.02776 | | No |
| P4Beam | 0.189896 | 0.277739 | 0.23204 | 0.33938 | | Yes |
| P4Col | 0.136168 | 0.136168 | 0.23575 | 0.23575 | | Yes |
| Pier5Beam | 0.189896 | 0.277739 | 0.23204 | 0.33938 | | Yes |
| Pier5Col | 0.136168 | 0.136168 | 0.23575 | 0.23575 | | Yes |
| R1-2 R14-15 | 0.003682 | 0.002451 | 0.18623 | 0.12043 | | No |
| R1LATERAL | 0.000182 | 0.000127 | 0.07102 | 0.04551 | | No |
| R3-4 R12-13 | 0.003682 | 0.002451 | 0.18623 | 0.12043 | | No |
| R5-7 R9-11 | 0.003525 | 0.002255 | 0.18894 | 0.11842 | | No |
| R8 | 0.003163 | 0.002156 | 0.1837 | 0.12096 | | No |
| STDSEC1 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC10 | 0. | 0. | 0.18365 | 0. | 0. | No |
| STDSEC11 | 0. | 0. | 0.18895 | 0. | 0. | No |
| STDSEC12 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC13 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC14 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC15 | 0. | 0. | 0.07103 | 0. | 0. | No |
| STDSEC16 | 0. | 0. | 0.07103 | 0. | 0. | No |
| STDSEC17 | 0. | 0. | 0.0947 | 0. | 0. | No |
| STDSEC18 | 0. | 0. | 0.0947 | 0. | 0. | No |
| STDSEC19 | 0. | 0. | 0.06025 | 0. | 0. | No |
| STDSEC2 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC3 | 0. | 0. | 0.31716 | 0. | 0. | No |
| STDSEC4 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC5 | 0. | 0. | 0.33676 | 0. | 0. | No |
| STDSEC6 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC7 | 0. | 0. | 0.1863 | 0. | 0. | No |
| STDSEC8 | 0. | 0. | 0.1863 | 0. | 0. | No |

Table:  Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| STDSEC9 | 0. | 0. | 0.18895 | 0. | 0. | No |
| TGDRT1-T3 T13-T15 | 0.006438 | 0.002345 | 0.34141 | 0.12217 | | No |
| TGDRT4-6 T10-12 | 0.006438 | 0.002345 | 0.34141 | 0.12217 | | No |
| TGDRT7-9 | 0.005005 | 0.002119 | 0.31701 | 0.12793 | | No |
| ULATERALS | 0.000182 | 0.000127 | 0.07102 | 0.04551 | | No |
| W30X108 | 0.000116 | 0.000015 | 0.08246 | 0.0149 | | No |

Table:  Frame Section Properties 01 - General, Part 5 of 8

Table:  Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| Cable | No | Cyan | 96.385 | 35.95 | No | 1. |
| FLBMS | No | White | 1029.448 | 383.95 | No | 1. |
| LLATERALS | No | White | 285.956 | 106.65 | No | 1. |
| P4Beam | No | Gray8Dark | 1854.997 | 691.86 | No | 1. |
| P4Col | No | Green | 1757.783 | 655.6 | No | 1. |
| Pier5Beam | No | Magenta | 1854.997 | 691.86 | No | 1. |
| Pier5Col | No | Gray8Dark | 1754.872 | 654.52 | No | 1. |
| R1-2 R14-15 | No | White | 775.511 | 289.24 | No | 1. |
| R1LATERAL | No | White | 37.195 | 13.87 | No | 1. |
| R3-4 R12-13 | No | White | 519.074 | 193.6 | No | 1. |
| R5-7 R9-11 | No | White | 574.544 | 214.29 | No | 1. |
| R8 | No | White | 154.893 | 57.77 | No | 1. |
| STDSEC1 | No | Cyan | 27.606 | 10.3 | No | 1. |
| STDSEC10 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC11 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC12 | No | Gray8Dark | 0. | 0. | No | 1. |
| STDSEC13 | No | Blue | 0. | 0. | No | 1. |
| STDSEC14 | No | Green | 0. | 0. | No | 1. |
| STDSEC15 | No | Cyan | 0. | 0. | No | 1. |
| STDSEC16 | No | Red | 0. | 0. | No | 1. |
| STDSEC17 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC18 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC19 | No | Gray8Dark | 0. | 0. | No | 1. |
| STDSEC2 | No | Red | 0. | 0. | No | 1. |
| STDSEC3 | No | Magenta | 0. | 0. | No | 1. |
| STDSEC4 | No | Yellow | 0. | 0. | No | 1. |
| STDSEC5 | No | Gray8Dark | 20.404 | 7.61 | No | 1. |
| STDSEC6 | No | Blue | 7.905 | 2.95 | No | 1. |
| STDSEC7 | No | Green | 0. | 0. | No | 1. |
| STDSEC8 | No | Cyan | 0. | 0. | No | 1. |
| STDSEC9 | No | Red | 0. | 0. | No | 1. |
| TGDRT1-T3 T13-T15 | No | White | 657.549 | 245.25 | No | 1. |
| TGDRT4-6 T10-12 | No | White | 818.63 | 305.33 | No | 1. |
| TGDRT7-9 | No | White | 240.673 | 89.76 | No | 1. |
| ULATERALS | No | White | 594.731 | 221.82 | No | 1. |

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt Kip | TotalMass Kip-s2/ft | FromFile | AMod |
|---|---|---|---|---|---|---|
| W30X108 | No | Green | 590.479 | 220.23 | Yes | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBMS | 1. | 1. | 1. | 1. | 1. | 1. |
| LLATERALS | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Beam | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Col | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Beam | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Col | 1. | 1. | 1. | 1. | 1. | 1. |
| R1-2 R14-15 | 1. | 1. | 1. | 1. | 1. | 1. |
| R1LATERAL | 1. | 1. | 1. | 1. | 1. | 1. |
| R3-4 R12-13 | 1. | 1. | 1. | 1. | 1. | 1. |
| R5-7 R9-11 | 1. | 1. | 1. | 1. | 1. | 1. |
| R8 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC10 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC11 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC12 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC13 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC14 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC15 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC16 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC17 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC18 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC19 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC2 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC3 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC4 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC5 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC6 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC7 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC8 | 1. | 1. | 1. | 1. | 1. | 1. |
| STDSEC9 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT1-T3 T13-T15 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT4-6 T10-12 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGDRT7-9 | 1. | 1. | 1. | 1. | 1. | 1. |
| ULATERALS | 1. | 1. | 1. | 1. | 1. | 1. |
| W30X108 | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Frame Section Properties 01 - General, Part 7 of 8

Table: Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| Cable | 1. | | | |

Table: Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| FLBMS | 1. | | | |
| LLATERALS | 1. | | | |
| P4Beam | 1. | | | |
| P4Col | 1. | | | |
| Pier5Beam | 1. | | | |
| Pier5Col | 1. | | | |
| R1-2 R14-15 | 1. | | | |
| R1LATERAL | 1. | | | |
| R3-4 R12-13 | 1. | | | |
| R5-7 R9-11 | 1. | | | |
| R8 | 1. | | | |
| STDSEC1 | 1. | | | |
| STDSEC10 | 1. | | | |
| STDSEC11 | 1. | | | |
| STDSEC12 | 1. | | | |
| STDSEC13 | 1. | | | |
| STDSEC14 | 1. | | | |
| STDSEC15 | 1. | | | |
| STDSEC16 | 1. | | | |
| STDSEC17 | 1. | | | |
| STDSEC18 | 1. | | | |
| STDSEC19 | 1. | | | |
| STDSEC2 | 1. | | | |
| STDSEC3 | 1. | | | |
| STDSEC4 | 1. | | | |
| STDSEC5 | 1. | | | |
| STDSEC6 | 1. | | | |
| STDSEC7 | 1. | | | |
| STDSEC8 | 1. | | | |
| STDSEC9 | 1. | | | |
| TGDRT1-T3 T13-T15 | 1. | | | |
| TGDRT4-6 T10-12 | 1. | | | |
| TGDRT7-9 | 1. | | | |
| ULATERALS | 1. | | | |
| W30X108 | 1. | W30X108 | c:\program files\computers and structures\sap2000 18\sections.pro | |

Table: Frame Section Properties 01 - General, Part 8 of 8

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| Cable | Added 5/30/2016 10:27:21 AM |
| FLBMS | Added 1/6/2014 5:03:09 PM |
| LLATERALS | Added 1/6/2014 4:44:00 PM |
| P4Beam | Added 3/5/2016 8:05:10 PM |
| P4Col | Added 3/5/2016 8:10:25 PM |
| Pier5Beam | Added 3/5/2016 8:23:10 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| Pier5Col | Added 3/5/2016 8:23:33 PM |
| R1-2 R14-15 | Added 1/5/2014 9:01:13 PM |
| R1LATERAL | Added 1/13/2014 11:02:26 PM |
| R3-4 R12-13 | Added 1/5/2014 9:09:56 PM |
| R5-7 R9-11 | Added 1/5/2014 9:13:37 PM |
| R8 | Added 1/5/2014 9:18:02 PM |
| STDSEC1 | Added 12/30/2013 8:15:26 PM |
| STDSEC10 | Added 12/30/2013 8:15:26 PM |
| STDSEC11 | Added 12/30/2013 8:15:26 PM |
| STDSEC12 | Added 12/30/2013 8:15:26 PM |
| STDSEC13 | Added 12/30/2013 8:15:26 PM |
| STDSEC14 | Added 12/30/2013 8:15:26 PM |
| STDSEC15 | Added 12/30/2013 8:15:26 PM |
| STDSEC16 | Added 12/30/2013 8:15:26 PM |
| STDSEC17 | Added 12/30/2013 8:15:26 PM |
| STDSEC18 | Added 12/30/2013 8:15:26 PM |
| STDSEC19 | Added 12/30/2013 8:15:26 PM |
| STDSEC2 | Added 12/30/2013 8:15:26 PM |
| STDSEC3 | Added 12/30/2013 8:15:26 PM |
| STDSEC4 | Added 12/30/2013 8:15:26 PM |
| STDSEC5 | Added 12/30/2013 8:15:26 PM |
| STDSEC6 | Added 12/30/2013 8:15:26 PM |
| STDSEC7 | Added 12/30/2013 8:15:26 PM |
| STDSEC8 | Added 12/30/2013 8:15:26 PM |
| STDSEC9 | Added 12/30/2013 8:15:26 PM |
| TGDRT1-T3 T13-T15 | Added 1/5/2014 1:51:50 PM |
| TGDRT4-6 T10-12 | Added 1/5/2014 8:34:10 PM |
| TGDRT7-9 | Added 1/5/2014 8:43:17 PM |
| ULATERALS | Added 1/12/2014 9:20:26 PM |
| W30X108 | Imported 3/10/2016 2:49:32 PM from SECTIONS.PRO |

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table: Frame Section Properties 02 - Concrete Column, Part 1 of 2

| SectionName | RebarMatL | RebarMatC | ReinfConfig | LatReinf | Cover ft | NumBars3Dir | NumBars2Dir |
|---|---|---|---|---|---|---|---|
| P4Beam | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |
| P4Col | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |
| Pier5Beam | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |
| Pier5Col | A615Gr60 | A615Gr60 | Rectangular | Ties | 0.01042 | 3 | 3 |

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table:  Frame Section Properties 02 - Concrete Column, Part 2 of 2

| SectionName | BarSizeL | BarSizeC | SpacingC | NumCBars2 | NumCBars3 | ReinfType |
|---|---|---|---|---|---|---|
| | | | ft | | | |
| P4Beam | #9 | #4 | 0.04167 | 3 | 3 | Design |
| P4Col | #9 | #4 | 0.04167 | 3 | 3 | Design |
| Pier5Beam | #9 | #4 | 0.04167 | 3 | 3 | Design |
| Pier5Col | #9 | #4 | 0.04167 | 3 | 3 | Design |

Table:  Link Property Definitions 01 - General, Part 1 of 3

Table:  Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| Pier4F | Linear | 0. | 0. | 0. | 0. | 0. |
| Pier5E | Linear | 0. | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 2 of 3

Table:  Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| Pier4F | 0.08333 | 0.0069 | 0. | 0. | 0. | 0. |
| Pier5E | 0.08333 | 0.0069 | 0. | 0. | 0. | 0. |

Table:  Link Property Definitions 01 - General, Part 3 of 3

Table:  Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| Pier4F | Cyan | 30d405fd-730f-41e3-bbea-244cda3e9650 | Added 3/5/2016 8:18:58 PM |
| Pier5E | Cyan | a2bde322-04e3-446c-ba4c-3fb7596045e1 | Added 3/5/2016 8:18:58 PM |

Table:  Link Property Definitions 02 - Linear

Table:  Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE | RotKE | TransCE | RotCE | DJ |
|---|---|---|---|---|---|---|---|
| | | | Kip/ft | Kip-ft/rad | Kip-s/ft | Kip-ft-s/rad | ft |
| Pier4F | U1 | No | 1200000. | | 0. | | |
| Pier4F | U2 | No | 1200000. | | 0. | | 0. |
| Pier4F | U3 | No | 1200000. | | 0. | | 0. |
| Pier4F | R1 | No | | 0. | | 0. | |
| Pier4F | R2 | No | | 0. | | 0. | |
| Pier4F | R3 | No | | 0. | | 0. | |
| Pier5E | U1 | No | 1200000. | | 0. | | |
| Pier5E | U2 | No | 1200. | | 0. | | 0. |
| Pier5E | U3 | No | 1200000. | | 0. | | 0. |
| Pier5E | R1 | No | | 0. | | 0. | |
| Pier5E | R2 | No | | 0. | | 0. | |

Table: Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE Kip/ft | RotKE Kip-ft/rad | TransCE Kip-s/ft | RotCE Kip-ft-s/rad | DJ ft |
|---|---|---|---|---|---|---|---|
| Pier5E | R3 | No | | 0. | | 0. | |

Table: Area Section Properties, Part 1 of 4

Table: Area Section Properties, Part 1 of 4

| Section | Material | MatAngle Degrees | AreaType | Type | DrillDOF | Thickness ft | BendThick ft |
|---|---|---|---|---|---|---|---|
| CONCDECK | 4000Psi | 0. | Shell | Shell-Thin | Yes | 0.06015 | 0.06015 |
| P4Shaft | 4000Psi | 0. | Shell | Shell-Thick | Yes | 0.94583 | 0.94583 |
| Pier5Shaft | 4000Psi | 0. | Shell | Shell-Thick | Yes | 1.01 | 1.01 |

Table: Area Section Properties, Part 2 of 4

Table: Area Section Properties, Part 2 of 4

| Section | Arc Degrees | InComp | CoordSys | Color | TotalWt Kip | TotalMass Kip-s2/ft |
|---|---|---|---|---|---|---|
| CONCDECK | | | | Red | 6047.367 | 1961.3 |
| P4Shaft | | | | Green | 2726.724 | 1016.99 |
| Pier5Shaft | | | | Green | 7775.441 | 2900.02 |

Table: Area Section Properties, Part 3 of 4

Table: Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| CONCDECK | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| P4Shaft | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| Pier5Shaft | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Area Section Properties, Part 4 of 4

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| CONCDECK | 1. | 1. | 1.15 | 758d35c5-1090-4412-961e-a55c3a7a8dcf | Added 3/13/2016 4:57:39 PM |
| P4Shaft | 1. | 1. | 1. | e23ce15c-c909-437f-a64a-f4b7fa56ca94 | Added 3/5/2016 8:14:07 PM |
| Pier5Shaft | 1. | 1. | 1. | 53f15048-2c5b-4fcb-a24a-21a06b537a20 | Added 3/5/2016 8:30:26 PM |

Table: Section Designer Properties 01 - General, Part 1 of 5

Table: Section Designer Properties 01 - General, Part 1 of 5

| SectionName | DesignType | DsgnOrChck | BaseMat | IncludeVStr | nTotalShp |
|---|---|---|---|---|---|
| R1-2 R14-15 | No Check/Design | Check | A572Gr50 | No | 4 |

Table: Section Designer Properties 01 - General, Part 1 of 5

| SectionName | DesignType | DsgnOrChck | BaseMat | IncludeVStr | nTotalShp |
|---|---|---|---|---|---|
| R1LATERAL | No Check/Design | Check | A572Gr50 | No | 4 |
| R3-4 R12-13 | No Check/Design | Check | A572Gr50 | No | 4 |
| R5-7 R9-11 | No Check/Design | Check | A572Gr50 | No | 4 |
| R8 | No Check/Design | Check | A572Gr50 | No | 4 |
| TGDRT1-T3 T13-T15 | No Check/Design | Check | A572Gr50 | No | 4 |
| TGDRT4-6 T10-12 | No Check/Design | Check | A572Gr50 | No | 4 |
| TGDRT7-9 | No Check/Design | Check | A572Gr50 | No | 4 |
| ULATERALS | No Check/Design | Check | A572Gr50 | No | 4 |

Table: Section Designer Properties 01 - General, Part 2 of 5

Table: Section Designer Properties 01 - General, Part 2 of 5

| SectionName | nIWideFlng | nChannel | nTee | nAngle | nDblAngle | nBoxTube |
|---|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 0 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 0 | 0 | 0 | 0 |
| R3-4 R12-13 | 0 | 0 | 0 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 0 | 0 | 0 | 0 |
| R8 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT1-T3 T13-T15 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 0 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 0 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 3 of 5

Table: Section Designer Properties 01 - General, Part 3 of 5

| SectionName | nPipe | nPlate | nSolidRect | nSolidCirc | nSolidSeg | nSolidSect |
|---|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 4 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 4 | 0 | 0 | 0 |
| R3-4 R12-13 | 0 | 0 | 4 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 4 | 0 | 0 | 0 |
| R8 | 0 | 0 | 4 | 0 | 0 | 0 |
| TGDRT1-T3 T13-T15 | 0 | 0 | 4 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 4 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 4 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 4 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 4 of 5

Table: Section Designer Properties 01 - General, Part 4 of 5

| SectionName | nPolygon | nReinfSing | nReinfLine | nReinfRect | nReinfCirc | nRefLine |
|---|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 0 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 0 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 4 of 5

| SectionName | nPolygon | nReinfSing | nReinfLine | nReinfRect | nReinfCirc | nRefLine |
|---|---|---|---|---|---|---|
| R3-4 R12-13 | 0 | 0 | 0 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 0 | 0 | 0 | 0 |
| R8 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT1-T3 T13-T15 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 0 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 0 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 0 | 0 | 0 | 0 |

Table: Section Designer Properties 01 - General, Part 5 of 5

Table: Section Designer Properties 01 - General, Part 5 of 5

| SectionName | nRefCirc | nCaltransSq | nCaltransCr | nCaltransHx | nCaltransOc |
|---|---|---|---|---|---|
| R1-2 R14-15 | 0 | 0 | 0 | 0 | 0 |
| R1LATERAL | 0 | 0 | 0 | 0 | 0 |
| R3-4 R12-13 | 0 | 0 | 0 | 0 | 0 |
| R5-7 R9-11 | 0 | 0 | 0 | 0 | 0 |
| R8 | 0 | 0 | 0 | 0 | 0 |
| TGDRT1-T3 T13-T15 | 0 | 0 | 0 | 0 | 0 |
| TGDRT4-6 T10-12 | 0 | 0 | 0 | 0 | 0 |
| TGDRT7-9 | 0 | 0 | 0 | 0 | 0 |
| ULATERALS | 0 | 0 | 0 | 0 | 0 |

Section 2 Page Avenue Bridge Load Cases

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |
| LIVELOAD | LinMoving | DEAD | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
| --- | --- | --- |
| DEAD | | |
| MODAL | | |
| LIVELOAD | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
| --- | --- | --- | --- |
| DEAD | Load pattern | DEAD | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
| --- | --- | --- | --- |
| DEAD | Full Load | U1 | 59 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
| --- | --- | --- | --- | --- | --- |
| DEAD | Unload Entire | None | Final State | 200 | 50 |

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
| --- | --- | --- | --- | --- | --- | --- |
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
| --- | --- | --- | --- | --- | --- |
| DEAD | 0.1 | 1.618 | | | |

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
| --- | --- | --- | --- | --- | --- | --- |
| DEAD | Yes | Yes | Yes | Yes | Yes | |

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |

Table: Case - Moving Load 1 - Lane Assignments

Table: Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HL93_ALL | 1. | 1 | 7 | 7 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CTRLANE2 |
| LIVELOAD | 1 | LTLANE21 |
| LIVELOAD | 1 | LTLANE22 |
| LIVELOAD | 1 | LTLANE23 |
| LIVELOAD | 1 | RTLANE21 |
| LIVELOAD | 1 | RTLANE22 |
| LIVELOAD | 1 | RTLANE23 |

Table: Case - Moving Load 3 - MultiLane Factors

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1.2 |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.85 |
| LIVELOAD | 4 | 0.65 |
| LIVELOAD | 5 | 0.65 |
| LIVELOAD | 6 | 0.65 |
| LIVELOAD | 7 | 0.65 |
| LIVELOAD | 8 | 0.65 |
| LIVELOAD | 9 | 0.65 |
| LIVELOAD | 10 | 0.65 |
| LIVELOAD | 11 | 0.65 |
| LIVELOAD | 12 | 0.65 |
| LIVELOAD | 13 | 0.65 |
| LIVELOAD | 14 | 0.75 |
| LIVELOAD | 15 | 0.75 |
| LIVELOAD | 16 | 0.75 |
| LIVELOAD | 17 | 0.75 |
| LIVELOAD | 18 | 0.75 |
| LIVELOAD | 19 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 20 | 0.75 |
| LIVELOAD | 21 | 0.75 |
| LIVELOAD | 22 | 0.75 |
| LIVELOAD | 23 | 0.75 |
| LIVELOAD | 24 | 0.75 |
| LIVELOAD | 25 | 0.75 |
| LIVELOAD | 26 | 0.75 |
| LIVELOAD | 27 | 0.75 |
| LIVELOAD | 28 | 0.75 |
| LIVELOAD | 29 | 0.75 |
| LIVELOAD | 30 | 0.75 |
| LIVELOAD | 31 | 0.75 |
| LIVELOAD | 32 | 0.75 |
| LIVELOAD | 33 | 0.75 |
| LIVELOAD | 34 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift | EigenCutoff | EigenTol |
|---|---|---|---|---|---|---|
| | | | | Cyc/sec | Cyc/sec | |
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 Page Avenue Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.8425 | 92.3113 |
| MODAL | Acceleration | UY | 99.9012 | 73.4875 |
| MODAL | Acceleration | UZ | 98.2203 | 44.9992 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| | | | Sec | | | | |
| MODAL | | | 0. | 0. | 7.161E-06 | 6.611E-13 | 0. |

Table: Modal Participating Mass Ratios, Part 2 of 3

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | | | 7.161E-06 | 6.611E-13 | 3.712E-05 | 2.092E-11 | 0.00024 |

Table: Modal Participating Mass Ratios, Part 3 of 3

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | | | 3.712E-05 | 2.092E-11 | 0.00024 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | RX |
|---|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft | Kip-ft |
| MODAL | | | 0. | 0. | -0.00017 | 6.981E-09 | 0.000335 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY | RZ | ModalMass | ModalStiff |
|---|---|---|---|---|---|---|
| | | | Kip-ft | Kip-ft | Kip-ft-s2 | Kip-ft |
| MODAL | | | 0.000143 | 2.634423 | 0. | 0. |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period | Frequency | CircFreq | Eigenvalue |
|---|---|---|---|---|---|---|
| | | | Sec | Cyc/sec | rad/sec | rad2/sec2 |
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

# APPENDIX D

# ANALYSIS OUTPUT FOR TENNESSEE RIVER BRIDGE

License #2010*1GRWHLW4599V5FQ

**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160603 Rev 022 HS20 C2F LBK FP Tennessee River 24 Bridge.xlsx.sdb**

**27 June 2016**

Section 1 US 24 Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 4000Psi | Concrete | Isotropic | No | Red | |
| A36 | Steel | Isotropic | No | Blue | |
| A416Gr270 | Tendon | Uniaxial | No | Cyan | |
| A514 | Steel | Isotropic | No | Cyan | |
| A588 | Steel | Isotropic | No | Cyan | |
| A615Gr60 | Rebar | Uniaxial | No | Green | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586G | Other | Isotropic | No | Gray8Dark | |
| Substr | Concrete | Isotropic | No | Red | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 4000Psi | Customary f'c 4000 psi 9/27/2014 9:39:17 PM |
| A36 | United States ASTM A36 Grade 36 added 9/28/2014 6:52:31 PM |
| A416Gr270 | ASTM A416 Grade 270 2/7/2016 6:46:12 PM |
| A514 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| A588 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| A615Gr60 | ASTM A615 Grade 60 2/7/2016 6:46:12 PM |
| A992Fy50 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| ASTM A586G | MAT added 2/7/2016 10:55:03 PM |
| Substr | Customary f'c 4000 psi 9/27/2014 9:39:17 PM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight Kip/ft3 | UnitMass Kip-s2/ft4 | E1 Kip/ft2 | G12 Kip/ft2 | U12 | A1 1/F |
|---|---|---|---|---|---|---|
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 155740. | 64891.67 | 0.2 | 5.5000E-06 |
| A36 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A514 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A588 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| ASTM A586G | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| Substr | 1.5000E-01 | 4.6621E-03 | 155740. | 64891.67 | 0.2 | 5.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy | Fu | EffFy | EffFu | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| | Kip/ft2 | Kip/ft2 | Kip/ft2 | Kip/ft2 | | | |
| A36 | 5184. | 8352. | 7776. | 9187.2 | Simple | Kinematic | 0.02 |
| A514 | 14400. | 17280. | 14400. | 17280. | Simple | Kinematic | 0.015 |
| A588 | 7200. | 10080. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A36 | 0.14 | 0.2 | -0.1 |
| A514 | 0.11 | 0.17 | -0.1 |
| A588 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| | Kip/ft2 | | | | | | |
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| Substr | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle | DAngle |
|---|---|---|
| | Degrees | Degrees |
| 4000Psi | 0. | 0. |
| Substr | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 8

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| ARL0R1 | A992Fy50 | SD Section | | | |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3<br>ft | t2<br>ft | tf<br>ft |
|---|---|---|---|---|---|
| ARR1R3 | A992Fy50 | SD Section | | | |
| ARR3R4 | A992Fy50 | SD Section | | | |
| ARR4R7 | A992Fy50 | SD Section | | | |
| Cable | ASTM A586G | General | 1. | 1. | |
| DIAR1 | A992Fy50 | I/Wide Flange | 3. | 1.25 | 0.0729 |
| DIAR2R7 | A992Fy50 | I/Wide Flange | 2.9729 | 1.25 | 0.0625 |
| FLBM37 | A36 | I/Wide Flange | 6.0625 | 1.3333 | 0.1146 |
| FLBM5 | A36 | I/Wide Flange | 6.0938 | 1.3333 | 0.1302 |
| FLBMT0 | A36 | I/Wide Flange | 5.9792 | 1.3333 | 0.0729 |
| FLBMT1246 | A36 | I/Wide Flange | 6.1458 | 1.3333 | 0.1563 |
| FSEC1 | A992Fy50 | I/Wide Flange | 1. | 0.41667 | 0.03167 |
| HP14X102 | A36 | I/Wide Flange | 1.16667 | 1.23333 | 0.05875 |
| HP14X73 | A36 | I/Wide Flange | 1.13333 | 1.21667 | 0.04208 |
| HP14X89 | A36 | I/Wide Flange | 1.15 | 1.225 | 0.05125 |
| Portal Brace | A992Fy50 | I/Wide Flange | 2.2917 | 1.25 | 0.0625 |
| STRUTR2R7 | A992Fy50 | I/Wide Flange | 2.9729 | 1.25 | 0.0625 |
| TGL0L2 | A992Fy50 | SD Section | | | |
| TGL2L6 | A992Fy50 | SD Section | | | |
| TGL6L8 | A992Fy50 | SD Section | | | |
| W30X116 | A36 | I/Wide Flange | 2.5 | 0.875 | 0.0708 |
| W30X99 | A36 | I/Wide Flange | 2.475 | 0.875 | 0.0558 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw<br>ft | t2b<br>ft | tfb<br>ft | Area<br>ft2 | TorsConst<br>ft4 | I33<br>ft4 |
|---|---|---|---|---|---|---|
| ARL0R1 | | | | 1.3718 | 1.889054 | 1.96309 |
| ARR1R3 | | | | 1.3001 | 1.837566 | 1.893222 |
| ARR3R4 | | | | 1.229 | 1.781335 | 1.824012 |
| ARR4R7 | | | | 1.1579 | 1.720006 | 1.754793 |
| Cable | | | | 0.0442 | 0.000311 | 0.000156 |
| DIAR1 | 0.0729 | 1.25 | 0.0729 | 0.3903 | 0.000674 | 0.53171 |
| DIAR2R7 | 0.0625 | 1.25 | 0.0625 | 0.3342 | 0.000426 | 0.451229 |
| FLBM37 | 0.0365 | 1.3333 | 0.1146 | 0.5185 | 0.00136 | 3.306855 |
| FLBM5 | 0.0365 | 1.3333 | 0.1302 | 0.5601 | 0.001935 | 3.691192 |
| FLBMT0 | 0.0365 | 1.3333 | 0.0729 | 0.4073 | 0.000427 | 2.299202 |
| FLBMT1246 | 0.0365 | 1.3333 | 0.1563 | 0.6297 | 0.003238 | 4.342553 |
| FSEC1 | 0.02083 | 0.41667 | 0.03167 | 0.0459 | 0.000011 | 0.007615 |
| HP14X102 | 0.05875 | 1.23333 | 0.05875 | 0.2083 | 0.00026 | 0.050637 |
| HP14X73 | 0.04208 | 1.21667 | 0.04208 | 0.1486 | 0.000097 | 0.035156 |
| HP14X89 | 0.05125 | 1.225 | 0.05125 | 0.1813 | 0.000173 | 0.043596 |
| Portal Brace | 0.0625 | 1.25 | 0.0625 | 0.2917 | 0.00037 | 0.247143 |
| STRUTR2R7 | 0.0625 | 1.25 | 0.0625 | 0.3342 | 0.000426 | 0.451229 |
| TGL0L2 | | | | 1.5212 | 2.985977 | 21.111538 |
| TGL2L6 | | | | 1.5853 | 3.009519 | 22.486462 |
| TGL6L8 | | | | 1.3929 | 2.93165 | 18.380184 |
| W30X116 | 0.0471 | 0.875 | 0.0708 | 0.235 | 0.000278 | 0.234322 |
| W30X99 | 0.0433 | 0.875 | 0.0558 | 0.2 | 0.00016 | 0.190534 |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARL0R1 | 1.105147 | 0. | 1.0352 | 0.3048 | 1.090229 | 0.982353 |
| ARR1R3 | 1.048333 | 0. | 0.9697 | 0.3044 | 1.050469 | 0.931851 |
| ARR3R4 | 0.990627 | 0. | 0.9045 | 0.3039 | 1.011048 | 0.880557 |
| ARR4R7 | 0.931581 | 0. | 0.8388 | 0.3036 | 0.971582 | 0.828072 |
| Cable | 0.000156 | 0. | 0.0398 | 0.0398 | 1. | 1. |
| DIAR1 | 0.023823 | 0. | 0.2187 | 0.1519 | 0.354473 | 0.038116 |
| DIAR2R7 | 0.020403 | 0. | 0.1858 | 0.1302 | 0.303562 | 0.032645 |
| FLBM37 | 0.045294 | 0. | 0.2213 | 0.2547 | 1.090921 | 0.067943 |
| FLBM5 | 0.051457 | 0. | 0.2224 | 0.2893 | 1.211458 | 0.077187 |
| FLBMT0 | 0.028821 | 0. | 0.2182 | 0.162 | 0.769067 | 0.043233 |
| FLBMT1246 | 0.061767 | 0. | 0.2243 | 0.3473 | 1.413177 | 0.092653 |
| FSEC1 | 0.000382 | 0. | 0.0208 | 0.022 | 0.01523 | 0.001836 |
| HP14X102 | 0.018326 | 0. | 0.0685 | 0.1208 | 0.086806 | 0.029717 |
| HP14X73 | 0.012587 | 0. | 0.0477 | 0.0853 | 0.06204 | 0.020691 |
| HP14X89 | 0.015721 | 0. | 0.0589 | 0.1046 | 0.075819 | 0.025668 |
| Portal Brace | 0.020389 | 0. | 0.1432 | 0.1302 | 0.215686 | 0.032623 |
| STRUTR2R7 | 0.020403 | 0. | 0.1858 | 0.1302 | 0.303562 | 0.032645 |
| TGL0L2 | 1.392646 | 0. | 0.7611 | 0.5887 | 4.564657 | 0.903242 |
| TGL2L6 | 1.443454 | 0. | 0.7637 | 0.6407 | 4.851029 | 0.936199 |
| TGL6L8 | 1.291031 | 0. | 0.7551 | 0.4856 | 3.992047 | 0.837327 |
| W30X116 | 0.007926 | 0. | 0.1178 | 0.1033 | 0.187458 | 0.018116 |
| W30X99 | 0.006246 | 0. | 0.1072 | 0.0814 | 0.153967 | 0.014277 |

Table: Frame Section Properties 01 - General, Part 4 of 8

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARL0R1 | 1.442008 | 1.18804 | 1.19625 | 0.89756 | | No |
| ARR1R3 | 1.380691 | 1.124189 | 1.20675 | 0.89798 | | No |
| ARR3R4 | 1.319954 | 1.06015 | 1.21826 | 0.8978 | | No |
| ARR4R7 | 1.259211 | 0.995372 | 1.23104 | 0.89695 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| DIAR1 | 0.415201 | 0.060745 | 1.16715 | 0.24705 | | No |
| DIAR2R7 | 0.354102 | 0.051609 | 1.16189 | 0.24707 | | No |
| FLBM37 | 1.219316 | 0.103804 | 2.5254 | 0.29556 | | No |
| FLBM5 | 1.345766 | 0.11767 | 2.56712 | 0.3031 | | No |
| FLBMT0 | 0.884589 | 0.06674 | 2.37588 | 0.26601 | | No |
| FLBMT1246 | 1.55867 | 0.140869 | 2.62606 | 0.31319 | | No |
| FSEC1 | 0.017346 | 0.00285 | 0.4073 | 0.09128 | | No |
| HP14X102 | 0.097801 | 0.045602 | 0.49301 | 0.29659 | | No |
| HP14X73 | 0.068287 | 0.031597 | 0.48638 | 0.29103 | | No |
| HP14X89 | 0.084491 | 0.039178 | 0.49044 | 0.29451 | | No |
| Portal Brace | 0.247509 | 0.050944 | 0.92051 | 0.2644 | | No |
| STRUTR2R7 | 0.354102 | 0.051609 | 1.16189 | 0.24707 | | No |
| TGL0L2 | 5.205132 | 1.360108 | 3.7254 | 0.95683 | | No |

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| TGL2L6 | 5.502079 | 1.409543 | 3.76623 | 0.95422 | | No |
| TGL6L8 | 4.613239 | 1.261238 | 3.63259 | 0.96274 | | No |
| W30X116 | 0.215982 | 0.028411 | 0.9986 | 0.18365 | | No |
| W30X99 | 0.178582 | 0.022469 | 0.97609 | 0.17673 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 8

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| ARL0R1 | No | Green | 144.721 | 4.5 | No | 1. |
| ARR1R3 | No | Red | 258.583 | 8.04 | No | 1. |
| ARR3R4 | No | Yellow | 116.26 | 3.61 | No | 1. |
| ARR4R7 | No | Blue | 315.891 | 9.82 | No | 1. |
| Cable | No | Gray8Dark | 35.721 | 1.11 | No | 1. |
| DIAR1 | No | Green | 37.347 | 1.16 | No | 1. |
| DIAR2R7 | No | Yellow | 149.857 | 4.66 | No | 1. |
| FLBM37 | No | Cyan | 40.321 | 1.25 | No | 1. |
| FLBM5 | No | Magenta | 29.037 | 0.9 | No | 1. |
| FLBMT0 | No | White | 21.116 | 0.66 | No | 1. |
| FLBMT1246 | No | Blue | 130.58 | 4.06 | No | 1. |
| FSEC1 | No | Cyan | 0. | 0. | No | 1. |
| HP14X102 | No | Gray8Dark | 18.196 | 0.57 | Yes | 1. |
| HP14X73 | No | Red | 64.898 | 2.02 | Yes | 1. |
| HP14X89 | No | Yellow | 15.83 | 0.49 | Yes | 1. |
| Portal Brace | No | Magenta | 11.864 | 0.37 | No | 1. |
| STRUTR2R7 | No | Gray8Dark | 82.872 | 2.58 | No | 1. |
| TGL0L2 | No | Blue | 261.723 | 8.13 | No | 1. |
| TGL2L6 | No | Magenta | 545.515 | 16.96 | No | 1. |
| TGL6L8 | No | Gray8Dark | 119.827 | 3.72 | No | 1. |
| W30X116 | No | Yellow | 338.379 | 10.52 | No | 1. |
| W30X99 | No | Red | 0. | 0. | No | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARL0R1 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR1R3 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR3R4 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR4R7 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| DIAR1 | 1. | 1. | 1. | 1. | 1. | 1. |
| DIAR2R7 | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBM37 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBM5 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBMT0 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBMT1246 | 1. | 1. | 1. | 1. | 1. | 1.15 |

Table:  Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| FSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| HP14X102 | 1. | 1. | 1. | 1. | 1. | 1. |
| HP14X73 | 1. | 1. | 1. | 1. | 1. | 1. |
| HP14X89 | 1. | 1. | 1. | 1. | 1. | 1. |
| Portal Brace | 1. | 1. | 1. | 1. | 1. | 1. |
| STRUTR2R7 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL0L2 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| TGL2L6 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| TGL6L8 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| W30X116 | 1. | 1. | 1. | 1. | 1. | 1.1 |
| W30X99 | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Frame Section Properties 01 - General, Part 7 of 8

Table:  Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| ARL0R1 | 1.2 | | | |
| ARR1R3 | 1.2 | | | |
| ARR3R4 | 1.2 | | | |
| ARR4R7 | 1.2 | | | |
| Cable | 1. | | | |
| DIAR1 | 1. | | | |
| DIAR2R7 | 1. | | | |
| FLBM37 | 1.15 | | | |
| FLBM5 | 1.15 | | | |
| FLBMT0 | 1.15 | | | |
| FLBMT1246 | 1.15 | | | |
| FSEC1 | 1. | | | |
| HP14X102 | 1. | HP14X102 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| HP14X73 | 1. | HP14X73 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| HP14X89 | 1. | HP14X89 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| Portal Brace | 1. | | | |
| STRUTR2R7 | 1. | | | |
| TGL0L2 | 1.15 | | | |
| TGL2L6 | 1.15 | | | |
| TGL6L8 | 1.15 | | | |
| W30X116 | 1.1 | | | |
| W30X99 | 1. | | | |

Table:  Frame Section Properties 01 - General, Part 8 of 8

Table:  Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARL0R1 | Added 2/7/2016 7:18:29 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARR1R3 | Added 2/7/2016 8:23:51 PM |
| ARR3R4 | Added 2/7/2016 8:29:59 PM |
| ARR4R7 | Added 2/7/2016 8:32:35 PM |
| Cable | Added 5/31/2016 9:59:30 PM |
| DIAR1 | Added 2/7/2016 10:35:01 PM |
| DIAR2R7 | Added 2/7/2016 10:38:41 PM |
| FLBM37 | Added 9/28/2014 7:12:14 PM |
| FLBM5 | Added 9/28/2014 7:13:11 PM |
| FLBMT0 | Added 9/28/2014 7:07:51 PM |
| FLBMT1246 | Added 9/28/2014 7:10:48 PM |
| FSEC1 | Added 9/27/2014 9:39:49 PM |
| HP14X102 | Imported 9/28/2014 8:17:56 PM from AISC13.pro |
| HP14X73 | Imported 9/28/2014 8:18:59 PM from AISC13.pro |
| HP14X89 | Imported 9/28/2014 8:19:10 PM from AISC13.pro |
| Portal Brace | Added 2/7/2016 10:01:07 PM |
| STRUTR2R7 | Added 2/7/2016 10:08:13 PM |
| TGL0L2 | Added 2/7/2016 6:44:03 PM |
| TGL2L6 | Added 2/7/2016 6:56:25 PM |
| TGL6L8 | Added 2/7/2016 7:04:47 PM |
| W30X116 | Added 2/7/2016 5:37:44 PM |
| W30X99 | Added 2/7/2016 5:34:08 PM |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass Kip-s2/ft | Weight Kip | RotInert1 Kip-ft-s2 | RotInert2 Kip-ft-s2 | RotInert3 Kip-ft-s2 |
|---|---|---|---|---|---|---|
| LINK1 | Linear | 0. | 0. | 0. | 0. | 0. |
| LINK2 | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength ft | DefArea ft2 | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| LINK1 | 1. | 1. | 0. | 0. | 0. | 0. |
| LINK2 | 1. | 1. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| LINK1 | Magenta | | Added 2/29/2016 3:34:56 PM |
| LINK2 | Magenta | | Added 2/29/2016 3:34:56 PM |

Table: Link Property Definitions 02 - Linear

Table: Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE | RotKE | TransCE | RotCE | DJ |
|---|---|---|---|---|---|---|---|
| | | | Kip/ft | Kip-ft/rad | Kip-s/ft | Kip-ft-s/rad | ft |
| LINK1 | U1 | No | 100000. | | 0. | | |
| LINK1 | U2 | No | 100000. | | 0. | | 0. |
| LINK1 | U3 | No | 100000. | | 0. | | 0. |
| LINK1 | R1 | No | | 0. | | 0. | |
| LINK1 | R2 | No | | 0. | | 0. | |
| LINK1 | R3 | No | | 0. | | 0. | |
| LINK2 | U1 | No | 100000. | | 0. | | |
| LINK2 | U2 | No | 100. | | 0. | | 0. |
| LINK2 | U3 | No | 100000. | | 0. | | 0. |
| LINK2 | R1 | No | | 0. | | 0. | |
| LINK2 | R2 | No | | 0. | | 0. | |
| LINK2 | R3 | No | | 0. | | 0. | |

Table: Area Section Properties, Part 1 of 4

Table: Area Section Properties, Part 1 of 4

| Section | Material | MatAngle | AreaType | Type | DrillDOF | Thickness | BendThick |
|---|---|---|---|---|---|---|---|
| | | Degrees | | | | ft | ft |
| ASEC1 | A36 | 0. | Shell | Shell-Thin | Yes | 1. | 1. |
| ConcDeck | 4000Psi | 0. | Shell | Shell-Thin | Yes | 0.6667 | 0.6667 |

Table: Area Section Properties, Part 2 of 4

Table: Area Section Properties, Part 2 of 4

| Section | Arc | InComp | CoordSys | Color | TotalWt | TotalMass |
|---|---|---|---|---|---|---|
| | Degrees | | | | Kip | Kip-s2/ft |
| ASEC1 | | | | Green | 5333.16 | 165.76 |
| ConcDeck | | | | 12615935 | 2388.592 | 74.24 |

Table: Area Section Properties, Part 3 of 4

Table: Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| ConcDeck | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Area Section Properties, Part 4 of 4

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 6f5825de-a2dc-451c-a3c5-5df2377eea92 | Added 2/15/2016 12:48:48 PM |

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| ConcDeck | 1. | 1.2 | 1.2 | 6aa652a7-753e-47a5-9f99-1d2dc88054b2 | Added 2/15/2016 12:49:15 PM |

Section 2 US 24 Bridge Load Cases

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| LIVELOAD | LinMoving | Zero | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING _DEAD | LinBuckling | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | No | Not Run |
| BUCKLING _DEAD | DEAD | Prog Det | Other | None | No | Not Run |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| LIVELOAD | | |
| PDELTA | | |
| BUCKLING _DEAD | | |
| MODAL | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |

Table:  Case - Static 2 - Nonlinear Load Application

Table:  Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 14 |
| PDELTA | Full Load | U1 | 14 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table:  Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |
| PDELTA | 10 | 0.01 | 1. | No |

Table: Case - Moving Load 1 - Lane Assignments

Table: Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 0 | 2 | 6 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CENLANES |
| LIVELOAD | 1 | CNTLANE2 |
| LIVELOAD | 1 | LFTLANE1 |
| LIVELOAD | 1 | LFTLANE2 |
| LIVELOAD | 1 | RGTLANE1 |
| LIVELOAD | 1 | RTLANE2 |

Table: Case - Moving Load 3 - MultiLane Factors

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1.2 |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.85 |
| LIVELOAD | 4 | 0.65 |
| LIVELOAD | 5 | 0.65 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |
| LIVELOAD | 10 | 0.75 |
| LIVELOAD | 11 | 0.75 |
| LIVELOAD | 12 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift | EigenCutoff | EigenTol |
|---|---|---|---|---|---|---|
| | | | | Cyc/sec | Cyc/sec | |
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 US 24 Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.7876 | 56.8782 |
| MODAL | Acceleration | UY | 99.7729 | 55.5977 |
| MODAL | Acceleration | UZ | 95.4678 | 17.9913 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period Sec | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 1.945338 | 0.28182 | 4.900E-18 | 6.877E-05 | 0.28182 |
| MODAL | Mode | 2. | 1.641859 | 2.771E-17 | 0.15365 | 2.345E-17 | 0.28182 |
| MODAL | Mode | 3. | 1.607784 | 0.09449 | 0. | 3.354E-05 | 0.37631 |
| MODAL | Mode | 4. | 1.148779 | 1.661E-17 | 0.00891 | 6.595E-19 | 0.37631 |
| MODAL | Mode | 5. | 1.00383 | 0.14589 | 1.060E-16 | 2.030E-05 | 0.5222 |
| MODAL | Mode | 6. | 0.936634 | 3.151E-17 | 0.00017 | 7.515E-18 | 0.5222 |
| MODAL | Mode | 7. | 0.870946 | 3.139E-05 | 6.446E-18 | 0.02624 | 0.52224 |
| MODAL | Mode | 8. | 0.652339 | 0.00154 | 6.671E-15 | 0.13933 | 0.52378 |
| MODAL | Mode | 9. | 0.556076 | 4.818E-17 | 0.00679 | 2.864E-17 | 0.52378 |
| MODAL | Mode | 10. | 0.54103 | 2.470E-17 | 1.442E-06 | 3.475E-17 | 0.52378 |
| MODAL | Mode | 11. | 0.456406 | 0.00064 | 9.192E-17 | 0.00017 | 0.52442 |
| MODAL | Mode | 12. | 0.425114 | 8.941E-16 | 9.399E-05 | 1.761E-16 | 0.52442 |
| MODAL | Mode | 13. | 0.413113 | 1.824E-15 | 6.507E-05 | 1.137E-16 | 0.52442 |
| MODAL | Mode | 14. | 0.352426 | 8.384E-15 | 0.07429 | 5.664E-15 | 0.52442 |
| MODAL | Mode | 15. | 0.351373 | 7.693E-15 | 2.964E-09 | 2.112E-15 | 0.52442 |
| MODAL | Mode | 16. | 0.310727 | 0.00148 | 2.062E-15 | 0.00489 | 0.52591 |
| MODAL | Mode | 17. | 0.302514 | 3.823E-15 | 0.00026 | 1.868E-15 | 0.52591 |
| MODAL | Mode | 18. | 0.277762 | 1.438E-14 | 0.00022 | 1.440E-14 | 0.52591 |
| MODAL | Mode | 19. | 0.256964 | 8.798E-14 | 0.21877 | 5.042E-14 | 0.52591 |
| MODAL | Mode | 20. | 0.245218 | 0.03091 | 7.719E-14 | 0.00438 | 0.55682 |
| MODAL | Mode | 21. | 0.245169 | 4.397E-14 | 0.06244 | 2.079E-13 | 0.55682 |
| MODAL | Mode | 22. | 0.233681 | 5.603E-16 | 0.00094 | 5.651E-14 | 0.55682 |
| MODAL | Mode | 23. | 0.225049 | 0.01104 | 2.529E-15 | 0.00083 | 0.56786 |
| MODAL | Mode | 24. | 0.218159 | 4.617E-13 | 2.363E-05 | 2.044E-15 | 0.56786 |
| MODAL | Mode | 25. | 0.200153 | 9.087E-16 | 0.01034 | 1.383E-14 | 0.56786 |
| MODAL | Mode | 26. | 0.194539 | 4.720E-14 | 0.00525 | 7.732E-15 | 0.56786 |
| MODAL | Mode | 27. | 0.191342 | 8.180E-15 | 0.01304 | 2.551E-14 | 0.56786 |
| MODAL | Mode | 28. | 0.18975 | 4.522E-14 | 0.00048 | 3.444E-14 | 0.56786 |
| MODAL | Mode | 29. | 0.18761 | 0.00092 | 7.011E-15 | 0.00396 | 0.56878 |
| MODAL | Mode | 30. | 0.178726 | 3.436E-15 | 0.00026 | 1.153E-13 | 0.56878 |

Table: Modal Participating Mass Ratios, Part 2 of 3

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 4.900E-18 | 6.877E-05 | 4.059E-18 | 0.00126 | 1.052E-17 |
| MODAL | Mode | 2. | 0.15365 | 6.877E-05 | 0.46157 | 2.207E-18 | 1.121E-05 |
| MODAL | Mode | 3. | 0.15365 | 0.0001 | 0. | 0.05213 | 8.473E-20 |
| MODAL | Mode | 4. | 0.16256 | 0.0001 | 0.0034 | 2.160E-20 | 6.599E-05 |
| MODAL | Mode | 5. | 0.16256 | 0.00012 | 1.157E-16 | 0.00206 | 2.440E-16 |
| MODAL | Mode | 6. | 0.16273 | 0.00012 | 0.00011 | 8.085E-18 | 0.01893 |
| MODAL | Mode | 7. | 0.16273 | 0.02636 | 3.191E-18 | 2.195E-07 | 1.468E-18 |
| MODAL | Mode | 8. | 0.16273 | 0.16568 | 3.231E-15 | 1.973E-06 | 7.878E-15 |
| MODAL | Mode | 9. | 0.16952 | 0.16568 | 0.0033 | 2.514E-17 | 8.167E-06 |
| MODAL | Mode | 10. | 0.16952 | 0.16568 | 2.873E-06 | 9.145E-18 | 0.04514 |
| MODAL | Mode | 11. | 0.16952 | 0.16586 | 7.827E-18 | 0.00743 | 6.501E-17 |
| MODAL | Mode | 12. | 0.16961 | 0.16586 | 0.00037 | 1.539E-15 | 0.01877 |
| MODAL | Mode | 13. | 0.16968 | 0.16586 | 0.01206 | 1.950E-15 | 0.00141 |
| MODAL | Mode | 14. | 0.24396 | 0.16586 | 0.05418 | 4.429E-17 | 4.497E-06 |
| MODAL | Mode | 15. | 0.24396 | 0.16586 | 2.054E-07 | 1.912E-14 | 0.00143 |
| MODAL | Mode | 16. | 0.24396 | 0.17075 | 1.261E-19 | 0.00015 | 3.403E-14 |
| MODAL | Mode | 17. | 0.24422 | 0.17075 | 0.00023 | 1.310E-14 | 0.00119 |
| MODAL | Mode | 18. | 0.24444 | 0.17075 | 0.00013 | 1.028E-14 | 0.24666 |
| MODAL | Mode | 19. | 0.46321 | 0.17075 | 0.11494 | 3.440E-16 | 0.00054 |
| MODAL | Mode | 20. | 0.46321 | 0.17513 | 1.182E-14 | 0.00025 | 4.579E-15 |
| MODAL | Mode | 21. | 0.52565 | 0.17513 | 0.04168 | 2.790E-15 | 0.00056 |
| MODAL | Mode | 22. | 0.52659 | 0.17513 | 0.0002 | 8.311E-15 | 0.13031 |
| MODAL | Mode | 23. | 0.52659 | 0.17595 | 3.493E-15 | 0.00676 | 6.356E-14 |
| MODAL | Mode | 24. | 0.52661 | 0.17595 | 2.978E-05 | 1.914E-13 | 0.0166 |
| MODAL | Mode | 25. | 0.53695 | 0.17595 | 0.00556 | 3.527E-18 | 0.00193 |
| MODAL | Mode | 26. | 0.5422 | 0.17595 | 0.00077 | 8.926E-16 | 0.00042 |
| MODAL | Mode | 27. | 0.55524 | 0.17595 | 0.00112 | 5.307E-17 | 0.00251 |
| MODAL | Mode | 28. | 0.55572 | 0.17595 | 5.045E-05 | 3.497E-15 | 3.841E-05 |
| MODAL | Mode | 29. | 0.55572 | 0.17991 | 4.749E-15 | 8.091E-06 | 4.515E-15 |
| MODAL | Mode | 30. | 0.55598 | 0.17991 | 4.094E-06 | 1.027E-13 | 8.706E-06 |

Table: Modal Participating Mass Ratios, Part 3 of 3

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | Mode | 1. | 4.059E-18 | 0.00126 | 1.052E-17 |
| MODAL | Mode | 2. | 0.46157 | 0.00126 | 1.121E-05 |
| MODAL | Mode | 3. | 0.46157 | 0.05339 | 1.121E-05 |
| MODAL | Mode | 4. | 0.46497 | 0.05339 | 7.721E-05 |
| MODAL | Mode | 5. | 0.46497 | 0.05545 | 7.721E-05 |
| MODAL | Mode | 6. | 0.46508 | 0.05545 | 0.019 |
| MODAL | Mode | 7. | 0.46508 | 0.05545 | 0.019 |
| MODAL | Mode | 8. | 0.46508 | 0.05545 | 0.019 |
| MODAL | Mode | 9. | 0.46837 | 0.05545 | 0.01901 |
| MODAL | Mode | 10. | 0.46838 | 0.05545 | 0.06415 |
| MODAL | Mode | 11. | 0.46838 | 0.06288 | 0.06415 |
| MODAL | Mode | 12. | 0.46875 | 0.06288 | 0.08292 |

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | Mode | 13. | 0.48081 | 0.06288 | 0.08434 |
| MODAL | Mode | 14. | 0.53499 | 0.06288 | 0.08434 |
| MODAL | Mode | 15. | 0.53499 | 0.06288 | 0.08577 |
| MODAL | Mode | 16. | 0.53499 | 0.06303 | 0.08577 |
| MODAL | Mode | 17. | 0.53522 | 0.06303 | 0.08696 |
| MODAL | Mode | 18. | 0.53535 | 0.06303 | 0.33362 |
| MODAL | Mode | 19. | 0.65029 | 0.06303 | 0.33416 |
| MODAL | Mode | 20. | 0.65029 | 0.06328 | 0.33416 |
| MODAL | Mode | 21. | 0.69197 | 0.06328 | 0.33473 |
| MODAL | Mode | 22. | 0.69217 | 0.06328 | 0.46504 |
| MODAL | Mode | 23. | 0.69217 | 0.07004 | 0.46504 |
| MODAL | Mode | 24. | 0.6922 | 0.07004 | 0.48164 |
| MODAL | Mode | 25. | 0.69776 | 0.07004 | 0.48357 |
| MODAL | Mode | 26. | 0.69853 | 0.07004 | 0.48399 |
| MODAL | Mode | 27. | 0.69965 | 0.07004 | 0.4865 |
| MODAL | Mode | 28. | 0.6997 | 0.07004 | 0.48654 |
| MODAL | Mode | 29. | 0.6997 | 0.07005 | 0.48654 |
| MODAL | Mode | 30. | 0.6997 | 0.07005 | 0.48655 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | RX |
|---|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft | Kip-ft |
| MODAL | Mode | 1. | 1.945338 | -15.498306 | -6.433E-08 | 0.242095 | 2.907E-06 |
| MODAL | Mode | 2. | 1.641859 | -1.532E-07 | 11.69422 | 1.414E-07 | -1002.09197 |
| MODAL | Mode | 3. | 1.607784 | 8.974157 | 1.844E-09 | -0.16908 | -1.771E-07 |
| MODAL | Mode | 4. | 1.148779 | 1.194E-07 | 2.798335 | -2.371E-08 | 82.038883 |
| MODAL | Mode | 5. | 1.00383 | -11.151026 | 3.016E-07 | 0.131531 | -0.000016 |
| MODAL | Mode | 6. | 0.936634 | 1.621E-07 | 0.359254 | -8.003E-08 | -13.912451 |
| MODAL | Mode | 7. | 0.870946 | 0.164114 | 6.708E-08 | 4.728703 | -2.158E-06 |
| MODAL | Mode | 8. | 0.652339 | 1.147153 | -2.344E-06 | 10.897205 | 0.00008 |
| MODAL | Mode | 9. | 0.556076 | 2.073E-07 | 1.724925 | 1.562E-07 | -41.26951 |
| MODAL | Mode | 10. | 0.54103 | 1.427E-07 | -0.029147 | 1.721E-07 | 2.095357 |
| MODAL | Mode | 11. | 0.456406 | 0.743851 | 2.095E-07 | -0.382597 | 2.918E-07 |
| MODAL | Mode | 12. | 0.425114 | 8.964E-07 | -0.207637 | -3.874E-07 | 58.296911 |
| MODAL | Mode | 13. | 0.413113 | -1.269E-06 | -1.926522 | 3.113E-07 | 264.095732 |
| MODAL | Mode | 14. | 0.352426 | 2.669E-06 | 7.65279 | -2.197E-06 | -319.195484 |
| MODAL | Mode | 15. | 0.351373 | -2.483E-06 | -0.008426 | 1.342E-06 | 1.081083 |
| MODAL | Mode | 16. | 0.310727 | 1.121891 | 1.300E-06 | 2.042244 | 2.102E-06 |
| MODAL | Mode | 17. | 0.302514 | 1.784E-06 | -0.503169 | -1.262E-06 | 24.243717 |
| MODAL | Mode | 18. | 0.277762 | -3.473E-06 | 0.437386 | 3.503E-06 | -16.692993 |
| MODAL | Mode | 19. | 0.256964 | 8.739E-06 | 13.934405 | -6.556E-06 | -509.622446 |
| MODAL | Mode | 20. | 0.245218 | 5.138776 | -8.321E-06 | -1.931528 | -0.000145 |
| MODAL | Mode | 21. | 0.245169 | -6.303E-06 | 6.985699 | 0.000013 | -277.332101 |
| MODAL | Mode | 22. | 0.233681 | -7.826E-07 | -0.928845 | 6.940E-06 | 22.56955 |
| MODAL | Mode | 23. | 0.225049 | 3.057414 | 2.271E-06 | -0.838758 | 0.000036 |
| MODAL | Mode | 24. | 0.218159 | -0.00002 | -0.012234 | -1.320E-06 | 17.462826 |

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | RX |
|---|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft | Kip-ft |
| MODAL | Mode | 25. | 0.200153 | 8.825E-07 | 3.18138 | -3.434E-06 | -121.471866 |
| MODAL | Mode | 26. | 0.194539 | 6.390E-06 | -2.026315 | -2.567E-06 | 34.650261 |
| MODAL | Mode | 27. | 0.191342 | 2.683E-06 | 3.105497 | -4.663E-06 | -34.575269 |
| MODAL | Mode | 28. | 0.18975 | 6.273E-06 | -0.56999 | -5.418E-06 | 5.958077 |
| MODAL | Mode | 29. | 0.18761 | 0.896553 | -2.714E-06 | -1.837404 | 0.000117 |
| MODAL | Mode | 30. | 0.178726 | -1.444E-06 | -0.412503 | -9.915E-06 | -0.464659 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY | RZ | ModalMass | ModalStiff |
|---|---|---|---|---|---|---|
| | | | Kip-ft | Kip-ft | Kip-ft-s2 | Kip-ft |
| MODAL | Mode | 1. | -263.331681 | 0.000023 | 1. | 10.43205 |
| MODAL | Mode | 2. | 0.000011 | 29.637681 | 1. | 14.64496 |
| MODAL | Mode | 3. | 1694.968966 | -2.168E-06 | 1. | 15.2723 |
| MODAL | Mode | 4. | 1.115E-06 | 66.130451 | 1. | 29.91484 |
| MODAL | Mode | 5. | -337.030932 | -0.000112 | 1. | 39.17776 |
| MODAL | Mode | 6. | -0.000021 | -1141.54683 | 1. | 45.00073 |
| MODAL | Mode | 7. | 3.511425 | -7.929E-06 | 1. | 52.04485 |
| MODAL | Mode | 8. | -10.432281 | 0.000626 | 1. | 92.77116 |
| MODAL | Mode | 9. | 0.000038 | -18.670764 | 1. | 127.67054 |
| MODAL | Mode | 10. | -0.000023 | -1571.06947 | 1. | 134.8703 |
| MODAL | Mode | 11. | 640.067378 | -0.000056 | 1. | 189.5207 |
| MODAL | Mode | 12. | 0.000293 | 839.082673 | 1. | 218.4484 |
| MODAL | Mode | 13. | -0.000329 | -234.133665 | 1. | 231.32477 |
| MODAL | Mode | 14. | -0.00005 | 16.514474 | 1. | 317.85194 |
| MODAL | Mode | 15. | 0.001031 | -277.142197 | 1. | 319.75885 |
| MODAL | Mode | 16. | -90.108195 | -0.001251 | 1. | 408.88602 |
| MODAL | Mode | 17. | 0.000848 | -382.965623 | 1. | 431.38916 |
| MODAL | Mode | 18. | -0.000751 | -3634.943 | 1. | 511.69671 |
| MODAL | Mode | 19. | 0.000143 | -185.833288 | 1. | 597.87966 |
| MODAL | Mode | 20. | -118.162807 | -0.000673 | 1. | 656.53298 |
| MODAL | Mode | 21. | -0.000403 | 184.191866 | 1. | 656.79096 |
| MODAL | Mode | 22. | -0.000682 | -2673.01945 | 1. | 722.95761 |
| MODAL | Mode | 23. | -610.867416 | 0.001932 | 1. | 779.48072 |
| MODAL | Mode | 24. | -0.003267 | 917.691607 | 1. | 829.49691 |
| MODAL | Mode | 25. | -0.000014 | 302.096268 | 1. | 985.45459 |
| MODAL | Mode | 26. | 0.000225 | 128.276496 | 1. | 1043.14956 |
| MODAL | Mode | 27. | 0.000057 | -346.270742 | 1. | 1078.29891 |
| MODAL | Mode | 28. | 0.000443 | 42.646948 | 1. | 1096.46685 |
| MODAL | Mode | 29. | -20.526546 | -0.000394 | 1. | 1121.63023 |
| MODAL | Mode | 30. | 0.002396 | -17.438822 | 1. | 1235.89659 |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period Sec | Frequency Cyc/sec | CircFreq rad/sec | Eigenvalue rad2/sec2 |
|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 1.945338 | 5.1405E-01 | 3.2299E+00 | 1.0432E+01 |
| MODAL | Mode | 2. | 1.641859 | 6.0907E-01 | 3.8269E+00 | 1.4645E+01 |
| MODAL | Mode | 3. | 1.607784 | 6.2197E-01 | 3.9080E+00 | 1.5272E+01 |
| MODAL | Mode | 4. | 1.148779 | 8.7049E-01 | 5.4694E+00 | 2.9915E+01 |
| MODAL | Mode | 5. | 1.00383 | 9.9618E-01 | 6.2592E+00 | 3.9178E+01 |
| MODAL | Mode | 6. | 0.936634 | 1.0677E+00 | 6.7083E+00 | 4.5001E+01 |
| MODAL | Mode | 7. | 0.870946 | 1.1482E+00 | 7.2142E+00 | 5.2045E+01 |
| MODAL | Mode | 8. | 0.652339 | 1.5329E+00 | 9.6318E+00 | 9.2771E+01 |
| MODAL | Mode | 9. | 0.556076 | 1.7983E+00 | 1.1299E+01 | 1.2767E+02 |
| MODAL | Mode | 10. | 0.54103 | 1.8483E+00 | 1.1613E+01 | 1.3487E+02 |
| MODAL | Mode | 11. | 0.456406 | 2.1910E+00 | 1.3767E+01 | 1.8952E+02 |
| MODAL | Mode | 12. | 0.425114 | 2.3523E+00 | 1.4780E+01 | 2.1845E+02 |
| MODAL | Mode | 13. | 0.413113 | 2.4206E+00 | 1.5209E+01 | 2.3132E+02 |
| MODAL | Mode | 14. | 0.352426 | 2.8375E+00 | 1.7828E+01 | 3.1785E+02 |
| MODAL | Mode | 15. | 0.351373 | 2.8460E+00 | 1.7882E+01 | 3.1976E+02 |
| MODAL | Mode | 16. | 0.310727 | 3.2183E+00 | 2.0221E+01 | 4.0889E+02 |
| MODAL | Mode | 17. | 0.302514 | 3.3056E+00 | 2.0770E+01 | 4.3139E+02 |
| MODAL | Mode | 18. | 0.277762 | 3.6002E+00 | 2.2621E+01 | 5.1170E+02 |
| MODAL | Mode | 19. | 0.256964 | 3.8916E+00 | 2.4452E+01 | 5.9788E+02 |
| MODAL | Mode | 20. | 0.245218 | 4.0780E+00 | 2.5623E+01 | 6.5653E+02 |
| MODAL | Mode | 21. | 0.245169 | 4.0788E+00 | 2.5628E+01 | 6.5679E+02 |
| MODAL | Mode | 22. | 0.233681 | 4.2793E+00 | 2.6888E+01 | 7.2296E+02 |
| MODAL | Mode | 23. | 0.225049 | 4.4435E+00 | 2.7919E+01 | 7.7948E+02 |
| MODAL | Mode | 24. | 0.218159 | 4.5838E+00 | 2.8801E+01 | 8.2950E+02 |
| MODAL | Mode | 25. | 0.200153 | 4.9962E+00 | 3.1392E+01 | 9.8545E+02 |
| MODAL | Mode | 26. | 0.194539 | 5.1404E+00 | 3.2298E+01 | 1.0431E+03 |
| MODAL | Mode | 27. | 0.191342 | 5.2262E+00 | 3.2837E+01 | 1.0783E+03 |
| MODAL | Mode | 28. | 0.18975 | 5.2701E+00 | 3.3113E+01 | 1.0965E+03 |
| MODAL | Mode | 29. | 0.18761 | 5.3302E+00 | 3.3491E+01 | 1.1216E+03 |
| MODAL | Mode | 30. | 0.178726 | 5.5951E+00 | 3.5155E+01 | 1.2359E+03 |

License #2010*1GRWHLW4599V5FQ

**Static and Dynamic Characterizataion of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160603 Rev 021 HS20 C2F UBK FP Tennessee River 24 Bridge.xlsx.sdb**

**27 June 2016**

Section 1 US 24 Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 4000Psi | Concrete | Isotropic | No | Red | |
| A36 | Steel | Isotropic | No | Blue | |
| A416Gr270 | Tendon | Uniaxial | No | Cyan | |
| A514 | Steel | Isotropic | No | Cyan | |
| A588 | Steel | Isotropic | No | Cyan | |
| A615Gr60 | Rebar | Uniaxial | No | Green | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586G | Other | Isotropic | No | Gray8Dark | |
| Substr | Concrete | Isotropic | No | Red | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 4000Psi | Customary f'c 4000 psi 9/27/2014 9:39:17 PM |
| A36 | United States ASTM A36 Grade 36 added 9/28/2014 6:52:31 PM |
| A416Gr270 | ASTM A416 Grade 270 2/7/2016 6:46:12 PM |
| A514 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| A588 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| A615Gr60 | ASTM A615 Grade 60 2/7/2016 6:46:12 PM |
| A992Fy50 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| ASTM A586G | MAT added 2/7/2016 10:55:03 PM |
| Substr | Customary f'c 4000 psi 9/27/2014 9:39:17 PM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight Kip/ft3 | UnitMass Kip-s2/ft4 | E1 Kip/ft2 | G12 Kip/ft2 | U12 | A1 1/F |
|---|---|---|---|---|---|---|
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 591887. | 246619.58 | 0.2 | 5.5000E-06 |
| A36 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A514 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A588 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight | UnitMass | E1 | G12 | U12 | A1 |
|---|---|---|---|---|---|---|
| | Kip/ft3 | Kip-s2/ft4 | Kip/ft2 | Kip/ft2 | | 1/F |
| ASTM A586G | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| Substr | 1.5000E-01 | 4.6621E-03 | 591887. | 246619.58 | 0.2 | 5.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy | Fu | EffFy | EffFu | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| | Kip/ft2 | Kip/ft2 | Kip/ft2 | Kip/ft2 | | | |
| A36 | 5184. | 8352. | 7776. | 9187.2 | Simple | Kinematic | 0.02 |
| A514 | 14400. | 17280. | 14400. | 17280. | Simple | Kinematic | 0.015 |
| A588 | 7200. | 10080. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A36 | 0.14 | 0.2 | -0.1 |
| A514 | 0.11 | 0.17 | -0.1 |
| A588 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| | Kip/ft2 | | | | | | |
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| Substr | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle | DAngle |
|---|---|---|
| | Degrees | Degrees |
| 4000Psi | 0. | 0. |
| Substr | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 8

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 | t2 | tf |
|---|---|---|---|---|---|
| | | | ft | ft | ft |
| ARL0R1 | A992Fy50 | SD Section | | | |
| ARR1R3 | A992Fy50 | SD Section | | | |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3<br>ft | t2<br>ft | tf<br>ft |
|---|---|---|---|---|---|
| ARR3R4 | A992Fy50 | SD Section | | | |
| ARR4R7 | A992Fy50 | SD Section | | | |
| Cable | ASTM A586G | General | 1. | 1. | |
| DIAR1 | A992Fy50 | I/Wide Flange | 3. | 1.25 | 0.0729 |
| DIAR2R7 | A992Fy50 | I/Wide Flange | 2.9729 | 1.25 | 0.0625 |
| FLBM37 | A36 | I/Wide Flange | 6.0625 | 1.3333 | 0.1146 |
| FLBM5 | A36 | I/Wide Flange | 6.0938 | 1.3333 | 0.1302 |
| FLBMT0 | A36 | I/Wide Flange | 5.9792 | 1.3333 | 0.0729 |
| FLBMT1246 | A36 | I/Wide Flange | 6.1458 | 1.3333 | 0.1563 |
| FSEC1 | A992Fy50 | I/Wide Flange | 1. | 0.41667 | 0.03167 |
| HP14X102 | A36 | I/Wide Flange | 1.16667 | 1.23333 | 0.05875 |
| HP14X73 | A36 | I/Wide Flange | 1.13333 | 1.21667 | 0.04208 |
| HP14X89 | A36 | I/Wide Flange | 1.15 | 1.225 | 0.05125 |
| Portal Brace | A992Fy50 | I/Wide Flange | 2.2917 | 1.25 | 0.0625 |
| STRUTR2R7 | A992Fy50 | I/Wide Flange | 2.9729 | 1.25 | 0.0625 |
| TGL0L2 | A992Fy50 | SD Section | | | |
| TGL2L6 | A992Fy50 | SD Section | | | |
| TGL6L8 | A992Fy50 | SD Section | | | |
| W30X116 | A36 | I/Wide Flange | 2.5 | 0.875 | 0.0708 |
| W30X99 | A36 | I/Wide Flange | 2.475 | 0.875 | 0.0558 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw<br>ft | t2b<br>ft | tfb<br>ft | Area<br>ft2 | TorsConst<br>ft4 | I33<br>ft4 |
|---|---|---|---|---|---|---|
| ARL0R1 | | | | 1.3718 | 1.889054 | 1.96309 |
| ARR1R3 | | | | 1.3001 | 1.837566 | 1.893222 |
| ARR3R4 | | | | 1.229 | 1.781335 | 1.824012 |
| ARR4R7 | | | | 1.1579 | 1.720006 | 1.754793 |
| Cable | | | | 0.0442 | 0.000311 | 0.000156 |
| DIAR1 | 0.0729 | 1.25 | 0.0729 | 0.3903 | 0.000674 | 0.53171 |
| DIAR2R7 | 0.0625 | 1.25 | 0.0625 | 0.3342 | 0.000426 | 0.451229 |
| FLBM37 | 0.0365 | 1.3333 | 0.1146 | 0.5185 | 0.00136 | 3.306855 |
| FLBM5 | 0.0365 | 1.3333 | 0.1302 | 0.5601 | 0.001935 | 3.691192 |
| FLBMT0 | 0.0365 | 1.3333 | 0.0729 | 0.4073 | 0.000427 | 2.299202 |
| FLBMT1246 | 0.0365 | 1.3333 | 0.1563 | 0.6297 | 0.003238 | 4.342553 |
| FSEC1 | 0.02083 | 0.41667 | 0.03167 | 0.0459 | 0.000011 | 0.007615 |
| HP14X102 | 0.05875 | 1.23333 | 0.05875 | 0.2083 | 0.00026 | 0.050637 |
| HP14X73 | 0.04208 | 1.21667 | 0.04208 | 0.1486 | 0.000097 | 0.035156 |
| HP14X89 | 0.05125 | 1.225 | 0.05125 | 0.1813 | 0.000173 | 0.043596 |
| Portal Brace | 0.0625 | 1.25 | 0.0625 | 0.2917 | 0.00037 | 0.247143 |
| STRUTR2R7 | 0.0625 | 1.25 | 0.0625 | 0.3342 | 0.000426 | 0.451229 |
| TGL0L2 | | | | 1.5212 | 2.985977 | 21.111538 |
| TGL2L6 | | | | 1.5853 | 3.009519 | 22.486462 |
| TGL6L8 | | | | 1.3929 | 2.93165 | 18.380184 |
| W30X116 | 0.0471 | 0.875 | 0.0708 | 0.235 | 0.000278 | 0.234322 |
| W30X99 | 0.0433 | 0.875 | 0.0558 | 0.2 | 0.00016 | 0.190534 |

Table: Frame Section Properties 01 - General, Part 3 of 8

Table: Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARL0R1 | 1.105147 | 0. | 1.0352 | 0.3048 | 1.090229 | 0.982353 |
| ARR1R3 | 1.048333 | 0. | 0.9697 | 0.3044 | 1.050469 | 0.931851 |
| ARR3R4 | 0.990627 | 0. | 0.9045 | 0.3039 | 1.011048 | 0.880557 |
| ARR4R7 | 0.931581 | 0. | 0.8388 | 0.3036 | 0.971582 | 0.828072 |
| Cable | 0.000156 | 0. | 0.0398 | 0.0398 | 1. | 1. |
| DIAR1 | 0.023823 | 0. | 0.2187 | 0.1519 | 0.354473 | 0.038116 |
| DIAR2R7 | 0.020403 | 0. | 0.1858 | 0.1302 | 0.303562 | 0.032645 |
| FLBM37 | 0.045294 | 0. | 0.2213 | 0.2547 | 1.090921 | 0.067943 |
| FLBM5 | 0.051457 | 0. | 0.2224 | 0.2893 | 1.211458 | 0.077187 |
| FLBMT0 | 0.028821 | 0. | 0.2182 | 0.162 | 0.769067 | 0.043233 |
| FLBMT1246 | 0.061767 | 0. | 0.2243 | 0.3473 | 1.413177 | 0.092653 |
| FSEC1 | 0.000382 | 0. | 0.0208 | 0.022 | 0.01523 | 0.001836 |
| HP14X102 | 0.018326 | 0. | 0.0685 | 0.1208 | 0.086806 | 0.029717 |
| HP14X73 | 0.012587 | 0. | 0.0477 | 0.0853 | 0.06204 | 0.020691 |
| HP14X89 | 0.015721 | 0. | 0.0589 | 0.1046 | 0.075819 | 0.025668 |
| Portal Brace | 0.020389 | 0. | 0.1432 | 0.1302 | 0.215686 | 0.032623 |
| STRUTR2R7 | 0.020403 | 0. | 0.1858 | 0.1302 | 0.303562 | 0.032645 |
| TGL0L2 | 1.392646 | 0. | 0.7611 | 0.5887 | 4.564657 | 0.903242 |
| TGL2L6 | 1.443454 | 0. | 0.7637 | 0.6407 | 4.851029 | 0.936199 |
| TGL6L8 | 1.291031 | 0. | 0.7551 | 0.4856 | 3.992047 | 0.837327 |
| W30X116 | 0.007926 | 0. | 0.1178 | 0.1033 | 0.187458 | 0.018116 |
| W30X99 | 0.006246 | 0. | 0.1072 | 0.0814 | 0.153967 | 0.014277 |

Table: Frame Section Properties 01 - General, Part 4 of 8

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARL0R1 | 1.442008 | 1.18804 | 1.19625 | 0.89756 | | No |
| ARR1R3 | 1.380691 | 1.124189 | 1.20675 | 0.89798 | | No |
| ARR3R4 | 1.319954 | 1.06015 | 1.21826 | 0.8978 | | No |
| ARR4R7 | 1.259211 | 0.995372 | 1.23104 | 0.89695 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| DIAR1 | 0.415201 | 0.060745 | 1.16715 | 0.24705 | | No |
| DIAR2R7 | 0.354102 | 0.051609 | 1.16189 | 0.24707 | | No |
| FLBM37 | 1.219316 | 0.103804 | 2.5254 | 0.29556 | | No |
| FLBM5 | 1.345766 | 0.11767 | 2.56712 | 0.3031 | | No |
| FLBMT0 | 0.884589 | 0.06674 | 2.37588 | 0.26601 | | No |
| FLBMT1246 | 1.55867 | 0.140869 | 2.62606 | 0.31319 | | No |
| FSEC1 | 0.017346 | 0.00285 | 0.4073 | 0.09128 | | No |
| HP14X102 | 0.097801 | 0.045602 | 0.49301 | 0.29659 | | No |
| HP14X73 | 0.068287 | 0.031597 | 0.48638 | 0.29103 | | No |
| HP14X89 | 0.084491 | 0.039178 | 0.49044 | 0.29451 | | No |
| Portal Brace | 0.247509 | 0.050944 | 0.92051 | 0.2644 | | No |
| STRUTR2R7 | 0.354102 | 0.051609 | 1.16189 | 0.24707 | | No |
| TGL0L2 | 5.205132 | 1.360108 | 3.7254 | 0.95683 | | No |
| TGL2L6 | 5.502079 | 1.409543 | 3.76623 | 0.95422 | | No |

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33<br>ft3 | Z22<br>ft3 | R33<br>ft | R22<br>ft | EccV2<br>ft | ConcCol |
|---|---|---|---|---|---|---|
| TGL6L8 | 4.613239 | 1.261238 | 3.63259 | 0.96274 | | No |
| W30X116 | 0.215982 | 0.028411 | 0.9986 | 0.18365 | | No |
| W30X99 | 0.178582 | 0.022469 | 0.97609 | 0.17673 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 8

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt<br>Kip | TotalMass<br>Kip-s2/ft | FromFile | AMod |
|---|---|---|---|---|---|---|
| ARL0R1 | No | Green | 144.721 | 4.5 | No | 1. |
| ARR1R3 | No | Red | 258.583 | 8.04 | No | 1. |
| ARR3R4 | No | Yellow | 116.26 | 3.61 | No | 1. |
| ARR4R7 | No | Blue | 315.891 | 9.82 | No | 1. |
| Cable | No | Gray8Dark | 35.721 | 1.11 | No | 1. |
| DIAR1 | No | Green | 37.347 | 1.16 | No | 1. |
| DIAR2R7 | No | Yellow | 149.857 | 4.66 | No | 1. |
| FLBM37 | No | Cyan | 40.321 | 1.25 | No | 1. |
| FLBM5 | No | Magenta | 29.037 | 0.9 | No | 1. |
| FLBMT0 | No | White | 21.116 | 0.66 | No | 1. |
| FLBMT1246 | No | Blue | 130.58 | 4.06 | No | 1. |
| FSEC1 | No | Cyan | 0. | 0. | No | 1. |
| HP14X102 | No | Gray8Dark | 18.196 | 0.57 | Yes | 1. |
| HP14X73 | No | Red | 64.898 | 2.02 | Yes | 1. |
| HP14X89 | No | Yellow | 15.83 | 0.49 | Yes | 1. |
| Portal Brace | No | Magenta | 11.864 | 0.37 | No | 1. |
| STRUTR2R7 | No | Gray8Dark | 82.872 | 2.58 | No | 1. |
| TGL0L2 | No | Blue | 261.723 | 8.13 | No | 1. |
| TGL2L6 | No | Magenta | 545.515 | 16.96 | No | 1. |
| TGL6L8 | No | Gray8Dark | 119.827 | 3.72 | No | 1. |
| W30X116 | No | Yellow | 338.379 | 10.52 | No | 1. |
| W30X99 | No | Red | 0. | 0. | No | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARL0R1 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR1R3 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR3R4 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR4R7 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| DIAR1 | 1. | 1. | 1. | 1. | 1. | 1. |
| DIAR2R7 | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBM37 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBM5 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBMT0 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBMT1246 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| HP14X102 | 1. | 1. | 1. | 1. | 1. | 1. |
| HP14X73 | 1. | 1. | 1. | 1. | 1. | 1. |
| HP14X89 | 1. | 1. | 1. | 1. | 1. | 1. |
| Portal Brace | 1. | 1. | 1. | 1. | 1. | 1. |
| STRUTR2R7 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL0L2 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| TGL2L6 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| TGL6L8 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| W30X116 | 1. | 1. | 1. | 1. | 1. | 1.1 |
| W30X99 | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Frame Section Properties 01 - General, Part 7 of 8

Table: Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| ARL0R1 | 1.2 | | | |
| ARR1R3 | 1.2 | | | |
| ARR3R4 | 1.2 | | | |
| ARR4R7 | 1.2 | | | |
| Cable | 1. | | | |
| DIAR1 | 1. | | | |
| DIAR2R7 | 1. | | | |
| FLBM37 | 1.15 | | | |
| FLBM5 | 1.15 | | | |
| FLBMT0 | 1.15 | | | |
| FLBMT1246 | 1.15 | | | |
| FSEC1 | 1. | | | |
| HP14X102 | 1. | HP14X102 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| HP14X73 | 1. | HP14X73 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| HP14X89 | 1. | HP14X89 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| Portal Brace | 1. | | | |
| STRUTR2R7 | 1. | | | |
| TGL0L2 | 1.15 | | | |
| TGL2L6 | 1.15 | | | |
| TGL6L8 | 1.15 | | | |
| W30X116 | 1.1 | | | |
| W30X99 | 1. | | | |

Table: Frame Section Properties 01 - General, Part 8 of 8

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARL0R1 | Added 2/7/2016 7:18:29 PM |
| ARR1R3 | Added 2/7/2016 8:23:51 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARR3R4 | Added 2/7/2016 8:29:59 PM |
| ARR4R7 | Added 2/7/2016 8:32:35 PM |
| Cable | Added 5/31/2016 9:59:30 PM |
| DIAR1 | Added 2/7/2016 10:35:01 PM |
| DIAR2R7 | Added 2/7/2016 10:38:41 PM |
| FLBM37 | Added 9/28/2014 7:12:14 PM |
| FLBM5 | Added 9/28/2014 7:13:11 PM |
| FLBMT0 | Added 9/28/2014 7:07:51 PM |
| FLBMT1246 | Added 9/28/2014 7:10:48 PM |
| FSEC1 | Added 9/27/2014 9:39:49 PM |
| HP14X102 | Imported 9/28/2014 8:17:56 PM from AISC13.pro |
| HP14X73 | Imported 9/28/2014 8:18:59 PM from AISC13.pro |
| HP14X89 | Imported 9/28/2014 8:19:10 PM from AISC13.pro |
| Portal Brace | Added 2/7/2016 10:01:07 PM |
| STRUTR2R7 | Added 2/7/2016 10:08:13 PM |
| TGL0L2 | Added 2/7/2016 6:44:03 PM |
| TGL2L6 | Added 2/7/2016 6:56:25 PM |
| TGL6L8 | Added 2/7/2016 7:04:47 PM |
| W30X116 | Added 2/7/2016 5:37:44 PM |
| W30X99 | Added 2/7/2016 5:34:08 PM |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| LINK1 | Linear | 0. | 0. | 0. | 0. | 0. |
| LINK2 | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| LINK1 | 1. | 1. | 0. | 0. | 0. | 0. |
| LINK2 | 1. | 1. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| LINK1 | Magenta | | Added 2/29/2016 3:34:56 PM |
| LINK2 | Magenta | | Added 2/29/2016 3:34:56 PM |

Table:  Link Property Definitions 02 - Linear

Table:  Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE Kip/ft | RotKE Kip-ft/rad | TransCE Kip-s/ft | RotCE Kip-ft-s/rad | DJ ft |
|---|---|---|---|---|---|---|---|
| LINK1 | U1 | No | 100000. | | 0. | | |
| LINK1 | U2 | No | 100000. | | 0. | | 0. |
| LINK1 | U3 | No | 100000. | | 0. | | 0. |
| LINK1 | R1 | No | | 0. | | 0. | |
| LINK1 | R2 | No | | 0. | | 0. | |
| LINK1 | R3 | No | | 0. | | 0. | |
| LINK2 | U1 | No | 100000. | | 0. | | |
| LINK2 | U2 | No | 100000. | | 0. | | 0. |
| LINK2 | U3 | No | 100000. | | 0. | | 0. |
| LINK2 | R1 | No | | 0. | | 0. | |
| LINK2 | R2 | No | | 0. | | 0. | |
| LINK2 | R3 | No | | 0. | | 0. | |

Table:  Area Section Properties, Part 1 of 4

Table:  Area Section Properties, Part 1 of 4

| Section | Material | MatAngle Degrees | AreaType | Type | DrillDOF | Thickness ft | BendThick ft |
|---|---|---|---|---|---|---|---|
| ASEC1 | A36 | 0. | Shell | Shell-Thin | Yes | 1. | 1. |
| ConcDeck | 4000Psi | 0. | Shell | Shell-Thin | Yes | 0.6667 | 0.6667 |

Table:  Area Section Properties, Part 2 of 4

Table:  Area Section Properties, Part 2 of 4

| Section | Arc Degrees | InComp | CoordSys | Color | TotalWt Kip | TotalMass Kip-s2/ft |
|---|---|---|---|---|---|---|
| ASEC1 | | | | Green | 5333.16 | 165.76 |
| ConcDeck | | | | 12615935 | 2388.592 | 74.24 |

Table:  Area Section Properties, Part 3 of 4

Table:  Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| ConcDeck | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Area Section Properties, Part 4 of 4

Table:  Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 6f5825de-a2dc-451c-a3c5-5df2377eea92 | Added 2/15/2016 12:48:48 PM |
| ConcDeck | 1. | 1.2 | 1.2 | 6aa652a7-753e-47a5-9f99-1d2dc88054b2 | Added 2/15/2016 12:49:15 PM |

Table: Solid Property Definitions, Part 1 of 2

Table: Solid Property Definitions, Part 1 of 2

| SolidProp | Material | MatAngleA Degrees | MatAngleB Degrees | MatAngleC Degrees | InComp | Color |
|---|---|---|---|---|---|---|
| Substr | Substr | 0. | 0. | 0. | Yes | Green |

Table: Solid Property Definitions, Part 2 of 2

Table: Solid Property Definitions, Part 2 of 2

| SolidProp | GUID | Notes | TotalWt Kip | TotalMass Kip-s2/ft |
|---|---|---|---|---|
| Substr | | | 23374.8 | 726.51 |

Section 2 US 24 Bridge Load Cases

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| LIVELOAD | LinMoving | Zero | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING _DEAD | LinBuckling | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | No | Not Run |
| BUCKLING _DEAD | DEAD | Prog Det | Other | None | No | Not Run |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| LIVELOAD | | |
| PDELTA | | |

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
| --- | --- | --- |
| BUCKLING_DEAD | | |
| MODAL | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
| --- | --- | --- | --- |
| DEAD | Load pattern | DEAD | 1. |
| PDELTA | Load pattern | DEAD | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
| --- | --- | --- | --- |
| DEAD | Full Load | U1 | 14 |
| PDELTA | Full Load | U1 | 14 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
| --- | --- | --- | --- | --- | --- |
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
| --- | --- | --- | --- | --- | --- | --- |
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
| --- | --- | --- | --- | --- | --- |
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |
| PDELTA | 10 | 0.01 | 1. | No |

Table: Case - Moving Load 1 - Lane Assignments

Table: Case - Moving Load 1 - Lane Assignments

| Case | AssignNum | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HS20LOADING | 1. | 0 | 4 | 6 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CENLANES |
| LIVELOAD | 1 | CNTLANE2 |
| LIVELOAD | 1 | LFTLANE1 |
| LIVELOAD | 1 | LFTLANE2 |
| LIVELOAD | 1 | RGTLANE1 |
| LIVELOAD | 1 | RTLANE2 |

Table: Case - Moving Load 3 - MultiLane Factors

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 1 | 1. |
| LIVELOAD | 2 | 1. |
| LIVELOAD | 3 | 0.9 |
| LIVELOAD | 4 | 0.75 |
| LIVELOAD | 5 | 0.75 |
| LIVELOAD | 6 | 0.75 |
| LIVELOAD | 7 | 0.75 |
| LIVELOAD | 8 | 0.75 |
| LIVELOAD | 9 | 0.75 |
| LIVELOAD | 10 | 0.75 |
| LIVELOAD | 11 | 0.75 |

Table: Case - Moving Load 3 - MultiLane Factors

| Case | NumberLanes | ScaleFactor |
|---|---|---|
| LIVELOAD | 12 | 0.75 |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift | EigenCutoff | EigenTol |
|---|---|---|---|---|---|---|
| | | | | Cyc/sec | Cyc/sec | |
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Section 3 US 24 Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.3061 | 51.0424 |
| MODAL | Acceleration | UY | 98.0978 | 20.0672 |
| MODAL | Acceleration | UZ | 98.3971 | 17.2851 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| | | | Sec | | | | |
| MODAL | | | 0. | 0. | 1.281E-15 | 5.144E-06 | 0. |

Table: Modal Participating Mass Ratios, Part 2 of 3

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | | | 1.281E-15 | 5.144E-06 | 2.855E-14 | 1.346E-05 | 8.534E-15 |

Table: Modal Participating Mass Ratios, Part 3 of 3

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | | | 2.855E-14 | 1.346E-05 | 8.534E-15 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | RX |
|---|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft | Kip-ft |
| MODAL | | | 0. | 0. | 9.970E-07 | -0.081543 | 4.933E-06 |

Table: Modal Participation Factors, Part 2 of 2

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY | RZ | ModalMass | ModalStiff |
|---|---|---|---|---|---|---|
| | | | Kip-ft | Kip-ft | Kip-ft-s2 | Kip-ft |
| MODAL | | | 6.275691 | 0.000683 | 0. | 0. |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period | Frequency | CircFreq | Eigenvalue |
|---|---|---|---|---|---|---|
| | | | Sec | Cyc/sec | rad/sec | rad2/sec2 |
| MODAL | | | 0. | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 |

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**Static and Dynamic Characterization of Tied Arch Bridges**

Prepared for
**Missouri University of Science and Technology**

Prepared by
**John Finke**

**Model Name: 20160627 Rev 023 HL93 C2F LBK FP Tennessee River 24 Bridge.xlsx.sdb**

**27 June 2016**

Section 1 US 24 Bridge Analysis Input

Table: Material Properties 01 - General, Part 1 of 2

Table: Material Properties 01 - General, Part 1 of 2

| Material | Type | SymType | TempDepend | Color | GUID |
|---|---|---|---|---|---|
| 4000Psi | Concrete | Isotropic | No | Red | |
| A36 | Steel | Isotropic | No | Blue | |
| A416Gr270 | Tendon | Uniaxial | No | Cyan | |
| A514 | Steel | Isotropic | No | Cyan | |
| A588 | Steel | Isotropic | No | Cyan | |
| A615Gr60 | Rebar | Uniaxial | No | Green | |
| A992Fy50 | Steel | Isotropic | No | Cyan | |
| ASTM A586G | Other | Isotropic | No | Gray8Dark | |
| Substr | Concrete | Isotropic | No | Red | |

Table: Material Properties 01 - General, Part 2 of 2

Table: Material Properties 01 - General, Part 2 of 2

| Material | Notes |
|---|---|
| 4000Psi | Customary f'c 4000 psi 9/27/2014 9:39:17 PM |
| A36 | United States ASTM A36 Grade 36 added 9/28/2014 6:52:31 PM |
| A416Gr270 | ASTM A416 Grade 270 2/7/2016 6:46:12 PM |
| A514 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| A588 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| A615Gr60 | ASTM A615 Grade 60 2/7/2016 6:46:12 PM |
| A992Fy50 | ASTM A992 Grade 50 9/27/2014 9:39:17 PM |
| ASTM A586G | MAT added 2/7/2016 10:55:03 PM |
| Substr | Customary f'c 4000 psi 9/27/2014 9:39:17 PM |

Table: Material Properties 02 - Basic Mechanical Properties

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight Kip/ft3 | UnitMass Kip-s2/ft4 | E1 Kip/ft2 | G12 Kip/ft2 | U12 | A1 1/F |
|---|---|---|---|---|---|---|
| 4000Psi | 1.5000E-01 | 4.6621E-03 | 155740. | 64891.67 | 0.2 | 5.5000E-06 |
| A36 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A416Gr270 | 4.9000E-01 | 1.5230E-02 | 4104000. | | | 6.5000E-06 |
| A514 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A588 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| A615Gr60 | 4.9000E-01 | 1.5230E-02 | 4176000. | | | 6.5000E-06 |
| A992Fy50 | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |

Table: Material Properties 02 - Basic Mechanical Properties

| Material | UnitWeight Kip/ft3 | UnitMass Kip-s2/ft4 | E1 Kip/ft2 | G12 Kip/ft2 | U12 | A1 1/F |
|---|---|---|---|---|---|---|
| ASTM A586G | 4.9000E-01 | 1.5230E-02 | 4176000. | 1606153.85 | 0.3 | 6.5000E-06 |
| Substr | 1.5000E-01 | 4.6621E-03 | 155740. | 64891.67 | 0.2 | 5.5000E-06 |

Table: Material Properties 03a - Steel Data, Part 1 of 2

Table: Material Properties 03a - Steel Data, Part 1 of 2

| Material | Fy Kip/ft2 | Fu Kip/ft2 | EffFy Kip/ft2 | EffFu Kip/ft2 | SSCurveOpt | SSHysType | SHard |
|---|---|---|---|---|---|---|---|
| A36 | 5184. | 8352. | 7776. | 9187.2 | Simple | Kinematic | 0.02 |
| A514 | 14400. | 17280. | 14400. | 17280. | Simple | Kinematic | 0.015 |
| A588 | 7200. | 10080. | 7920. | 10296. | Simple | Kinematic | 0.015 |
| A992Fy50 | 7200. | 9360. | 7920. | 10296. | Simple | Kinematic | 0.015 |

Table: Material Properties 03a - Steel Data, Part 2 of 2

Table: Material Properties 03a - Steel Data, Part 2 of 2

| Material | SMax | SRup | FinalSlope |
|---|---|---|---|
| A36 | 0.14 | 0.2 | -0.1 |
| A514 | 0.11 | 0.17 | -0.1 |
| A588 | 0.11 | 0.17 | -0.1 |
| A992Fy50 | 0.11 | 0.17 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 1 of 2

Table: Material Properties 03b - Concrete Data, Part 1 of 2

| Material | Fc Kip/ft2 | LtWtConc | SSCurveOpt | SSHysType | SFc | SCap | FinalSlope |
|---|---|---|---|---|---|---|---|
| 4000Psi | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |
| Substr | 576. | No | Mander | Takeda | 0.002219 | 0.005 | -0.1 |

Table: Material Properties 03b - Concrete Data, Part 2 of 2

Table: Material Properties 03b - Concrete Data, Part 2 of 2

| Material | FAngle Degrees | DAngle Degrees |
|---|---|---|
| 4000Psi | 0. | 0. |
| Substr | 0. | 0. |

Table: Frame Section Properties 01 - General, Part 1 of 8

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3 ft | t2 ft | tf ft |
|---|---|---|---|---|---|
| ARL0R1 | A992Fy50 | SD Section | | | |
| ARR1R3 | A992Fy50 | SD Section | | | |
| ARR3R4 | A992Fy50 | SD Section | | | |

Table: Frame Section Properties 01 - General, Part 1 of 8

| SectionName | Material | Shape | t3<br>ft | t2<br>ft | tf<br>ft |
|---|---|---|---|---|---|
| ARR4R7 | A992Fy50 | SD Section | | | |
| Cable | ASTM A586G | General | 1. | 1. | |
| DIAR1 | A992Fy50 | I/Wide Flange | 3. | 1.25 | 0.0729 |
| DIAR2R7 | A992Fy50 | I/Wide Flange | 2.9729 | 1.25 | 0.0625 |
| FLBM37 | A36 | I/Wide Flange | 6.0625 | 1.3333 | 0.1146 |
| FLBM5 | A36 | I/Wide Flange | 6.0938 | 1.3333 | 0.1302 |
| FLBMT0 | A36 | I/Wide Flange | 5.9792 | 1.3333 | 0.0729 |
| FLBMT1246 | A36 | I/Wide Flange | 6.1458 | 1.3333 | 0.1563 |
| FSEC1 | A992Fy50 | I/Wide Flange | 1. | 0.41667 | 0.03167 |
| HP14X102 | A36 | I/Wide Flange | 1.16667 | 1.23333 | 0.05875 |
| HP14X73 | A36 | I/Wide Flange | 1.13333 | 1.21667 | 0.04208 |
| HP14X89 | A36 | I/Wide Flange | 1.15 | 1.225 | 0.05125 |
| Portal Brace | A992Fy50 | I/Wide Flange | 2.2917 | 1.25 | 0.0625 |
| STRUTR2R7 | A992Fy50 | I/Wide Flange | 2.9729 | 1.25 | 0.0625 |
| TGL0L2 | A992Fy50 | SD Section | | | |
| TGL2L6 | A992Fy50 | SD Section | | | |
| TGL6L8 | A992Fy50 | SD Section | | | |
| W30X116 | A36 | I/Wide Flange | 2.5 | 0.875 | 0.0708 |
| W30X99 | A36 | I/Wide Flange | 2.475 | 0.875 | 0.0558 |

Table: Frame Section Properties 01 - General, Part 2 of 8

Table: Frame Section Properties 01 - General, Part 2 of 8

| SectionName | tw<br>ft | t2b<br>ft | tfb<br>ft | Area<br>ft2 | TorsConst<br>ft4 | I33<br>ft4 |
|---|---|---|---|---|---|---|
| ARL0R1 | | | | 1.3718 | 1.889054 | 1.96309 |
| ARR1R3 | | | | 1.3001 | 1.837566 | 1.893222 |
| ARR3R4 | | | | 1.229 | 1.781335 | 1.824012 |
| ARR4R7 | | | | 1.1579 | 1.720006 | 1.754793 |
| Cable | | | | 0.0442 | 0.000311 | 0.000156 |
| DIAR1 | 0.0729 | 1.25 | 0.0729 | 0.3903 | 0.000674 | 0.53171 |
| DIAR2R7 | 0.0625 | 1.25 | 0.0625 | 0.3342 | 0.000426 | 0.451229 |
| FLBM37 | 0.0365 | 1.3333 | 0.1146 | 0.5185 | 0.00136 | 3.306855 |
| FLBM5 | 0.0365 | 1.3333 | 0.1302 | 0.5601 | 0.001935 | 3.691192 |
| FLBMT0 | 0.0365 | 1.3333 | 0.0729 | 0.4073 | 0.000427 | 2.299202 |
| FLBMT1246 | 0.0365 | 1.3333 | 0.1563 | 0.6297 | 0.003238 | 4.342553 |
| FSEC1 | 0.02083 | 0.41667 | 0.03167 | 0.0459 | 0.000011 | 0.007615 |
| HP14X102 | 0.05875 | 1.23333 | 0.05875 | 0.2083 | 0.00026 | 0.050637 |
| HP14X73 | 0.04208 | 1.21667 | 0.04208 | 0.1486 | 0.000097 | 0.035156 |
| HP14X89 | 0.05125 | 1.225 | 0.05125 | 0.1813 | 0.000173 | 0.043596 |
| Portal Brace | 0.0625 | 1.25 | 0.0625 | 0.2917 | 0.00037 | 0.247143 |
| STRUTR2R7 | 0.0625 | 1.25 | 0.0625 | 0.3342 | 0.000426 | 0.451229 |
| TGL0L2 | | | | 1.5212 | 2.985977 | 21.111538 |
| TGL2L6 | | | | 1.5853 | 3.009519 | 22.486462 |
| TGL6L8 | | | | 1.3929 | 2.93165 | 18.380184 |
| W30X116 | 0.0471 | 0.875 | 0.0708 | 0.235 | 0.000278 | 0.234322 |
| W30X99 | 0.0433 | 0.875 | 0.0558 | 0.2 | 0.00016 | 0.190534 |

Table:  Frame Section Properties 01 - General, Part 3 of 8

Table:  Frame Section Properties 01 - General, Part 3 of 8

| SectionName | I22 | I23 | AS2 | AS3 | S33 | S22 |
|---|---|---|---|---|---|---|
| | ft4 | ft4 | ft2 | ft2 | ft3 | ft3 |
| ARL0R1 | 1.105147 | 0. | 1.0352 | 0.3048 | 1.090229 | 0.982353 |
| ARR1R3 | 1.048333 | 0. | 0.9697 | 0.3044 | 1.050469 | 0.931851 |
| ARR3R4 | 0.990627 | 0. | 0.9045 | 0.3039 | 1.011048 | 0.880557 |
| ARR4R7 | 0.931581 | 0. | 0.8388 | 0.3036 | 0.971582 | 0.828072 |
| Cable | 0.000156 | 0. | 0.0398 | 0.0398 | 1. | 1. |
| DIAR1 | 0.023823 | 0. | 0.2187 | 0.1519 | 0.354473 | 0.038116 |
| DIAR2R7 | 0.020403 | 0. | 0.1858 | 0.1302 | 0.303562 | 0.032645 |
| FLBM37 | 0.045294 | 0. | 0.2213 | 0.2547 | 1.090921 | 0.067943 |
| FLBM5 | 0.051457 | 0. | 0.2224 | 0.2893 | 1.211458 | 0.077187 |
| FLBMT0 | 0.028821 | 0. | 0.2182 | 0.162 | 0.769067 | 0.043233 |
| FLBMT1246 | 0.061767 | 0. | 0.2243 | 0.3473 | 1.413177 | 0.092653 |
| FSEC1 | 0.000382 | 0. | 0.0208 | 0.022 | 0.01523 | 0.001836 |
| HP14X102 | 0.018326 | 0. | 0.0685 | 0.1208 | 0.086806 | 0.029717 |
| HP14X73 | 0.012587 | 0. | 0.0477 | 0.0853 | 0.06204 | 0.020691 |
| HP14X89 | 0.015721 | 0. | 0.0589 | 0.1046 | 0.075819 | 0.025668 |
| Portal Brace | 0.020389 | 0. | 0.1432 | 0.1302 | 0.215686 | 0.032623 |
| STRUTR2R7 | 0.020403 | 0. | 0.1858 | 0.1302 | 0.303562 | 0.032645 |
| TGL0L2 | 1.392646 | 0. | 0.7611 | 0.5887 | 4.564657 | 0.903242 |
| TGL2L6 | 1.443454 | 0. | 0.7637 | 0.6407 | 4.851029 | 0.936199 |
| TGL6L8 | 1.291031 | 0. | 0.7551 | 0.4856 | 3.992047 | 0.837327 |
| W30X116 | 0.007926 | 0. | 0.1178 | 0.1033 | 0.187458 | 0.018116 |
| W30X99 | 0.006246 | 0. | 0.1072 | 0.0814 | 0.153967 | 0.014277 |

Table:  Frame Section Properties 01 - General, Part 4 of 8

Table:  Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| ARL0R1 | 1.442008 | 1.18804 | 1.19625 | 0.89756 | | No |
| ARR1R3 | 1.380691 | 1.124189 | 1.20675 | 0.89798 | | No |
| ARR3R4 | 1.319954 | 1.06015 | 1.21826 | 0.8978 | | No |
| ARR4R7 | 1.259211 | 0.995372 | 1.23104 | 0.89695 | | No |
| Cable | 1. | 1. | 1. | 1. | 0. | No |
| DIAR1 | 0.415201 | 0.060745 | 1.16715 | 0.24705 | | No |
| DIAR2R7 | 0.354102 | 0.051609 | 1.16189 | 0.24707 | | No |
| FLBM37 | 1.219316 | 0.103804 | 2.5254 | 0.29556 | | No |
| FLBM5 | 1.345766 | 0.11767 | 2.56712 | 0.3031 | | No |
| FLBMT0 | 0.884589 | 0.06674 | 2.37588 | 0.26601 | | No |
| FLBMT1246 | 1.55867 | 0.140869 | 2.62606 | 0.31319 | | No |
| FSEC1 | 0.017346 | 0.00285 | 0.4073 | 0.09128 | | No |
| HP14X102 | 0.097801 | 0.045602 | 0.49301 | 0.29659 | | No |
| HP14X73 | 0.068287 | 0.031597 | 0.48638 | 0.29103 | | No |
| HP14X89 | 0.084491 | 0.039178 | 0.49044 | 0.29451 | | No |
| Portal Brace | 0.247509 | 0.050944 | 0.92051 | 0.2644 | | No |
| STRUTR2R7 | 0.354102 | 0.051609 | 1.16189 | 0.24707 | | No |
| TGL0L2 | 5.205132 | 1.360108 | 3.7254 | 0.95683 | | No |
| TGL2L6 | 5.502079 | 1.409543 | 3.76623 | 0.95422 | | No |
| TGL6L8 | 4.613239 | 1.261238 | 3.63259 | 0.96274 | | No |

Table: Frame Section Properties 01 - General, Part 4 of 8

| SectionName | Z33 | Z22 | R33 | R22 | EccV2 | ConcCol |
|---|---|---|---|---|---|---|
| | ft3 | ft3 | ft | ft | ft | |
| W30X116 | 0.215982 | 0.028411 | 0.9986 | 0.18365 | | No |
| W30X99 | 0.178582 | 0.022469 | 0.97609 | 0.17673 | | No |

Table: Frame Section Properties 01 - General, Part 5 of 8

Table: Frame Section Properties 01 - General, Part 5 of 8

| SectionName | ConcBeam | Color | TotalWt | TotalMass | FromFile | AMod |
|---|---|---|---|---|---|---|
| | | | Kip | Kip-s2/ft | | |
| ARL0R1 | No | Green | 144.721 | 4.5 | No | 1. |
| ARR1R3 | No | Red | 258.583 | 8.04 | No | 1. |
| ARR3R4 | No | Yellow | 116.26 | 3.61 | No | 1. |
| ARR4R7 | No | Blue | 315.891 | 9.82 | No | 1. |
| Cable | No | Gray8Dark | 35.721 | 1.11 | No | 1. |
| DIAR1 | No | Green | 37.347 | 1.16 | No | 1. |
| DIAR2R7 | No | Yellow | 149.857 | 4.66 | No | 1. |
| FLBM37 | No | Cyan | 40.321 | 1.25 | No | 1. |
| FLBM5 | No | Magenta | 29.037 | 0.9 | No | 1. |
| FLBMT0 | No | White | 21.116 | 0.66 | No | 1. |
| FLBMT1246 | No | Blue | 130.58 | 4.06 | No | 1. |
| FSEC1 | No | Cyan | 0. | 0. | No | 1. |
| HP14X102 | No | Gray8Dark | 18.196 | 0.57 | Yes | 1. |
| HP14X73 | No | Red | 64.898 | 2.02 | Yes | 1. |
| HP14X89 | No | Yellow | 15.83 | 0.49 | Yes | 1. |
| Portal Brace | No | Magenta | 11.864 | 0.37 | No | 1. |
| STRUTR2R7 | No | Gray8Dark | 82.872 | 2.58 | No | 1. |
| TGL0L2 | No | Blue | 261.723 | 8.13 | No | 1. |
| TGL2L6 | No | Magenta | 545.515 | 16.96 | No | 1. |
| TGL6L8 | No | Gray8Dark | 119.827 | 3.72 | No | 1. |
| W30X116 | No | Yellow | 338.379 | 10.52 | No | 1. |
| W30X99 | No | Red | 0. | 0. | No | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| ARL0R1 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR1R3 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR3R4 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| ARR4R7 | 1. | 1. | 1. | 1. | 1. | 1.2 |
| Cable | 1. | 1. | 1. | 1. | 1. | 1. |
| DIAR1 | 1. | 1. | 1. | 1. | 1. | 1. |
| DIAR2R7 | 1. | 1. | 1. | 1. | 1. | 1. |
| FLBM37 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBM5 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBMT0 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FLBMT1246 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| FSEC1 | 1. | 1. | 1. | 1. | 1. | 1. |
| HP14X102 | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Frame Section Properties 01 - General, Part 6 of 8

| SectionName | A2Mod | A3Mod | JMod | I2Mod | I3Mod | MMod |
|---|---|---|---|---|---|---|
| HP14X73 | 1. | 1. | 1. | 1. | 1. | 1. |
| HP14X89 | 1. | 1. | 1. | 1. | 1. | 1. |
| Portal Brace | 1. | 1. | 1. | 1. | 1. | 1. |
| STRUTR2R7 | 1. | 1. | 1. | 1. | 1. | 1. |
| TGL0L2 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| TGL2L6 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| TGL6L8 | 1. | 1. | 1. | 1. | 1. | 1.15 |
| W30X116 | 1. | 1. | 1. | 1. | 1. | 1.1 |
| W30X99 | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Frame Section Properties 01 - General, Part 7 of 8

Table: Frame Section Properties 01 - General, Part 7 of 8

| SectionName | WMod | SectInFile | FileName | GUID |
|---|---|---|---|---|
| ARL0R1 | 1.2 | | | |
| ARR1R3 | 1.2 | | | |
| ARR3R4 | 1.2 | | | |
| ARR4R7 | 1.2 | | | |
| Cable | 1. | | | |
| DIAR1 | 1. | | | |
| DIAR2R7 | 1. | | | |
| FLBM37 | 1.15 | | | |
| FLBM5 | 1.15 | | | |
| FLBMT0 | 1.15 | | | |
| FLBMT1246 | 1.15 | | | |
| FSEC1 | 1. | | | |
| HP14X102 | 1. | HP14X102 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| HP14X73 | 1. | HP14X73 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| HP14X89 | 1. | HP14X89 | C:\Program Files\Computers and Structures\SAP2000 18\aisc13.pro | |
| Portal Brace | 1. | | | |
| STRUTR2R7 | 1. | | | |
| TGL0L2 | 1.15 | | | |
| TGL2L6 | 1.15 | | | |
| TGL6L8 | 1.15 | | | |
| W30X116 | 1.1 | | | |
| W30X99 | 1. | | | |

Table: Frame Section Properties 01 - General, Part 8 of 8

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARL0R1 | Added 2/7/2016 7:18:29 PM |
| ARR1R3 | Added 2/7/2016 8:23:51 PM |
| ARR3R4 | Added 2/7/2016 8:29:59 PM |

Table: Frame Section Properties 01 - General, Part 8 of 8

| SectionName | Notes |
|---|---|
| ARR4R7 | Added 2/7/2016 8:32:35 PM |
| Cable | Added 5/31/2016 9:59:30 PM |
| DIAR1 | Added 2/7/2016 10:35:01 PM |
| DIAR2R7 | Added 2/7/2016 10:38:41 PM |
| FLBM37 | Added 9/28/2014 7:12:14 PM |
| FLBM5 | Added 9/28/2014 7:13:11 PM |
| FLBMT0 | Added 9/28/2014 7:07:51 PM |
| FLBMT1246 | Added 9/28/2014 7:10:48 PM |
| FSEC1 | Added 9/27/2014 9:39:49 PM |
| HP14X102 | Imported 9/28/2014 8:17:56 PM from AISC13.pro |
| HP14X73 | Imported 9/28/2014 8:18:59 PM from AISC13.pro |
| HP14X89 | Imported 9/28/2014 8:19:10 PM from AISC13.pro |
| Portal Brace | Added 2/7/2016 10:01:07 PM |
| STRUTR2R7 | Added 2/7/2016 10:08:13 PM |
| TGL0L2 | Added 2/7/2016 6:44:03 PM |
| TGL2L6 | Added 2/7/2016 6:56:25 PM |
| TGL6L8 | Added 2/7/2016 7:04:47 PM |
| W30X116 | Added 2/7/2016 5:37:44 PM |
| W30X99 | Added 2/7/2016 5:34:08 PM |

Table: Link Property Definitions 01 - General, Part 1 of 3

Table: Link Property Definitions 01 - General, Part 1 of 3

| Link | LinkType | Mass | Weight | RotInert1 | RotInert2 | RotInert3 |
|---|---|---|---|---|---|---|
| | | Kip-s2/ft | Kip | Kip-ft-s2 | Kip-ft-s2 | Kip-ft-s2 |
| LINK1 | Linear | 0. | 0. | 0. | 0. | 0. |
| LINK2 | Linear | 0. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 2 of 3

Table: Link Property Definitions 01 - General, Part 2 of 3

| Link | DefLength | DefArea | PDM2I | PDM2J | PDM3I | PDM3J |
|---|---|---|---|---|---|---|
| | ft | ft2 | | | | |
| LINK1 | 1. | 1. | 0. | 0. | 0. | 0. |
| LINK2 | 1. | 1. | 0. | 0. | 0. | 0. |

Table: Link Property Definitions 01 - General, Part 3 of 3

Table: Link Property Definitions 01 - General, Part 3 of 3

| Link | Color | GUID | Notes |
|---|---|---|---|
| LINK1 | Magenta | | Added 2/29/2016 3:34:56 PM |
| LINK2 | Magenta | | Added 2/29/2016 3:34:56 PM |

Table:  Link Property Definitions 02 - Linear

Table:  Link Property Definitions 02 - Linear

| Link | DOF | Fixed | TransKE<br>Kip/ft | RotKE<br>Kip-ft/rad | TransCE<br>Kip-s/ft | RotCE<br>Kip-ft-s/rad | DJ<br>ft |
|---|---|---|---|---|---|---|---|
| LINK1 | U1 | No | 100000. |  | 0. |  |  |
| LINK1 | U2 | No | 100000. |  | 0. |  | 0. |
| LINK1 | U3 | No | 100000. |  | 0. |  | 0. |
| LINK1 | R1 | No |  | 0. |  | 0. |  |
| LINK1 | R2 | No |  | 0. |  | 0. |  |
| LINK1 | R3 | No |  | 0. |  | 0. |  |
| LINK2 | U1 | No | 100000. |  | 0. |  |  |
| LINK2 | U2 | No | 100. |  | 0. |  | 0. |
| LINK2 | U3 | No | 100000. |  | 0. |  | 0. |
| LINK2 | R1 | No |  | 0. |  | 0. |  |
| LINK2 | R2 | No |  | 0. |  | 0. |  |
| LINK2 | R3 | No |  | 0. |  | 0. |  |

Table:  Area Section Properties, Part 1 of 4

Table:  Area Section Properties, Part 1 of 4

| Section | Material | MatAngle<br>Degrees | AreaType | Type | DrillDOF | Thicknes<br>s<br>ft | BendThick<br>ft |
|---|---|---|---|---|---|---|---|
| ASEC1 | A36 | 0. | Shell | Shell-<br>Thin | Yes | 1. | 1. |
| ConcDeck | 4000Psi | 0. | Shell | Shell-<br>Thin | Yes | 0.6667 | 0.6667 |

Table:  Area Section Properties, Part 2 of 4

Table:  Area Section Properties, Part 2 of 4

| Section | Arc<br>Degrees | InComp | CoordSys | Color | TotalWt<br>Kip | TotalMass<br>Kip-s2/ft |
|---|---|---|---|---|---|---|
| ASEC1 |  |  |  | Green | 5333.16 | 165.76 |
| ConcDeck |  |  |  | 12615935 | 2388.592 | 74.24 |

Table:  Area Section Properties, Part 3 of 4

Table:  Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| ConcDeck | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table:  Area Section Properties, Part 4 of 4

Table:  Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 6f5825de-a2dc-451c-a3c5-<br>5df2377eea92 | Added 2/15/2016 12:48:48 PM |

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| ConcDeck | 1. | 1.2 | 1.2 | 6aa652a7-753e-47a5-9f99-1d2dc88054b2 | Added 2/15/2016 12:49:15 PM |

Section 2 US 24 Bridge Load Cases

Table: Load Case Definitions, Part 1 of 3

Table: Load Case Definitions, Part 1 of 3

| Case | Type | InitialCond | ModalCase | BaseCase | MassSource | DesTypeOpt |
|---|---|---|---|---|---|---|
| DEAD | NonStatic | Zero | | | | Prog Det |
| LIVELOAD | LinMoving | Zero | | | | Prog Det |
| PDELTA | NonStatic | Zero | | | | Prog Det |
| BUCKLING_DEAD | LinBuckling | Zero | | | | Prog Det |
| MODAL | LinModal | DEAD | | | | Prog Det |

Table: Load Case Definitions, Part 2 of 3

Table: Load Case Definitions, Part 2 of 3

| Case | DesignType | DesActOpt | DesignAct | AutoType | RunCase | CaseStatus |
|---|---|---|---|---|---|---|
| DEAD | DEAD | Prog Det | Non-Composite | None | Yes | Finished |
| LIVELOAD | VEHICLE LIVE | Prog Det | Short-Term Composite | None | Yes | Finished |
| PDELTA | DEAD | Prog Det | Non-Composite | None | No | Not Run |
| BUCKLING_DEAD | DEAD | Prog Det | Other | None | No | Not Run |
| MODAL | OTHER | Prog Det | Other | None | Yes | Finished |

Table: Load Case Definitions, Part 3 of 3

Table: Load Case Definitions, Part 3 of 3

| Case | GUID | Notes |
|---|---|---|
| DEAD | | |
| LIVELOAD | | |
| PDELTA | | |
| BUCKLING_DEAD | | |
| MODAL | | |

Table: Case - Static 1 - Load Assignments

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| DEAD | Load pattern | DEAD | 1. |

Table: Case - Static 1 - Load Assignments

| Case | LoadType | LoadName | LoadSF |
|---|---|---|---|
| PDELTA | Load pattern | DEAD | 1. |

Table: Case - Static 2 - Nonlinear Load Application

Table: Case - Static 2 - Nonlinear Load Application

| Case | LoadApp | MonitorDOF | MonitorJt |
|---|---|---|---|
| DEAD | Full Load | U1 | 14 |
| PDELTA | Full Load | U1 | 14 |

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 1 of 5

| Case | Unloading | GeoNonLin | ResultsSave | MaxTotal | MaxNull |
|---|---|---|---|---|---|
| DEAD | Unload Entire | None | Final State | 200 | 50 |
| PDELTA | Unload Entire | Large Displ | Final State | 200 | 50 |

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 2 of 5

| Case | MaxIterCS | MaxIterNR | ItConvTol | UseEvStep | EvLumpTol | LSPerIter |
|---|---|---|---|---|---|---|
| DEAD | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |
| PDELTA | 10 | 40 | 1.0000E-04 | Yes | 0.01 | 20 |

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 3 of 5

| Case | LSTol | LSStepFact | StageSave | StageMinIns | StageMinTD |
|---|---|---|---|---|---|
| DEAD | 0.1 | 1.618 | | | |
| PDELTA | 0.1 | 1.618 | | | |

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 4 of 5

| Case | FrameTC | FrameHinge | CableTC | LinkTC | LinkOther | TimeDepMat |
|---|---|---|---|---|---|---|
| DEAD | Yes | Yes | Yes | Yes | Yes | |
| PDELTA | Yes | Yes | Yes | Yes | Yes | |

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| DEAD | 10 | 0.01 | 1. | No |

Table: Case - Static 4 - Nonlinear Parameters, Part 5 of 5

| Case | TFMaxIter | TFTol | TFAccelFact | TFNoStop |
|---|---|---|---|---|
| PDELTA | 10 | 0.01 | 1. | No |

Table: Case - Modal 1 - General, Part 1 of 2

Table: Case - Modal 1 - General, Part 1 of 2

| Case | ModeType | MaxNumModes | MinNumModes | EigenShift | EigenCutoff | EigenTol |
|---|---|---|---|---|---|---|
| | | | | Cyc/sec | Cyc/sec | |
| MODAL | Eigen | 30 | 1 | 0.0000E+00 | 0.0000E+00 | 1.0000E-09 |

Table: Case - Modal 1 - General, Part 2 of 2

Table: Case - Modal 1 - General, Part 2 of 2

| Case | AutoShift |
|---|---|
| MODAL | Yes |

Table: Case - Moving Load 1 - Lane Assignments

Table: Case - Moving Load 1 - Lane Assignments

| Case | Assign Num | VehClass | ScaleFactor | MinLoaded | MaxLoaded | NumLanes |
|---|---|---|---|---|---|---|
| LIVELOAD | 1 | HL93_ALL | 1. | 0 | 2 | 6 |

Table: Case - Moving Load 2 - Lanes Loaded

Table: Case - Moving Load 2 - Lanes Loaded

| Case | AssignNum | Lane |
|---|---|---|
| LIVELOAD | 1 | CENLANES |
| LIVELOAD | 1 | CNTLANE2 |
| LIVELOAD | 1 | LFTLANE1 |
| LIVELOAD | 1 | LFTLANE2 |
| LIVELOAD | 1 | RGTLANE1 |
| LIVELOAD | 1 | RTLANE2 |

Table: Area Section Properties, Part 1 of 4

Table: Area Section Properties, Part 1 of 4

| Section | Material | MatAngle | AreaType | Type | DrillDOF | Thickness | BendThick |
|---|---|---|---|---|---|---|---|
| | | Degrees | | | | ft | ft |
| ASEC1 | A36 | 0. | Shell | Shell-Thin | Yes | 1. | 1. |
| ConcDeck | 4000Psi | 0. | Shell | Shell-Thin | Yes | 0.6667 | 0.6667 |

Table: Area Section Properties, Part 2 of 4

Table: Area Section Properties, Part 2 of 4

| Section | Arc Degrees | InComp | CoordSys | Color | TotalWt Kip | TotalMass Kip-s2/ft |
|---|---|---|---|---|---|---|
| ASEC1 | | | | Green | 5333.16 | 165.76 |
| ConcDeck | | | | 12615935 | 2388.592 | 74.24 |

Table: Area Section Properties, Part 3 of 4

Table: Area Section Properties, Part 3 of 4

| Section | F11Mod | F22Mod | F12Mod | M11Mod | M22Mod | M12Mod | V13Mod |
|---|---|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| ConcDeck | 1. | 1. | 1. | 1. | 1. | 1. | 1. |

Table: Area Section Properties, Part 4 of 4

Table: Area Section Properties, Part 4 of 4

| Section | V23Mod | MMod | WMod | GUID | Notes |
|---|---|---|---|---|---|
| ASEC1 | 1. | 1. | 1. | 6f5825de-a2dc-451c-a3c5-5df2377eea92 | Added 2/15/2016 12:48:48 PM |
| ConcDeck | 1. | 1.2 | 1.2 | 6aa652a7-753e-47a5-9f99-1d2dc88054b2 | Added 2/15/2016 12:49:15 PM |

Section 3 US 24 Bridge Modal Analysis Output

Table: Modal Load Participation Ratios

Table: Modal Load Participation Ratios

| OutputCase | ItemType | Item | Static Percent | Dynamic Percent |
|---|---|---|---|---|
| MODAL | Acceleration | UX | 99.7876 | 56.8782 |
| MODAL | Acceleration | UY | 99.7729 | 55.5977 |
| MODAL | Acceleration | UZ | 95.4678 | 17.9913 |

Table: Modal Participating Mass Ratios, Part 1 of 3

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period Sec | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 1.945338 | 0.28182 | 4.900E-18 | 6.877E-05 | 0.28182 |
| MODAL | Mode | 2. | 1.641859 | 2.771E-17 | 0.15365 | 2.345E-17 | 0.28182 |
| MODAL | Mode | 3. | 1.607784 | 0.09449 | 0. | 3.354E-05 | 0.37631 |
| MODAL | Mode | 4. | 1.148779 | 1.661E-17 | 0.00891 | 6.595E-19 | 0.37631 |
| MODAL | Mode | 5. | 1.00383 | 0.14589 | 1.060E-16 | 2.030E-05 | 0.5222 |
| MODAL | Mode | 6. | 0.936634 | 3.151E-17 | 0.00017 | 7.515E-18 | 0.5222 |
| MODAL | Mode | 7. | 0.870946 | 3.139E-05 | 6.446E-18 | 0.02624 | 0.52224 |
| MODAL | Mode | 8. | 0.652339 | 0.00154 | 6.671E-15 | 0.13933 | 0.52378 |
| MODAL | Mode | 9. | 0.556076 | 4.818E-17 | 0.00679 | 2.864E-17 | 0.52378 |
| MODAL | Mode | 10. | 0.54103 | 2.470E-17 | 1.442E-06 | 3.475E-17 | 0.52378 |
| MODAL | Mode | 11. | 0.456406 | 0.00064 | 9.192E-17 | 0.00017 | 0.52442 |

Table: Modal Participating Mass Ratios, Part 1 of 3

| OutputCase | StepType | StepNum | Period Sec | UX | UY | UZ | SumUX |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 12. | 0.425114 | 8.941E-16 | 9.399E-05 | 1.761E-16 | 0.52442 |
| MODAL | Mode | 13. | 0.413113 | 1.824E-15 | 6.507E-05 | 1.137E-16 | 0.52442 |
| MODAL | Mode | 14. | 0.352426 | 8.384E-15 | 0.07429 | 5.664E-15 | 0.52442 |
| MODAL | Mode | 15. | 0.351373 | 7.693E-15 | 2.964E-09 | 2.112E-15 | 0.52442 |
| MODAL | Mode | 16. | 0.310727 | 0.00148 | 2.062E-15 | 0.00489 | 0.52591 |
| MODAL | Mode | 17. | 0.302514 | 3.823E-15 | 0.00026 | 1.868E-15 | 0.52591 |
| MODAL | Mode | 18. | 0.277762 | 1.438E-14 | 0.00022 | 1.440E-14 | 0.52591 |
| MODAL | Mode | 19. | 0.256964 | 8.798E-14 | 0.21877 | 5.042E-14 | 0.52591 |
| MODAL | Mode | 20. | 0.245218 | 0.03091 | 7.719E-14 | 0.00438 | 0.55682 |
| MODAL | Mode | 21. | 0.245169 | 4.397E-14 | 0.06244 | 2.079E-13 | 0.55682 |
| MODAL | Mode | 22. | 0.233681 | 5.603E-16 | 0.00094 | 5.651E-14 | 0.55682 |
| MODAL | Mode | 23. | 0.225049 | 0.01104 | 2.529E-15 | 0.00083 | 0.56786 |
| MODAL | Mode | 24. | 0.218159 | 4.617E-13 | 2.363E-05 | 2.044E-15 | 0.56786 |
| MODAL | Mode | 25. | 0.200153 | 9.087E-16 | 0.01034 | 1.383E-14 | 0.56786 |
| MODAL | Mode | 26. | 0.194539 | 4.720E-14 | 0.00525 | 7.732E-15 | 0.56786 |
| MODAL | Mode | 27. | 0.191342 | 8.180E-15 | 0.01304 | 2.551E-14 | 0.56786 |
| MODAL | Mode | 28. | 0.18975 | 4.522E-14 | 0.00048 | 3.444E-14 | 0.56786 |
| MODAL | Mode | 29. | 0.18761 | 0.00092 | 7.011E-15 | 0.00396 | 0.56878 |
| MODAL | Mode | 30. | 0.178726 | 3.436E-15 | 0.00026 | 1.153E-13 | 0.56878 |

Table: Modal Participating Mass Ratios, Part 2 of 3

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 1. | 4.900E-18 | 6.877E-05 | 4.059E-18 | 0.00126 | 1.052E-17 |
| MODAL | Mode | 2. | 0.15365 | 6.877E-05 | 0.46157 | 2.207E-18 | 1.121E-05 |
| MODAL | Mode | 3. | 0.15365 | 0.0001 | 0. | 0.05213 | 8.473E-20 |
| MODAL | Mode | 4. | 0.16256 | 0.0001 | 0.0034 | 2.160E-20 | 6.599E-05 |
| MODAL | Mode | 5. | 0.16256 | 0.00012 | 1.157E-16 | 0.00206 | 2.440E-16 |
| MODAL | Mode | 6. | 0.16273 | 0.00012 | 0.00011 | 8.085E-18 | 0.01893 |
| MODAL | Mode | 7. | 0.16273 | 0.02636 | 3.191E-18 | 2.195E-07 | 1.468E-18 |
| MODAL | Mode | 8. | 0.16273 | 0.16568 | 3.231E-15 | 1.973E-06 | 7.878E-15 |
| MODAL | Mode | 9. | 0.16952 | 0.16568 | 0.0033 | 2.514E-17 | 8.167E-06 |
| MODAL | Mode | 10. | 0.16952 | 0.16568 | 2.873E-06 | 9.145E-18 | 0.04514 |
| MODAL | Mode | 11. | 0.16952 | 0.16586 | 7.827E-18 | 0.00743 | 6.501E-17 |
| MODAL | Mode | 12. | 0.16961 | 0.16586 | 0.00037 | 1.539E-15 | 0.01877 |
| MODAL | Mode | 13. | 0.16968 | 0.16586 | 0.01206 | 1.950E-15 | 0.00141 |
| MODAL | Mode | 14. | 0.24396 | 0.16586 | 0.05418 | 4.429E-17 | 4.497E-06 |
| MODAL | Mode | 15. | 0.24396 | 0.16586 | 2.054E-07 | 1.912E-14 | 0.00143 |
| MODAL | Mode | 16. | 0.24396 | 0.17075 | 1.261E-19 | 0.00015 | 3.403E-14 |
| MODAL | Mode | 17. | 0.24422 | 0.17075 | 0.00023 | 1.310E-14 | 0.00119 |
| MODAL | Mode | 18. | 0.24444 | 0.17075 | 0.00013 | 1.028E-14 | 0.24666 |
| MODAL | Mode | 19. | 0.46321 | 0.17075 | 0.11494 | 3.440E-16 | 0.00054 |
| MODAL | Mode | 20. | 0.46321 | 0.17513 | 1.182E-14 | 0.00025 | 4.579E-15 |
| MODAL | Mode | 21. | 0.52565 | 0.17513 | 0.04168 | 2.790E-15 | 0.00056 |
| MODAL | Mode | 22. | 0.52659 | 0.17513 | 0.0002 | 8.311E-15 | 0.13031 |
| MODAL | Mode | 23. | 0.52659 | 0.17595 | 3.493E-15 | 0.00676 | 6.356E-14 |
| MODAL | Mode | 24. | 0.52661 | 0.17595 | 2.978E-05 | 1.914E-13 | 0.0166 |

Table: Modal Participating Mass Ratios, Part 2 of 3

| OutputCase | StepType | StepNum | SumUY | SumUZ | RX | RY | RZ |
|---|---|---|---|---|---|---|---|
| MODAL | Mode | 25. | 0.53695 | 0.17595 | 0.00556 | 3.527E-18 | 0.00193 |
| MODAL | Mode | 26. | 0.5422 | 0.17595 | 0.00077 | 8.926E-16 | 0.00042 |
| MODAL | Mode | 27. | 0.55524 | 0.17595 | 0.00112 | 5.307E-17 | 0.00251 |
| MODAL | Mode | 28. | 0.55572 | 0.17595 | 5.045E-05 | 3.497E-15 | 3.841E-05 |
| MODAL | Mode | 29. | 0.55572 | 0.17991 | 4.749E-15 | 8.091E-06 | 4.515E-15 |
| MODAL | Mode | 30. | 0.55598 | 0.17991 | 4.094E-06 | 1.027E-13 | 8.706E-06 |

Table: Modal Participating Mass Ratios, Part 3 of 3

Table: Modal Participating Mass Ratios, Part 3 of 3

| OutputCase | StepType | StepNum | SumRX | SumRY | SumRZ |
|---|---|---|---|---|---|
| MODAL | Mode | 1. | 4.059E-18 | 0.00126 | 1.052E-17 |
| MODAL | Mode | 2. | 0.46157 | 0.00126 | 1.121E-05 |
| MODAL | Mode | 3. | 0.46157 | 0.05339 | 1.121E-05 |
| MODAL | Mode | 4. | 0.46497 | 0.05339 | 7.721E-05 |
| MODAL | Mode | 5. | 0.46497 | 0.05545 | 7.721E-05 |
| MODAL | Mode | 6. | 0.46508 | 0.05545 | 0.019 |
| MODAL | Mode | 7. | 0.46508 | 0.05545 | 0.019 |
| MODAL | Mode | 8. | 0.46508 | 0.05545 | 0.019 |
| MODAL | Mode | 9. | 0.46837 | 0.05545 | 0.01901 |
| MODAL | Mode | 10. | 0.46838 | 0.05545 | 0.06415 |
| MODAL | Mode | 11. | 0.46838 | 0.06288 | 0.06415 |
| MODAL | Mode | 12. | 0.46875 | 0.06288 | 0.08292 |
| MODAL | Mode | 13. | 0.48081 | 0.06288 | 0.08434 |
| MODAL | Mode | 14. | 0.53499 | 0.06288 | 0.08434 |
| MODAL | Mode | 15. | 0.53499 | 0.06288 | 0.08577 |
| MODAL | Mode | 16. | 0.53499 | 0.06303 | 0.08577 |
| MODAL | Mode | 17. | 0.53522 | 0.06303 | 0.08696 |
| MODAL | Mode | 18. | 0.53535 | 0.06303 | 0.33362 |
| MODAL | Mode | 19. | 0.65029 | 0.06303 | 0.33416 |
| MODAL | Mode | 20. | 0.65029 | 0.06328 | 0.33416 |
| MODAL | Mode | 21. | 0.69197 | 0.06328 | 0.33473 |
| MODAL | Mode | 22. | 0.69217 | 0.06328 | 0.46504 |
| MODAL | Mode | 23. | 0.69217 | 0.07004 | 0.46504 |
| MODAL | Mode | 24. | 0.6922 | 0.07004 | 0.48164 |
| MODAL | Mode | 25. | 0.69776 | 0.07004 | 0.48357 |
| MODAL | Mode | 26. | 0.69853 | 0.07004 | 0.48399 |
| MODAL | Mode | 27. | 0.69965 | 0.07004 | 0.4865 |
| MODAL | Mode | 28. | 0.6997 | 0.07004 | 0.48654 |
| MODAL | Mode | 29. | 0.6997 | 0.07005 | 0.48654 |
| MODAL | Mode | 30. | 0.6997 | 0.07005 | 0.48655 |

Table: Modal Participation Factors, Part 1 of 2

Table: Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | RX |
|---|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft | Kip-ft |
| MODAL | Mode | 1. | 1.945338 | -15.498306 | -6.433E-08 | 0.242095 | 2.907E-06 |

Table:  Modal Participation Factors, Part 1 of 2

| OutputCase | StepType | StepNum | Period | UX | UY | UZ | RX |
|---|---|---|---|---|---|---|---|
| | | | Sec | Kip-ft | Kip-ft | Kip-ft | Kip-ft |
| MODAL | Mode | 2. | 1.641859 | -1.532E-07 | 11.69422 | 1.414E-07 | -1002.09197 |
| MODAL | Mode | 3. | 1.607784 | 8.974157 | 1.843E-09 | -0.16908 | -1.771E-07 |
| MODAL | Mode | 4. | 1.148779 | 1.194E-07 | 2.798335 | -2.371E-08 | 82.038883 |
| MODAL | Mode | 5. | 1.00383 | -11.151026 | 3.016E-07 | 0.131531 | -0.000016 |
| MODAL | Mode | 6. | 0.936634 | 1.621E-07 | 0.359254 | -8.003E-08 | -13.912451 |
| MODAL | Mode | 7. | 0.870946 | 0.164114 | 6.708E-08 | 4.728703 | -2.158E-06 |
| MODAL | Mode | 8. | 0.652339 | 1.147153 | -2.344E-06 | 10.897205 | 0.00008 |
| MODAL | Mode | 9. | 0.556076 | 2.073E-07 | 1.724925 | 1.562E-07 | -41.26951 |
| MODAL | Mode | 10. | 0.54103 | 1.427E-07 | -0.029147 | 1.721E-07 | 2.095357 |
| MODAL | Mode | 11. | 0.456406 | 0.743851 | 2.095E-07 | -0.382597 | 2.918E-07 |
| MODAL | Mode | 12. | 0.425114 | 8.964E-07 | -0.207637 | -3.874E-07 | 58.296911 |
| MODAL | Mode | 13. | 0.413113 | -1.269E-06 | -1.926522 | 3.113E-07 | 264.095732 |
| MODAL | Mode | 14. | 0.352426 | 2.669E-06 | 7.65279 | -2.197E-06 | -319.195484 |
| MODAL | Mode | 15. | 0.351373 | -2.483E-06 | -0.008426 | 1.342E-06 | 1.081083 |
| MODAL | Mode | 16. | 0.310727 | 1.121891 | 1.300E-06 | 2.042244 | 2.102E-06 |
| MODAL | Mode | 17. | 0.302514 | 1.784E-06 | -0.503169 | -1.262E-06 | 24.243717 |
| MODAL | Mode | 18. | 0.277762 | -3.473E-06 | 0.437386 | 3.503E-06 | -16.692993 |
| MODAL | Mode | 19. | 0.256964 | 8.739E-06 | 13.934405 | -6.556E-06 | -509.622446 |
| MODAL | Mode | 20. | 0.245218 | 5.138776 | -8.321E-06 | -1.931528 | -0.000145 |
| MODAL | Mode | 21. | 0.245169 | -6.303E-06 | 6.985699 | 0.000013 | -277.332101 |
| MODAL | Mode | 22. | 0.233681 | -7.826E-07 | -0.928845 | 6.940E-06 | 22.56955 |
| MODAL | Mode | 23. | 0.225049 | 3.057414 | 2.271E-06 | -0.838758 | 0.000036 |
| MODAL | Mode | 24. | 0.218159 | -0.00002 | -0.012234 | -1.320E-06 | 17.462826 |
| MODAL | Mode | 25. | 0.200153 | 8.825E-07 | 3.18138 | -3.434E-06 | -121.471866 |
| MODAL | Mode | 26. | 0.194539 | 6.390E-06 | -2.026315 | -2.567E-06 | 34.650261 |
| MODAL | Mode | 27. | 0.191342 | 2.683E-06 | 3.105497 | -4.663E-06 | -34.575269 |
| MODAL | Mode | 28. | 0.18975 | 6.273E-06 | -0.56999 | -5.418E-06 | 5.958077 |
| MODAL | Mode | 29. | 0.18761 | 0.896553 | -2.714E-06 | -1.837404 | 0.000117 |
| MODAL | Mode | 30. | 0.178726 | -1.444E-06 | -0.412503 | -9.915E-06 | -0.464659 |

Table:  Modal Participation Factors, Part 2 of 2

Table:  Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY | RZ | ModalMass | ModalStiff |
|---|---|---|---|---|---|---|
| | | | Kip-ft | Kip-ft | Kip-ft-s2 | Kip-ft |
| MODAL | Mode | 1. | -263.331681 | 0.000023 | 1. | 10.43205 |
| MODAL | Mode | 2. | 0.000011 | 29.637681 | 1. | 14.64496 |
| MODAL | Mode | 3. | 1694.968966 | -2.168E-06 | 1. | 15.2723 |
| MODAL | Mode | 4. | 1.115E-06 | 66.130451 | 1. | 29.91484 |
| MODAL | Mode | 5. | -337.030932 | -0.000112 | 1. | 39.17776 |
| MODAL | Mode | 6. | -0.000021 | -1141.54683 | 1. | 45.00073 |
| MODAL | Mode | 7. | 3.511425 | -7.929E-06 | 1. | 52.04485 |
| MODAL | Mode | 8. | -10.432281 | 0.000626 | 1. | 92.77116 |
| MODAL | Mode | 9. | 0.000038 | -18.670764 | 1. | 127.67054 |
| MODAL | Mode | 10. | -0.000023 | -1571.06947 | 1. | 134.8703 |
| MODAL | Mode | 11. | 640.067378 | -0.000056 | 1. | 189.5207 |
| MODAL | Mode | 12. | 0.000293 | 839.082673 | 1. | 218.4484 |
| MODAL | Mode | 13. | -0.000329 | -234.133665 | 1. | 231.32477 |
| MODAL | Mode | 14. | -0.00005 | 16.514474 | 1. | 317.85194 |

Table: Modal Participation Factors, Part 2 of 2

| OutputCase | StepType | StepNum | RY | RZ | ModalMass | ModalStiff |
|---|---|---|---|---|---|---|
| | | | Kip-ft | Kip-ft | Kip-ft-s2 | Kip-ft |
| MODAL | Mode | 15. | 0.001031 | -277.142197 | 1. | 319.75885 |
| MODAL | Mode | 16. | -90.108195 | -0.001251 | 1. | 408.88602 |
| MODAL | Mode | 17. | 0.000848 | -382.965623 | 1. | 431.38916 |
| MODAL | Mode | 18. | -0.000751 | -3634.943 | 1. | 511.69671 |
| MODAL | Mode | 19. | 0.000143 | -185.833288 | 1. | 597.87966 |
| MODAL | Mode | 20. | -118.162807 | -0.000673 | 1. | 656.53298 |
| MODAL | Mode | 21. | -0.000403 | 184.191866 | 1. | 656.79096 |
| MODAL | Mode | 22. | -0.000682 | -2673.01945 | 1. | 722.95761 |
| MODAL | Mode | 23. | -610.867416 | 0.001932 | 1. | 779.48072 |
| MODAL | Mode | 24. | -0.003267 | 917.691607 | 1. | 829.49691 |
| MODAL | Mode | 25. | -0.000014 | 302.096268 | 1. | 985.45459 |
| MODAL | Mode | 26. | 0.000225 | 128.276496 | 1. | 1043.14956 |
| MODAL | Mode | 27. | 0.000057 | -346.270742 | 1. | 1078.29891 |
| MODAL | Mode | 28. | 0.000443 | 42.646948 | 1. | 1096.46685 |
| MODAL | Mode | 29. | -20.526546 | -0.000394 | 1. | 1121.63023 |
| MODAL | Mode | 30. | 0.002396 | -17.438822 | 1. | 1235.89659 |

Table: Modal Periods And Frequencies

Table: Modal Periods And Frequencies

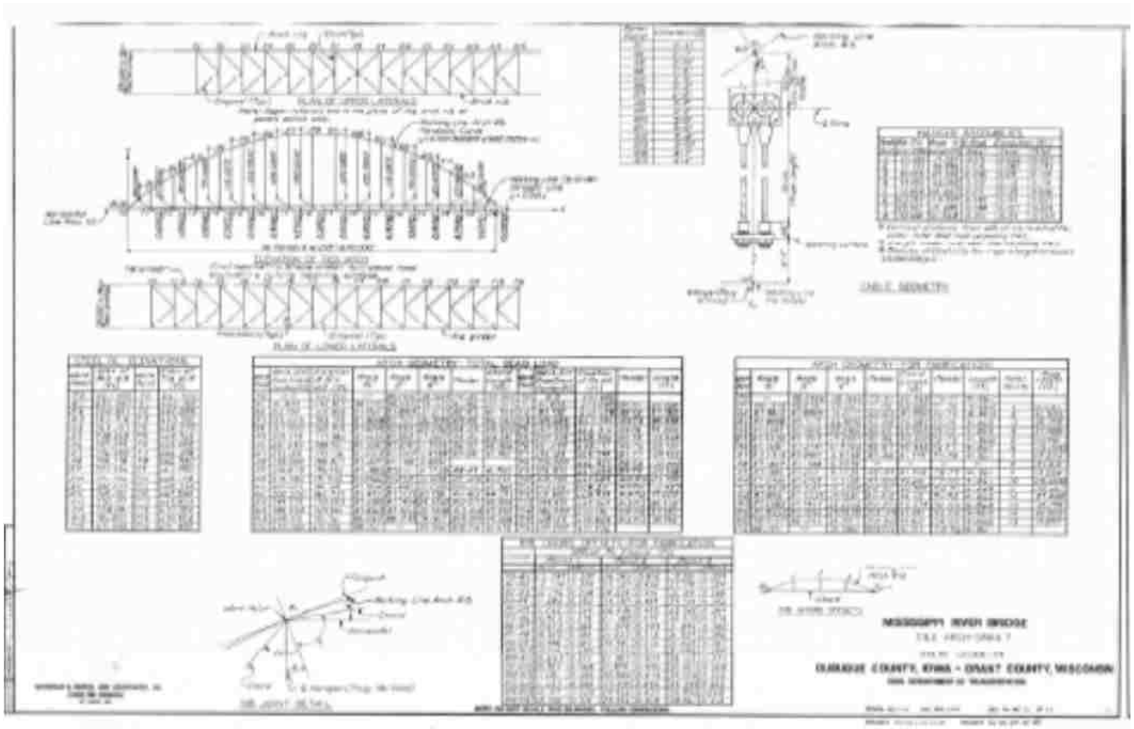
| OutputCase | StepType | StepNum | Period | Frequency | CircFreq | Eigenvalue |
|---|---|---|---|---|---|---|
| | | | Sec | Cyc/sec | rad/sec | rad2/sec2 |
| MODAL | Mode | 1. | 1.945338 | 5.1405E-01 | 3.2299E+00 | 1.0432E+01 |
| MODAL | Mode | 2. | 1.641859 | 6.0907E-01 | 3.8269E+00 | 1.4645E+01 |
| MODAL | Mode | 3. | 1.607784 | 6.2197E-01 | 3.9080E+00 | 1.5272E+01 |
| MODAL | Mode | 4. | 1.148779 | 8.7049E-01 | 5.4694E+00 | 2.9915E+01 |
| MODAL | Mode | 5. | 1.00383 | 9.9618E-01 | 6.2592E+00 | 3.9178E+01 |
| MODAL | Mode | 6. | 0.936634 | 1.0677E+00 | 6.7083E+00 | 4.5001E+01 |
| MODAL | Mode | 7. | 0.870946 | 1.1482E+00 | 7.2142E+00 | 5.2045E+01 |
| MODAL | Mode | 8. | 0.652339 | 1.5329E+00 | 9.6318E+00 | 9.2771E+01 |
| MODAL | Mode | 9. | 0.556076 | 1.7983E+00 | 1.1299E+01 | 1.2767E+02 |
| MODAL | Mode | 10. | 0.54103 | 1.8483E+00 | 1.1613E+01 | 1.3487E+02 |
| MODAL | Mode | 11. | 0.456406 | 2.1910E+00 | 1.3767E+01 | 1.8952E+02 |
| MODAL | Mode | 12. | 0.425114 | 2.3523E+00 | 1.4780E+01 | 2.1845E+02 |
| MODAL | Mode | 13. | 0.413113 | 2.4206E+00 | 1.5209E+01 | 2.3132E+02 |
| MODAL | Mode | 14. | 0.352426 | 2.8375E+00 | 1.7828E+01 | 3.1785E+02 |
| MODAL | Mode | 15. | 0.351373 | 2.8460E+00 | 1.7882E+01 | 3.1976E+02 |
| MODAL | Mode | 16. | 0.310727 | 3.2183E+00 | 2.0221E+01 | 4.0889E+02 |
| MODAL | Mode | 17. | 0.302514 | 3.3056E+00 | 2.0770E+01 | 4.3139E+02 |
| MODAL | Mode | 18. | 0.277762 | 3.6002E+00 | 2.2621E+01 | 5.1170E+02 |
| MODAL | Mode | 19. | 0.256964 | 3.8916E+00 | 2.4452E+01 | 5.9788E+02 |
| MODAL | Mode | 20. | 0.245218 | 4.0780E+00 | 2.5623E+01 | 6.5653E+02 |
| MODAL | Mode | 21. | 0.245169 | 4.0788E+00 | 2.5628E+01 | 6.5679E+02 |
| MODAL | Mode | 22. | 0.233681 | 4.2793E+00 | 2.6888E+01 | 7.2296E+02 |
| MODAL | Mode | 23. | 0.225049 | 4.4435E+00 | 2.7919E+01 | 7.7948E+02 |
| MODAL | Mode | 24. | 0.218159 | 4.5838E+00 | 2.8801E+01 | 8.2950E+02 |
| MODAL | Mode | 25. | 0.200153 | 4.9962E+00 | 3.1392E+01 | 9.8545E+02 |
| MODAL | Mode | 26. | 0.194539 | 5.1404E+00 | 3.2298E+01 | 1.0431E+03 |
| MODAL | Mode | 27. | 0.191342 | 5.2262E+00 | 3.2837E+01 | 1.0783E+03 |

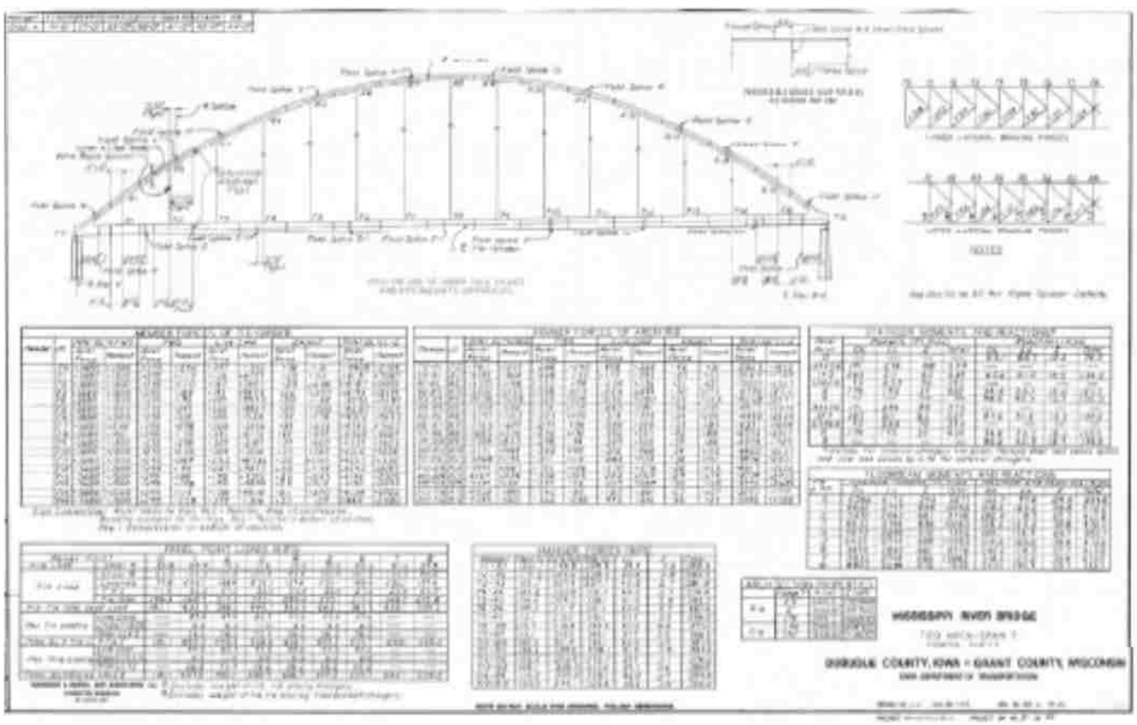
Table: Modal Periods And Frequencies

| OutputCase | StepType | StepNum | Period<br>Sec | Frequency<br>Cyc/sec | CircFreq<br>rad/sec | Eigenvalue<br>rad2/sec2 |
|---|---|---|---|---|---|---|
| MODAL | Mode | 28. | 0.18975 | 5.2701E+00 | 3.3113E+01 | 1.0965E+03 |
| MODAL | Mode | 29. | 0.18761 | 5.3302E+00 | 3.3491E+01 | 1.1216E+03 |
| MODAL | Mode | 30. | 0.178726 | 5.5951E+00 | 3.5155E+01 | 1.2359E+03 |

**APPENDIX E**

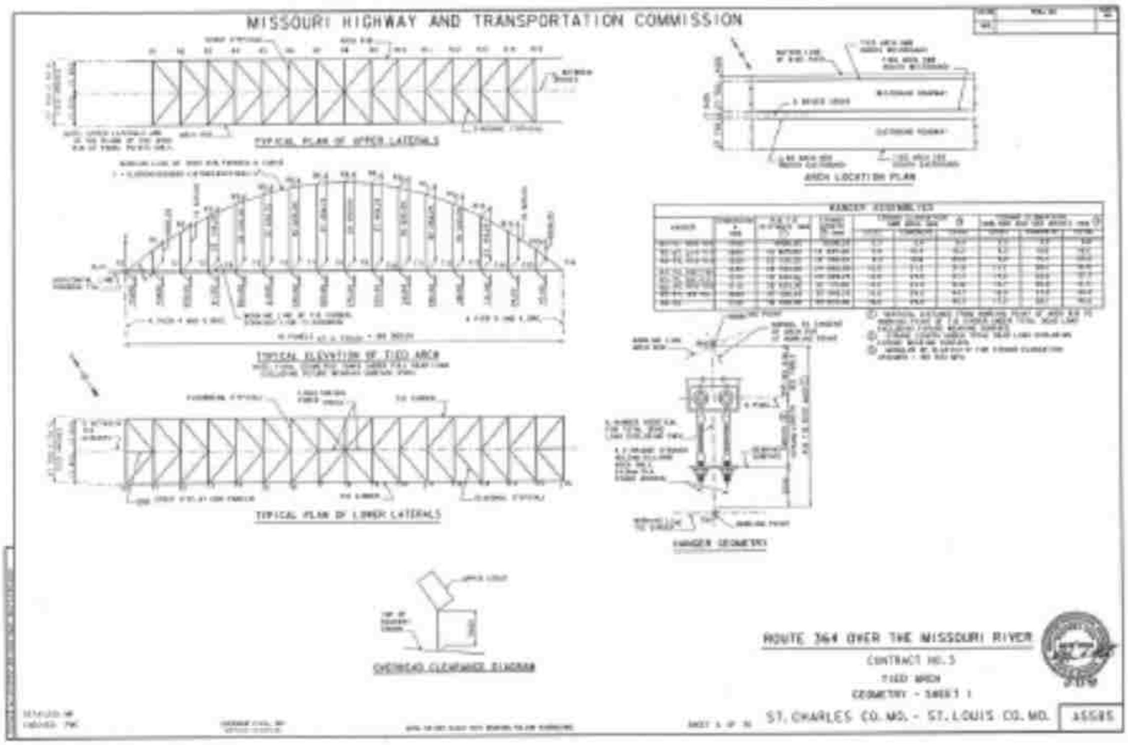
**DESIGN PLANS FOR CITY ISLAND BRIDGE**

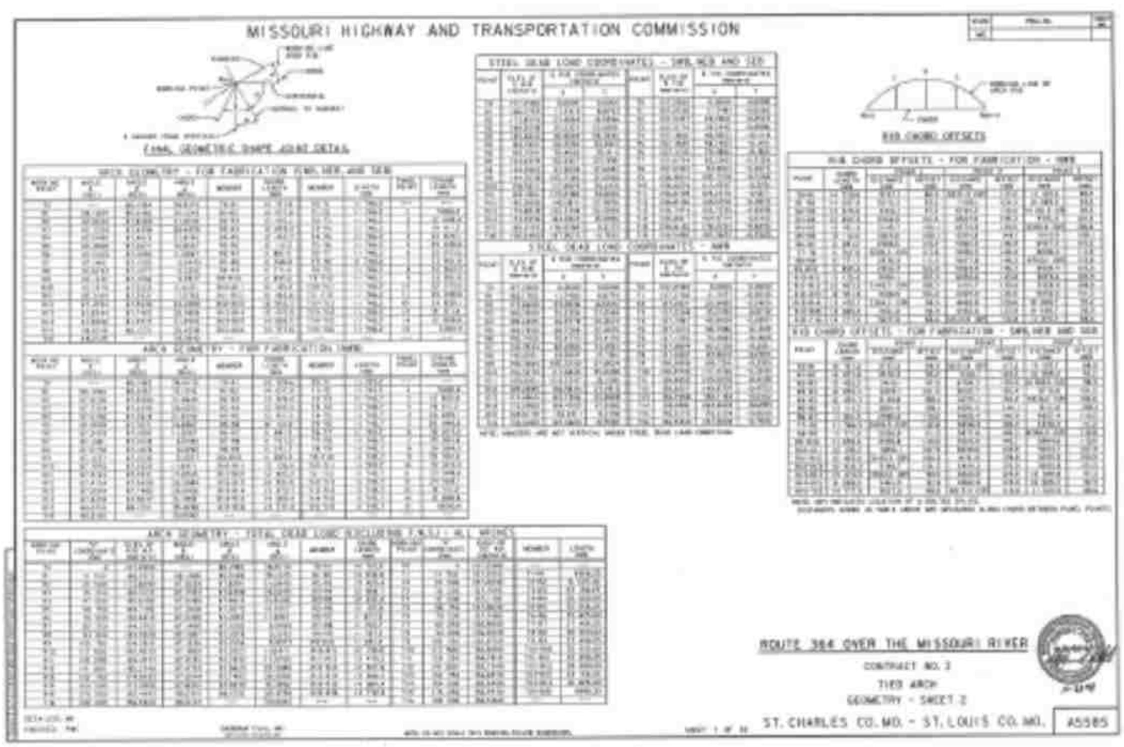

MISSISSIPPI RIVER BRIDGE
DUBUQUE COUNTY, IOWA - GRANT COUNTY, WISCONSIN

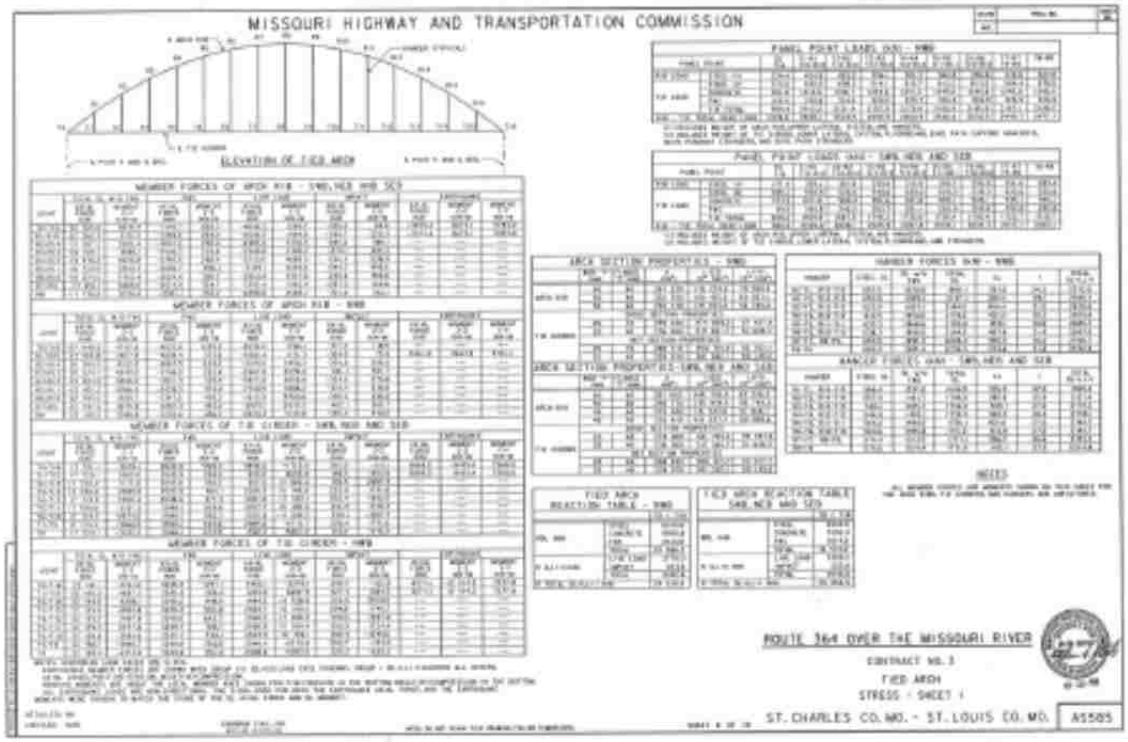

MISSISSIPPI RIVER BRIDGE
DUBUQUE COUNTY, IOWA - GRANT COUNTY, WISCONSIN

**APPENDIX F**

**DESIGN PLANS FOR PAGE AVENUE BRIDGE**

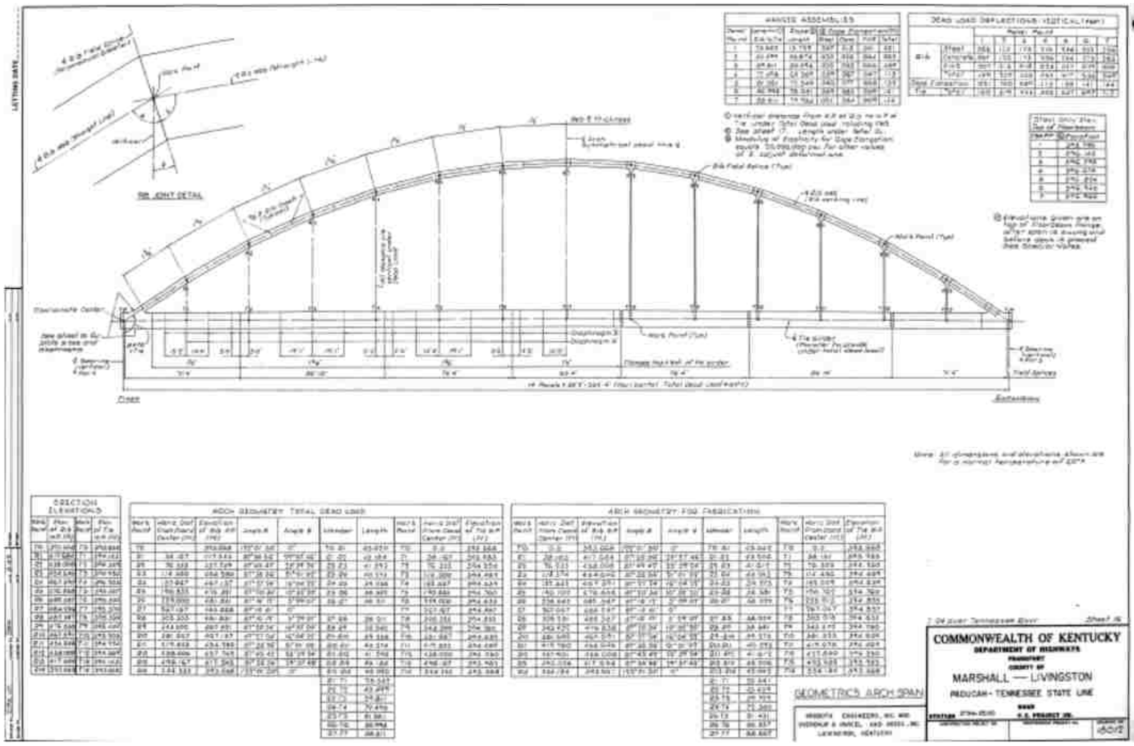

MISSOURI HIGHWAY AND TRANSPORTATION COMMISSION
TYPICAL PLAN OF UPPER LATERALS
ARCH LOCATION PLAN
TYPICAL ELEVATION OF TIED ARCH
HANGER ASSEMBLIES
TYPICAL PLAN OF LOWER LATERALS
HANGER GEOMETRY
OVERHEAD CLEARANCE DIAGRAM
ROUTE 364 OVER THE MISSOURI RIVER
CONTRACT NO. 3
TIED ARCH
GEOMETRY - SHEET 1
ST. CHARLES CO. MO. - ST. LOUIS CO. MO.
A5585

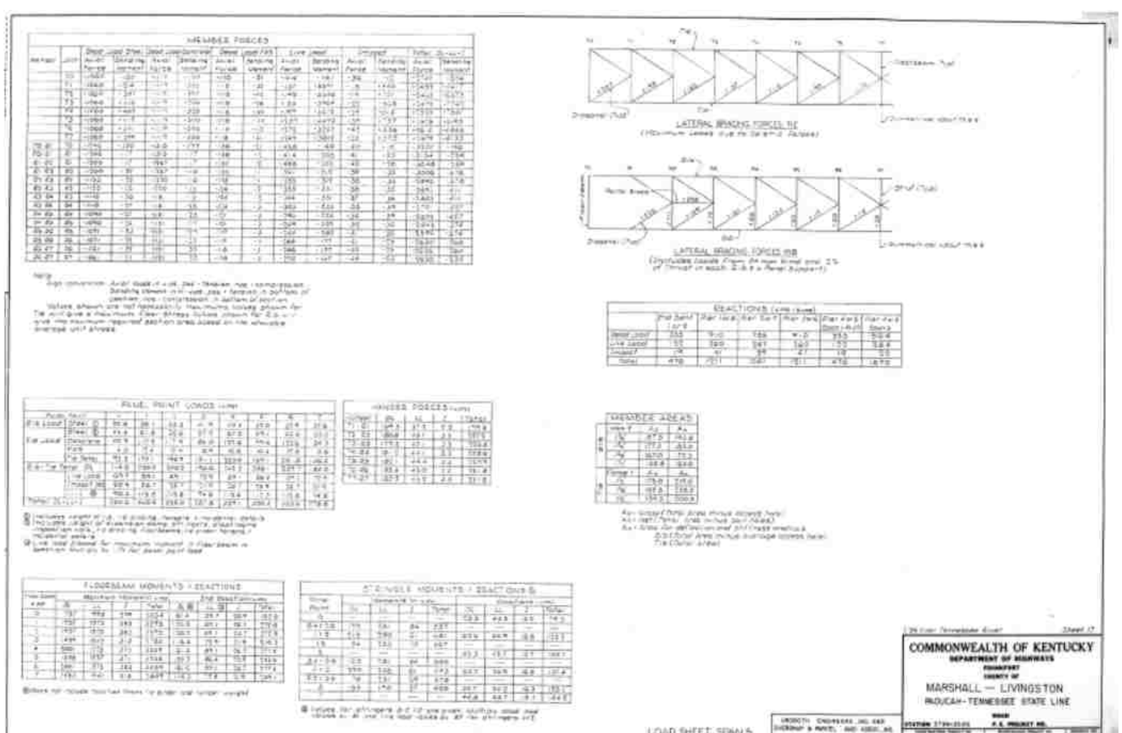

MISSOURI HIGHWAY AND TRANSPORTATION COMMISSION
FINAL GEOMETRIC SHAPE JOINT DETAIL
TIE CHORD OFFSETS
ROUTE 364 OVER THE MISSOURI RIVER
CONTRACT NO. 3
TIED ARCH
GEOMETRY - SHEET 2
ST. CHARLES CO. MO. - ST. LOUIS CO. MO.
A5585


MISSOURI HIGHWAY AND TRANSPORTATION COMMISSION
ELEVATION OF TIED ARCH
PANEL POINT LOADS
MEMBER FORCES OF ARCH RIB
MEMBER FORCES OF TIE GIRDER
ARCH SECTION PROPERTIES
HANGER FORCES
TIED ARCH REACTION TABLE
NOTES
ROUTE 364 OVER THE MISSOURI RIVER
CONTRACT NO. 3
TIED ARCH
STRESS - SHEET 1
ST. CHARLES CO. MO. - ST. LOUIS CO. MO.
A5505

**APPENDIX G**

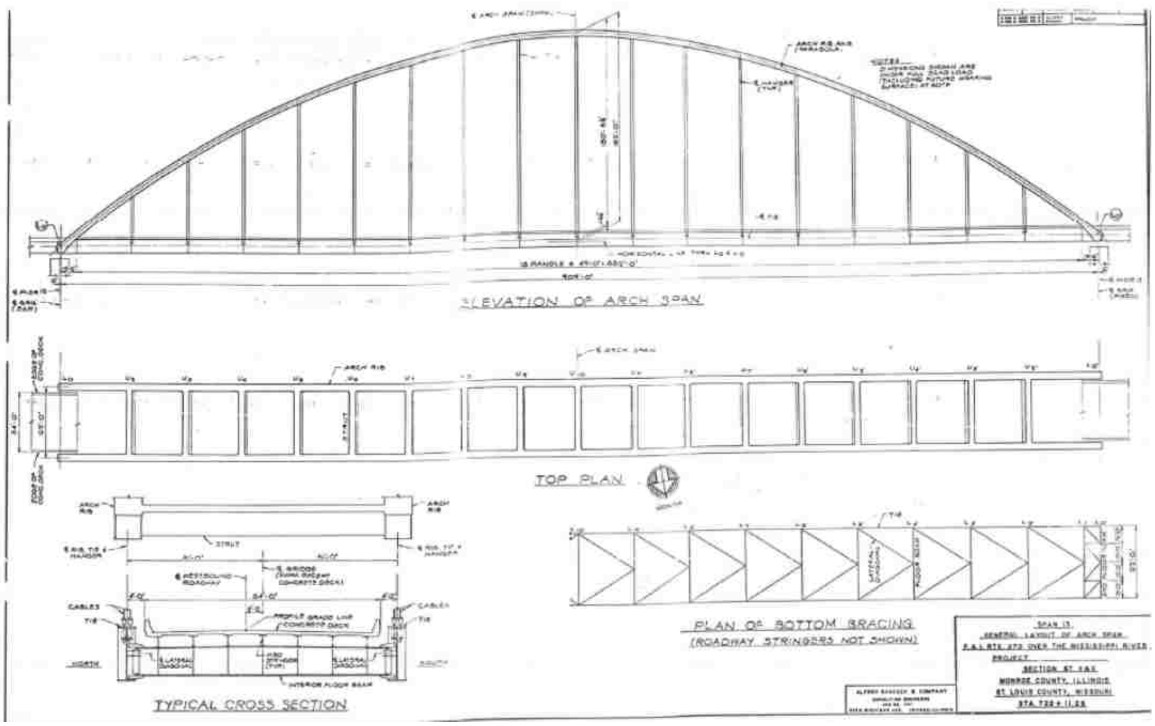
**DESIGN PLANS FOR TENNESSEE RIVER BRIDGE**

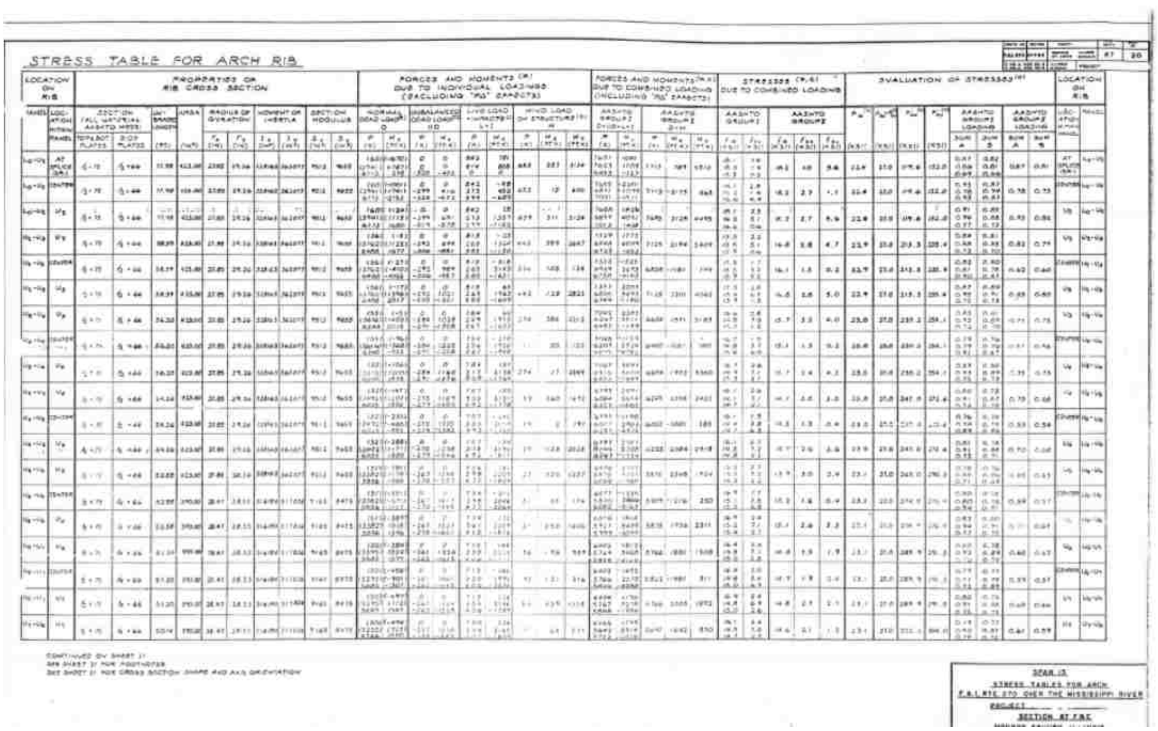

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
MARSHALL — LIVINGSTON
PADUCAH - TENNESSEE STATE LINE
GEOMETRICS ARCH SPAN
ARCH GEOMETRY TOTAL DEAD LOAD
ARCH GEOMETRY FOR FABRICATION
RIB JOINT DETAIL


MEMBER FORCES
LATERAL BRACING FORCES
REACTIONS
MEMBER AREAS
PANEL POINT LOADS
FLOORBEAM MOMENTS + REACTIONS
COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
MARSHALL — LIVINGSTON
PADUCAH - TENNESSEE STATE LINE
LOAD SHEET SPAN 5

APPENDIX H

DESIGN PLANS FOR JEFFERSON BARRACKS BRIDGE


ELEVATION OF ARCH SPAN
TOP PLAN
TYPICAL CROSS SECTION
PLAN OF BOTTOM BRACING
(ROADWAY STRINGERS NOT SHOWN)
SPAN 13
GENERAL LAYOUT OF ARCH SPAN
F.A.I. RTE 270 OVER THE MISSISSIPPI RIVER
SECTION 87 F&S
MONROE COUNTY, ILLINOIS
ST. LOUIS COUNTY, MISSOURI


STRESS TABLE FOR ARCH RIB
SPAN 13
STRESS TABLES FOR ARCH
F.A.I. RTE 270 OVER THE MISSISSIPPI RIVER

## STRESS TABLE FOR ARCH RIB (CONTINUED FROM SHEET 85)

LOCATION ON RIB · PROPERTIES OF RIB CROSS SECTION · FORCES AND MOMENTS DUE TO INDIVIDUAL LOADINGS (EXCLUDING "AE" EFFECTS) · FORCES AND MOMENTS DUE TO COMBINED LOADING (INCLUDING "AE" EFFECTS) · STRESSES DUE TO COMBINED LOADING · EVALUATION OF STRESSES · LOCATION ON RIB

## STRESS TABLE FOR ARCH TIE

LOCATION ON TIE · PROPERTIES OF TIE CROSS SECTION · FORCES AND MOMENTS ("AE" EFFECTS INCLUDED IN INDIVIDUAL LOADINGS) · STRESSES · ALLOWABLE STRESSES · LOCATION ON TIE

FOOTNOTES TO RIB AND TIE STRESS TABLES

ARCH RIB · ARCH TIE

CROSS SECTION SHAPES

## STRESS TABLE FOR BOTTOM LATERALS

(W) 75 PSF ON ARCH RIB; 50 PSF ON TIE AND PARAPET

BOTTOM LATERAL SECTION

## STRESS TABLE FOR HANGERS

* SEE FOOTNOTE (H) TO RIB & TIE STRESS TABLES, SHT. 87

## STRESS TABLE FOR TOP STRUTS

(W) 75 PSF ON ARCH RIB; 50 PSF ON TIE AND PARAPET

(A) FROM AASHTO SPEC.

(S) CATEGORY C DETAIL; 100,000 CYCLES.

TOP STRUT SECTION

## DEAD LOAD REACTIONS ON ARCH

| | FLOOR STEEL | DECK CONCRETE | FUTURE WEARING SURFACE | TOTAL |
|---|---|---|---|---|
| [illegible] | 19 | 22 | 4 | 45 |
| [illegible] | 58 | 91 | 17 | 166 |
| [illegible] | 33 | 184 | 24 | 246 |

(*) ON ONE ARCH

## LIVE LOAD REACTIONS ON ARCH

| | TRUCK LOADING | LANE LOADING: DEFLECTION DIAGRAM | LANE LOADING: CONCENTRATED |
|---|---|---|---|
| [illegible] | 29 | 6 | 31 |
| [illegible] | 101 | 34 | 31 |
| [illegible] | 112 | 54 | 31 |

(*) MAX. ON ONE ARCH INCLUDING REDUCTION FOR MULTIPLE LANES

## REACTIONS ON ARCH BEARINGS

| DIRECTION OF REACTION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| VERTICAL | 5500 | | 270 | 1440 | 1405 | 1345 | | |
| LONGITUDINAL | — | | — | 0 | 590 | 465 | — | |
| TRANSVERSE | — | | — | 580 | 545 | 140 | — | |

(W) 75 PSF ON ARCH RIB; 50 PSF ON TIE AND PARAPET

(X) AT FIXED ... ONLY

(Z) MAX. VALUES; FORCES DO NOT OCCUR SIMULTANEOUSLY.

SPAN 15

STRESS TABLES FOR ARCH

F.A.I. RTE. 270 OVER THE MISSISSIPPI RIVER

PROJECT

SECTION 87 FKE

MONROE COUNTY, ILLINOIS

ST. LOUIS COUNTY, MISSOURI

STA. 722+11.28

ALFRED BENESCH & COMPANY

**INDEX**

**REFERENCES**


Ahlborn, T. M., R. Shuchman, L. L. Sutter, C. N. Brooks, D. K. Harris, J. W. Burns, K. A. Endsley, D. C. Evans, K. Vaghefi, and R. C. Oates. "State of the Practice of Modern Structural Health Monitoring for Bridge: A Comprehensive Review." (2010): n. pag. Web. Michigan Tech.

Airong, Liu, Shen Fulin, Yu Qicai, and Zhang Junping. "Seismic Analysis on Long Span Steel-Truss Arch Bridge with Continuous Rigid-Frame." 2010 International Conference On Optoelectronics and Image Processing (2010): 372-75. Print.

Bazant, Zdenek P., and Luigi Cedolin. Stability of Structures. Dover Publications, 2003. Print.

Binns, Jessica, "Arch Bridge Uses Posttensioned Concrete Girders", Civil Engineering, October 2004, American Society of Civil Engineers, pp. 20-21.

Blakemore, Frank, and Natalie McCombs. "Replacing Amelia's Bridge." Modern Steel Construction 1 Dec. 2012: 28-32. Print.

Blockley, David . *Bridges*. First. Oxford: Oxford University Press, 2010. Print.

Bridge Engineering Handbook, edited by Wai-Fah Chen and Lian Duan, CRC Press, 2000, pp. 17-5, 17-7.

Brabaccia, Tina G. "Making History Again." Better Roads 2009. Print.

Brockenbrough, Roger L., and Federick S. Merritt. Structural Steel Designer's Hanbook. 2nd ed. McGraw-Hill, 1994. Print.

Brownjohn, J. M W. "Structural Health Monitoring of Civil Infrastructure." *Philosophical Transactions of the Royal Society* (2006): 589-622. Web.

Cassity, Patrick, Kenneth Serzan, and Norman McDonald. "Fit to Be Tied." Roads and Bridges 1 Nov. 2003: 28-31. Print.

Cortright, Robert. *Bridging the World*. First. Wilsonville: Bridge Ink, 2003. Print.

*CSI Analysis Reference Manual*. 15th ed. Berkeley: Computer & Structures, 2015. Print.

De Backer, Hans, Amelie Outtier, and Philiippe Van Bogaert. "Buckling Design of Steel Tied-Arch Bridges." Journal of Constructional Steel Research 103 (2014): 159-67. Print.

Dupre, Judith. *Bridges*. First. New York: Black Dog & Leventhal, 1997. Print.

Fu, Chung C., and Shuqing Wang. Computational Analysis and Design of Bridge Structures. CRC, 2015. Print.

Furrer, Martin, Hasbrouck, Greg. “An Innovative Tied Arch Solution to Spanning the Mississippi.” International Bridge Conference, Proceedings of the International Bridge Conference, Pittsburgh, Pennsylvania: Engineer’s Society of Western Pennsylvania, 2011.

Gale, Lori, and Ruchu Hsu. "Tying It All to Together." *Civil Engineering* 1 Mar. 2004: 46-51. Print.

Gastroni, Vincent. "Record Setting Freestanding Arch, a 21st Century Main Street Landmark, Hastings, MN: Redundancy and Service Life." Ohio Transportation Engineering Conference, Financing Our Future, Innovative Bridge Design. Columbus, OH. 25 Oct. 2011. Address.

Garrelts, J.M. "Design of St. Georges Tied Arch Span." *Transactions of the American Society of Civil Engineers* 108.1 (1943): 543-54. Print.

Goguen, Claude. "Understanding AASHTO." National Precast Concrete Association. National Precast Concrete Association, 12 Apr. 2011. Web. 3 Mar. 2016. <http://precast.org/2011/04/understanding-aashto/>.

Hague, Steven T., and Frank P. Blakemore. "Gateway Boulevard over The Cumberland River." 2004 ASCE Structures Congress (2004). Print.

Hague, Steven T., James Selbert, and Richard Ortman. "Icon Rising." Roads & Bridges 1 Nov. 2008: 38-42. Print.

Hall, Dann H., and Richard Lawin. "Design of Steel Tied Arch Bridges: An Alternative." (1985). Print.

Harichandran, Ronald S., Ahmad Hawwari, and Basheer N. Sweidan. "Response of Long-Span Bridges to Spatially Varying Ground Motion." Journal of Structural Engineering 122.5 (1996): 476-84. Print.

Hearn, George, and Rene B. Testa. "Modal Analysis Damage Detection in Structures." *Journal of Structural Engineering* 117.10 (1991): 3042-063. Web.

Hetherly, Pam, and Keith Wood. "A New Landmark for Norridgewock." Structure 1 Apr. 2009: 30-31. Print.

Hong, Robert, and Soliman Khudeira. "Chicago's First Tied Arch Bridge." Practice Periodical on Structural Design and Construction 19.3 (2013): 04014011-7. Print.

Kreyszig, Erwin. *Advanced Engineering Mathematics*. 7th ed. New York: John Wiley & Sons, 1993. Print.

Leonhardt, Fritz . *Brucken/Bridges*. First. Cambridge: The MIT Press, 1982. Print.

Miller, Howard. *The Eads Bridge*. 2nd. St. Louis: Missouri Historical Society Press, 1999. Print.

Liu, Chengyin, John T. DeWolf, and Jeong-Ho Kim. "Development of a Baseline for Structural Health Monitoring for a Curved Post-Tensioned Concrete Box-Girder Bridge." Engineering Structures 31 (2009): 3107-115. Print.

Liu, W. David, Roy A. Imbsen, Richard J. LeBeau, Farid S. Nobari, and Lelio H. Mejia. "Seismic Evaluation of the Tied Arch Bridge Across the Mississippi River on I-40." 13th ASCE Structures Congress (1994): 355-60. Print.

Londono, Nicolas A., David T. Lau, and Muhammad Rahman. "Characteristics of Dynamic Monitoring Data and Observed Behaviour of the Confederation Bridge Due to Operational Load Variations." Canadian Journal of Civil Engineering 40 (2013): 393-409. Print.

Lou, Menglin, Qiang Li, and Shan Gao. "Response Analysis of a Long-Span Arch Bridge under Seismic Traveling Excitation." ASCE Structures Congress 2013 (2013): 2860-871. Print.

Martin, Barney T., and Blaise A. Blabac. "Replacing the Suspender Ropes of a Tied Arch Bridge Using Suspension Bridge Methods." Print.

Miller, Howard S., and Quinta Scott. The Eads Bridge. 2nd ed. St. Louis: Missouri HIstorical Society, 1999. Print.

Moen, Christopher, Elaine Shapiro, and Julia Hart. "Structural Analysis and Load Test of a 19th Century Iron Bowstring Arch-Truss Bridge." *Journal of Bridge Engineering* 18.3 (2013). Print.

Meyer, Christian, ed. *Finite Element Idealization: For Linear Elastic Static and Dynamic Analysis of Structures in Engineering Practice*. New York: ASCE, 1987. Print. Prepared by the Task Committee on Finite Element Idealization.

Nair, R. Shankar. "Buckling and Vibration of Arches and Tied Arches." Journal of Structural Engineering 112.6 (1986): 1429-440. Print.

Robert, Niemietz D., and Bauer J. Michael. "Spanning the Mississippi." *Modern Steel Construction* Sept. 1999. Print.

Nettleton, Douglas A., and John S. Torkelson. "Arch Bridges." FHWA, 1977, Print.

Outtier, A., H. De Backer, and Ph. Van Bogaert. "Assessment of the Out-Of-Plane Imperfections of a Steel Tied Arch Bridge." 5th International Conference On Arch Bridges (2007): 251-56. Print.

Outtier, A., H. De Backer, and Ph. Van Bogaert. "Numerical Approach to the Lateral Buckling of Steel Tied Arch Bridges." 5th International Conference On Arch Bridges (2007): 483-90. Print.

Petzold, E. (2005). “Design, Fabrication and Erection Issues for Long Span Steel Tied Arches: A Case Study,” Time for Steel, Steel for Time, Proceedings, 2005 World Steel Bridge Symposium, National Steel Bridge Alliance, 11 pp.

Priestley, M. J. N., F. Seible, and G. M. Calvi. *Seismic Design and Retrofit of Bridges*. New York: John Wiley & Sons, 1996. Print.

Reid, Robert L. "Replacement Bridge with Unique Cable Pattern Floated into Position." Civil Engineering 1 May 2008: 24-25. Print.

Reid, Robert L. "Structural Health Monitoring Tests Planned for Bridges." *Civil Engineering* Apr. 2012: 38-39. Print.

Ren, Wei-Xin, Tong Zhao, and Issam E. Harik. "Experimental and Analytical Modal Analysis of Steel Arch Bridge." *Journal of Structural Engineering* 130.7 (2004): 1022-031. Print.

Schultz, Arturo, and David Thompson. "Development of an Advanced Structural Monitoring System." *Department of Civil Engineering, University of Minnesota* CTS Project #2010013 (2010). Print.

Spreng, Stefan, “An Investigation of the Structural Efficiency of Tied Arches”, School of the Built Environment, University of Ulster, May 2003.

Tessiatore, Robert, and Kent Nusekabel. "Tied Arch Redecking - Rock Island Centennial Bridge." *Practical Solutions for Bridge Strengthening and Rehabilitation* (1997): 387-96. Print.

"The History of ASTM International." ASTM International. ASTM International. Web. 3 Mar. 2016. <http://www.astm.org/HISTORY/hist_chapter1.html>.

“Tied Arch Bridges”, Technical Advisory T5140.4, US Department of Transportation, Federal Highway Administration, September 28, 1978.

Troitsky, M. S., Orthotropic Bridges, Theory and Design, Second Edition, The James F. Lincoln Arc Welding Foundation, March 1987, pp. 4-21 to 4-23.

Tyrrell, Henry. *History of Bridge Engineering*. First. Chicago : The G. B. Williams CO, 1911. Print.

Tveit, Per. "An Introduction to the Network Arch: Lectures at NTNU Trondheim on August 15, 2006." *Information on the Network Arch*. N.p., n.d. Web. 10 July 2014.

Tveit, P. (2012) Network Arches: The World's Lightest Arch Bridges. Sustainable Transportation Systems: pp. 473-480. doi: 10.1061/9780784412299.0057.

Valenzuela, Matias A., Franco R. Rojas, and Angel C. Aparicio. "Finite-element Nonlinear Geometric Analysis for a Proposal Steel Arch Bridge over the Llobregat River in Barcelona." 576-83. Print.

Wen, Robert K. "Seismic Response of and Design Aids for Arch Bridges." Journal of Structural Engineering 119.10 (1993): 2969-985. Print.

Whelan, Matthew J., Michael V. Gangone, Kerop D. Janoyan, and Ratneshwar Jha. "Real-time Wireless Vibration Monitoring for Operational Modal Analysis of an Integral Abutment Highway Bridge." Engineering Structures (2009): 2224-235. Print.

Wright, William J., PhD. *Steel Bridge Design Handbook: Bridge Steels and Their Mechanical Properties*. Washington D.C.: FHWA, 2012. Print. FHWA-IF-12-052-Vol. 1.

Xanthakos, Petros P. *Theory and Design of Bridges*. John Wiley & Sons, 1994. Print.

Yarnold, M.T., and F.L. Moon. "Temperature-Based Structural Health Monitoring Baseline for Long-Span Bridges." Engineering Structures 86 (2015): 157-67. Print.

Yau, Jong-Dar. "Vibration of Parabolic Tied-Arch Beams Due to Moving Loads." *International Journal of Structural Stability and Dynamics* 6.2 (2006): 193-214. Print.

Yi, Jin-Hak, Dookie Kim, Sunghyuk Go, Jeong-Tae Kim, Jae-Hyung Park, Maria Q. Feng, and Keum-Seok Kang. "Application of Structural Health Monitoring System for Reliable Seismic Performance." Advances in Structural Engineering 15.6 (2012): 955-67. Print.

# VITA

John Edward Finke was born on November 18, 1964 in St. Louis, Missouri, USA. He graduated from the University of Missouri at Rolla (UMR) with a Bachelor of Science Degree in Civil Engineering in December 1989. Upon completion of his Bachelor's degree he worked for the Missouri Highway and Transportation Comission (MHTC) as a construction inspector where he worked on the Rte 370 Bridge over the Missouri River. Following the opening of the bridge, he left St. Louis to work in the Bridge Division for MHTC until 1994. In 1995 he enrolled in the Sever Institute of Technology at Washington University in St. Louis, Missouri. At Washington University he earned a graduate certificate in earthquake engineering, in 1996, and with further focus on structural engineering completed his Masters degree in 1998. While at Washington University he continued to work as an engineering consultant in heavy civil infrastructure industry. Following four semesters as a lectuerer at the Southern Illinois University at Edwardsville, he enrolled in the Doctorate of Engineering in Civil Engineering at UMR completing the degree in December 2016 at the Missouri University of Science and Technology. Throughout his career he has remained active in the American Society of Civil Engineers, Earthquake Engineering Research Institute, and Structural Engineers Association of Kansas and Missouri. He has held registrations as a professional engineer in six states and a license as a structural engineer in Illinois.