1-1-1991

Galloping and broken conductor analysis of transmission lines

Reza Anjam
Iowa State University

Galloping and broken conductor analysis of transmission lines

by

Reza Anjam

A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

Department: Civil and Construction Engineering
Major: Structural Engineering

Iowa State University

Ames, Iowa

1991

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I would like to express my gratitude to my major professors Dr. Mardith Baenziger and Dr. Terry J. Wipf. Their guidance and understanding has been most appreciated.

I would also like to thank Dr. Fouad Fanous and Dr. Frederick Graham for their participation as members of my graduate committee.

A special thank is extended to my good friend Mr. Sanjeev Gupta whose dedication and hard work was instrumental in the success of the project.

Finally my deepest thanks are extended to my parents Dr. Ali Anjam and Mrs. Ashraf Aletaha for their kindness and support.

1. INTRODUCTION

1.1 General Statement of the Problem

Failure of transmission lines is often due to the conductor forces exerted on the supporting structures, the insulators and the towers. These failures can sometimes be contributed to defective design or faulty components. In many other instances, however, a lack of knowledge of the severe loads, which the structure could be subjected to at some point during its lifetime, results in designing the structure for loads much lower than it would experience. In this study, a conductor line analysis was undertaken in association with the failure of the 345 KV Lehigh / Sycamore line, Fig. 1-1, owned by the Iowa Power Company of Des Moines, Iowa (IP) and several other midwest utilities. The project, funded by the owners of the line, was divided into three tasks; a study of the supporting towers, also performed at I.S.U. [1], an analytical study of the conductors and an experimental study of the insulator components. The last two tasks are presented in this thesis.

1.2 Analysis of Conductor Lines

1.2a Types of conductor loads and conductor motions

The conductor loads investigated in this study were due to galloping and loss of line tension due to failure of support structures. These conductor loads, and the conductor

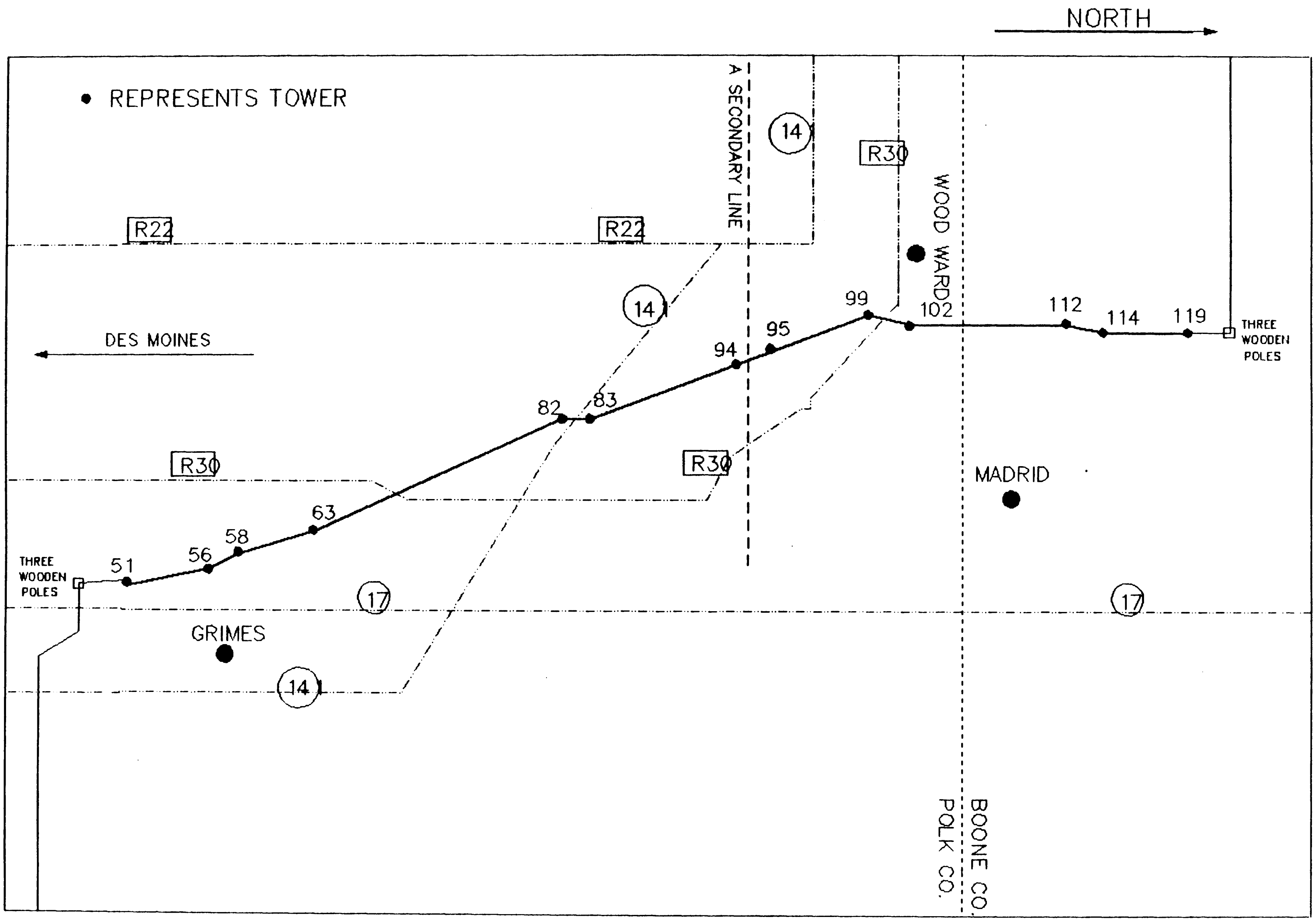


Fig. 1-1 : Lay out of the transmission line motions associated with them, often play a prominent role in the failure of transmission lines. Some of the terms used in describing these conductor loads and motions are defined below.

Galloping motion of a conductor is believed to occur due to flow of air over conductors, especially conductors covered with asymmetrical ice. Although quite complicated, the galloping motion can be simplified to a primarily vertical harmonic motion [2]. Galloping motion magnifies the loads in a conductor, especially the vertical end forces on the supports. Conductor galloping is cyclic in nature and under sustained winds can cause fatigue problems in support components.

Conductor sag can be defined as the distance between the lowest point in the conductor and the cord connecting the end points of the conductor, Fig. 1-2. Conductor sag and shape are closely related to the forces in the conductor. For a given span, conductor sag is inversely related to the horizontal force in the conductor. The shape of a conductor can be defined by catenary formulas [3].

Loss of line tension due to failure of a support structure or a break in a conductor has become known as a broken conductor failure. This is a dynamic problem resulting from a sudden force imbalance due to breaking of a conductor, tower failure or a broken insulator. The two dimensional transmission line towers are designed primarily to support the

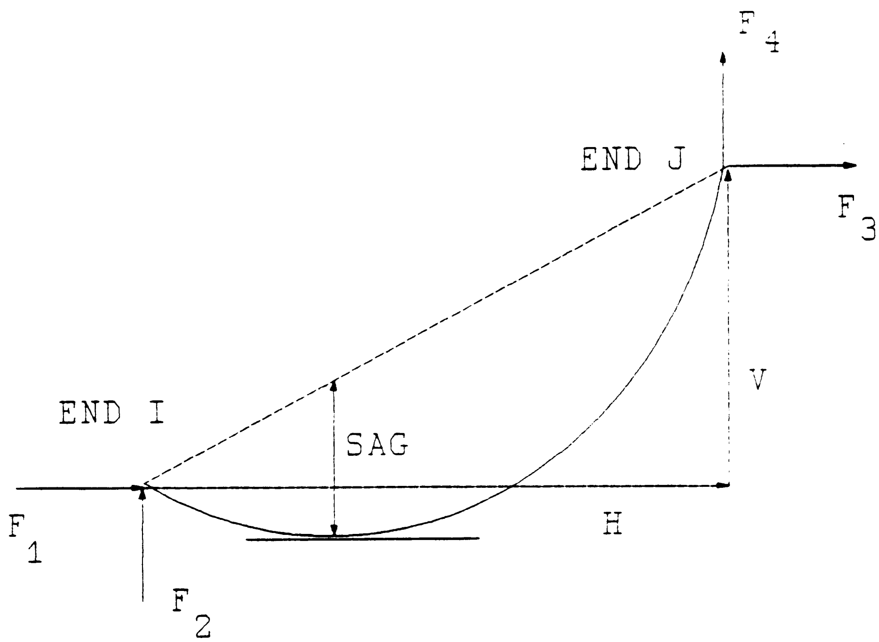


Fig. 1-2 : Conductor sag and end forces

weight of the conductors, with the conductors strung such that the horizontal forces in the conductors of all the spans are equal. Following a break in a conductor line, the adjacent structures experience a force imbalance by virtue of supporting conductors on one side only. This force imbalance is magnified significantly by the dynamic motion associated with the break.

1.2b Types and extent of damage in transmission line systems

The forces from conductors are directly applied to the supporting insulators which are in turn supported by the transmission line towers. In the event of occurrence of galloping or broken conductor, all of the components of a transmission line could be exposed to loads beyond the anticipated design loads. The damage due to these excessive forces can be classified broadly as follows:

- The conductors
  - Excessive stretching
  - Excessive sag
  - Rupture
  - Separation from the insulator
- The insulators
  - Rupture of the insulator rods
  - Shearing of the insulator rods [4]
  - Separation from the tower
- The towers
  - Buckling under longitudinal forces
  - Buckling and turning under torsional forces
  - Shearing of the crossarm
  - Buckling of the bracing
  - Failure of the connections

1.3 The Iowa Power Project

1.3a The description of the Lehigh/ Sycamore 345 kv line

On March 7, 1990, a portion of the Lehigh/ Sycamore 345 kv line, shown in Fig. 1-1, was completely destroyed. The damaged portion , between structures 51 and 119, consisted of spans between 875 feet to 1550 feet. The towers, H frame steel structures (Fig. 1-3), ranged in height from 75 to 130 feet. The conductors were of the type 795 MCM 26/7 ACSR (DRAKE) and were running in three phases with two conductors per phase. The stringing tension for the conductors was 6000 lbs. Fig. 1-4 shows a segment of the line and some of the design parameters.

Following the event, Tower No. 99 was the only structure that remained standing. Towers No. 100 to 119 were deformed away from Tower No. 99, in a northerly direction; and Towers No. 98 to 51 were deformed away from Tower No. 99 in a southerly direction.

The weather conditions that led to this event were described in a report that was received from the state of Iowa climatologist [5]. In short, heavy rainfall and freezing conditions contributed to heavy ice formations on the conductors which along with moderate winds created unfavorable conditions for the line. The amount of ice recorded on the following morning, 14 hours later and at 40 F, was between 1.25 to 1.5 inches. The average wind speed during the event was 12.1 MPH with a peak wind gust of 31 MPH.

From eyewitness accounts, there was a noticeable sag in the line under the ice; and one eyewitness reported to have seen some galloping of the conductors, prior to the collapse of the line. In addition to eyewitness accounts, several trips were made to the sight to document the damage. The data

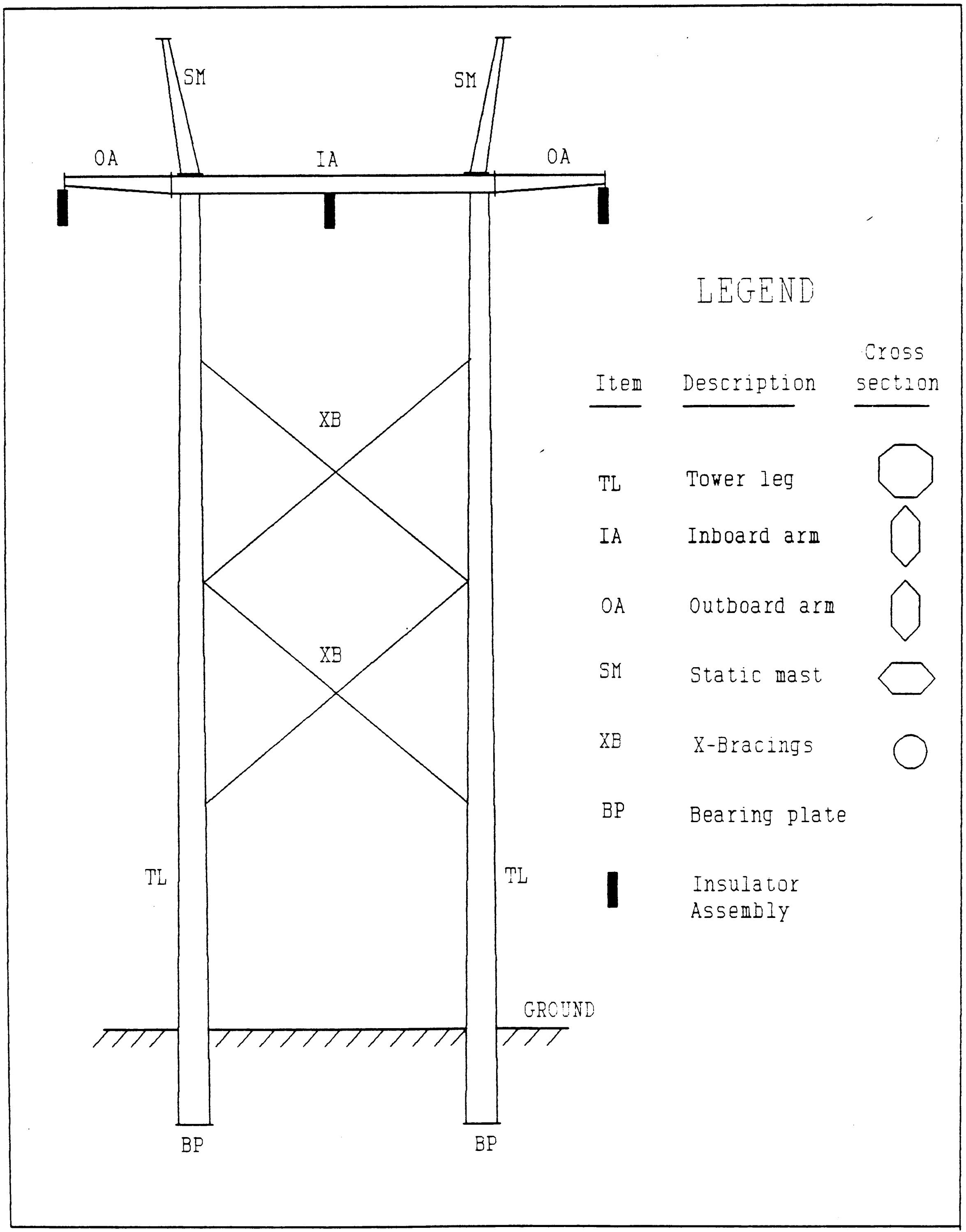


Fig. 1-3 : A typical transmission line tower

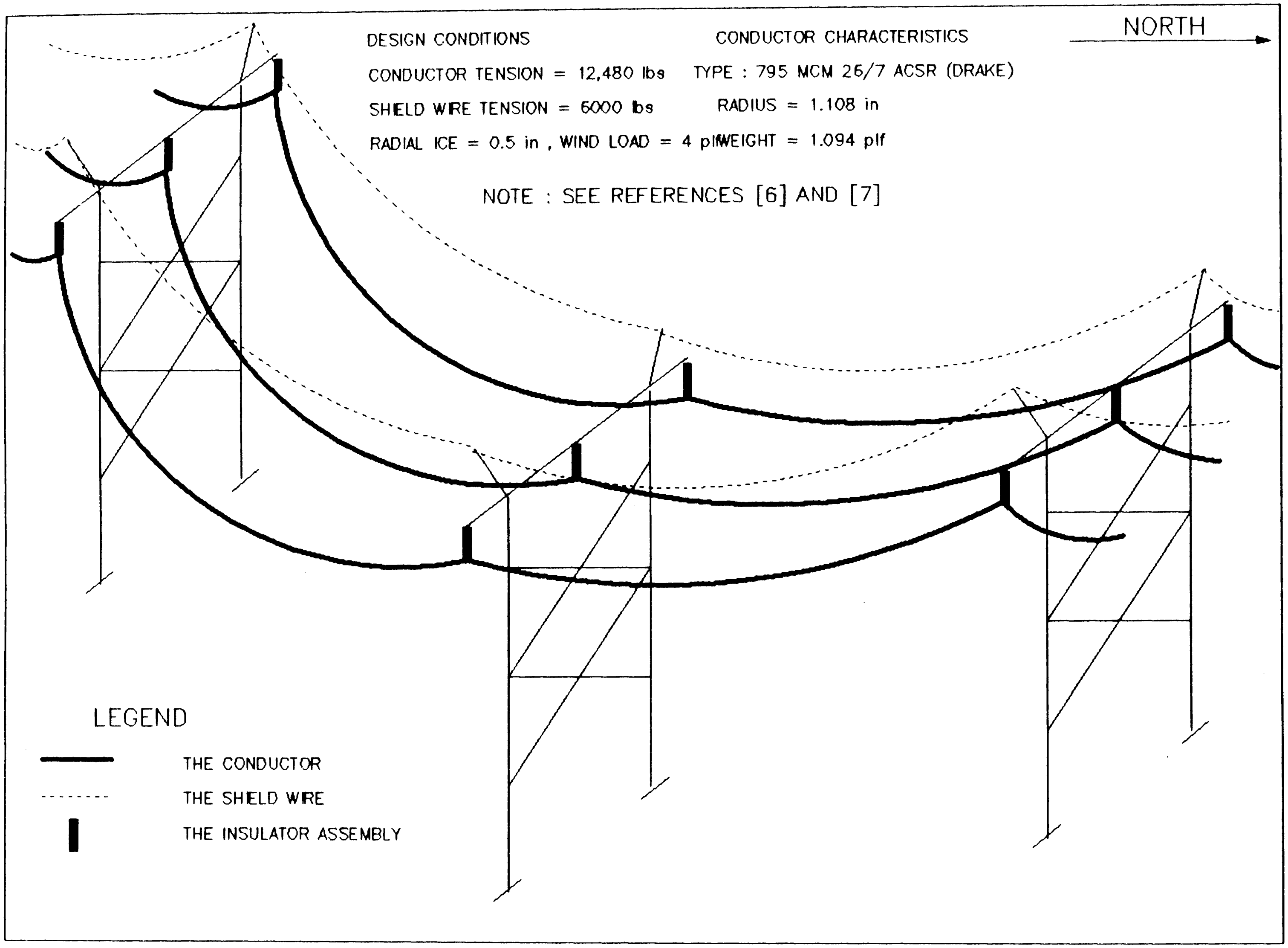


Fig. 1-4 : A segment of the transmission line and the design parameters collected (measurements, pictures, video tapes etc.) were summarized in a report to IP [5]. All the typical damage types, described earlier, were observed throughout the line. Here are some of the noticeable distresses observed:

- Tension failure and bunching of the strands of the conductors and shield wires, Fig. 1-5.
- Separation of conductors from insulators and separation of shield wires from static masts, Fig. 1-6.
- Separation of insulators from towers at inboard and outboard arms, Fig. 1-7.
- Breaking of the insulators into pieces and shattering of the insulator glass bells, Fig. 1-8.
- Buckling and tearing of the bracing, Fig. 1-9.
- Dragging of the crossarm from "A" to "B" (see Fig. 1-10); and dragging of other components, such as the insulators, after contacting the ground.

1.3b The scope of the project

The objective of the project, as outlined in I.S.U.'s proposal accepted by IP, was to document the structural distresses especially in the vicinity of Towers No. 98, 99 and 100 and to determine from analysis the most likely cause of failure. Four tasks were outlined:

1- Documentation of the failures near the structures 98, 99 and 100 to clearly describe the event.

2- Identification of failures, including the structural frame, conductor connections, insulators, etc. Analysis of the documented failures to determine the magnitude of the loads to cause the failure. This analysis includes numerical calculations and experimental tests on components

3- Determination of the possible failure scenarios based on the analysis in part 2 and a structural analysis of the intact system comprised of towers and conductors [1]. An evaluation of the most likely scenario by working backward to determine the type and the magnitude of the forces.

4- A final report that includes the results of all the tasks outlined.

The structural analysis of the intact system, referred to in Task 3, was undertaken by Mr. Sanjeev Gupta [1]. The research presented in this thesis was closely tied to Mr. Gupta's work especially in the areas of providing input loads and verifying the conductor loads obtained by Mr. Gupta's analysis, which was performed on a transmission line finite element analysis package referred to as ETADS [1].

Fig. 1-5 (a) : Conductor tension failure

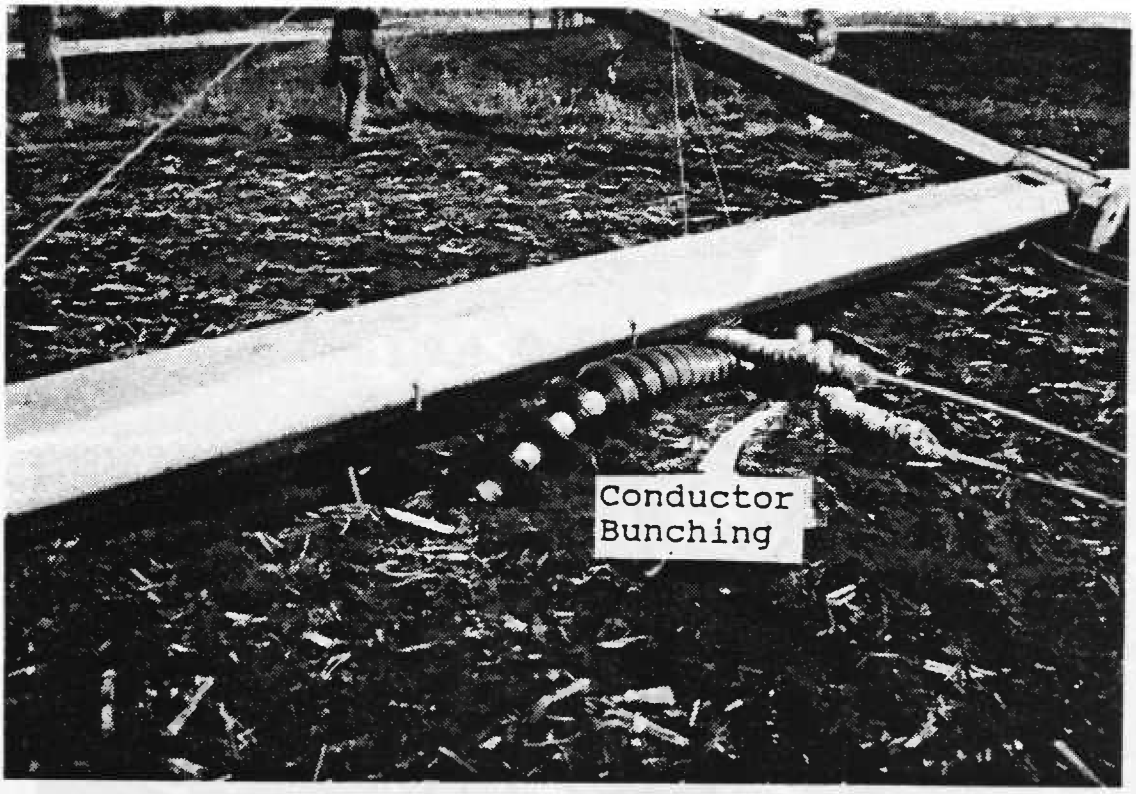
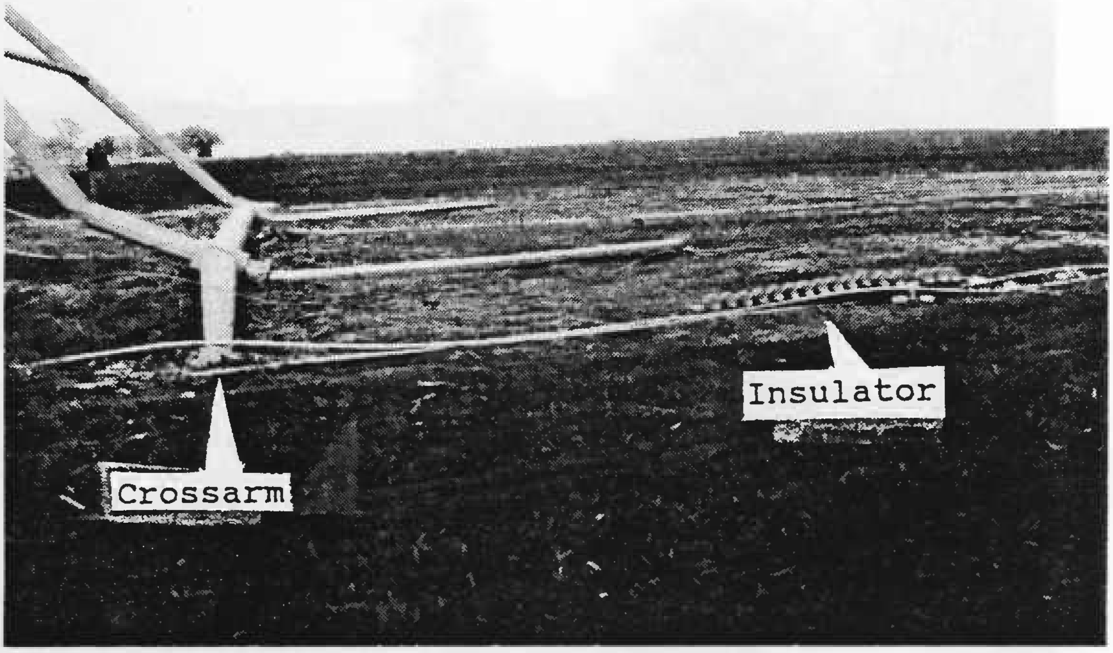


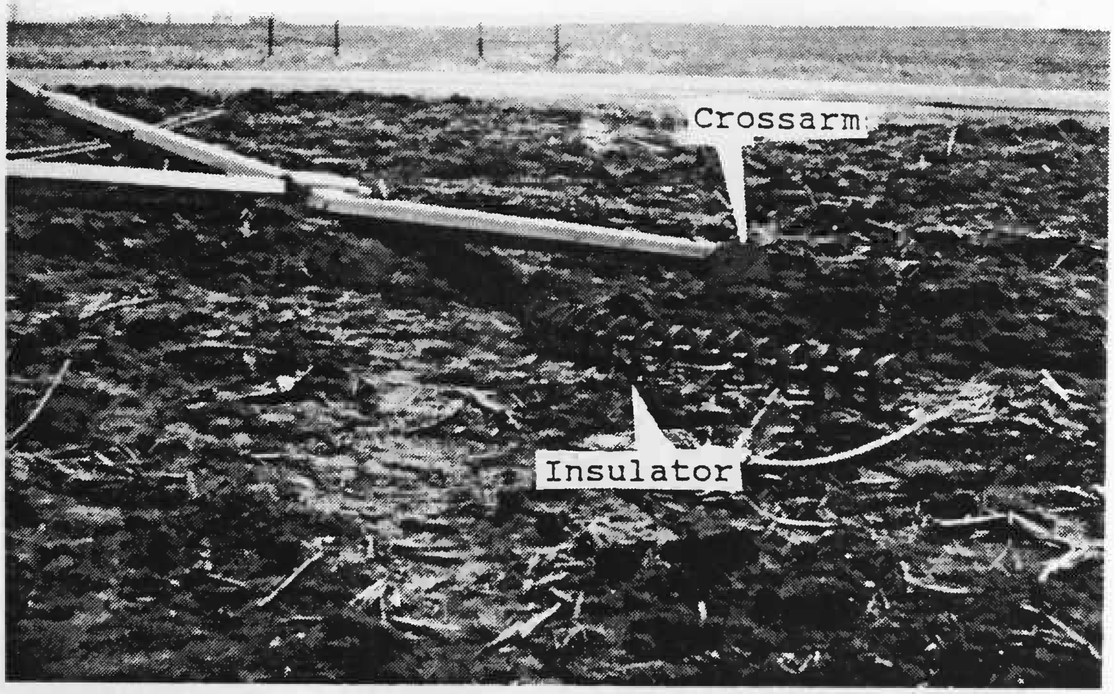
Fig. 1-5 (b) : Bunching of the strands of the conductor

Fig. 1-6 (a) : Conductor after separation from insulator

Fig. 1-6 (b) : Shield wire after separation from static mast



(a)



(b)

Fig. 1-7 : Separation of insulators from the crossarm

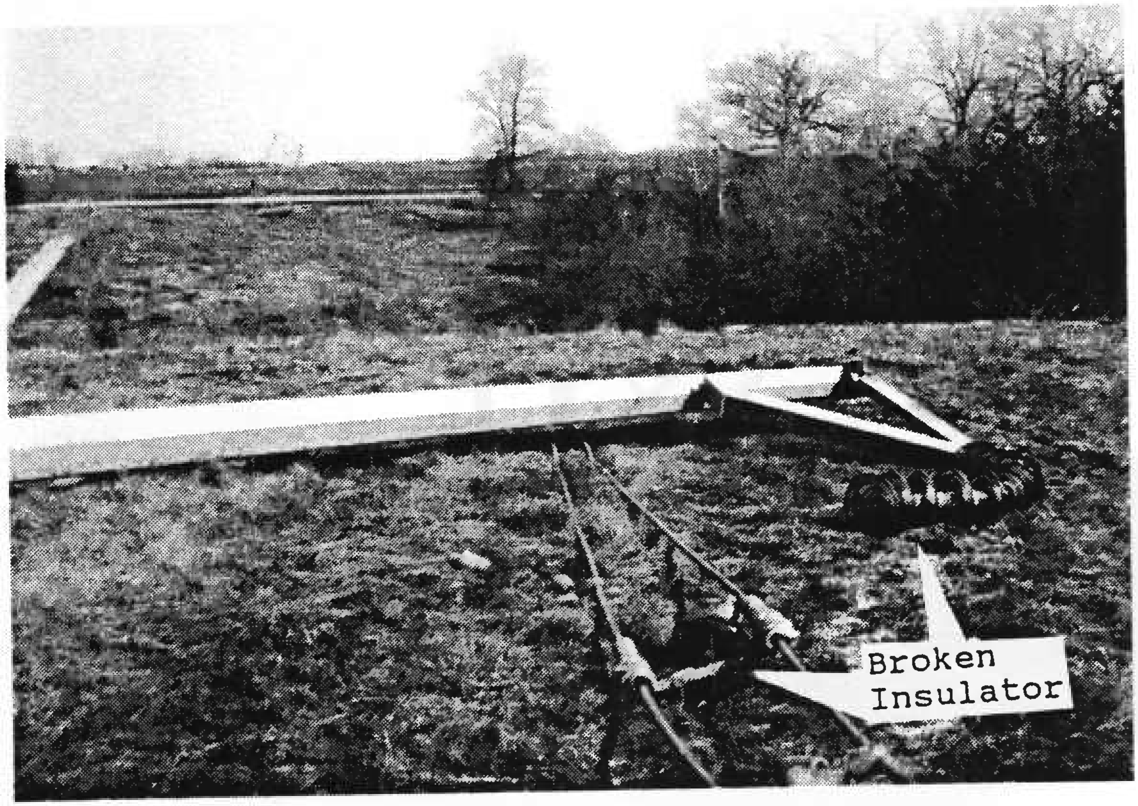


Fig. 1-8 (a) : Broken insulator

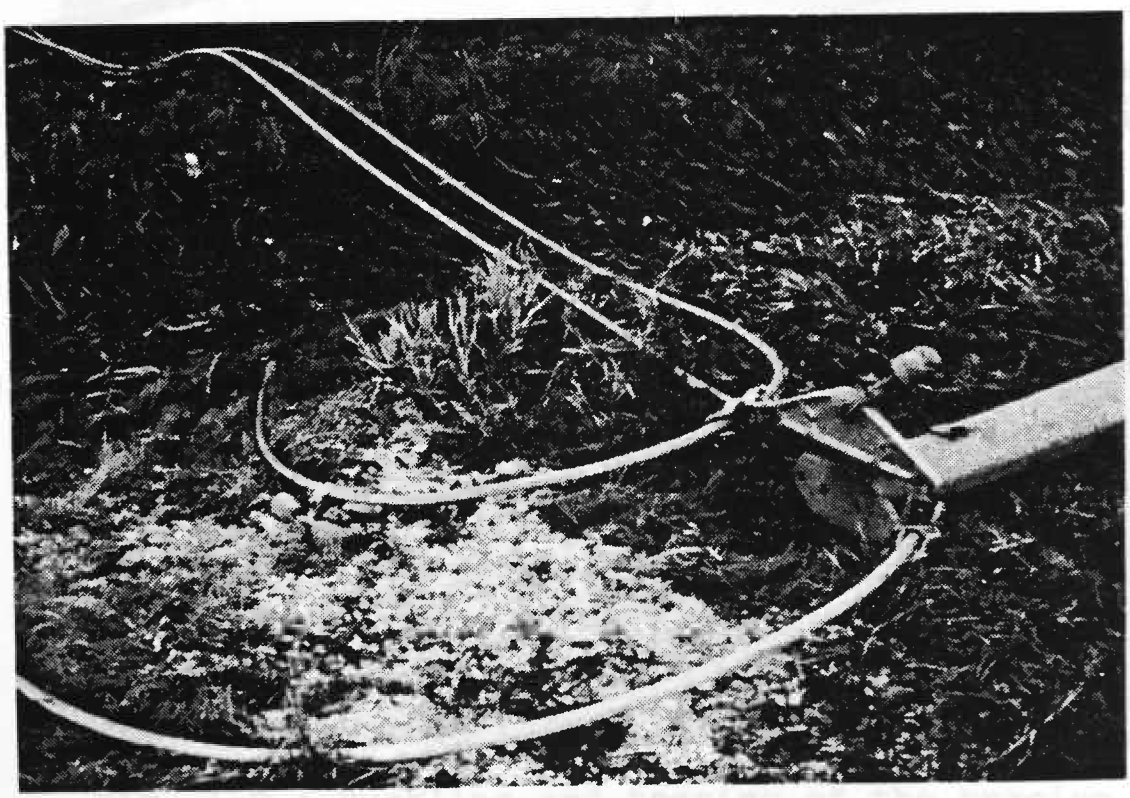
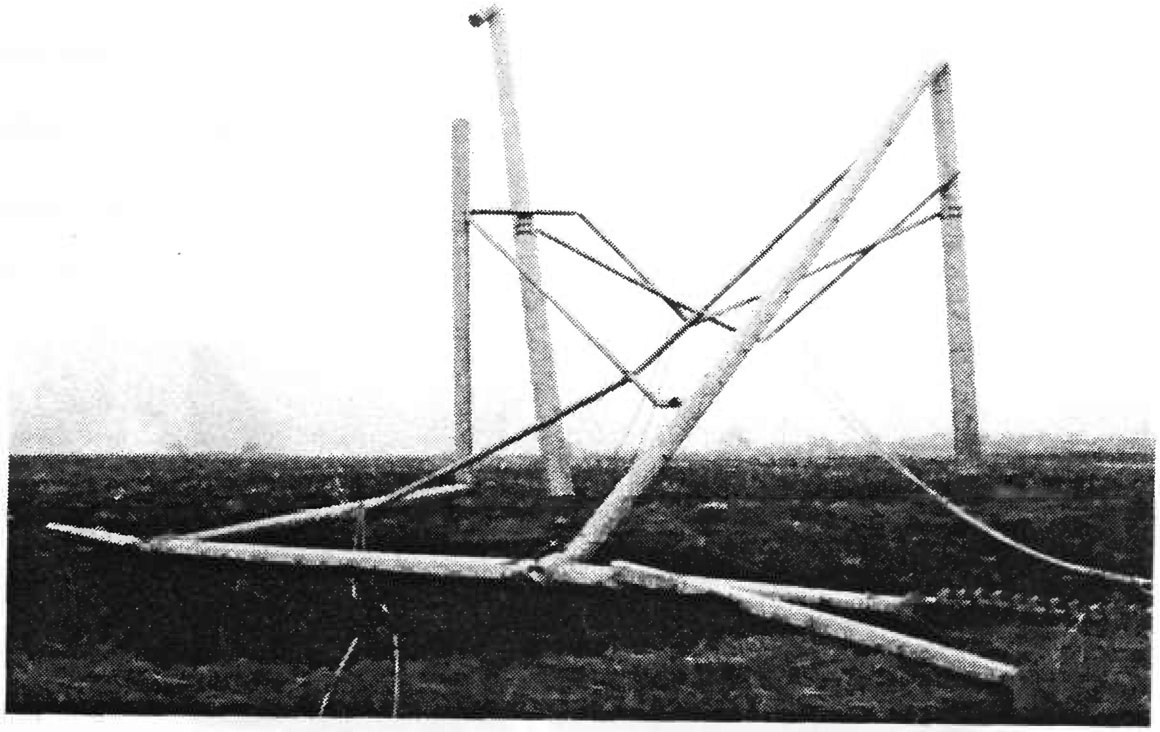
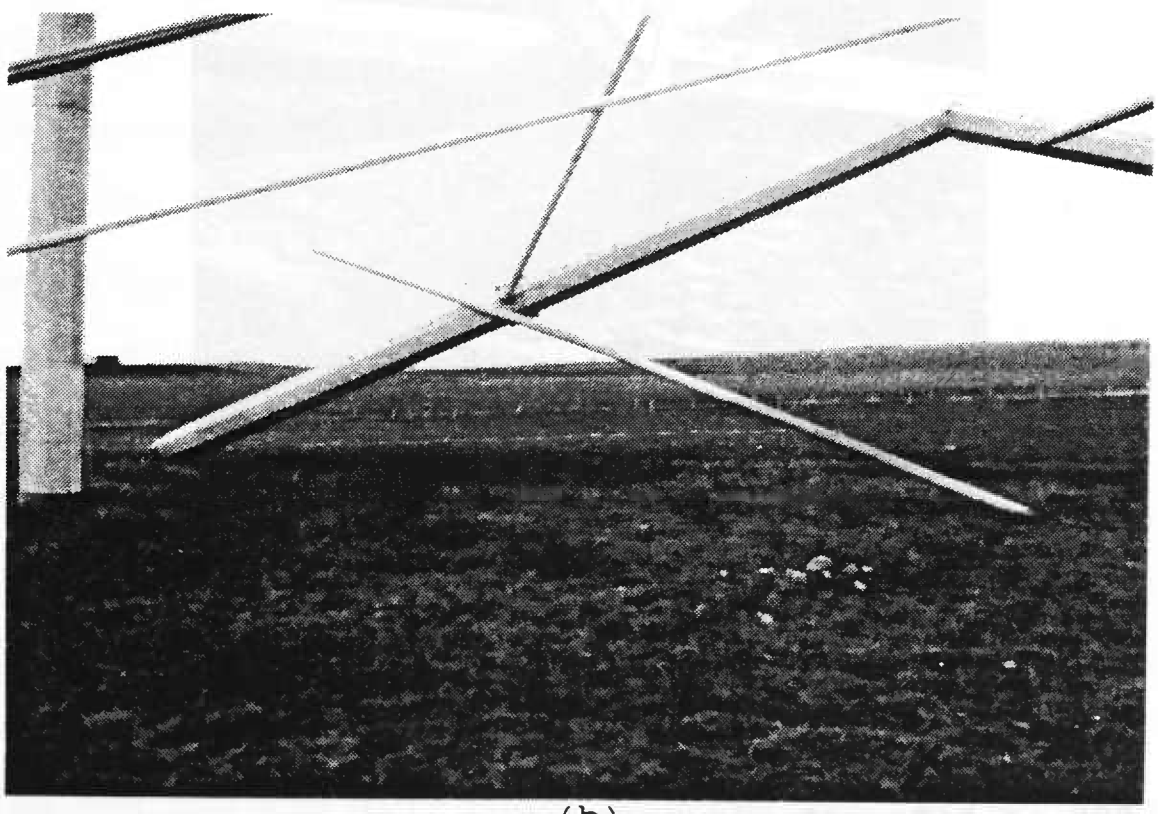


Fig. 1-8 (b) : Shattered insulator glasses



(a)



(b)

Fig. 1-9 : Buckling and tearing of the bracing

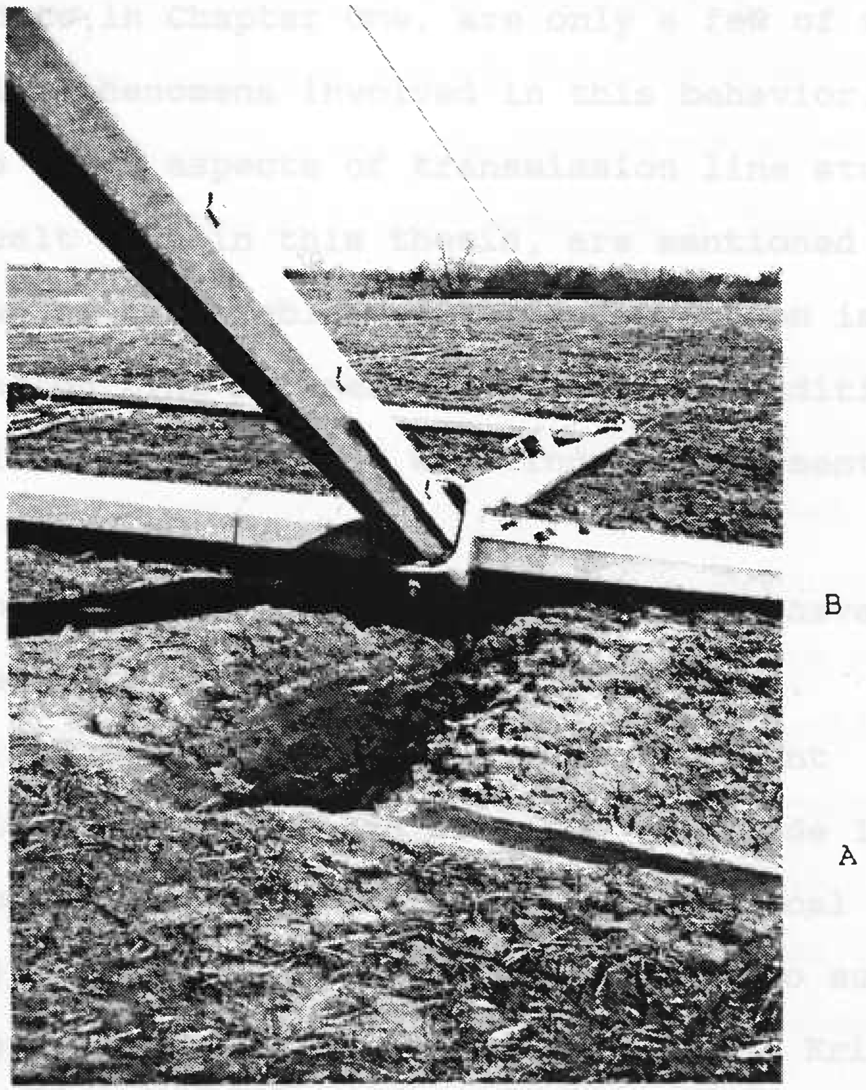


Fig. 1-10 : Drag of the crossarm from "A" to "B"

2. Literature Review and Background

2.1 General

The behavior of a transmission line as a continuous structural systems is a very complicated problem. S. Bhattacharya has discussed the complexity of the problem and some of the variables involved [8]. The conductor motions and loads, referred to in Chapter One, are only a few of the transmission line phenomena involved in this behavior. These and some of the other aspects of transmission line studies, not directly dealt with in this thesis, are mentioned here.

An overview of the problem of conductor motion is given in the Transmission Line Reference Book [6]. In addition to galloping, aeolian vibration and wake-induced movement of the conductors are discussed.

The loading on the conductors, ice and wind, have been studied by researchers such as F.A. Hoffmann and S. Krishnasamy [9,10]. Hoffmann has discussed different categories of ice loading and has compared the guide lines for ice-plus-wind combinations in the National Electrical Safety Code (NESC) [7] with his statistical approach, also suggested by the American Society of Civil Engineers (ASCE). Krishnasamy analyzed the data from the response of actual lines to ice and wind loads, including galloping. He showed the importance of assessing the ice and wind loads more realistically than in the past.

For the study of unbalanced tensions in transmission lines, Campbell has looked at incremental displacement methods [11]. Peyrot and Goulois have developed a similar, but much more general, method [12].

Two theories have been proposed to explain galloping of conductors, Den Hartog theory, which considers a vertical motion mode, and the torsional theory [13]. Neither approach had produced simple formulas for the load transferred to the conductor supports. However, Li Li developed a simplified formula to estimate these loads [2].

The major parameters affecting the peak loads on the transmission line towers, following a break in the conductor, were determined by full scale tests by Haro , Govers and Peyrot [14,15,16] and small scale model tests by Govers, Ferry-Borges and Mozer [15,17,18]. These parameters are : span length, initial tension, insulator length, tower stiffness, number of spans and conductor material. Peyrot developed a semi-analytical formula for the impact factor, ratio of peak tensions to residual tension in the line. Baenziger (formerly Thomas) developed a dynamic model to produce the time history of the broken conductor loads [19].

2.2 The Cable Element

A transmission line system may be analyzed as a system of supports interconnected by conductors. The transmission line

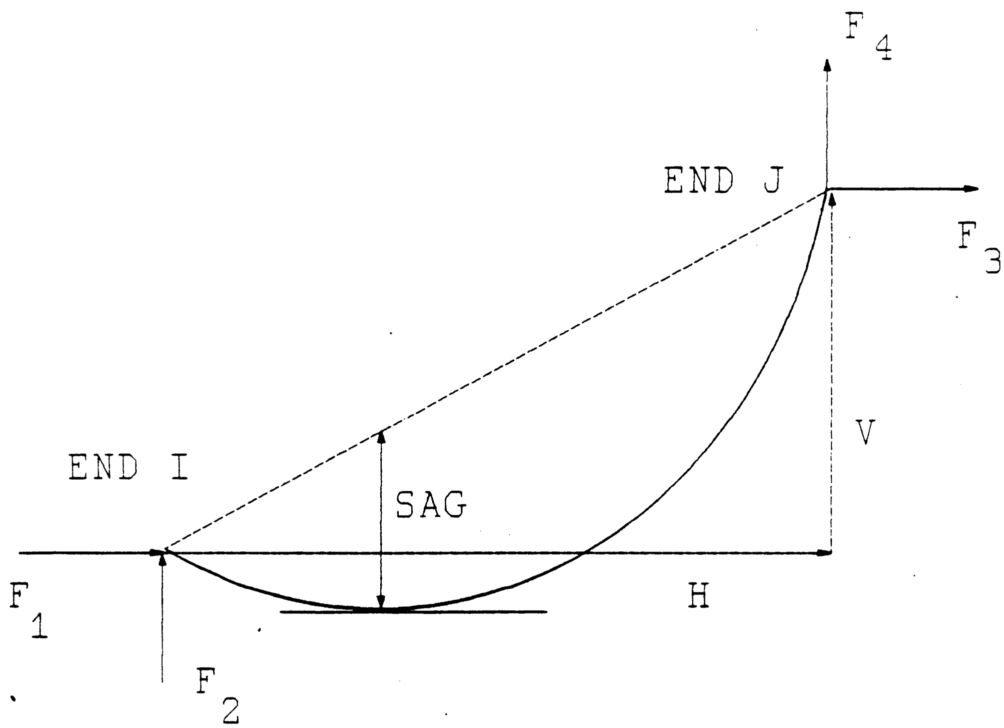


Fig. 2-1 : The cable element

conductors, in turn, can satisfactorily be modeled by lumped masses connected by cable elements, which is a massless four degree of freedom element stretched in a vertical plane in the shape of a catenary, Fig. 2-1. The governing relationships, for the elastic cable element can be found in Appendix A. The relationships in Appendix A are based on a linear cable element. However, the nonlinear properties of conductors, even though complex in nature because the conductors are usually made of interwoven strands of different metals, can be incorporated into the linear cable element by a correction factor applied to the unstretched length of the conductor.

This factor can be obtained from manufacturer's data based on the anticipated load levels [12].

2.3 Related Works by Dr. Alain Peyrot

The major difficulty in the analysis of the cable element is that the unstretched length of the cable can not easily be measured physically and does not easily lend itself to mathematical expressions. Therefore, the analytical relationships for some of the variables of the catenary cable element, given in Appendix A, can not be solved explicitly. Dr. Peyrot used arguments and variables of computer subroutines to describe the relationships between these variables. He, then, used an iterative technique to solve for these variables. The subroutines involved in this technique have been referred to as PCAXLO and PCAFX [12].

2.3a The subroutine PCAXLO

This subroutine uses Eq. A-1 of the catenary relationships, to obtain the actual length of the conductor from installation conditions. Assuming a constant force throughout the conductor, the original length of the conductor can be closely approximated, equation A-7 Appendix A. Where more accuracy is needed, e.g. to obtain valid results in a dynamic analysis, the original length can be exactly obtained by iterative interaction with PCAFX which does not use approximate equations [12].

2.3b The subroutine PCAFX

Knowing the physical properties of the conductor and its original length, from PCAXLO, the cable element end forces can be obtained, for given conductor horizontal and vertical projections, Appendix A.

PCAFX uses catenary relationships and the equations of static to obtain the cable vertical and horizontal projections in terms of the forces at the first point. The misclosure, from comparing the projections obtained here with the known values, is used to obtain linear corrections to be applied to the forces at the first end. This process is repeated until the misclosure is less than a preset tolerance. This iterative approach requires starting values for the forces at the first end. After convergence, the values for the remaining end forces, tensions and the stretched length are obtained. The equations for this solution are presented in Appendix A.

The coordinates of the points along the cable can be obtained by dividing the cable into segments, and using Eqs. A-4 and A-5 with the unstretched length equal to the length of the segment. The lowest point of the conductor, the sag point, occurs where the conductor has a slope of zero, or where the vertical force is zero. This corresponds to a length of segment, equal to the vertical force at the first end divided by the weight of the conductor per unit length.

Another application of PCAFX, discussed by Dr. Peyrot, is an algorithm to find the forces in, and the configuration of a conductor resting on the ground. This algorithm is explained in detail in Chapter 3, where a computer subroutine based on this algorithm is developed.

2.4 Related Works by Dr. Mardith Baenziger

The conductor analysis portion of this project used two computer programs developed by Dr. Baenziger. These programs, used for static and dynamic analysis of conductors, have been referred to as CABLE and CABLE 7, respectively.

2.4a The program CABLE

This program is a user friendly utility which uses the subroutines PCAXLO and PCAFX to analyze one span of a conductor line. The program provides the user with conductor end forces and configuration at stringing and after loading with ice or temperature change. The attachment points of the conductor to the vertical insulators define the location of the end points; and the cartesian coordinate system has its origin at the first point.

The program requires the following information as input:

- Elevation of the attachment points

- The horizontal span
- Cable properties

  Diameter

  Weight

  Cross sectional area
- Material properties (of each material used)

  Modulus of elasticity

  Coefficient of expansion
- Stringing tension
- Temperature at stringing
- Temperature after loading
- Amount of ice (radial thickness or weight)

The input to CABLE is interactive and it has an editing feature for easy modifications.

2.4b The program CABLE 7

This program, originally written in FORTRAN, simulates the broken conductor problem [19]. Following a rupture in a conductor line, a sudden horizontal force imbalance initiates movements in the insulator of the adjacent span. This force imbalance is often the result of a break in the conductors, the insulators or the collapse of one of the supporting structures. The insulator motion contributes to development of dynamic loads of larger magnitudes in the first span. The dynamic forces on the supporting structures, recorded following a break in actual lines, have consistently shown the existence of two major peaks in the load diagram [19].

Two prominent mechanisms have been associated with these peaks. The first peak is the result of the recoil of the insulator, in the adjacent span, away from the break and occurs when the insulator has swung to a horizontal orientation, where no more recoil is possible. Following the recoil of the insulator, the adjacent span has decreased by the length of the insulator. The conductor in this span bottoms down, drops under the force of gravity to a point where there is no slack in it, giving rise to the second major peak. These major peaks generally occur within 2 to 5 seconds of the break. Since the peaks occur with the insulator in a horizontal position, the impact on the towers is particularly severe since they have been primarily designed to support vertical not longitudinal loads.

In CABLE 7, the line is modeled as a plane system of lumped masses interconnected by cable elements and attached to springs or fixed supports, Fig. 2-2. The spring constants are equivalent to the horizontal stiffness of the supports including contributions from the remaining attached components such as the conductors and the shield wires. The plane system assumption is valid for the majority of the cases since the force on the tower adjacent to the break is not greatly affected by the line configuration a few spans away from the

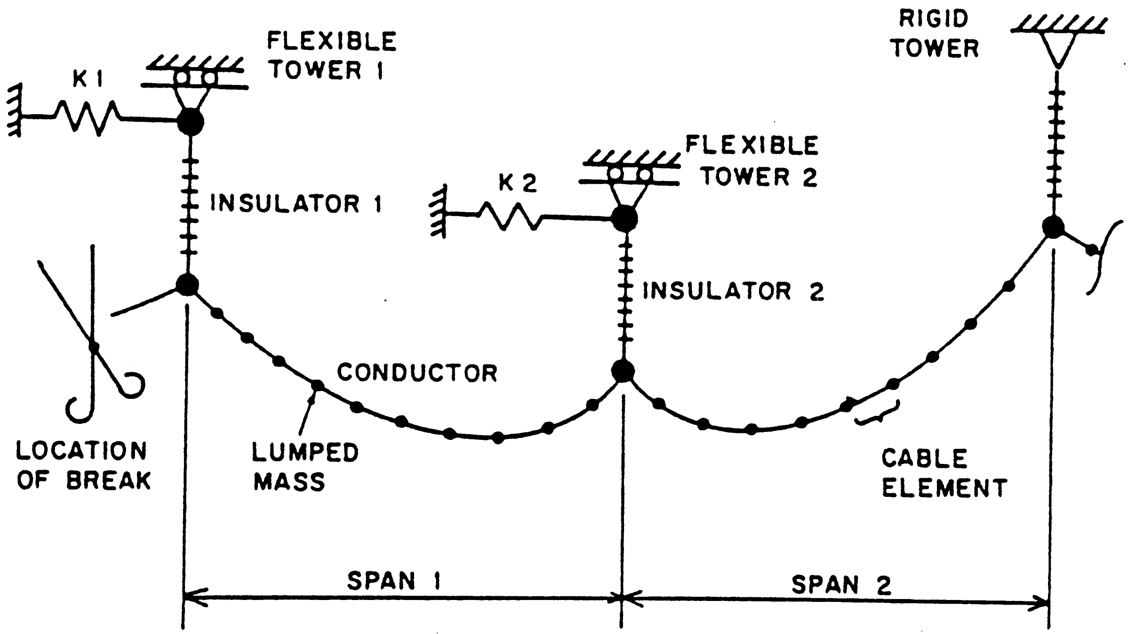


Fig. 2-2 : Lumped mass model of a conductor line

break.

CABLE 7 uses an iterative linear acceleration method to compute the movement of the lumped masses. The corresponding forces in the cable elements are obtained by calling PCAFX. Dynamic equilibrium at each lumped mass is checked at the beginning and end of the time interval [19].

Fig. 2-3 shows the forces acting on a typical lumped mass, tensions from cable elements, damping forces and inertial forces. The acceleration corresponding to the force imbalance in the direction of each degree of freedom is used to obtain the displacement of the lumped masses at the end of

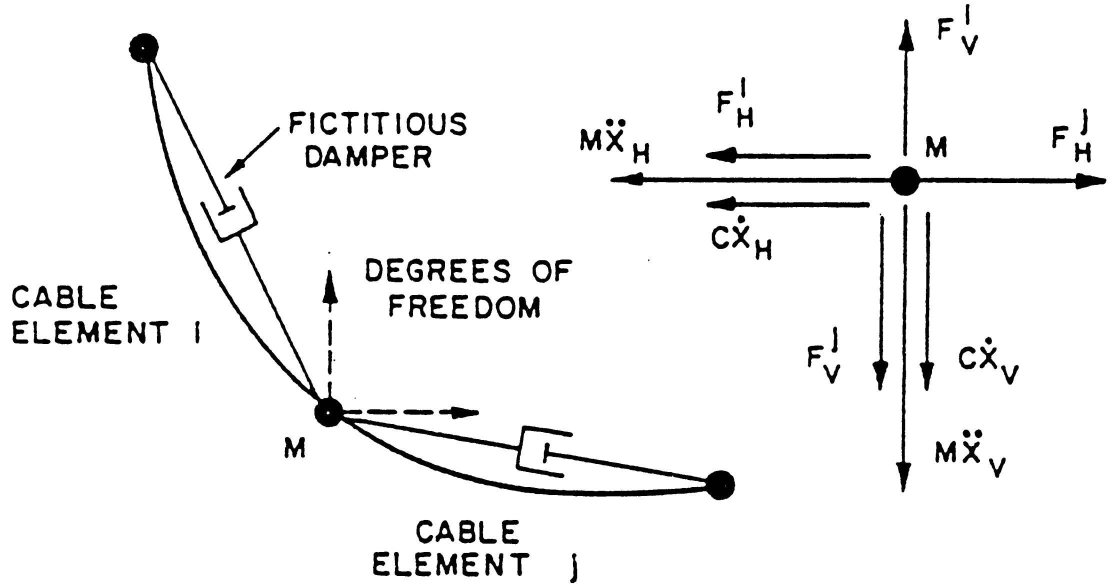


Fig. 2-3 : Dynamic forces Acting on a lumped mass

the time interval. The acceleration corresponding to this force imbalance is compared to the acceleration from the linear acceleration assumption. If the difference is not within acceptable tolerance, the constant of linear acceleration is proportionally modified and the procedure is repeated. The equations for this solution are presented in Appendix A.

The input to CABLE 7 consists of the following [20]:

- Number of spans considered
- Number of cable elements per conductor span
- Initial horizontal line tension
- The length of time and the time interval used
- The line configuration

Elevation of the supports

The horizontal span between the supports

The length of the insulators

- Conductor properties

    Cross sectional area

    Modulus of elasticity

    Weight per unit length

- Insulator properties

    Weight

    Axial Stiffness

- Tower properties

    Weight

    Horizontal stiffness

CABLE 7 is capable of providing the following output for the span adjacent to the break [20]:

- The force in the first insulator versus time
- The force in the second insulator versus time
- The horizontal and vertical components of the above forces
- The displacement of the first tower and insulator
- The displacement of the second tower and insulator
- The displacement of the conductor at midspan
- The maximum and minimum values for all the above
- Force versus time plots
- Displacement versus time plots

The broken conductor forces from CABLE 7 are consistent with the mechanisms recognized for this phenomena. It has been shown that the maximum displacement of the lower end of the first insulator coincides with the first peak; and that the maximum displacement of the conductor midspan coincides with the second peak. In addition, CABLE 7 output is in close agreement with many full and reduced scale model studies [20].

2.5 Related Works by Mr. Li Li

2.5a The galloping problem

Aerodynamic forces from air passing over a conductor (especially one covered with ice) produce a motion in the conductor referred to as galloping. Galloping is a large amplitude, low frequency motion, that occurs primarily in the vertical plane [2]. Using cable dynamics theory and the theory of partial differential equations, Mr. Li Li was able to develop a simplified approach to determine the dynamic loads on the supporting structures due to vertical plane galloping of conductors.

Assuming a constant galloping amplitude and an initial sinusoidal displaced shape, Mr. Li Li developed relationships to express the galloping frequency, the galloping amplitude and the maximum galloping force in terms of known line parameters. Some of the relationships developed by Mr. Li Li are given in Appendix A [2]. The relationships given in the appendix are for a conductor with both ends at the same level and a symmetrical shape.

In order to verify his simplified approach, Mr. Li Li made a comparison with a set of field test data. He was able to show good agreement, within 6% of the magnification factor for vertical end forces , between the results from his approach and the result of the field tests [2].

3. DEVELOPMENT AND APPLICATION OF COMPUTER SIMULATION

3.1 Software Developed for the Project

As discussed in the previous chapter, conductor analysis is often performed through computer simulation. Computer simulation of the conductor lines for this project was performed with three primary objectives in mind:

1- To obtain the loads due to conductors for the various types of conductor motion believed to have occurred in the transmission line.

2- To verify the conductor loads given by ETADS.

3- To provide input to ETADS, for conductor analysis cases not available on ETADS.

The in-house software available at I.S.U., CABLE and CABLE 7, seemed adequate for the most part in meeting the above objectives. Nevertheless, some modifications and additions were deemed necessary.

3.1a Additions and modifications to CABLE

A second option was added to determine conductor configuration and tension when the conductor original length is known. This option is useful in determining if a conductor has lowered to the point that it touches the ground, following a change in the conductor tension or end positions.

In visiting the area near Towers No. 98, 99 and 100, the eastern conductor, originally spanning between Towers No. 98

and 99 and between Towers No. 99 and 100, was lying on the ground ,realigned between towers No. 98 and 100, Fig. 3-1. This suggested that the conductor had separated from the eastern insulator of Tower No. 99, which was still hanging from the tower. The conductor span was at that point defined as the distance between Towers No. 98 and 100. This appeared to have occurred prior to the collapse of the line. In investigating this scenario, it was essential to obtain the residual conductor loads, in the separated conductor, to determine the resulting horizontal force imbalance exerted on Towers No. 98 and 100. The change in the load in the separated conductor would depend on whether or not the conductor was touching the ground.

The original conductor length for the span between Towers No. 98 and 99 and Towers No. 99 and 100 was determined using Option 1 of CABLE. The combined length was then used with Option 2 to determine the configuration of the conductor between Towers No. 98 and 100.

If a conductor is touching the ground, the forces in that conductor, depending on the length of the conductor resting on the ground, will significantly be reduced; thereby creating a sizable horizontal force imbalance in the supporting towers. An option was required to determine the configuration of the grounded conductor and the corresponding loads in that conductor. Therefore, Option 3 of CABLE was developed.

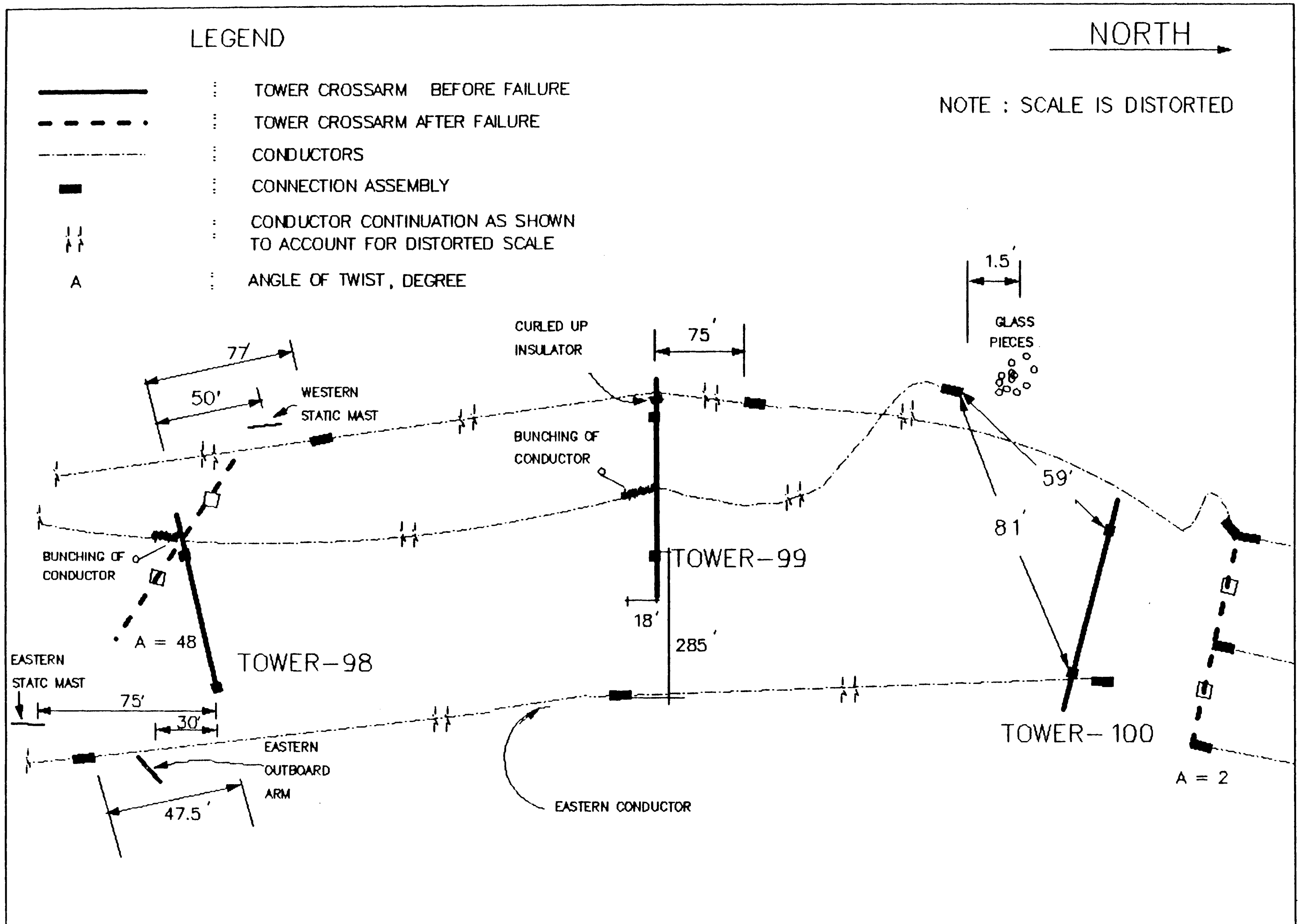


Fig. 3-1 : Plan view of area near Towers No. 98, 99 and 100 after transmission line failure

The algorithm used was obtained from reference [12]. The assumption was made that the grounded conductor could slide on the ground until the tensions at the left and the right of the conductor are the same. The first step, in Option 3, is to call PCAFX to locate the lowest point in the conductor had the ground not existed. This point is then brought up to the level of the ground. This point will be referred to as the original ground point. By calling PCAFX, the low point of the conductor portion to the left of the original ground point is located and this segment is horizontally stretched along the ground. This procedure is continued until no conductor segments sag lower than the ground level. The position of the last point touching the ground is adjusted to ensure the difference in tension between the grounded portion and the hanging portion is within a specified tolerance. If the tension in the grounded portion is less than the tension in the hanging portion, the grounded portion is stretched more by moving the last point closer to the support. This procedure is repeated for the portion of the conductor to the right of the original ground point.

The sliding of the conductor on the ground is accounted for by adjusting the location of the original ground point. By moving this point toward the portion with higher tension, the horizontal tension imbalance at the original ground point is reduced. This movement is proportional to the tension imbalance and the rate of change of that imbalance with movement. The algorithm finally converges when the difference in the horizontal component of tension, between the left and the right portions of the conductor, at the original ground point, is within a specified tolerance. The galloping option is incorporated in options 1 and 2 to obtain the maximum end loads under a harmonic galloping motion. Such motion is expected to take place with an ice covered conductor line and in the presence of sustained winds, conditions encountered typically during an ice storm. There was evidence of such motion prior to the collapse of the Lehigh-Sycamore line according to one of the eyewitnesses.

The approach used in this modification to CABLE was Mr. Li Li's simplified approach, discussed in the previous chapter. After the conductor end loads, in Options 1 and 2, are obtained, the galloping magnification factors, for the vertical and horizontal end loads are applied to obtain the maximum values of these cyclic loads. The frequency of the motion and the galloping amplitudes are also determined from the approximate formulas. Based on the galloping frequencies and the maximum loads, time histories of these simplified galloping loads can be obtained. See Appendix C.

A few modifications were needed in order to apply the galloping factors to the end forces from CABLE. The simplified approach is based on a symmetrical conductor shape with the ends of the conductor at the same level. This assumption is not true for the majority of existing lines. However, the value of the sag based on this assumption is a good approximation of the actual sag since the vertical projection of the ends of conductor is small compared to the span length. For this reason, the galloping magnification factors were obtained based on the approximate sag formula used in Mr. Li Li's approach, to simulate the symmetrical shape of the conductor, and applied to the forces at each end. This would be equivalent to galloping in a slightly tilted plane; however, the angle of the tilt is so small that it does not change the direction of the end forces significantly.

3.1b Additions and modifications to CABLE 7

The loads for a broken conductor phenomena, discussed in the previous chapter, could be obtained by using CABLE 7. Sudden force imbalance was suspected to have taken place at several locations in the IP line studied. The force imbalance could have been introduced due to the collapse of an adjacent tower or due to the grounding or rupture of the conductor on one side of a tower.

CABLE 7 was originally written in ASCII FORTRAN without any interactive capabilities and a slower, less powerful computer. Modifications were necessary to adapt CABLE 7 to a micro-computer. The objectives were to make CABLE 7 more user friendly and to create more flexibility with respect to input and output, especially the graphics. A graphic screen was added to display the movement of the conductor in the span adjacent to the break. This conductor-movement option had not been available before; and it was hoped that it would enhance the understanding of the broken conductor problem.

MICRO SOFT QUICK BASIC was chosen because of its graphic and animation capabilities. The following features were added to CABLE 7:

1- A graphic screen demonstrating the motion with time of the conductor and insulators, in the span adjacent to the break. In the lower portion of this screen, a plot of the load versus time for the first insulator is shown. See figures 3-2 and 3-3.

2- A post processor to create plots of selected load and displacement variables versus time.

These plots and the conductor motion screen are very useful in monitoring and documenting the broken conductor phenomena. They make possible correlating conductor loads to conductor and insulator motions at any given time. Using these features, the following observations were made.

Following a break, two major peaks in the insulator load time history are expected. The mechanisms involved with each peak can clearly be seen on the conductor motion screen. The insulator adjacent to the break, is seen to recoil from its

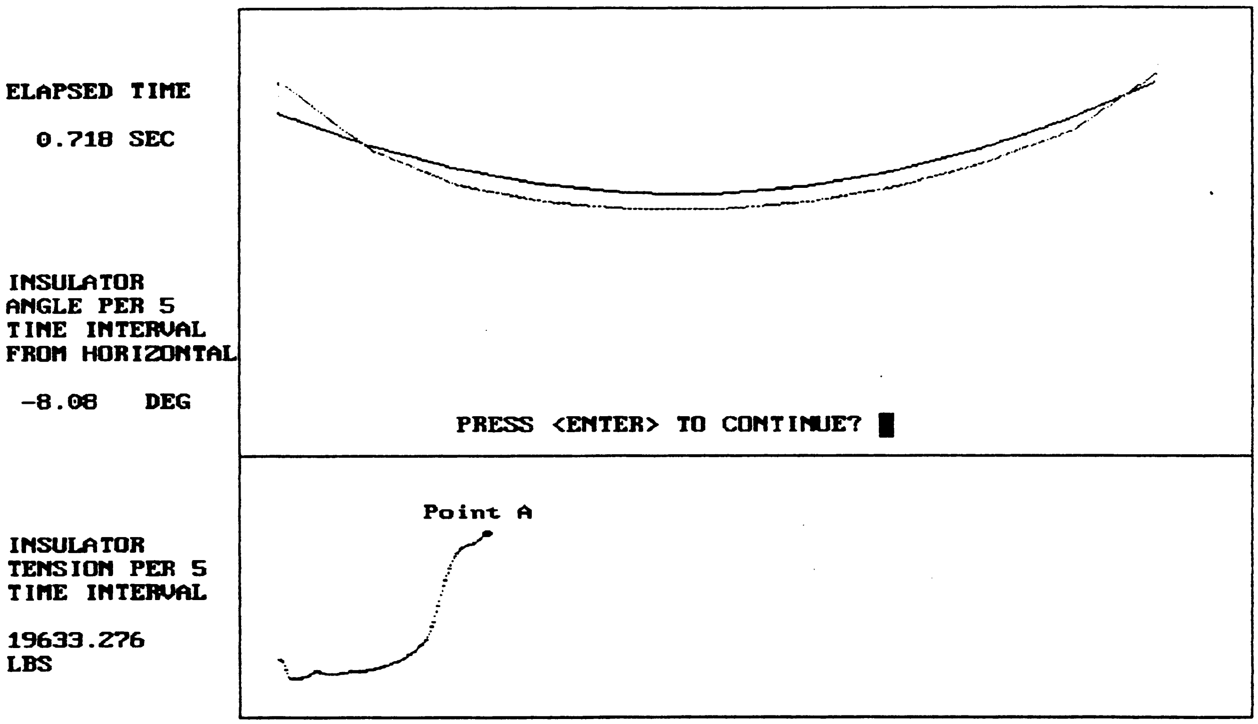


Fig. 3-2 : Displaced conductor at first peak

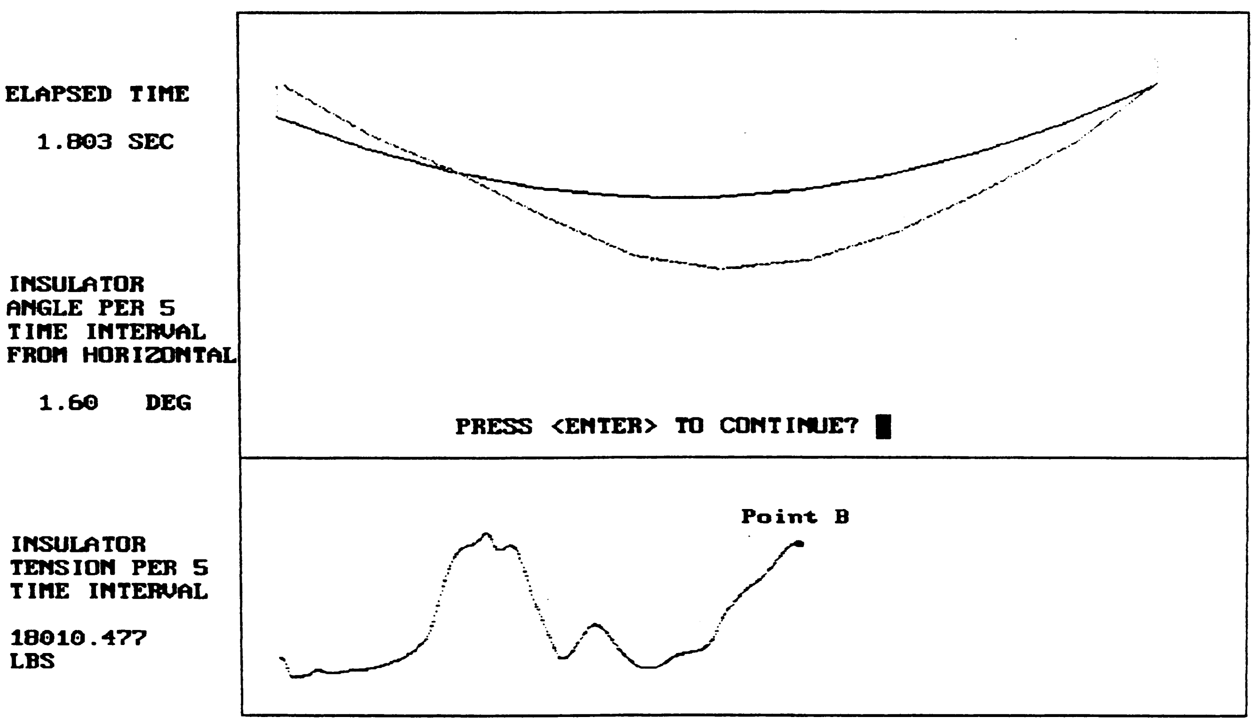
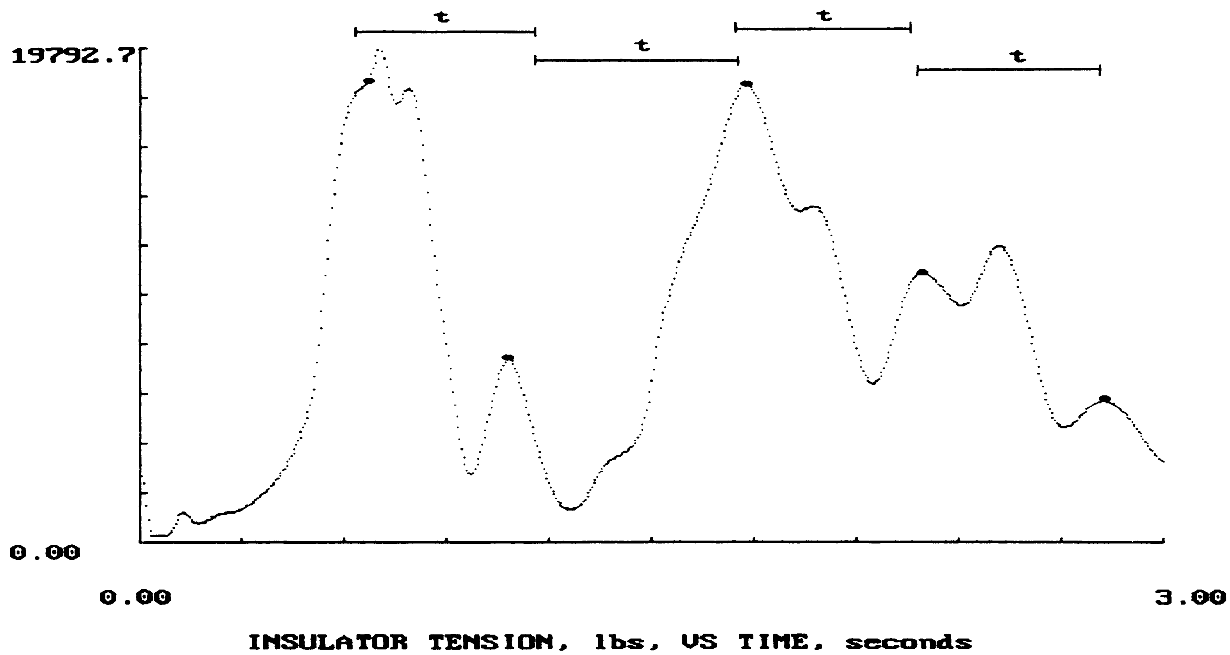


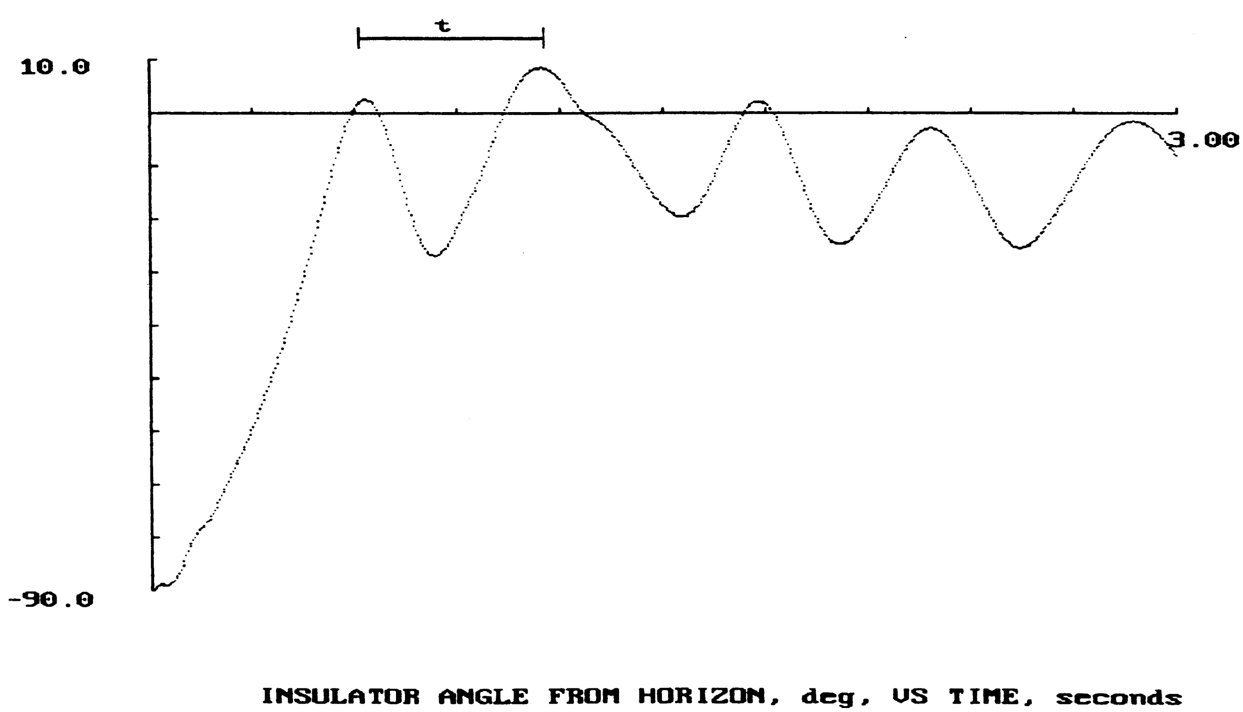
Fig. 3-3 : Displaced conductor at second peak original position and swing into a horizontal position. The corresponding load in the insulator, from the tension plot in the lower portion of the screen, is indeed the first major peak before the load begins to drop (point A in Fig. 3-2). The insulator remains in a predominantly horizontal position. The second peak is seen to occur when the conductor has dropped to a point where there is no additional slack in it. This corresponds to the bottoming down of the conductor (point B in Fig. 3-3).

In addition to the two major peaks, a series of minor peaks appear in the load diagram of the insulator, Fig. 3-4. A description of the source of these minor peaks could not be given before. However, with modified CABLE 7, these minor peaks can be tied to the insulator motion. After swinging horizontally, the insulator oscillates up and down in that horizontal position. The minor peaks, as well as the two major peaks, seem to correspond to these oscillations. In fact, the average period of this oscillation seems to roughly match the time between these peaks. See Fig. 3-4.

The oscillating motion in the first insulator, and in the conductor of the first span, is initiated by the force imbalance due to a break in the system. The amplitude of this motion, and the corresponding force on the tower, begin to damp out after the second major peak, Fig. 3-5. In this figure, point A in Fig. 3-5 (b) is the point of maximum



(a)



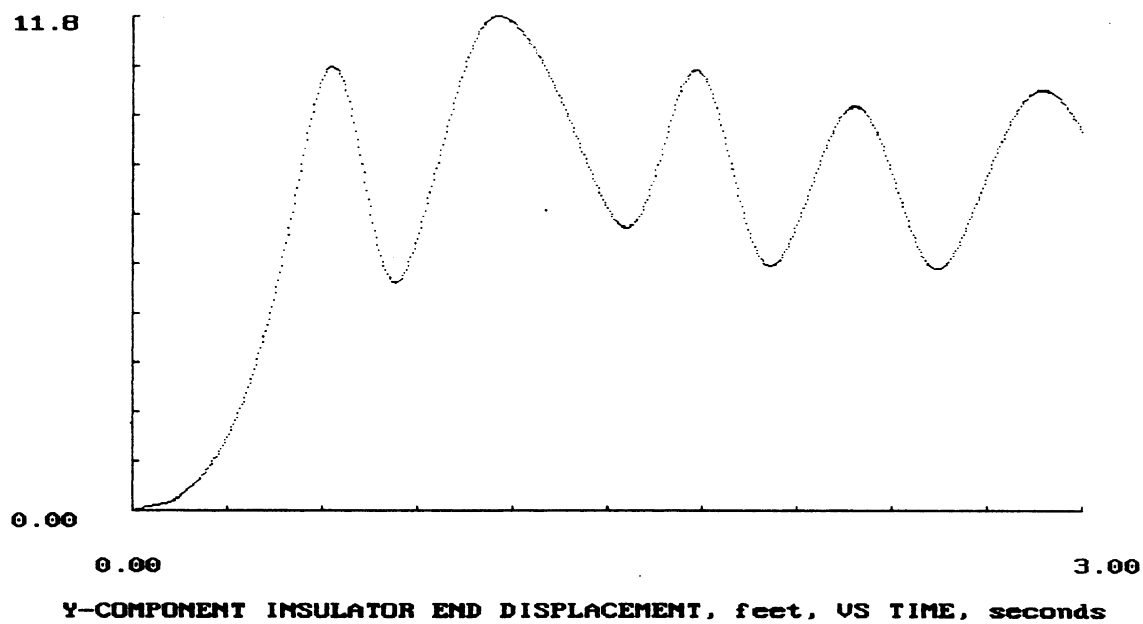
(b)

Fig. 3-4 : An example of the loads and displacements in the insulator adjacent to the break displacement of the conductor at midspan which corresponds to bottoming down or the second peak. Therefore, it can be said that if the tower of the first insulator withstands the two major peaks, the dynamic forces will dampen out and cascading of the towers should not take place. However, if the first tower fails, an entirely new force imbalance is introduced at the second tower and the cascading of the towers could take place.

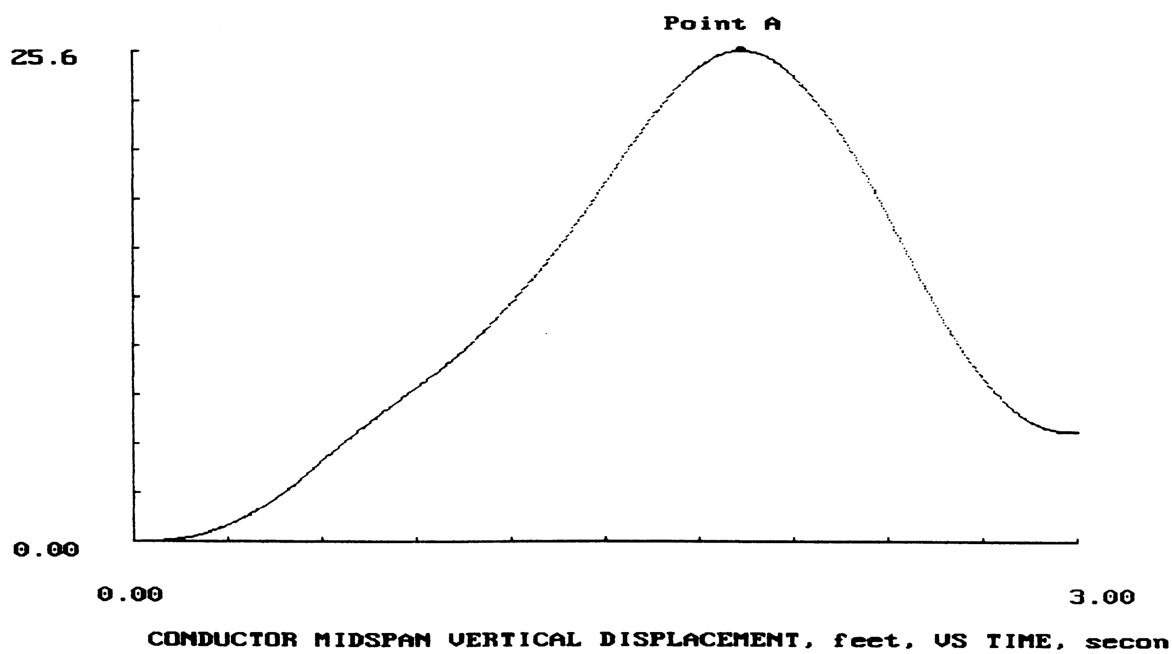
In addition to the up and down motion of the conductor described above, a wave motion, which propagates away from the break, has been detected in conductors following a break. This wave motion can also be observed in the conductor motion displayed in CABLE 7. This, and the other features of CABLE 7 discussed above, strongly suggest that CABLE 7 does closely simulate the broken conductor phenomena.

The format of the input file for the modified CABLE 7 has generally been kept unchanged . One exception is the addition of the variable GINT which represents the number of time intervals for which the displaced conductor shape is displayed. Appendix B contains a brief user manual for the modified version of CABLE 7.

Another important modification to CABLE 7 was the inclusion of provisions to allow for the analysis of dead end towers which do not have any hanging insulators. By specifying 0.0 for the variables related to the insulator of the dead end



(a)



(b)

Fig. 3-5 : Insulator and conductor movement, seen in a broken conductor phenomena tower, the program renumbers the degrees of freedom omitting insulator. The output file was also modified, substituting the first conductor cable element for the first insulator.

The dead end feature was used for Tower No. 100. The load and displacement plots of this tower did not demonstrate the same characteristics as the plots of towers with hanging insulators. The plots for this, and the other towers studied, are given in the next section. A discussion of the results and the differences observed in the results are presented in the following chapter.

3.2 Application of Software to the Project

The second task of the project was to identify the failures documented in task one, and to determine the magnitude of the loads required to cause these failures. Determination of some of these loads was pursued by the application of the modified versions of CABLE and CABLE 7.

3.2a The eastern insulator of Tower No. 99

One of the pieces recovered from the area near Tower No. 99 was identified as the socket y clevis, Fig. 3-6, a component of the eastern heavy angle insulator suspension assembly, Fig 3-7. The ultimate capacity of this piece was rated at 36 kips [5]. The possibility of the failure of this component as the initiator of the event was investigated by application of Option 1 of CABLE.

The resultant force, in the suspension insulator under consideration, was due to conductors spanning between Towers No. 98 and 99 and between Towers No. 99 and 100, which formed an angle of 148.92 degrees at Tower NO. 99. The forces in each conductor of these spans, for various radial ice thicknesses formed on the conductors, are given in Table C-2 of Appendix C. The resultant forces at the eastern insulator of Tower No. 99, for the various radial ice thicknesses, have been plotted in Fig. 3-8. In this plot, the solid line represents the resultant force without the galloping effects; and the dotted line represents the resultant force when galloping effects are included. The galloping forces in this figure are based on the assumption that the lines gallop with the same frequency and completely in-phase. This is not an unreasonable assumption since the frequency of galloping in individual conductors did not vary by very much (less than 10%), and the span lengths were also similar. See Appendix C. However, the main reason for this assumption was that when the conductors gallop in phase, the vertical forces created are additive resulting in the maximum force through the insulator.

It can be seen, from Fig. 3-8, that the ultimate capacity of the insulator, 36 kips, is reached with 1.5 inches of radial ice when galloping is considered, and with 1.7 inches

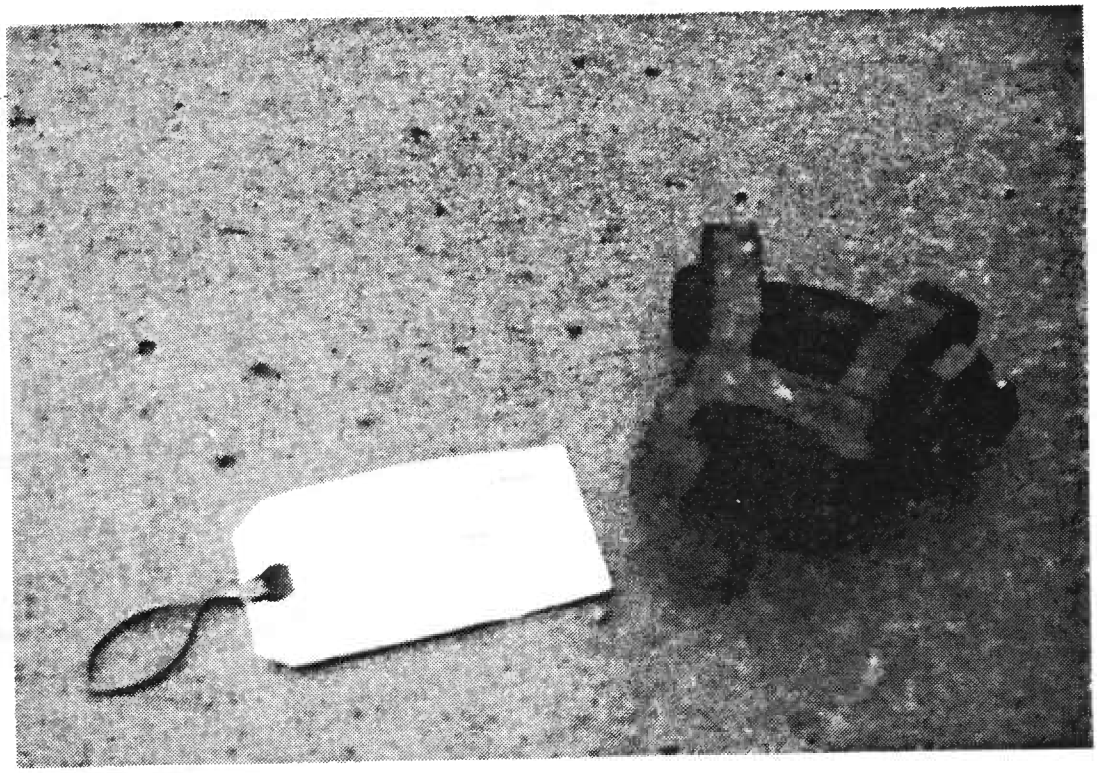


Fig. 3-6 : The socket Y clevis of Tower No. 99, recovered after the failure

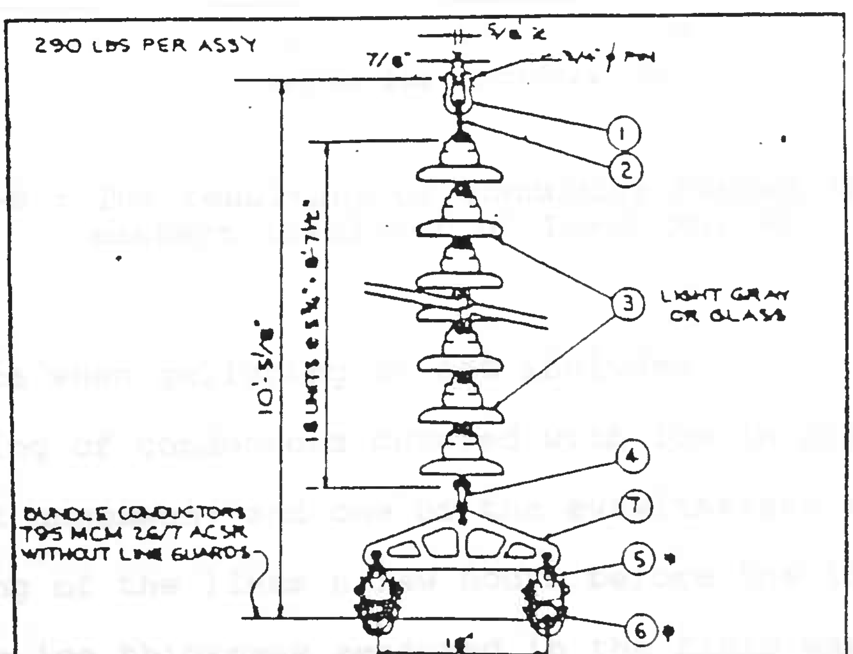


Fig. 3-7 : Heavy angle insulator suspension assembly

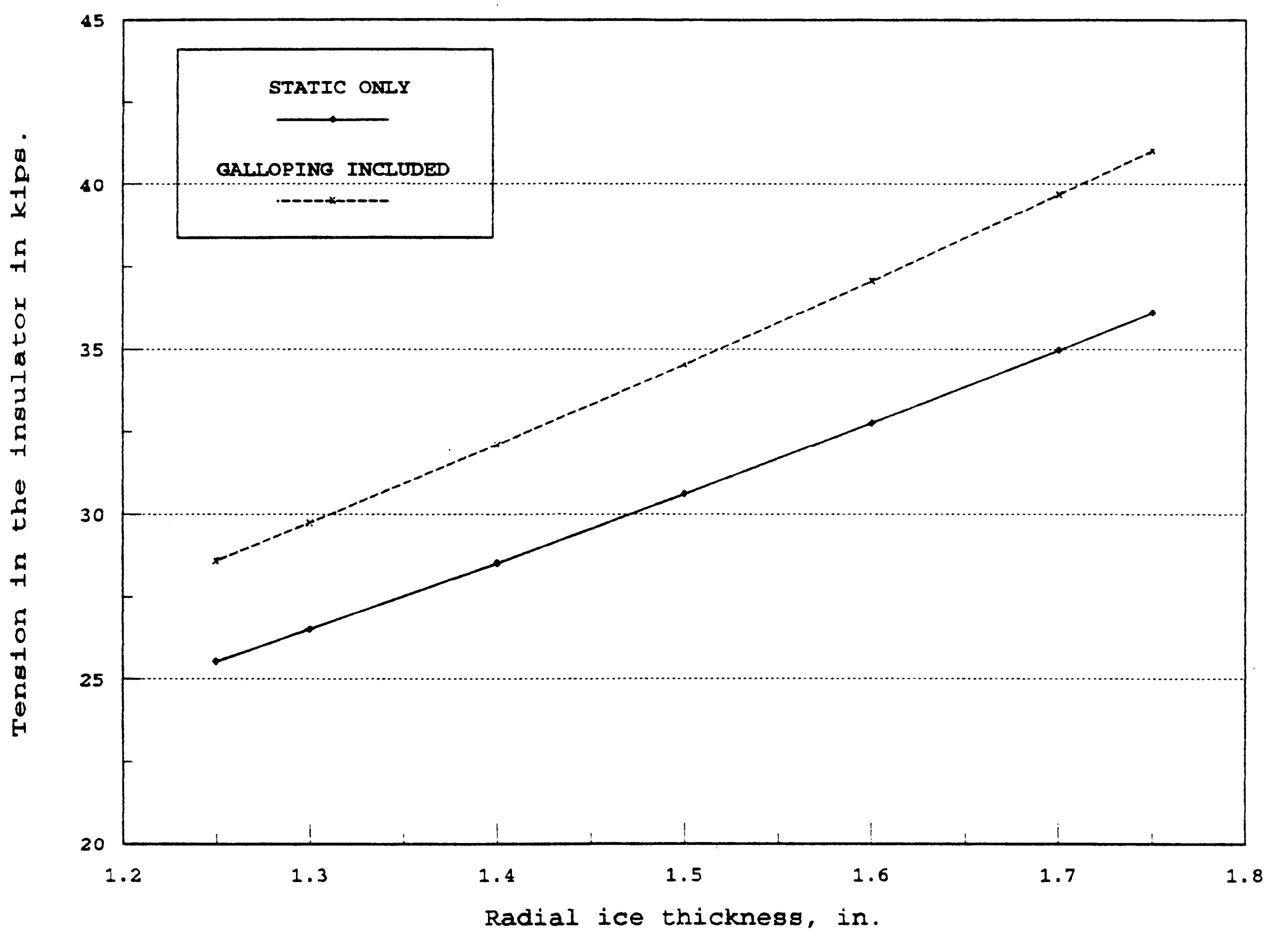


Fig. 3-8 : The resultant of conductor forces in the eastern insulator of Tower No. 99

of radial ice when galloping is not included.

Galloping of conductors covered with ice in presence of winds is not uncommon; and one of the eyewitnesses reported the galloping of the lines a few hours before the line failure. The ice thickness measured in the field was 1.25 to 1.5 inches at 40 °F and fourteen hours after collapse of the line. Since the temperature remained near freezing for the most part of that fourteen hours [4], it would be reasonable to assume 1.5 inches of ice formed on the conductors. This lower value of ice thickness suggests that galloping could have occurred and thus contributed to the breaking of the eastern insulator socket y clevis.

When considering the effects of galloping, fatigue analysis should be considered due to cyclic loading at high stresses. A thorough fatigue analysis for the insulator could not be performed, due to the hindrances encountered in running the required experimental tests. However, a simplified study of the fatigue in the insulator revealed that only 1.3 inches of radial ice was required to exceed the capacity of the insulator. See Appendix D. The ice thickness considered for the events following the insulator break will be maintained at 1.5 inches based on the field evidence and the uncertainty of fatigue study to predict the loss of strength in the insulator. It can be concluded that the forces in the conductors, due to accumulation of ice, were sufficient to cause the separation of the conductors from the eastern insulator of Tower No. 99. This indicates that the scenario which considers the breaking of this insulator to be the initiator of the collapse of the line could be a valid one.

3.2b Forces in the separated conductor

After the separation of the conductors from the eastern insulator of Tower No. 99, presumed to have taken place with 1.5 inches of radial ice, the conductors would have been spanning between Towers No. 98 and 100. This would mean a shorter horizontal span for the same unstretched length of the conductor. The configuration of the conductors for this new shorter span was obtained by application of Option 2 of CABLE. The results of this analysis, for the assumed conditions, are given in Table C-3 of Appendix C.

Comparing the horizontal tension in the conductor from Tables C-2 and C-3, we can see that the tension in each conductor would have dropped by about 10 kips, from about 24 kips to about 14 kips. However, the distance between the first attachment point and the lowest point in the separated conductor exceeds the height of the tower, 307 feet versus 80 feet. Therefore, a large segment of the separated eastern conductors must have been resting on the ground; and the forces in those conductors would have significantly less than 10 kips.

3.2c Forces in the grounded conductors

After verifying that the separated eastern conductors were lying on the ground, it was necessary to determine the length of each conductor on the ground and the forces in each conductor. This was accomplished by the application of Option 3 of CABLE. The results of this analysis, for the conditions stated for span 98 to 100, are given in Table C-4 of Appendix C.

From this table, about 92% of the original length of conductors had been resting on the ground after the failure of the eastern insulator; and as a result of that, the residual forces in the grounded conductor was negligible for all practical purposes. Consequently, a large imbalance of force was created on the eastern outboard arm of the towers supporting the grounded conductor, Tower No. 98 and Tower No. 100. On the North side of Tower No. 100 and on the South side of Tower No. 98, the horizontal force in each conductor was about 24 kips, for 1.5 inches of radial ice. On the side of these towers with the grounded conductors, the horizontal force had been reduced to less than one kip. Therefore, the eastern insulators at Towers No. 98 and the eastern outboard arm of Tower No. 100 suddenly experienced a force imbalance of approximately 48 kips, 24 kips in each conductor. This sudden force imbalance is sufficient to cause a broken conductor phenomena.

3.2d The broken conductor phenomena

The buckling of Towers No. 98 and 100 could have been due to the large force imbalance of 48 kips and/or the broken conductor forces resulting from this imbalance. The broken conductor forces in the eastern insulator of Towers No. 98 and the eastern outboard arm of Tower No. 100, following the separation of the eastern conductor at Tower No. 99, were determined by CABLE 7.

Plots of force and displacement versus time for the eastern insulator of Tower No. 98 can be found in Fig. 3-11 and Appendix C. The maximum and minimum values for variables of interest are shown in Fig. 3-9. The input data, used in performing this analysis, can be found in Appendix C. Fig. 3-11 contains the plots of insulator tension, insulator angle displacement and conductor midspan displacement. From this figure, it can be seen that the initial imbalance of 48 kips has increased to more than 63 kips, an increase of almost 30 percent.

Similarly, for Tower No. 100 plots of force and displacement versus time were developed. These plots are presented in Fig. 3-12 and Appendix C. Fig. 3-10 shows the maximum and minimum values for variables plotted. Tower No. 100 was a unique tower in that there were no vertical suspension insulators. Instead, dead end insulators were used to implement electric phase transfer at this tower. The length and other characteristics of this insulator are replaced by 0.0 in the input file and the insulator is considered to be part of the conductor. Refer to Appendix C. Fig. 3-12 contains

MAXIMUM AND MINIMUM VALUES OF TENSIONS AND DISPLACEMENT

1ST TOWER INSULATOR TENSION=	0.6323D+05	AT	3.366	SEC	0.2230D+03	AT	0.166	SEC
1ST SPAN CONDUCTOR TENSION=	0.6183D+05	AT	3.381	SEC	0.4006D+04	AT	0.301	SEC
2ND TOWER INSULATOR TENSION=	0.3744D+05	AT	1.381	SEC	0.7489D+04	AT	0.476	SEC
1ST TOWER HORIZONTAL FORCE=	0.5921D+05	AT	3.401	SEC	0.1077D+01	AT	0.001	SEC
1ST TOWER VERTICAL FORCE=	0.5768D+03	AT	1.776	SEC	-.2386D+05	AT	0.921	SEC
1ST TOWER INSULATOR HOR. DIS. (LOWER END)=	0.1949D+02	AT	3.141	SEC	0.8479D-03	AT	0.001	SEC
1ST TOWER INSULATOR VERT. DIS.(LOWER END)=	0.1242D+02	AT	0.596	SEC	0.1381D-03	AT	0.001	SEC
VERT. DISPLACEMENT AT MIDSPAN OF CONDUCTOR=	0.0000D+00	AT	0.000	SEC	-.3792D+02	AT	2.761	SEC
2ND TOWER INSULATOR HOR.DIS.(LOWER END)=	0.1183D+02	AT	1.056	SEC	-.3059D-06	AT	0.046	SEC
2ND TOWER INSULATOR VERT. DIS.(LOWER END)=	0.5905D+01	AT	0.936	SEC	-.7105D+00	AT	2.481	SEC
1ST TOWER HORIZONTAL DISPLACEMENT=	0.3462D+01	AT	3.171	SEC	0.7303D-09	AT	0.001	SEC
2ND TOWER HORIZONTAL DISPLACEMENT=	0.1423D+01	AT	1.486	SEC	-.2909D+00	AT	2.621	SEC

Fig. 3-9 : Maximum and minimum values for broken conductor analysis of Tower No. 98

MAXIMUM AND MINIMUM VALUES OF TENSIONS AND DISPLACEMENT

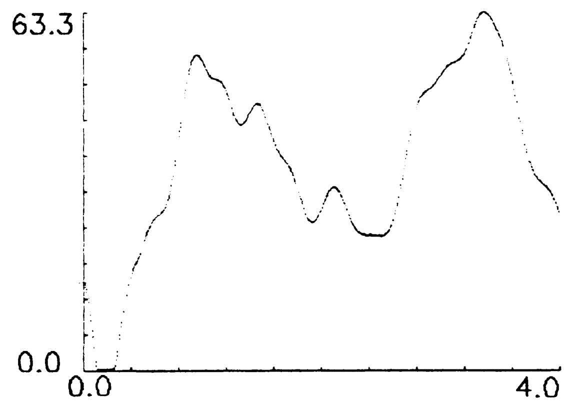
1ST SPAN CONDUCTOR TENSION=	0.5633D+05	AT	0.526	SEC	0.2132D+05	AT	0.146	SEC
2ND TOWER INSULATOR TENSION=	0.1964D+05	AT	0.806	SEC	0.6395D+04	AT	0.466	SEC
1ST TOWER HORIZONTAL FORCE=	0.5547D+05	AT	0.526	SEC	0.2096D+05	AT	0.146	SEC
1ST TOWER VERTICAL FORCE=	0.0000D+00	AT	0.000	SEC	-.9833D+04	AT	2.701	SEC
VERT. DISPLACEMENT AT MIDSPAN OF CONDUCTOR=	0.3662D-08	AT	0.011	SEC	-.5435D+01	AT	2.231	SEC
2ND TOWER INSULATOR HOR.DIS.(LOWER END)=	0.2575D+01	AT	0.561	SEC	-.1019D-05	AT	0.056	SEC
2ND TOWER INSULATOR VERT. DIS.(LOWER END)=	0.8760D+00	AT	0.481	SEC	-.5866D+00	AT	0.806	SEC
1ST TOWER HORIZONTAL DISPLACEMENT=	0.2831D+01	AT	2.736	SEC	0.9097D-04	AT	0.001	SEC
2ND TOWER HORIZONTAL DISPLACEMENT=	0.2070D+00	AT	0.886	SEC	-.1029D+00	AT	1.981	SEC

Fig. 3-10 : Maximum and minimum values for broken conductor analysis of Tower No. 100

the plots of conductor tension, tower displacement and conductor midspan displacement. For this tower the initial imbalance has increased to more than 56 kips. This is an increase of only 17 percent.

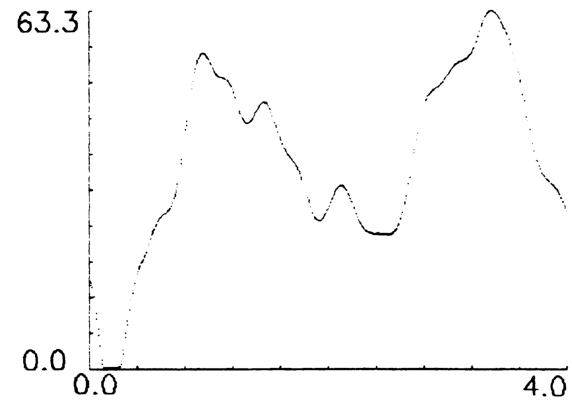
In figures 3-11 and 3-12, the tension plot is placed above each of the other two plots, so that the relationships between the peaks in tension and the displacements in the first span are more obvious. In both figures, the second peak corresponds to the maximum displacement of the midspan of the conductor. In Fig. 3-11, the tension peaks correspond to the changes in the angle of the insulator. Refer to Section 3.1. In Fig. 3-12, the peaks in tension correspond to the displacement of the tower. Refer to Chapter 4.

Most of the input variables required by CABLE 7 were obtained from drawings and specifications provided by IP [5]. However, the values used for the variables AM, the tower mass, AEI, area times modulus of elasticity for the insulator, and AKT, the tower stiffness, required separate calculations. The values used for mass of the towers, AM, at the nodes representing the towers, was simply the total mass of the tower divided by two. This is assumed to be the mass displaced by the force from the insulator when one conductor phase is moving. This simple approach was used in view of the fact that CABLE 7 results are not significantly affected by AM [20].



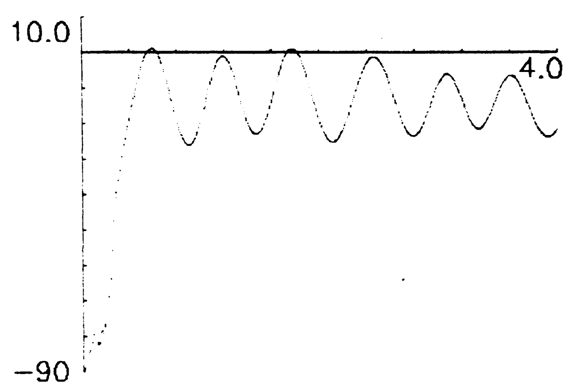
Insulator tension in kips

(a)



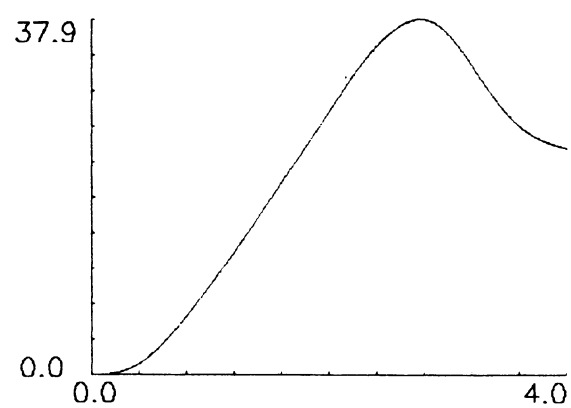
Insulator tension in kips

(b)



Insulator angle from horizontal in degrees

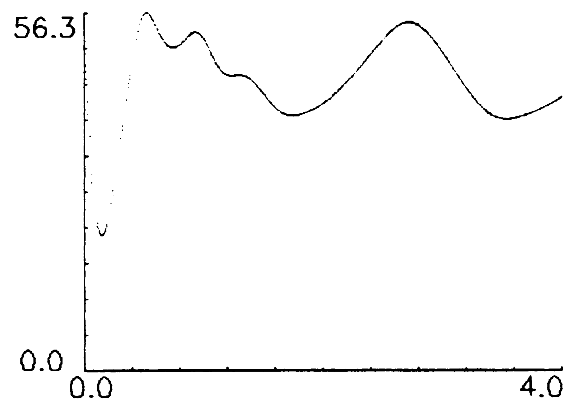
(c)



Vertical displacement of conductor midspan in feet

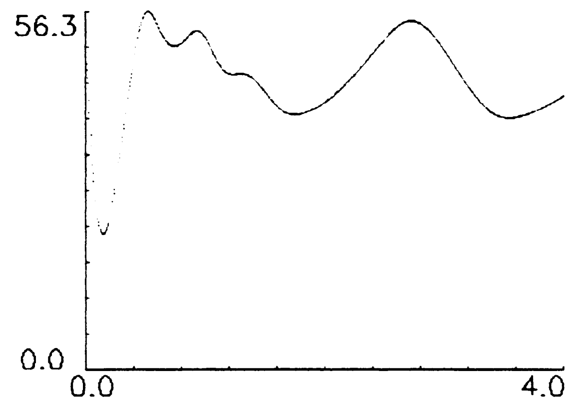
(d)

Fig. 3-11 : Broken conductor time plots, seconds, Tower No. 98



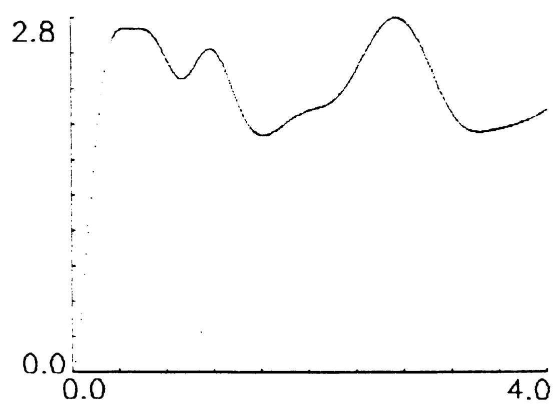
Conductor tension in kips

(a)



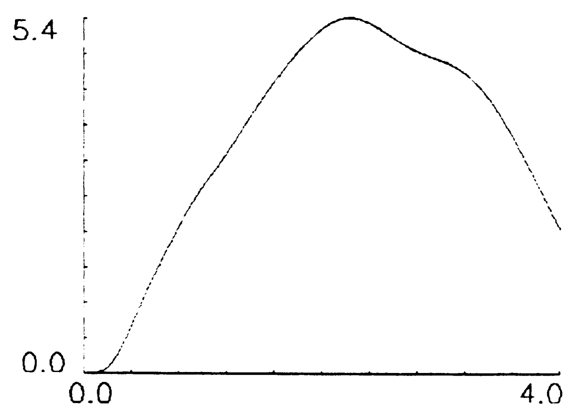
Conductor tension in kips

(b)



Horizontal displacement of first tower in feet

(c)



Vertical displacement of conductor midspan in feet

(d)

Fig. 3-12 : Broken conductor time plots, seconds, Tower No. 100

AEI, area times modulus of elasticity of the insulator, is a measure of the axial rigidity of this member. In CABLE 7, the insulator is modeled by a cable element to provide for the insulator's bending flexibility. In reality, the insulator is a more complex element which has not successfully been modeled in detail. Therefore, a good approximate value for AEI was not known. Fortunately, CABLE 7 is not very sensitive to AEI [20]; and in this case a value of 10^5 was used to obtain a smoother plot of force versus time.

AKT represents the stiffness of the tower and attached conductors and shield wires. For the lines under consideration, the stiffness of the towers and the connecting wires at the connection point of the insulator ranged between 2000 to 4000 lbs per ft, based on the finite element model of the towers on ETADS [1]. However, for large displacements at the top of the towers, the contributions to tower stiffness from the conductors increase significantly, due to direct stretching of the conductors. Fig. 3-13 shows the forces required to increase the span of one of the central conductors between Towers No. 98 and 99, similar conditions exist in the other spans. This figure was created by increasing the span length, for a fixed original conductor length, using Option 2 of CABLE. Similarly, Fig. 3-14 shows the decrease in the horizontal force in that conductor when the span length is decreasing. Nevertheless, the contributions from the conductors to the stiffness of the towers are limited by their load carrying capacity. The conductors under consideration have a load carrying capacity of 31.5 kips, about 6 kips in addition to 25 kips resultant load carried under 1.5 inches of ice. Therefore, from the four attached conductors, up to 24 kips per foot can resist the movement of the tip of the eastern outboard arm. Based on these values, a conservative approximate value for AKT of 20 kips per foot was used. See Table C-5 Appendix C.

With the buckling of Towers No. 98 and 100, the cascading failure of the other towers would most likely have been initiated. The major difference in the broken conductor phenomena of these other towers was that the three conductor phases experienced the force imbalance simultaneously. With the buckling of an adjacent tower, the forces in the three conductor phases on that side suddenly drop, eliminating the contribution to AKT from the conductors, and creating three separate broken conductor phenomena if the interaction through the tower crossarm is ignored. Due to lack of contribution from the conductors, the stiffness of towers, AKT, will only be about 2000 lbs per foot. The mass of the towers, AM, was modified. Since the broken conductor phenomena of these towers was considered in all three phases, the tower mass was further divided by three. The broken conductor loads for some selected

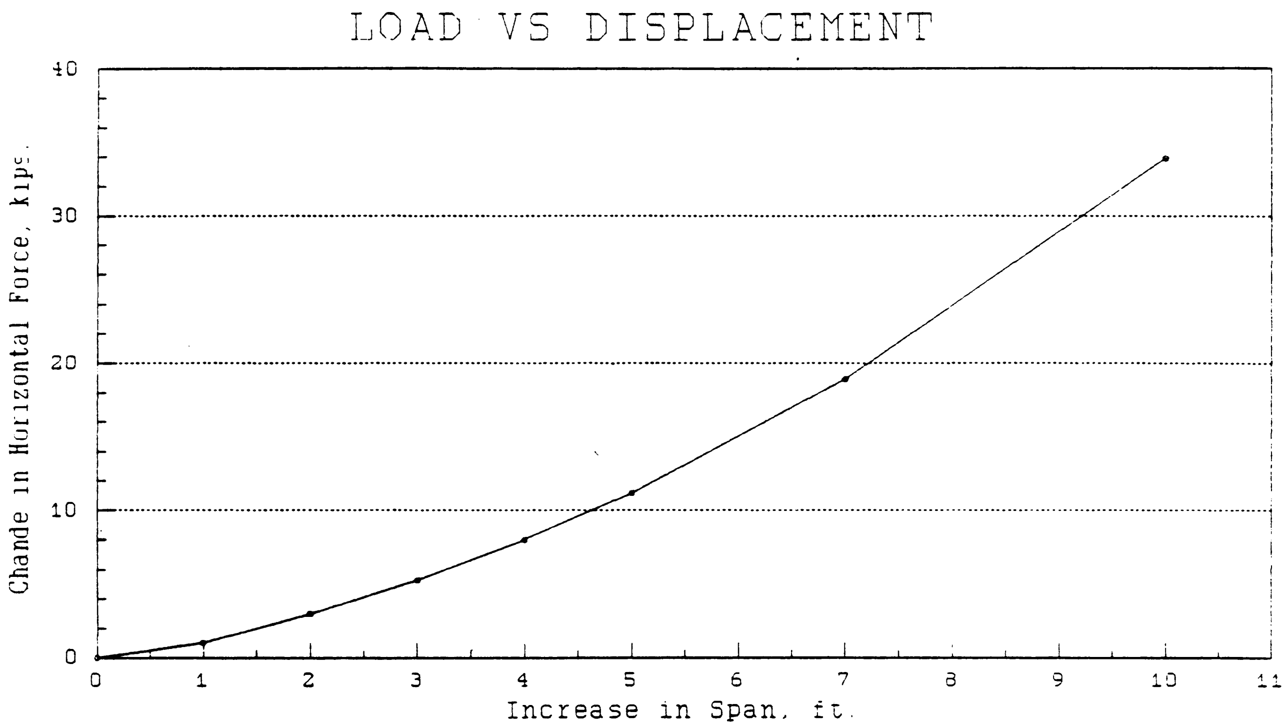


Fig. 3-13 : Change in conductor horizontal tension with increase in span length

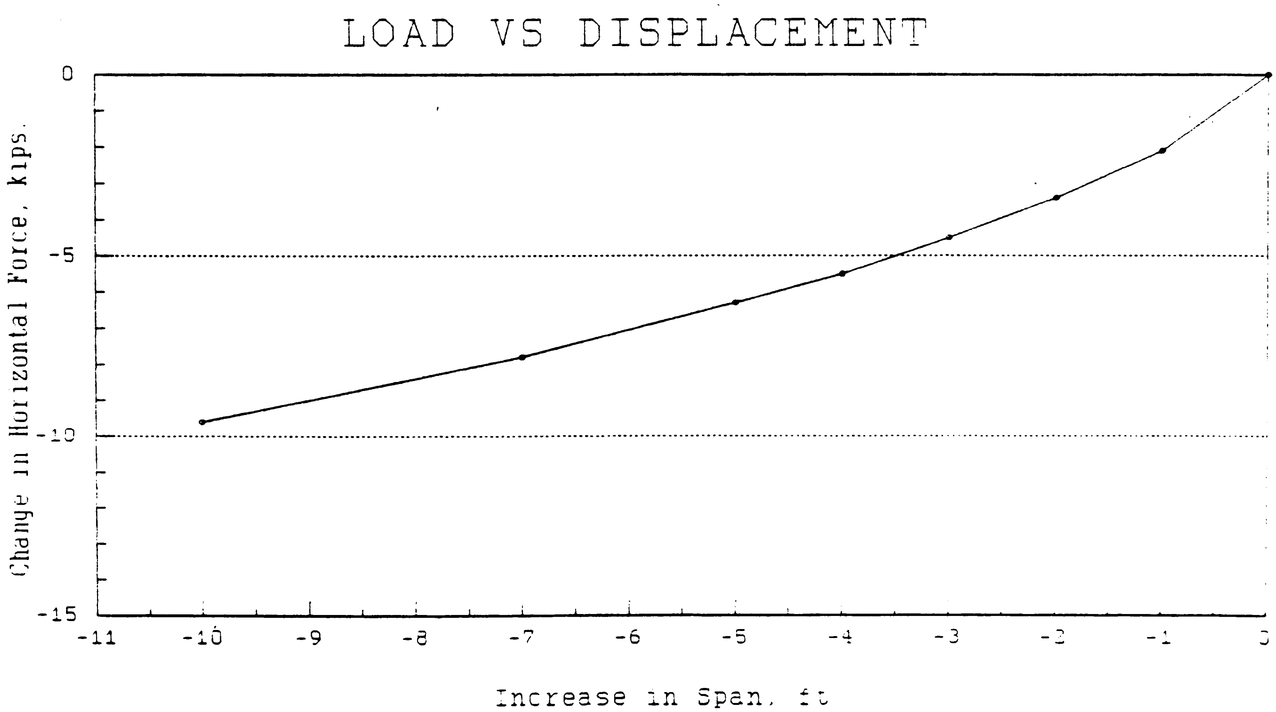


Fig. 3-14 : Change in conductor horizontal tension with decrease in span length

towers having various span characteristics are given in Appendix C.

3.2e Galloping forces experienced by Tower No. 100

Tower-100 is of particular interest when considering forces from galloping. Under normal circumstances, the conductor forces balance each other at the towers. During galloping, the conductors in adjacent spans can gallop with different frequencies, due to the differences in span lengths, elevation of end points, ice formation and the direction of the wind. This could result in galloping forces of different magnitudes in the spans supported by one tower. If the frequency of galloping in the spans on either side of the tower are similar, the peaks in galloping forces could compound or cancel each other depending on the timing of the peaks. With a hanging insulator, the resultant of the horizontal forces will cause the insulator to swing in the direction of the force imbalance, thereby dissipating some of the energy which otherwise would have been transferred to the tower. In the case of dead end conductors, the galloping forces are directly transferred to the supporting towers. Therefore it was speculated that Tower-100 would have experienced larger lateral forces due to galloping than the other towers in the line.

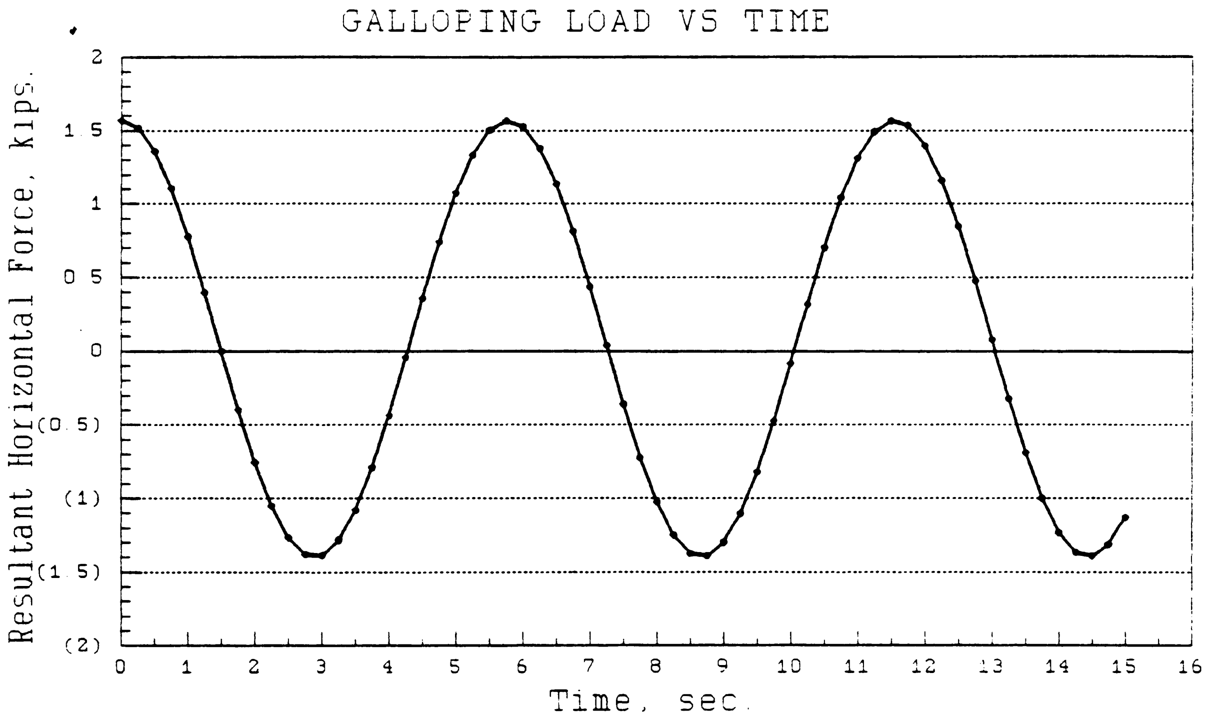
To estimate the galloping forces on Tower-100, three extreme cases of conductor galloping were considered:

Loadcase-1 Galloping in the span to the north only.

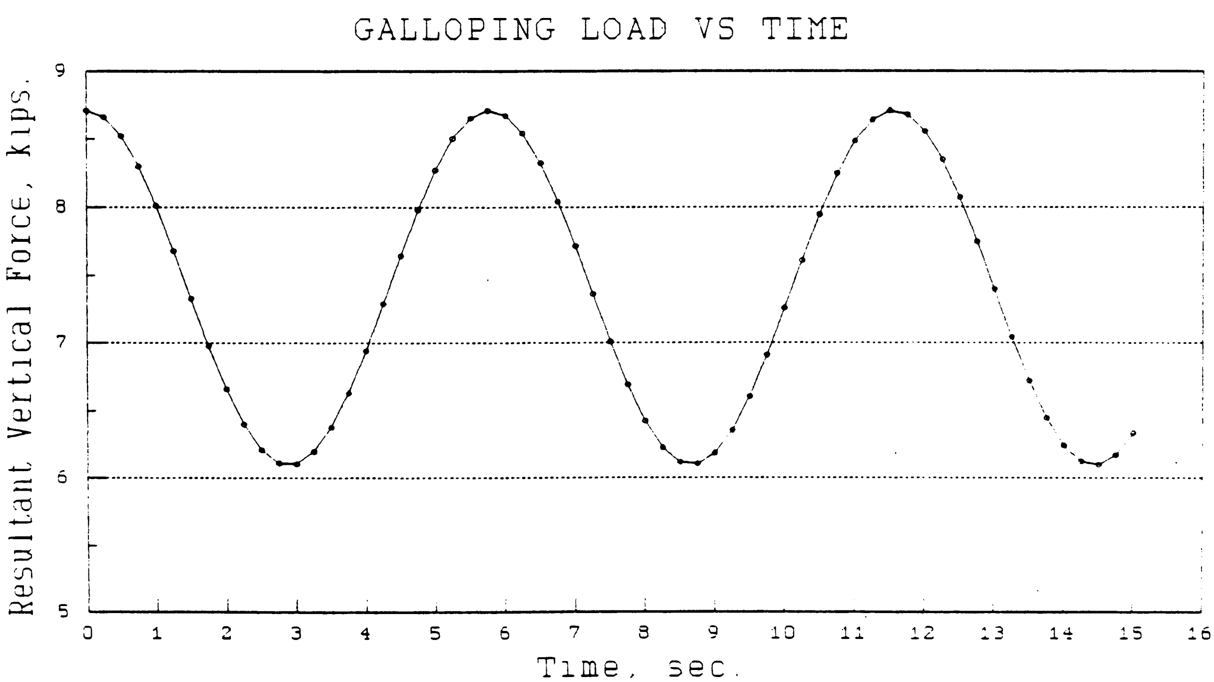
Loadcase-2 Both spans galloping, but out of phase.

Loadcase-3 Both spans galloping in phase.

The galloping forces in the spans on either side of Tower-100 are given in Appendix C. The frequency of galloping forces shown in these figures are 1.05 and 1.09 radians per seconds, respectively. To simulate Loadcase-2 and 3 an average frequency of 1.07 radians per seconds was assumed for both spans. The resultant of the components of the galloping forces on Tower-100 for the three loadcases are given in figures 3-15 through 3-17. From these figures it can be seen that Loadcase-2 results in the maximum resultant horizontal force, and Loadcase-3 results in the maximum resultant vertical force, on the tower. Loadcase-1 is believed to be the least likely to occur because of the similar conditions of the two spans involved (i.e. span lengths, ice formation, angle with respect to the direction of the wind).

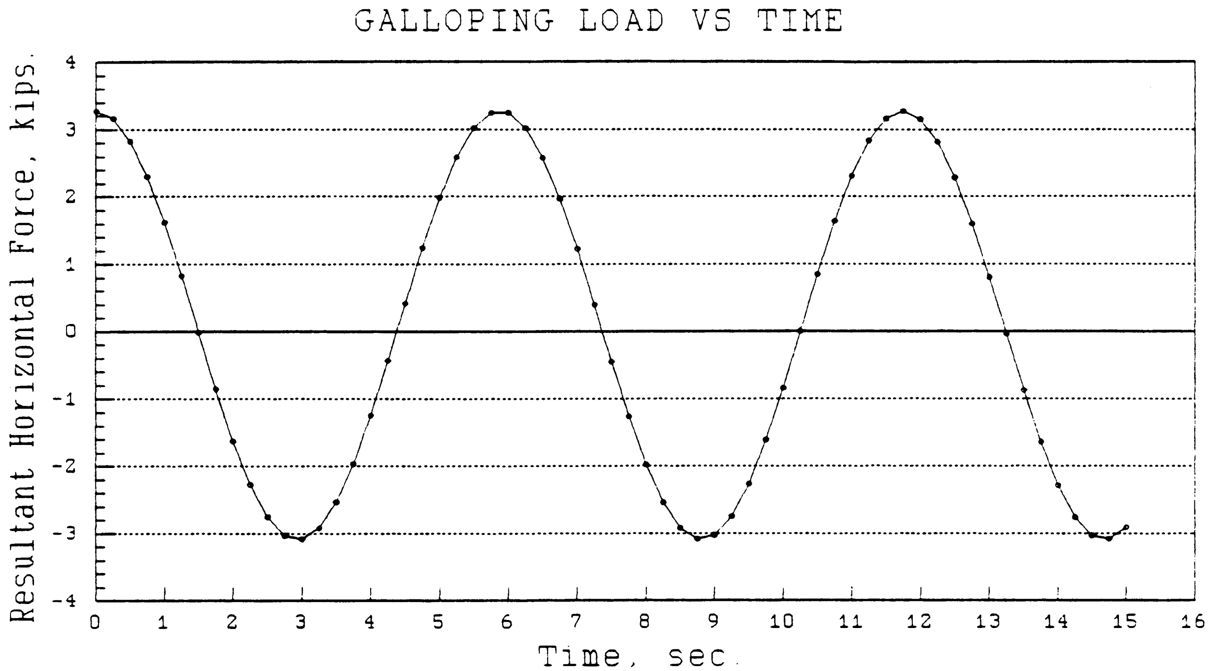


(a)

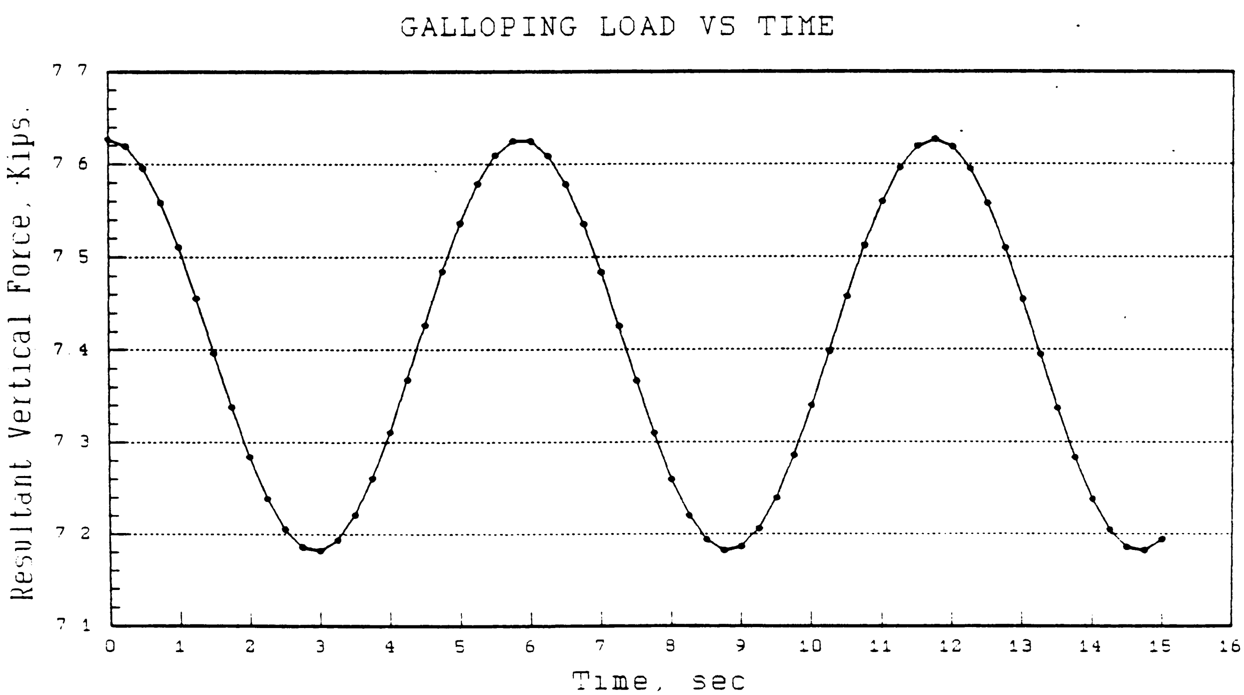


(b)

Fig. 3-15 : Tower No. 100, resultant galloping forces, Load Case 1

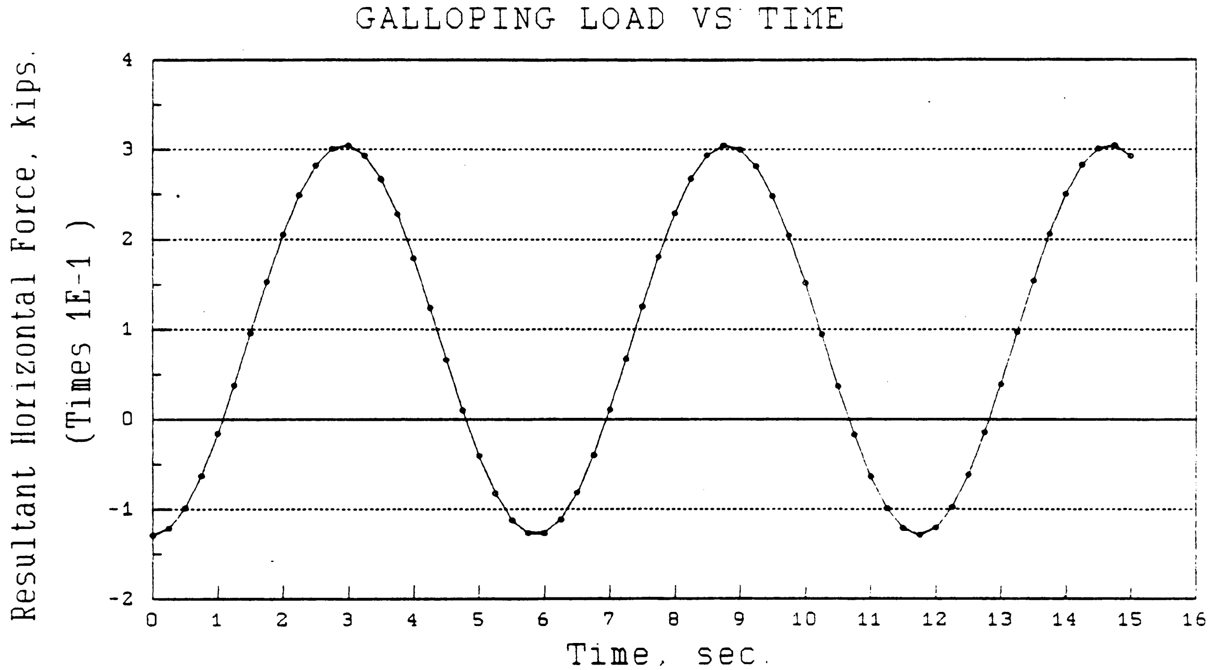


(a)

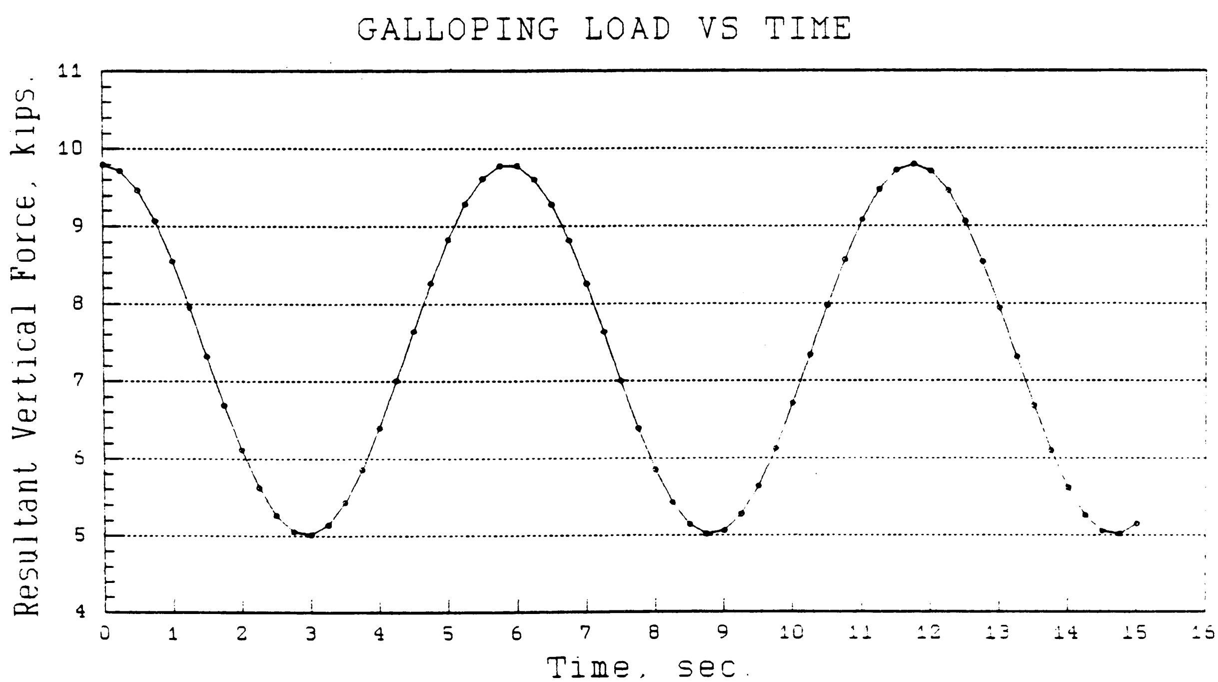


(b)

Fig. 3-16 : Tower No. 100, resultant galloping forces, Load Case 2



(a)



(b)

Fig. 3-17 : Tower No. 100, resultant galloping forces, Load Case 3

4. DISCUSSION OF THE RESULTS

In the previous chapter, the results of the various analyses were presented. These analyses concentrated on the investigation of failure scenarios deemed likely based on the evidence gathered from the field. The fact that Tower No. 99 was the only tower to remain standing strongly suggested that the initiation of the event took place in the area near this tower. In this chapter, a more detailed discussion of the results and the failure scenarios will be given.

4.1 Failure Scenario One

This failure scenario assumes that the failure began with the break of the eastern insulator at Tower No. 99 thus causing the separation of the eastern conductors from Tower No. 99. Following this separation, the resulting force imbalance and the broken conductor loads could have resulted in the collapse of the towers to the north and to the south of this tower.

In Chapter 3, it was concluded that a radial ice thickness of about 1.5 inches on the conductors could have been expected, prior to the collapse of the conductor line. For that thickness of ice, the load in the eastern insulator of Tower No. 99 would reach the ultimate capacity of that insulator and the separation of the eastern conductors would follow. Consequently, Towers No. 98 and 100 would have experienced a horizontal imbalance of more than 48 kips from the eastern conductors.

A finite element analysis of the conductor line model on ETADS [1] was consistent with the results presented in chapter 3, in the evaluation of the forces in the insulator and the conductors. Furthermore, the finite element analysis indicated that this force imbalance was sufficient to result in the buckling of the towers. In fact, a buckling analysis of Towers No. 98 and 100 on ETADS [1] showed that the towers could only withstand 6 to 7 kips of horizontal force imbalance, applied at the eastern outboard arms of the towers, before instabilities in the computer solution develop.

The estimated time for the crossarm of one of the towers to hit the ground, based on a simple upside down pendulum approximation, was about 2.2 seconds. Refer to Appendix C. This is enough time for the first peak of the broken conductor tension to develop. However, it is evident from the results of the finite element model analysis [1] that the towers were not stable enough to allow for the development of the broken conductor loads, and would have buckled as soon as the initial imbalance was applied.

Even though the broken conductor loads given in this thesis were never reached, there are a few interesting points to be discussed with respect to these plots.

4.1a Discussion of the broken conductor loads

In comparing the load versus time plots for different towers, it can be seen that the plots for each tower are markedly different from the others, with the exception of Tower No. 72 and Tower No. 102 which have almost identical plots. The input and output data, referred to in this section, are presented in Chapter 3 and Appendix C.

The plot of insulator tension versus time for Tower No. 98 is the only plot which distinctly exhibits the two major peaks of the broken conductor phenomena. The stiffness used for this tower was significantly greater than the stiffness used in the other towers, with the exception of Tower No. 100, since the attached conductors were included for these models. When the tower stiffness is large enough to only permit small tower displacements, compared to the length of the insulator, the initial displacement in the span adjacent to the break is primarily due to the swing of the insulator; and the two major peaks associated with that swing can be expected. However, if the tower is so flexible that its displacement under the initial imbalance is significant compared to the length of the insulator, the insulator swing becomes less of a factor and the two peaks associated with it become less significant. This situation can be observed in the plots of Towers No. 72, 102 and 106 which have extremely small tower stiffness compared to the imbalance applied, 48000 lbs versus 2000 lbs per foot.

The plots of Towers No. 72 and 102 are almost identical but the plot of Tower No. 106 looks quite different. The reason for this difference is the span lengths. The first span for Tower No. 106 is 879 feet versus span lengths of 1455 feet and 1462 feet for Towers No. 72 and 102, respectively. This indicates that length of the first span has a major affect on the load in the insulator. This conclusion is consistent with the parameter study undertaken in reference [20].

The dead end tower, Tower No. 100, represents a unique situation in that it has no hanging insulators. Naturally, the mechanisms associated with the swing of the insulator do not apply here. In this case, the displacement in the first span is a direct result of the displacement of the tower. In fact, in comparing the plot of load versus time with the plot of displacement versus time for this tower, it can be seen that the two plots follow a similar pattern. In addition, since Tower No. 100 was one of the more rigid towers in the line, the displacement of this tower, compared to the length of the insulator for Tower No. 98, was small. And the variation in the load imbalance was not as pronounced as for Tower No. 98.

4.2 Failure Scenario Two

A second failure was considered because of the unique situation of Tower No. 100. The lack of hanging insulators at this tower meant that any horizontal imbalance had to be directly resisted by the tower. As discussed in Chapter 3, the galloping forces in the adjacent spans of this tower could have created a resultant horizontal force imbalance. Since the tower is primarily designed to withstand vertical loads, the presence of any horizontal loading is cause for concern. The galloping forces for the three loadcases discussed in Chapter 3 were considered for application to the finite element model of Tower No. 100 on ETADS. Loadcases No. 2 and 3 would have resulted in the maximum horizontal and vertical resultant forces on Tower No. 100, respectively; and for that reason, these loadcases were identified as the critical loadcases.

The analysis results from ETADS [1] for the dynamic analysis under the galloping forces of Loadcase No. 2 showed that 70% of the peak loads would be sufficient to cause instability and hence buckling of the tower. On the other hand, for Loadcase No. 3, the analysis showed that the buckling failure of the tower would not occur.

Although Loadcase No. 2 would have been severe enough to result in the buckling of Tower No. 100, the occurrence of this loadcase is highly debateable, since the spans involved were similar in many aspects and would not be expected to gallop completely out of phase. Moreover, the post-failure layout of the line near Towers No. 98, 99 and 100 contradicts this scenario. As shown in Fig. 3-1 of the previous chapter, at Tower No. 100 the end of the eastern conductor was lying very near the tower foundation suggesting that it must have separated before the tower collapsed.

Based on the above discussion, the first scenario is believed to be the more likely scenario since it is consistent with the physical evidence gathered from the field. From the analyses presented in this thesis, the conditions prevailing on the day of the event were severe enough to support the hypotheses of scenario one.

5. CONCLUSIONS

The investigation of the collapse of the Lehigh-Sycamore 345 KV line due to an ice storm event has been presented in this thesis and in reference one. The investigation consisted of the analysis of the loads developed in the conductors, presented in this thesis, and the analysis of the entire system, including the supporting structures, presented in reference one. The software developed for the conductor analysis and the analytical approaches and formulas used in the conductor analysis have been discussed in previous chapters.

The investigation showed that the magnitude of the forces induced in the transmission line system on the day of the ice storm was much larger than the system was designed to handle. Several cases of conductor loading, which were believed to have contributed to the collapse of the system, and various aspects of the interaction of the conductor loads and the system components were studied. Based on the studies, the sequence of events, referred to as failure scenarios, which could have lead up to the collapse of the system were identified.

Two different failure scenario were considered. However, based on analysis and field data a most likely failure scenario was identified. This failure scenario is believed to have been initiated by the break of the eastern insulator of

Tower No. 99, and the separation of the eastern conductors from Tower No. 99. The subsequent horizontal force imbalance is believed to have been the cause of the buckling of the towers in the system in a cascading pattern.

It is evident from this study that the insulators and the connections between the conductors and the transmission towers can play a major role in the failure of a transmission line. The failure of a small component, such as the socket y clevis, could result in large force imbalances capable of producing critical stresses which undermine the integrity of the system. In this study, it was also shown that the towers in the system were inadequate to withstand the force imbalances induced in the system. A more conservative design philosophy would take into consideration methods of increasing the stability of the system with respect to the potential force imbalances.

Further study is recommended in the following areas. In the galloping study of the forces in the conductors, the interactions between the adjacent spans were ignored. A study using a multi-span model is recommended. In the simplified analysis of the fatigue problem, it was shown that fatigue could contribute significantly to the failure of the insulator assemblies. A more complete study of the insulators under cyclic loading is recommended. The broken conductor program used, CABLE 7, ignored the interaction between the conductor phases through the crossarm. This shortcoming could be eliminated by including the crossarm and the other conductor phases in the model. A multi-lane broken conductor analysis is recommended.

REFERENCES

1. S. Gupta. "Non linear analysis of transmission line structures subjected to ice loading." Thesis, Iowa State University, 1991.

2. Li Li. "Dynamic loads on pole transmission line structures from galloping conductors." Thesis, Iowa State University, 1990.

3. E. S. Doocy, A. R. Hard, C. B. Rawlins and R. Ikegami. "Transmission line reference book." EPRI, Palo Alto, California, 1979.

4. T. V. Gopalan. "Fatigue failure of insulator string of over head transmission line." Journal of Engineering Mechanics, 117 (January 1991).

5. T. J. Wipf, M. Baenziger, F. Fanous, S. Gupta and R. Anjam. "Documentation and analysis of failed transmission structures, Lehigh-Sycamore 345 KV transmission line." Ames, Iowa, August, 1991.

6. "Plan and Profile Map of Lehigh-Sycamore 345 KV Transmission Line." Iowa Power and Light Company, Des Moines, Iowa, 1971.

7. IEEE. "National electric safety code." IEEE, Inc., New York, 1981.

8. S. Bhattacharya. "Computer use in transmission line design." Transmission Line and Substation Design Seminar, Chicago, December, 1970.

9. E. A. Hoffmann. "Ice loading of transmission lines." Sargent & Lundy Eight Blennial Transmission and Substatio Conference, Chicago, Illinois, November, 1984.

10. S. Krishnasamy. "wind and ice loads on over head transmission lines." Ontario Hydro Research Review, 3 (June 1981): 11-18.

11. D. B. Campbell. "Unbalanced tensions in transmission lines." Journal of the Structural Division ASCE, 96 (October 1970): 2189-2207.

12. A. H. Peyrot and A. M. Goulois. "Analysis of Flexible Transmission Lines." Journal of the Structural Division ASCE, 104 (May 1978): 763-779.

13. R. N. Dubey and C. Sahey. "Vibration of over head transmission lines III." Shock & Vibration Digest, 12 (Dec. 1980): 11-14.

14. L. Haro., B. Magnusson and K. Ponni. "Investigations on forces acting on a support after conductor breakage." International Conference on Large Electric Systems, Paper No. 210 (1956).

15. A. Govers. "On the impact of uni-directional forces on high-voltage towers following conductor breakage." International Conference on Large Electric Systems, Paper No. 22-03 (1970).

16. A. H. Peyrot. "Longitudinal loading tests on a transmission line." EPRI, Final Report Project 1096-1 (September 1978).

17. J. Ferry-Borges. "Experimental study of the stresses created by the breakage of conductors in high voltage lines." Department of Public Works, National Civil Engineering Laboratory, Lisbon, Portugal (November 1968).

18. J. D. Mozer. "Longitudinal unbalanced loads on transmission line structures." EPRI, Final Report Project 561 (August 1978).

19. M. B. Thomas and A. H. Peyrot. "Dynamic response of ruptured conductors in transmission lines." IEEE PAS 101 (September 1982).

20. M. B. Thomas. "Broken conductor loads on transmission line structures." Dissertation, University of Wisconsin-Madison, 1981.

21. P. A. Tipler. "Physics." 2nd ed. Worth Publishers, Inc., New York, 1982.

22. J. Rhudie. "Iowa Power project: Electric transmission tower failure fatigue study." Iowa State University, Ames, Iowa, May, 1991.

23. C. F. Walton. "Iron castings hand book." Iron Casting Society, Inc., 1981.

24. H. Boyer and T. L. Gall. "Metals hand book." Desk edition American Society for Metals, Metals Park, Ohio, 1958.

APPENDIX A. SUMMARY OF PERTINENT EQUATIONS

The equations referred to in Chapter 2 are given in this appendix. Most of these equations have been used, directly or indirectly, in the computer programs discussed in this thesis.

A.1 Equations Used in Cable Subroutines

The equations presented here define the relationships between the variables of the cable element. See Fig. 2-1. The actual length of the cable element, L, from the catenary relationship

$$L^2 = V^2 + H^2 \frac{Sinh^2[\lambda]}{\lambda^2} \qquad \text{(A-1)}$$

where

$$\lambda = \frac{wH}{2F_H} \qquad \text{(A-2)}$$

The vertical force, F_2, at the initial end is

$$F_2 = \frac{w}{2}\left(-V\frac{\cosh[\lambda]}{\sinh[\lambda]} + L\right) \qquad \text{(A-3)}$$

The horizontal projection, H, of the conductor is

$$H = -F_1 \left(\frac{L_u}{EA} + \frac{1}{w} \log \frac{F_4 + T_J}{T_I - F_2} \right) \tag{A-4}$$

The vertical projection, V, of the conductor is given by

$$V = \frac{1}{2EAw} (T_J^2 - T_I^2) + \frac{T_J - T_I}{w} \tag{A-5}$$

The length of the conductor including elastic stretching is

$$L = L_u + \frac{1}{2EAw} \left(F_4 T_J + F_2 T_I + F_1^2 \log \frac{F_4 + T_J}{T_I - F_2} \right) \tag{A-6}$$

In addition, we know from equations of statics that

$F_4 = -F_2 + w\ L_u$; $F_3 = -F_1$; $T_I = (F_1^2 + F_2^2)^{1/2}$; $T_J = (F_3^2 + F_4^2)^{1/2}$

A very good approximation of the unstretched length of the conductor, assuming a constant tension throughout the conductor, can be obtained by

$$L_{uo} = L \left(1 - \frac{F_H L}{AEH} \right) (1 + T \times ET)^{-1} \tag{A-7}$$

In the iterative process to determine the cable element forces, a starting value for the horizontal force at end one can be obtained from

$$F_1^0 = -\frac{wH}{2\lambda^0} \tag{A-8}$$

which is Eq. A-1 rewritten with the stretched length, L, replaced by the unstretched length, L_u. L_u was obtained from PCAXLO and $(\text{Sinh}^2\lambda)/(\lambda^2)$ was replaced by the first two terms of its series expansion. Similarly, Eq. A-3 is rewritten to obtain a starting value for the vertical force at the initial end of the element.

$$F_2^0 = \frac{w}{2}\left(-V\frac{\cosh[\lambda^0]}{\sinh[\lambda^0]} + L_u\right) \tag{A-9}$$

The terms in these expressions are those of the author of reference 12, and are defined as follows:

w = weight of cable per unit length

E = modulus of elasticity

A = cross sectional area

T, ET = temperature and coefficient of thermal expansion

H = horizontal projection of the ends of the cable

V = vertical projection of the ends of the cable

T_I = tension at the initial end

T_J = tension at the final end

L = actual cable length

L_u = unstressed length at temperature T

L_{uo} = unstressed length at reference temperature

F_H = horizontal tension

F_1, F_2 = Horizontal and vertical components of T_I

F_3, F_2 = Horizontal and vertical components of T_J

A.2 The Equations for CABLE 7

The equations of equilibrium for the lumped mass shown in figure 2-3 are:

$$M \ddot{X} = F_H^j - F_H^i - C \dot{X}_H \quad \text{(A-10)}$$

$$M \ddot{X} = F_V^i - F_V^j - C \dot{X}_V \quad \text{(A-11)}$$

Assuming a linear acceleration over a small time interval, the equations for the velocity and displacement at the end of the time interval are:

$$\ddot{X}(t_1) = \ddot{X}(t_0) + a\,\Delta t \quad \text{(A-12)}$$

$$\dot{X}(t_1) = \dot{X}(t_0) + \ddot{X}(t_0)\,\Delta t + a\,\frac{(\Delta t)^2}{2} \quad \text{(A-13)}$$

$$X(t_1) = X(t_0) + \dot{X}(t_0)\,\Delta t + \ddot{X}(t_0)\,\frac{(\Delta t)^2}{2} + a\,\frac{(\Delta t)^3}{6} \quad \text{(A-14)}$$

The terms in these expressions are those of the author of reference 19, and are defined as follows:

M = mass at degree of freedom

C = constant of critical damping, 20%

F_H = horizontal force at degree of freedom

F_V = vertical force at degree of freedom

$\dot{X}_H$ = horizontal velocity at degree of freedom

$\dot{X}_V$ = vertical velocity at degree of freedom

$\ddot{X}_H$ = horizontal acceleration at degree of freedom

$\ddot{X}_V$ = vertical acceleration at degree of freedom

X_H = horizontal displacement at degree of freedom

X_V = vertical displacement at degree of freedom

Δt = the time interval

t_o, t_1 = time at the beginning and end of the interval

A.3 The Galloping Equations

The following relationships, for a conductor with the ends at the same level, have been developed by Mr. Li Li:

The vertical component of the static tension plus the vertical component of the additional tension is given by

$$(V+V)=\frac{}{L}[4S_0+n\pi a_0\cos(\omega_n t)]*[\frac{}{n\pi H}\cos(\omega_n t)+H] \quad \text{(A-15)}$$

The maximum vertical tension is

$$(V+v)_{\max} = \frac{1}{L}[4s_0+n\pi a_0]\,[\frac{2a_0 k_e wL}{n\pi H}+H] \tag{A-16}$$

The galloping amplitude from the initial static sag position is

$$a_0 = \frac{0.26\,V_w(2\pi)}{2\ \omega_n} \tag{A-17}$$

The equivalent stiffness of the system is defined by

$$k_e = \frac{1}{\frac{1}{k_c}+\frac{1}{k_i}} \tag{A-18}$$

where the stiffness of the conductor is

$$k_c = \frac{EA}{L_c} \tag{A-19}$$

and the stiffness of the insulator is

$$k_i = \frac{W+0.5W_i}{L_i} \tag{A-20}$$

The line static sag is approximated by

$$s_o = \frac{wL^2}{8H} \tag{A-21}$$

The horizontal component of the additional tension is

$$h = \frac{2a_0 k_e wL}{n\pi H}\cos(\omega_n t) \tag{A-22}$$

and the maximum of the horizontal component of the additional tension is

$$h_{max} = \frac{2a_0 k_e wL}{n\pi H} \tag{A-23}$$

The natural frequency of the conductor is

$$\omega_n = \{\frac{H}{m}[bL + (\frac{n\pi}{L})^2]\}^{1/2} \tag{A-24}$$

where

$$b = \frac{8s_0 k_e w}{H^2 L^2} \tag{A-25}$$

The ratio of total vertical force to static vertical force is

$$R_v = \frac{(V+v)_{max}}{V} \qquad \text{(A-26)}$$

and the ratio of total horizontal force to static horizontal force is

$$R_H = \frac{(H+h)_{max}}{H} \qquad \text{(A-27)}$$

The terms in these expressions are those of the author of reference 2, and are defined as follows:

V = vertical component of static tension in the conductor

v = vertical component of additional tension in the conductor

H = horizontal component of static tension in the conductor

h = horizontal component of additional tension in conductor

L = line span length

S_o = line static sag

n = number of galloping loops per span
1 for single loop galloping

a_o = galloping amplitude

ω_n = symmetric mode natural circular frequency

t = time

K_e = equivalent stiffness of the system

k_c = stiffness of the conductor

k_i = stiffness of insulator in the longitudinal directio

of the conductor

EA = area times modulus of elasticity for conductor

L_c = length of the conductor

L_i = length of the insulator

W_i = insulator weight

W = total conductor weight per span

w = total conductor weight per unit length

m = total conductor mass per unit length

V_w = wind velocity

R_v = galloping amplification for the vertical force

R_h = galloping amplification for the horizontal force

APPENDIX B. MODIFIED CABLE 7 USER MANUAL

The program CABLE 7 can be used to obtain the broken conductor loads on the towers of the span adjacent to the break in a conductor line. The assumptions regarding the modeling of the conductor line are explained in this thesis and in reference [20]. In this appendix, the inputs and outputs of CABLE 7 are briefly discussed.

The input for CABLE 7 is read from an input file. The name of the input file should consist of a base name and an extension of ".IN" (e.g. INPUT.IN). The general format of the input file is shown in Fig. B-1. The variables represented in each row are:

First row,

NSPAN = number of spans

NSEG = maximum number of conductor spans used

NUNIT = 0, metric units

= 1, U.S. units

ICODE = code to specify the output desired

0, displacements, forces and summary of data

1, forces, and summary of data

2, summary of data, no conductor movement displayed

3, summary of data

4, generate dynamic data at time T = 0.0

KINT = data is stored every KINT intervals

GINT = displaced conductor displayed every GINT intervals

Second row,

PH = initial horizontal line tension at T = 0.0

PCL1 = default 1.0. See reference [20]

EPSF = default 10.0. See reference [20]

DT = time interval used

TF = length of time for the simulation

The remaining rows (one row for each span),

VI = length of the insulator, 0 if no hanging insulator

HC = horizontal projection of the conductor

VC = vertical projection of the conductor ends

WOI = total weight of the insulator, 0 if no hanging insulator

WOC = weight of conductor, including ice, per unit length

* AEI = area times modulus of elasticity for the insulator, 0 if no insulator

AEC = area times modulus of elasticity for the conductor

* NSEG = number of cable elements to represent the conductor

* NPT = 0, fixed support
  = 1, support free to displace horizontally

AKT = equivalent tower stiffness

AM = mass of the tower

A more complete description of the above variables can be found in reference [20].

The program is started by typing cable7 at the DOS prompt. The user is prompted to enter the base name to be associated with that run. To work with a directory other than the default directory, the base name should include the directory specification. The user is given the choice of a new run or the plots from existing files. By typing "N" a new run is started. For each new run, the user can specify a title. The program can be paused at any time by typing "O". CABLE 7 creates an output file with a ".OUT" extension; and two other files with ".PL1" and ".PL2" extensions, which are for use by CABLE 7's post processor. Also created are the files TEMP1.DAT, TEMP2.DAT and TEMP3.DAT for the internal use of the program. The user is encouraged to delete these files in the interest of saving disk space.

When the run is complete, a post processing screen is displayed, Fig. B-2. The user has the option of seven different time plots. The seven time plots available consist of insulator tension and its X-Y components, X-Y components of the displacement of the lower end of the insulator, insulator angle from horizontal and conductor midspan vertical

NSPAN, NSEG, NUNIT, ICODE, KINT, GINT

PH, PCLD, EPSF, DT, TF

VI, HC, VC, WOI, WOC, AEI, AEC, NSEG, NPT, AKT, AM

VI, HC, VC, WOI, WOC, AEI, AEC, NSEG, NPT, AKT, AM

VI, HC, VC, WOI, WOC, AEI, AEC, NSEG, NPT, AKT, AM

VI, HC, VC, WOI, WOC, AEI, AEC, NSEG, NPT, AKT, AM

Fig. B-1 : The input file for CABLE 7 (four spans)

```
*********************************************************
         MENU
*********************************************************
 1   PLOT INSULATOR TENSION VS TIME

 2   PLOT HORIZONTAL COMPONENT OF
     INSULATOR TENSION VS TIME

 3   PLOT VERTICAL COMPONENT OF
     INSULATOR TENSION VS TIME

 4   PLOT HORIZONTAL DISPLACEMENT
     OF LOWER END OF INSULATOR ONE

 5   PLOT VERTIAL DISPLACEMENT
     OF LOWER END OF INSULATOR ONE

 6   PLOT INSULATOR ANGLE FROM
     HORIZONTAL VS TIME

 7   PLOT CONDUCTOR MIDSPAN VERTICAL
     DISPLACEMENT VS TIME

 E   END PLOT
************************************
ENTER: selection > 6
```

Fig. B-2 : The options available on the post processor of CABLE 7 displacement. Examples of these plots can be found in Chapter 3 and Appendix C.

APPENDIX C. NUMERICAL DATA FOR ANALYSES

The analyses presented in Chapter 3 were based on the numerical data given in this appendix. As mentioned in that chapter, the analyses were performed using the modified versions of CABLE and CABLE 7.

Table No C-2 : Forces in conductors supported by the eastern insulator of Tower No. 99

Radial Ice, in	Span	Without Galloping			With Galloping			Galloping Frequency, rad/sec
		Vert Force Kips		Hor Force Kips	Vert Force Kips		Hor Force Kips	
		End j	End i		End j	End i		
1.25	98-99	3.28	2.85	20.80	4.24	3.68	21.59	0.978
	99-100	2.65	3.13	20.51	3.51	4.14	21.78	1.071
1.3	98-99	3.44	2.99	21.55	4.43	3.85	22.39	0.975
	99-100	2.78	3.28	21.23	3.68	4.33	22.58	1.068
1.4	98-99	3.76	3.28	23.07	4.83	4.22	24.01	0.968
	99-100	3.05	3.58	22.70	4.03	4.73	24.21	1.063
1.5	98-99	4.09	3.58	24.63	5.27	4.61	25.68	0.962
	99-100	3.34	3.90	24.22	4.40	5.15	25.89	1.058
1.6	98-99	4.45	3.90	26.22	5.71	5.01	27.39	0.956
	99-100	3.64	4.24	25.76	4.79	5.59	27.61	1.053
1.7	98-99	4.82	4.23	27.85	6.18	5.43	29.15	0.951
	99-100	3.95	4.59	27.33	5.20	6.04	29.37	1.049
1.75	98-99	5.01	4.41	28.68	6.42	5.65	30.04	0.948
	99-100	4.11	4.77	28.12	5.42	6.28	30.27	1.047

C.1 Tension in the Insulator of Tower No. 99

In order to obtain the forces in the insulator of Tower No. 99 prior to the collapse of the line, the forces in the two eastern conductors supported by this insulator were obtained. Table C-1 contains the prevailing conditions for the spans involved. These conditions were used in Option 1 of CABLE to obtain the results which are given in Table C-2. The forces applied to the eastern insulator of Tower No. 99 were obtained from the second end (end j) of span 98 - 99 and the first end (end i) of span 99 - 100.

Table No. C-1 : The condition of the spans from Tower No. 98 to Tower No. 100

	Span No.		
	98 - 99	99 - 100	98-100
H. projection, ft	1304.6	1230.51	2442.52
V. Projection, ft	-13.5	14.25	0.75
Original Conductor Length, ft	1306.83	1232.29	2539.12
Insulator Weight, lbs	290	250	-
Insulators per span	2	1	-
Insulator length, ft	10.5	10.5	-
Stringing Tension, lbs	6000		
Temperature Change, °F	-28		
Wind Velocity, ft/sec	17.75		

C.2 The Forces in the Separated Conductor

The conditions for the span between Towers No. 98 and No. 100 is given in Table No. C-1. This is the alignment which the eastern conductors will assume after they separate from Tower No. 99. The horizontal projection is therefore, the length of the straight line connecting Tower No. 98 to Tower No. 100. The original conductor length in this span is simply the summation of the original conductor lengths in the other two spans. Table No. C-3 contains the forces and the sag for these conductors which are obtained by Option 2 of CABLE.

Table No. C-4 : The conditions of the eastern conductor when resting on the ground

Radial Ice, in	Span	Resultant Force, kips		Angle of force from Vert., deg		H. force kips	First Ground Point, ft	Second Ground Point, ft
		End i	End j	End i	End j			
1.5	98-100	0.577	0.120	78.0	4.1	0.130	53.7	2394.9

C.3 The Forces in the Grounded Conductor

The excessive sag, 307 feet measured from the first attachment point, in the separated conductors indicates that the conductors would be lying on the ground after the separation. Option 3 of CABLE was used to obtain the forces in these grounded conductors which are given in Table No. C-4. The span referred to, between Tower No. 98 and Tower No. 100 is described in Table C-1.

Table No. C-3 : The conditions of the eastern conductors after separation from Tower No. 99

Radial Ice, in	Span	V. force, kips		H. force, kips	Sag, ft
		End i	End j		
1.5	98-100	7.46	7.45	14.49	307.72

Note: Sag is measured from the first attachment point

C.4 The Broken Conductor Phenomena

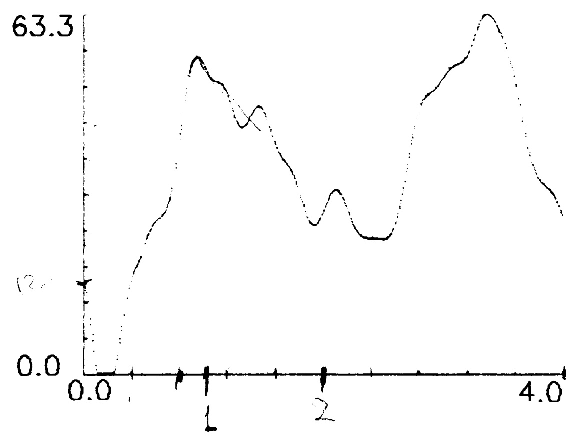
The input data for the various towers analyzed are given in Table No. C-5. In this table, the spans included for each analysis are described. The insulator and conductor characteristics were the same in all the spans except for Tower No. 100 which did not have any hanging insulators. Each insulator supported two lines of conductor. Therefore, conductor characteristics were doubled to account for that fact.

Some of the broken conductor plots for Towers No. 98 and 100 were included in Chapter 3. The complete set of plots for Towers No. 98 and 100 and the additional towers are given in figures C-1 through C-10.

Table No. C-5 : Spans considered for broken conductor analyses

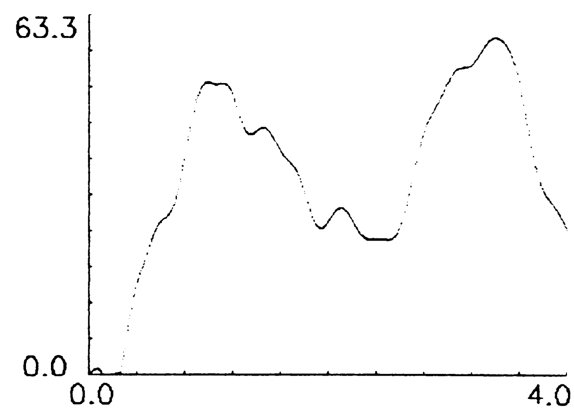
Tower No.	Spans Included	Horizontal Projection, ft	Vertical Projection, ft	Tower Stiffness, lbs/ft	Tower Mass, slugs
Tower 72	72-71	1455	-6	2000	83.3
	71-70	1345	1	2000	83.3
	70-69	1455	27	2000	83.3
	69-68	1345	0	2000	83.3
Tower 98	98-97	1348	8	20000	242
	97-96	1540	3	20000	276
	96-95	1360	-13	20000	276
	95-94	1410	-18	20000	266
Tower 100	100-101	1175	-26	20000	247
	101-102	1203	19	20000	231
	102-103	1462	8	20000	402
	103-104	1470	-1	20000	276
Tower 102	102-103	1463	8	20000	83.3
	103-104	1470	-2	2000	83.3
	104-105	1486	-4	2000	83.3
	105-106	1449	-35	2000	83.3
Tower 106	106-107	879	-4	2000	83.3
	107-108	919	11	2000	83.3
	108-109	1730	18	2000	83.3
	109-110	1330	-22	2000	83.3
Conductor Area * Elasticity Modulus, psi			18578000		
Conductor mass, lbs/ft			11.746		
Insulator Area * Elasticity Modulus, psi			100000		
Insulator Length, ft			10.5		
Insulator Weight, lbs			214		

Note : Tower No. 100 did not have any hanging insulators.



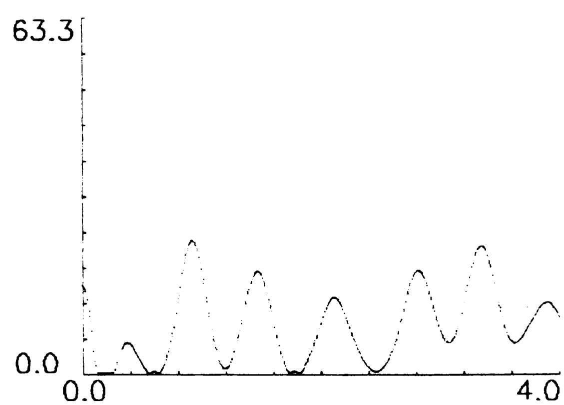
Insulator tension in kips

(a)



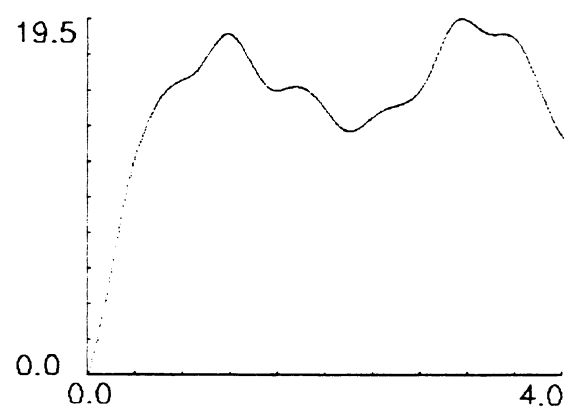
Horizontal tension in the insulator in kips

(b)



Vertical tension in the the insulator in kips

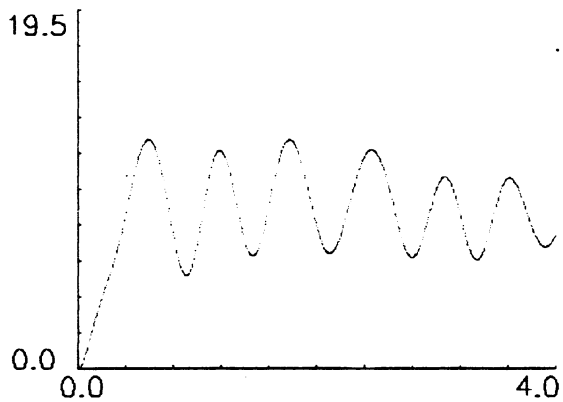
(c)



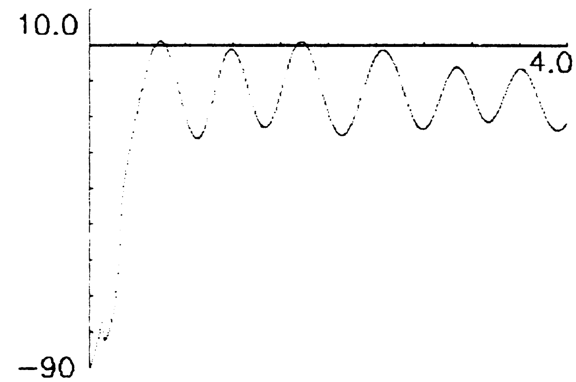
Horizontal displacement of the insulator end in feet

(d)

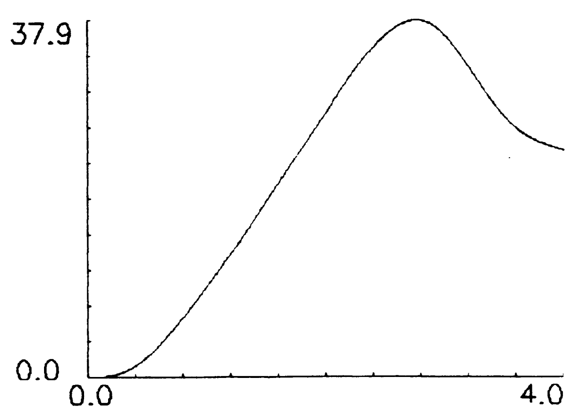
Fig. C-1 : Broken conductor time plots, seconds, Tower No. 98



Vertical displacement of insulator end in feet
(e)

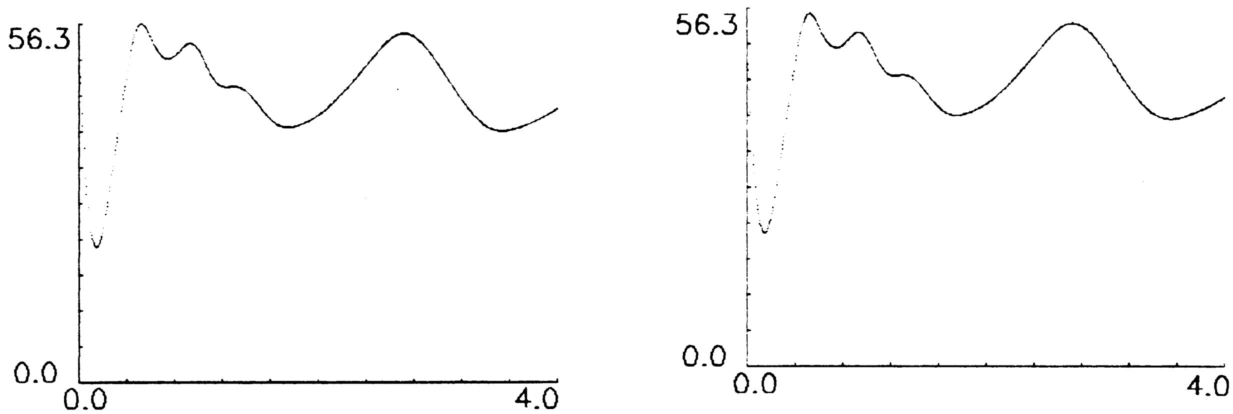


Insulator angle from horizontal in degrees
(f)



Vertical displacement of conductor midspan in feet
(g)

Fig. C-2 : Broken conductor time plots, seconds, Tower No. 98

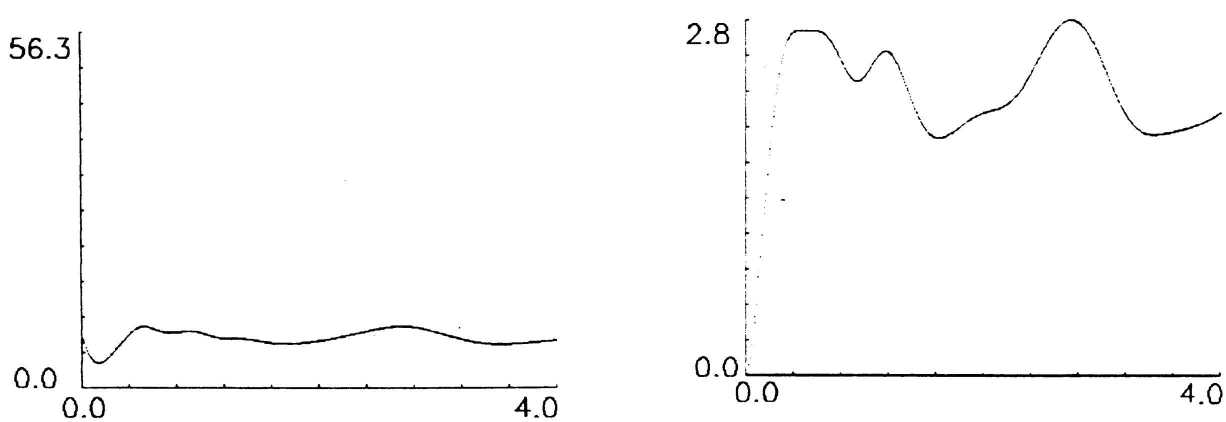


Conductor tension in kips

(a)

Horizontal tension in the conductor in kips

(b)



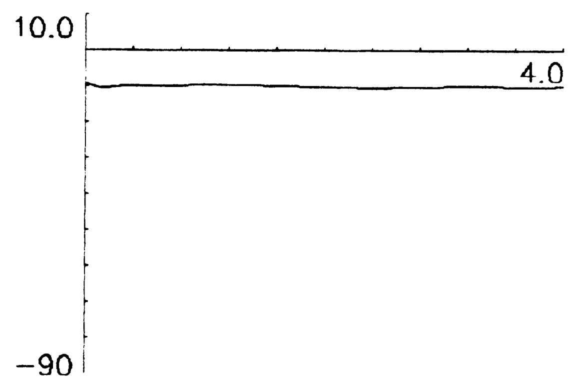
Vertical tension in the the conductor in kips

(c)

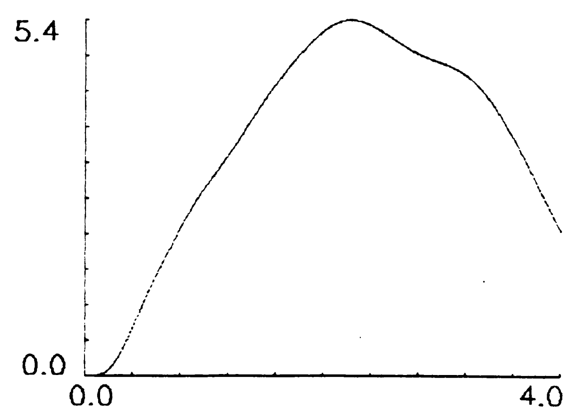
Horizontal displacement of the first tower in feet

(d)

Fig. C-3 : Broken conductor time plots, seconds, Tower No. 100

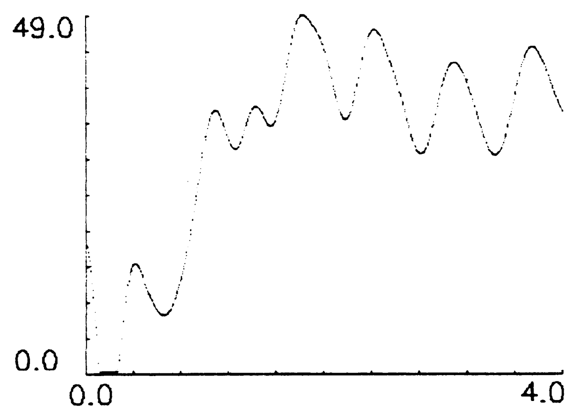


Conductor angle from
horizontal in degrees
(f)



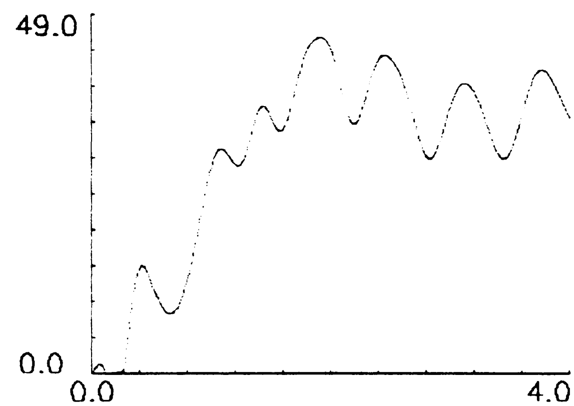
Vertical displacement of
conductor midspan in feet
(f)

Fig. C-4 : Broken conductor time plots, seconds, Tower No. 10

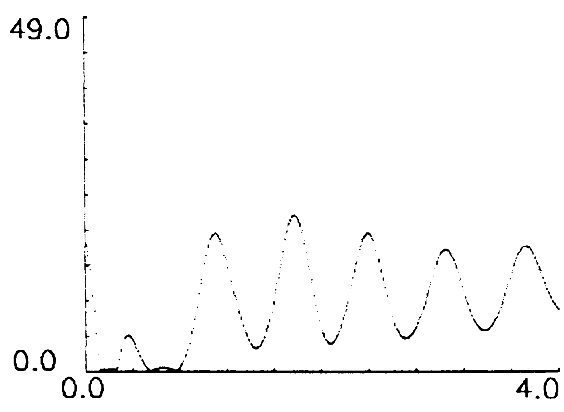


Insulator tension in kips

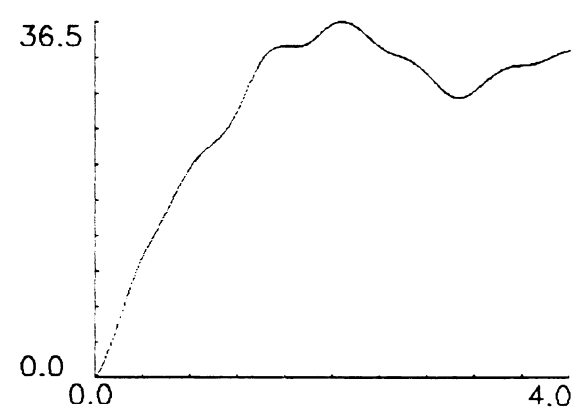
(a)



Horizontal tension in the insulator in kips
(b)

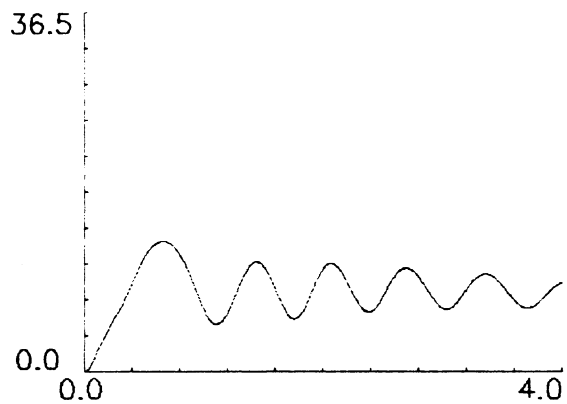


Vertical tension in the the insulator in kips
(c)

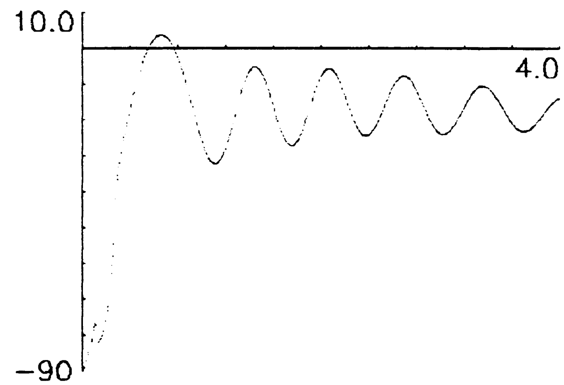


Horizontal displacement of the insulator end in feet
(d)

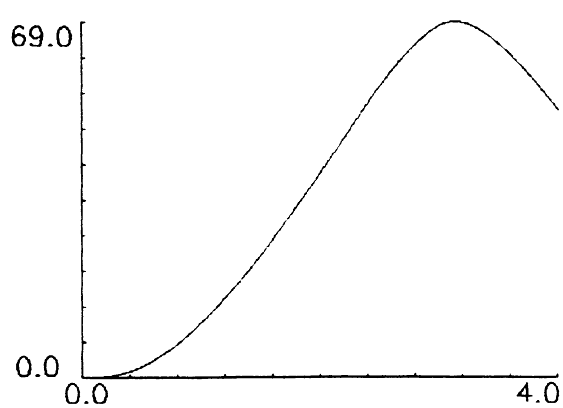
Fig. C-5 : Broken conductor time plots Tower No. 72



Vertical displacement of
insulator end in feet
(e)

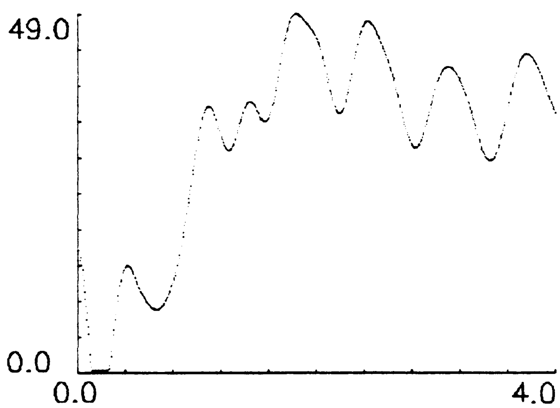


Insulator angle from
horizontal in degrees
(f)



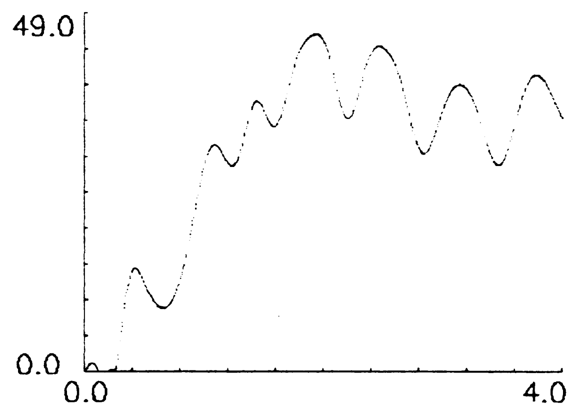
Vertical displacement of
conductor midspan in feet
(g)

Fig. C-6 : Broken conductor time plots Tower No. 72



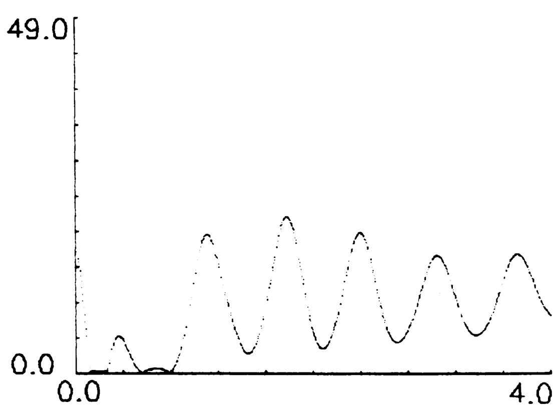
Insulator tension in kips

(a)



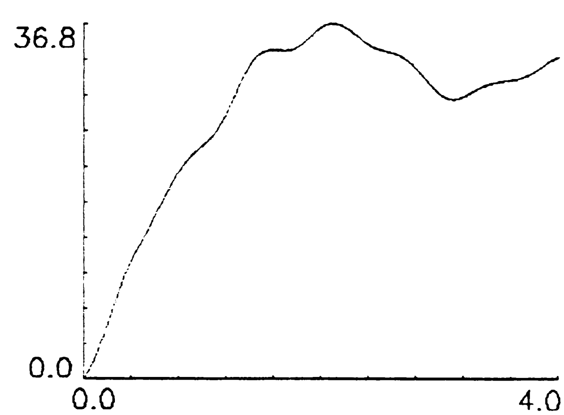
Horizontal tension in the insulator in kips

(b)



Vertical tension in the the insulator in kips

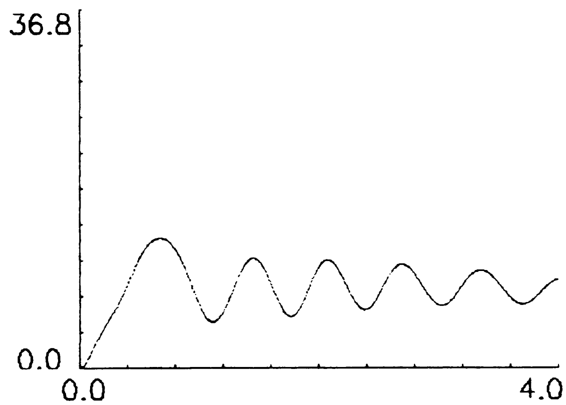
(c)



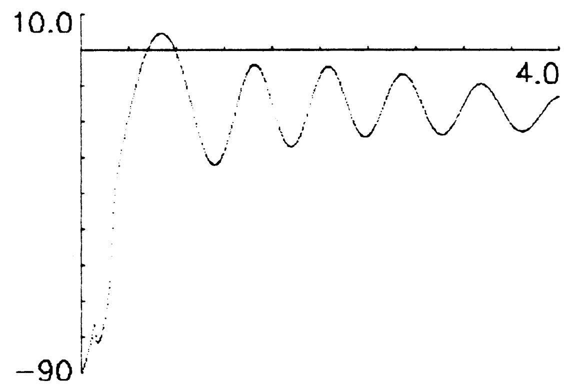
Horizontal displacement of the insulator end in feet

(d)

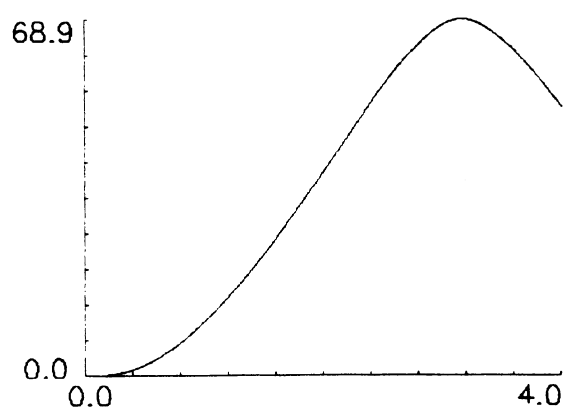
Fig. C-7 : Broken conductor time plots, seconds, Tower No. 102



Vertical displacement of
insulator end in feet
(e)

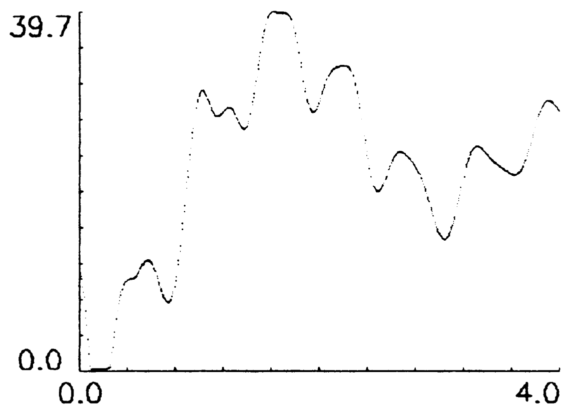


Insulator angle from
horizontal in degrees
(f)



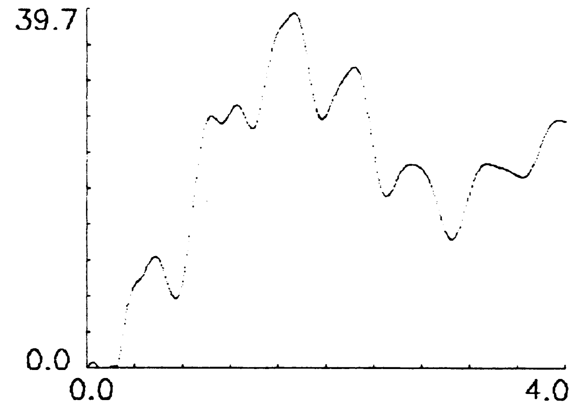
Vertical displacement of
conductor midspan in feet
(g)

Fig. C-8 : Broken conductor time plots, seconds, Tower No. 10;



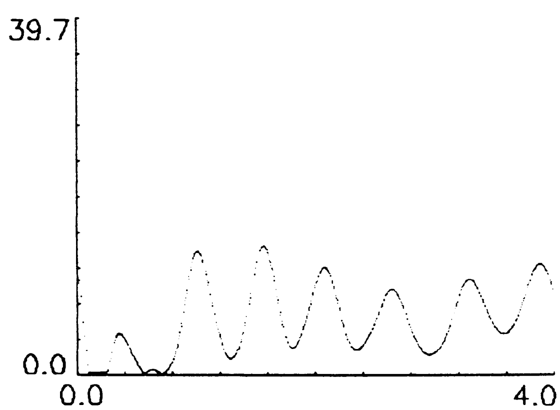
Insulator tension in kips

(a)



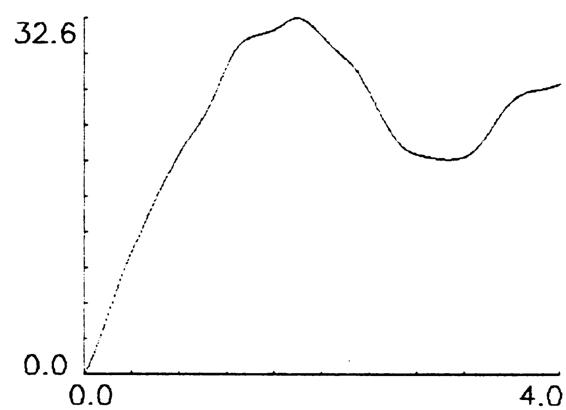
Horizontal tension in the insulator in kips

(b)



Vertical tension in the the insulator in kips

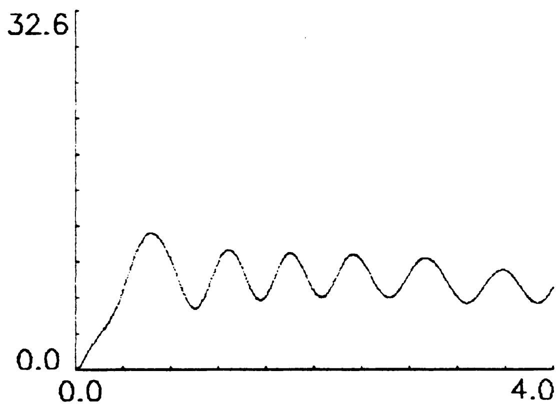
(c)



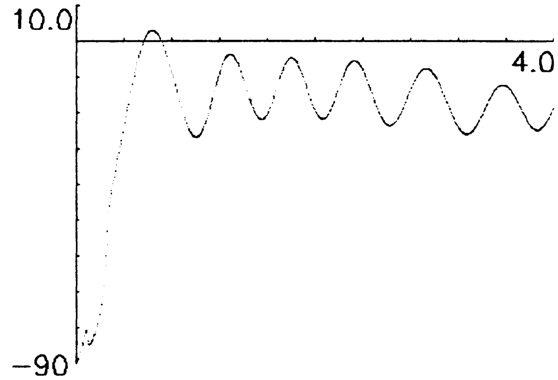
Horizontal displacement of the insulator end in feet

(d)

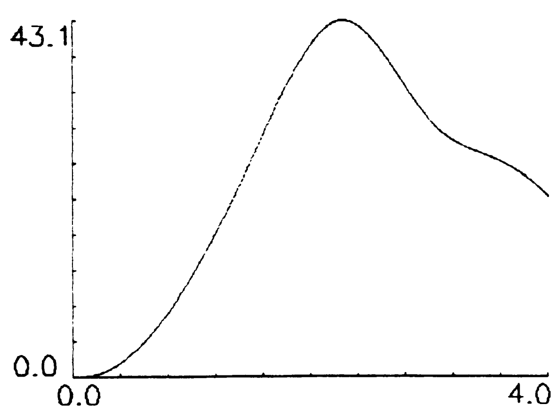
Fig. C-9 : Broken conductor time plots, seconds, Tower No. 106



Vertical displacement of insulator end in feet
(e)



Insulator angle from horizontal in degrees
(f)

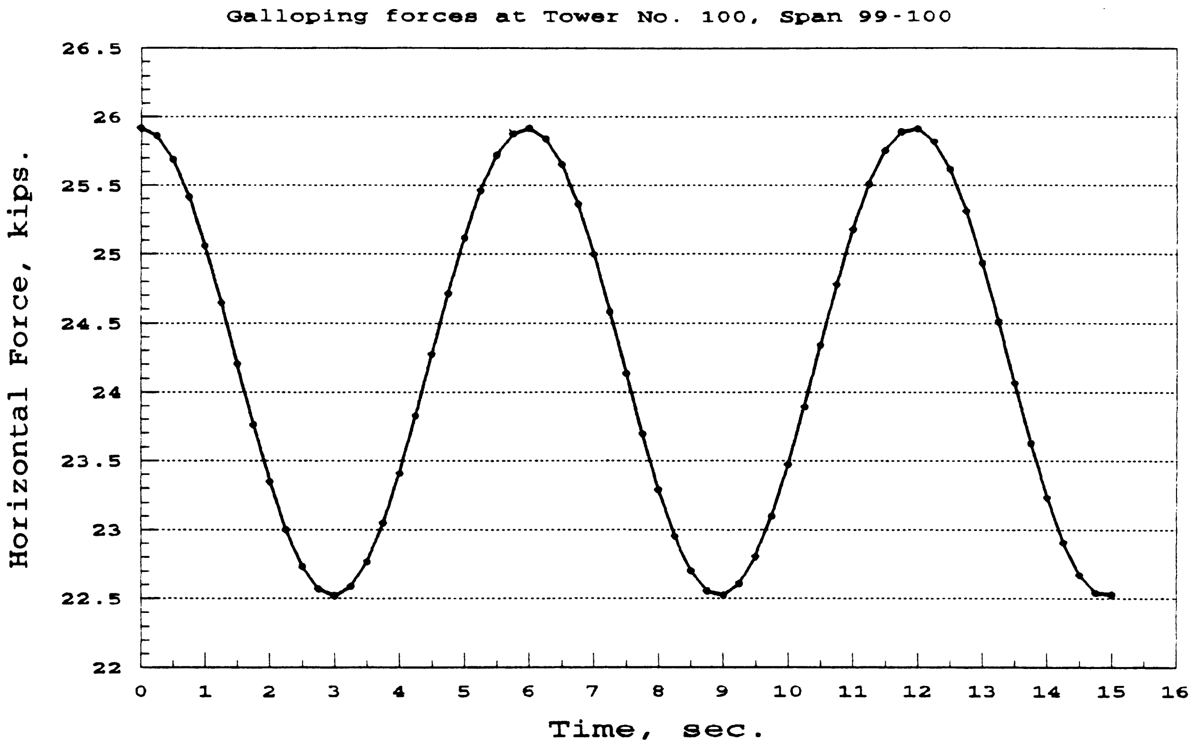


Vertical displacement of conductor midspan in feet
(g)

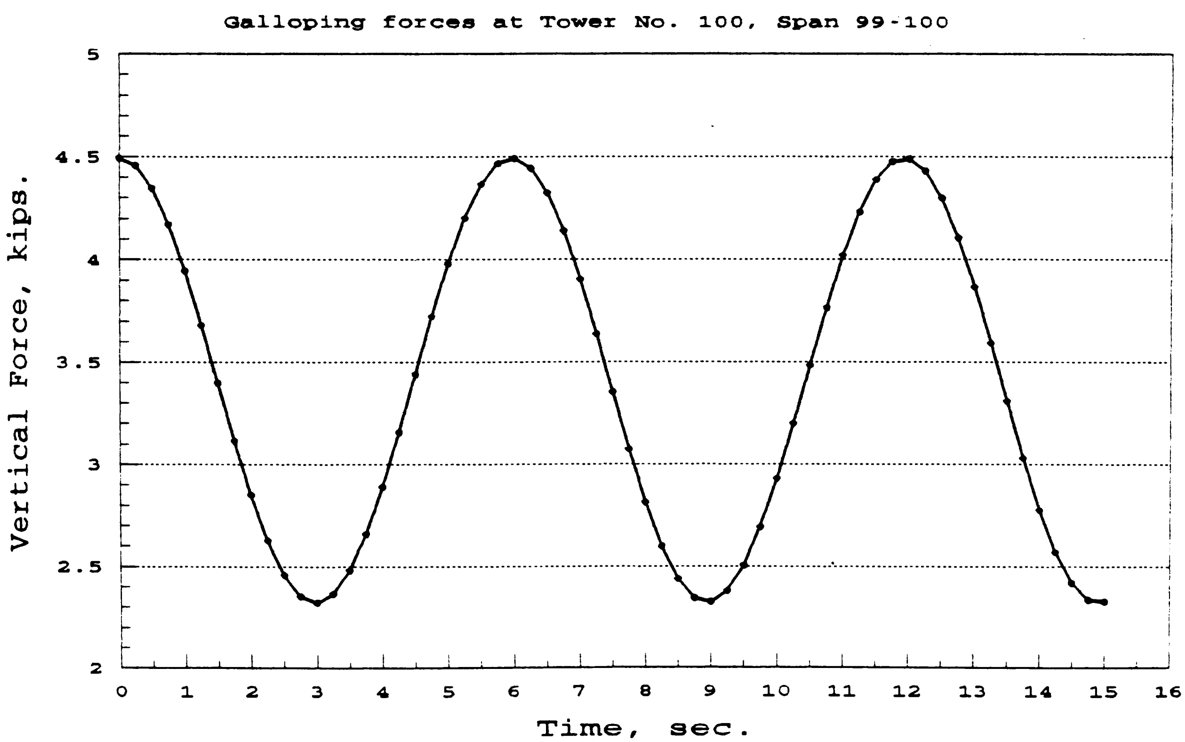
Fig. C-10 : Broken conductor time plots seconds, Tower No. 10€

C.5 Galloping Forces at Tower No. 100

The components of the galloping forces in the conductors applied to Tower No. 100 are given in this section. These forces were obtained by the application of Option 1 of CABLE. The spans involved are from Tower No. 99 to 100 and from Tower No. 100 to 101. The characteristics of these spans are given in Tables C-1 and C-5, respectively. These galloping forces are plotted in figures C-11 and C-12.

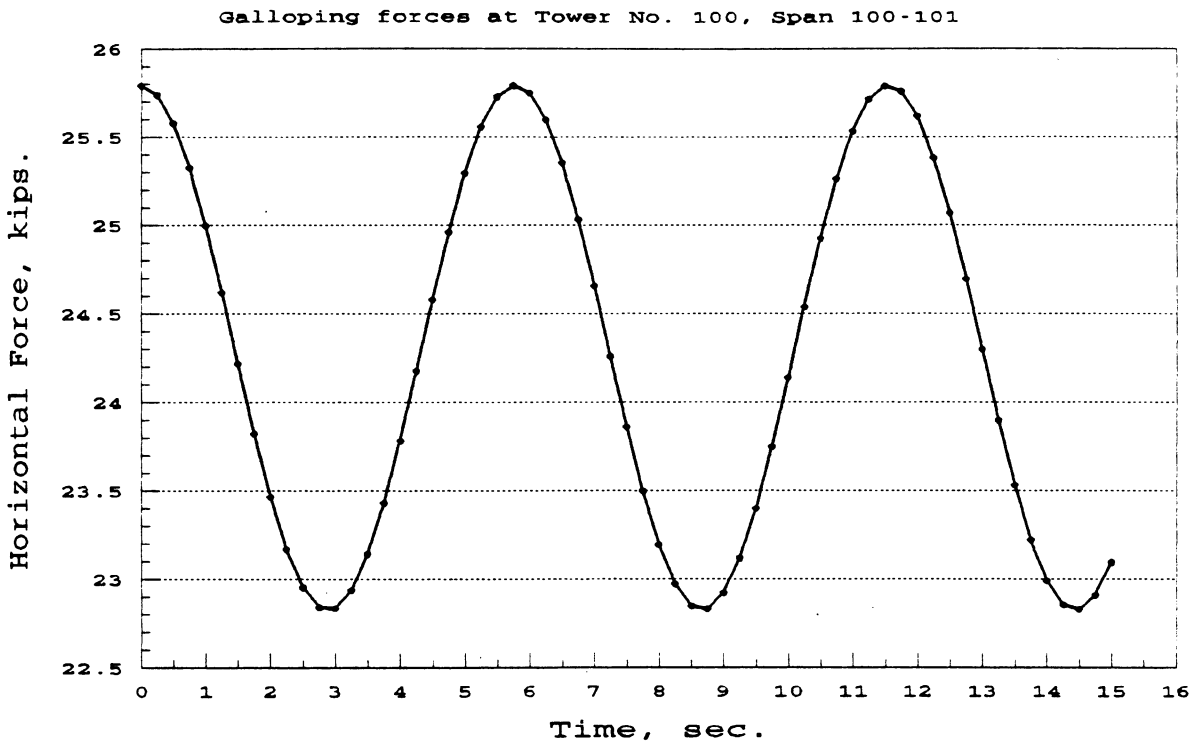


(a)

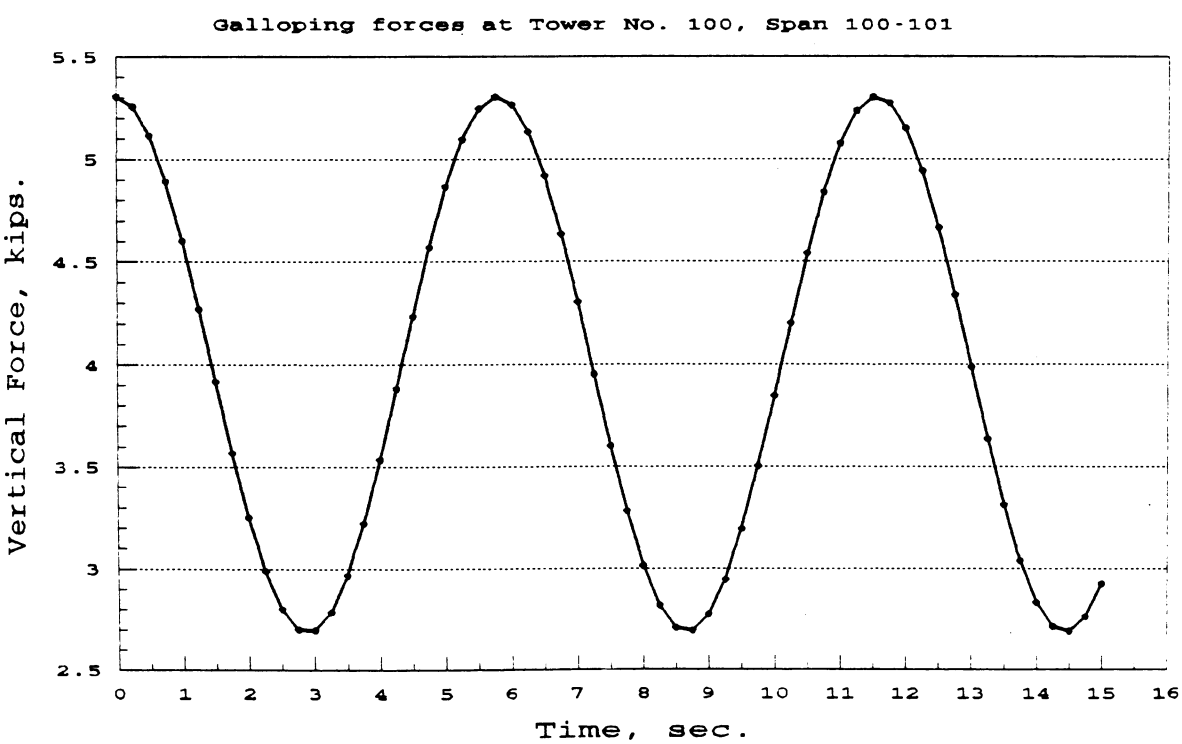


(b)

Fig. C-11 : Galloping forces at Tower No. 100, Span 99 to 100



(a)



(b)

Fig. C-12 : Galloping forces at Tower No. 100, Span 100 to 101

C.6 Estimated Time for One Tower to Collapse

The time that it takes for one of the towers to hit the ground after it buckles was approximated based on an inverted simple pendulum. From reference [21], the governing equations for a simple pendulum with small amplitude are:

$\theta = \theta_o \cos \bar{\omega} t$

$\bar{\omega} = (g/L)^{1/2}$

$T = 2\,\pi$

t = time, sec.

θ = angle of swing, radian

g = acceleration of gravity, ft per sec^2

L = length of the pendulum

$\theta_o = \theta$ at $t = 0$

$\bar{\omega}$ = circular frequency, radian per sec.

T = the period, sec.

For large amplitudes, a correction needs to be applied to the period, T, which is defined by

$$T = T' \left(1+\frac{1}{2^2}\sin^2\frac{1}{2}\theta_0+\frac{1}{2^2}\frac{3}{4^2}\sin^4\frac{1}{2}\theta_0\right) \qquad \text{(C-1)}$$

For a typical tower, the following values were used:

L = 85 ft

$\theta_o = \pi$ radian

$\theta = \pi/2$ radian

From the above equations, the following results:

ω = 0.615 radian per sec.

T = 10.2 sec.

T' = 13.2 sec.

t = 2.2 sec.

APPENDIX D. FATIGUE ANALYSIS

Due to the cyclic nature of the galloping forces, fatigue must be taken into consideration. The study of fatigue for this problem was focused on the fatigue behavior of the hanging insulators which may have been subjected directly to galloping loads. Two types of fatigue tests were considered. The first test would subject the entire insulator assembly to the galloping loads. The second test would produce a plot of stress versus number of cycles, fatigue S-N curve, for specimens made from components of the insulators which were suspected to be the weak links. Dr. B. S. Biner, metallurgist at Iowa State University, suggested the testing of the components over the assembly because of more variable control and ease of testing.

A second type of test was considered. In this test, the remaining capacity of the insulators would be determined by loading them until they failed. By measuring the axial stretching of the insulators at various load levels, an indication of the axial stiffness of these members would also be obtained. Unfortunately, complete insulator assemblies were not made available and these tests were not performed.

D.1 The Testing of the Insulator Components

In collecting the components of the insulators from the field, it was observed that the socket y clevis and the anchor shackle had broken more often than any other components. These components were too small to be made into acceptable fatigue specimens. Therefore, it was decided to make the specimens from the larger insulator rods which were believed to be made of the same material. Later, it was discovered that the rods were made of forged steel and not malleable iron as with the other two components. Nevertheless, the forged steel specimens were tested [22]. In this test, it was verified that the insulator rods could not have been susceptible to fatigue failure under the loads due to galloping.

Since malleable iron components could not be made, it was decided to determine the fatigue strength using fatigue curves from cast iron references. For the particular type of malleable iron used in the insulators, grade 32510, a fatigue curve was located in reference [23]. This curve is reproduced in Fig. D-1. From this figure, it can be seen that the plot of stress versus number of cycles has a small slope and that a small increase in the stress level sharply reduces the fatigue life of the material. Therefore, it can be concluded that this grade of malleable iron is highly susceptible to fatigue failure and is probably not a good choice for insulator components.

The number of galloping cycles during the event was estimated to be 7000 based on twelve hours of galloping and an average frequency of one cycle per second, close to the

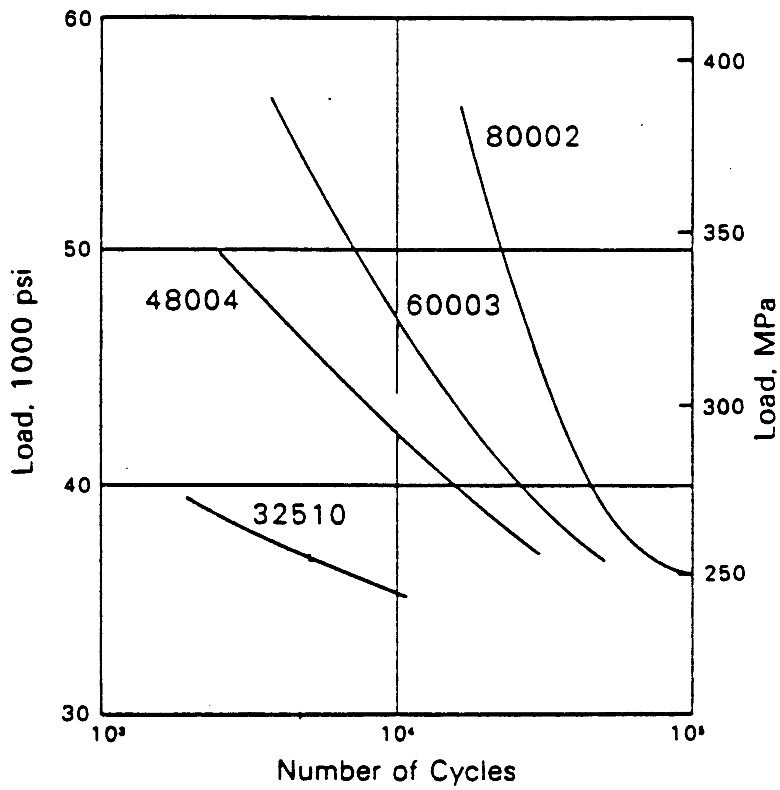


Fig. D-1 : Malleable iron fatigue curves

galloping frequency calculated for the conductors. Refer to Appendix C. Twelve hours was an intentionally high estimate of the duration of the ice storm event, 7:00 am to 5:00 pm, to be conservative and to account for some weathering effects otherwise not considered. It can be seen from Fig. D-1 that at 7000 cycles, the capacity of the material drops to about 37 ksi. This is about 74% of the ultimate capacity of this grade of malleable iron, which is about 50 ksi [24].

Based on a simple proportionality approach, the capacity of the insulator at Tower No. 99 would have also dropped to

74% of 36 kips, or 26.6 kips. From Fig. 3-8, this force in the insulator is reached with about 1.3 inches of radial ice on the conductors.

Although this approach may be a simplification, it can be said that fatigue could have played a major role in reducing the capacity of the insulator. A more detailed fatigue analysis may be required for more reliable quantitative results.

APPENDIX E. COMPUTER PROGRAMS LISTING

```
*************************************************
.EIP.BAS   cable forces and configuration
*************************************************
L A-H, P, S-T, V-X
COOR(2, 199), FOC(4), IMBAL(2)
P
 "*************************"
 "    WELCOME  TO  CABLE "
 "*************************"


 "ENTER: file name for output >": FILENAME$
 FILENAME$ FOR OUTPUT AS #2
JT "ENTER: file name for iteration output >"; ITERFILE$
N ITERFILE$ FOR OUTPUT AS #3
$ = "   ##   ####.##   ####.##       ##   ####.##   ####.##"
$ = "& ########.###"
$ = "& ###.###  &"
$ = "& ####.###"
$ = "& ###"
$ = "& #.###^^^^&"
EN 9, 1
R

T "*************************"
T "         MENU"
T "*************************"
T " 1  Given: line tension"
T "    Find : sag at stringing"
T "           sag with load"
T "    Find : galloping loads "
T ""
T " 2  Given: conductor length"
T "    Find : tension & sag"
T "    Find : galloping loads "
T ""
T " 3  Conductor on the ground"
T ""
T " E  EXIT CABLE"
T "*************************"
JT "ENTER: selection > ", MAINOPT$
MAINOPT$ = "1" THEN GOTO PROBLEM1
MAINOPT$ = "2" THEN GOTO PROBLEM1
MAINOPT$ = "3" THEN GOTO PROBLEM1
E #2


ER IS PROMPTED FOR THE INPUT VALUES

BLEM1:

NT
```

```
[ "   TOWER PROPERTIES"
[
3 ENTERHP
3 ENTERET1
3 ENTERET2
VP = ET2 - ET1
T
T USING "& ###.## &": "vertical projection of conductor =": VP; " feet"
T : PRINT
T "   CONDUCTOR PROPERTIES"
T "Note: for steel with aluminum - modify program for other materials"
B ENTERDIAMC
B ENTERAREA
B ENTERAREAA
  AREAS = AREA - AREAA
T USING "& ##.#### &": " area of steel strands =": AREAS; " in2"
UB ENTERES
UB ENTEREA
= 30000000
= 10000000
  E = ES * AREAS / AREA + EA * AREAA / AREA
T USING "& ########.# &": " modified E = ": E; "psi"
UB ENTERETS
UB ENTERETA
 = .0000065
 = .0000128
= (ETS * ES * AREAS / AREA + ETA * EA * AREAA / AREA) / E
=(ETS*AREAS/AREA+ETA*AREAA/AREA)
=.0000133 STILL TOO LOW
T USING "& #.######## &": " modified coef. of exp. = "; ET; " per deg F"
UB ENTERWC

R OPTION 1 THE STRINGING CONDITIONS ARE NEEDED
EREAS FOR OPTION 2 AND 3 THE ORIGINAL UNSTRETCHED LENGTH IS REQUIRED

MAINOPT$ = "1" THEN
PRINT : PRINT
PRINT "   STRINGING CONDITIONS"
PRINT
GOSUB ENTERTEMPS
GOSUB ENTERP
E
GOSUB ENTERXLO
GXLO = XLO
 IF
NT : PRINT
NT "   LOADING CONDITIONS"
NT
IF MAINOPT$ = "1" THEN
  GOSUB ENTERTEMPICE
  DELTEMP = TEMPICE - TEMPS
  PRINT USING "& ###.## &": "temperature change = ": DELTEMP; " degrees F"
```

```
.SE
! GOSUB ENTERTEMPICE
ID IF
| "ENTER: Do you want to enter  T=ice thickness or W=weight ? > ", A$
| = "T" OR A$ = "t" THEN
)SUB ENTERRICE
ICE = 3.14159 * 56 / 144 * ((DIAMC / 2 + RICE) ^ 2 - (DIAMC ^ 2 / 4))
RINT USING "& ##.### &": "ice load = "; WICE; "  pounds/ft"

OSUB ENTERWICE
IF
T #2, "############################################################"
IT #2, "CABLE output created on:"; DATE$; "  at:"; TIME$
IT #2,
IT #2, "Output file name:"; FILENAME$
IT #2, "############################################################"
JB PRINTCOND
INT = 0
RT = 0
/ = 0
3 = 33
MAINOPT$ = "3" THEN NPTS = 99
D = 1
MAINOPT$ = "2" THEN GOTO PROBLEM2
MAINOPT$ = "3" THEN GOTO PROBLEM2
******
CABLE:
******
= WC
= AREA * E
MP$ = "INIT"
UB SOLXLO
 = HP: VER = VP
NT #2, CHR$(12)
NT #2, "############################################################"
NT #2, "          LINE CONFIGURATION AT STRINGING"
NT #2, "############################################################"
NT #2, : PRINT #2,
NT , CHR$(12)
NT , "############################################################"
NT , "          LINE CONFIGURATION AT STRINGING FOLLOWS"
NT , "############################################################"
NT , : PRINT ,
ATE 23, 20: INPUT "Press <ENTER> to continue", A$
INT = 1
V = 1
UB PCAFX
*****
LOAD:
*****
WICE > 0 OR DELTEMP <> 0 THEN
WD = WC + WICE
```

```
P$ = "LOAD"
NT #2, CHR$(12)
NT #2, "###########################################################"
NT #2, "    LINE CONFIGURATION AFTER ICE OR TEMPERATURE CHANGE"
NT #2, "###########################################################"
NT #2, : PRINT #2,
NT , CHR$(12)
NT , "###########################################################"
NT , "LINE CONFIGURATION AFTER ICE OR TEMPERATURE CHANGE FOLLOWS"
NT , "###########################################################"
NT , : PRINT ,
 23, 30: INPUT "Press <ENTER> to continue", A$
NT = 1
/ = 1
MAINOPT$ = "2" OR MAINOPT$ = "3" THEN
OTO PROBLEM2
E
OSUB PCAFX
 IF
F
INOPT$ = "1" THEN
 IEDIT = 0
 GOTO EDITMENU

F

ification factors for gallooing and its frequency

EM4:

 ENTERNJ
 ENTERNL
 ENTERWI
 ENTERLI
 ENTERWIND

used is based on horizontal soan assumption

= WO * HP ^ 2 / (8 * ABS(FOC(1)))
WO * HP
(WT + .5 * WI) / LI
AE / HP
1 / (1 / KC + NJ / KI)
8 * ABS(GSAG) * KE * WO) / (HP * HP * FOC(1) * FOC(1))
= WO / 32.16
N = SQR(ABS(FOC(1)) / MASS * (B * HP + (NL * 3.14159 / HP) ^ 2))
= .26 * WIND * 2 * 3.14159 / OMEGAN
YMAX / 2
1 + (40.74 * KE * GSAG ^ 2 / (NL * WO * HP ^ 3) + .785 * NL / ABS(GSAG)) * AO + 32 * KE * ABS(GSAG) * AO ^ 2 / (

1 + 2 * AO * KE * WO * HP / (NL * 3.14159 * FOC(1) ^ 2) + AO ^ 2 * KE * WO * HP / (2 * GSAG * FOC(1) ^ 2) + NL *

 (4 * GSAG)
```

```
AXI = R * FOC(2)
AXJ = R * FOC(4)
X = 2 * A0 * KE * WT / (NL * 3.14159 * ABS(FOC(1)))
AX = ABS(FOC(1)) + HMAX
= ABS(HHMAX / FOC(1))
SIONI = SQR(HHMAX ^ 2 + WMAXI ^ 2)
SIONJ = SQR(HHMAX ^ 2 + WMAXJ ^ 2)
T
NT "######################################################################"
NT "                    GALLOPING CONDITIONS AND ANALYSIS                  "
NT "######################################################################"
NT
INT "Number of hanging insulators per span                       = "; NJ
INT "Number of galloping loops assumed                           = "; NL
INT "Weight of each insulator (pounds)                           = "; WI
INT "Length of each insulator (feet)                             = "; LI
INT "Wind velocity (ft/sec)                                      = "; WIND
INT USING "& #####.##": "Sag used (feet)                                         = "; GSAG
INT USING "& ##.###": "Natural frequency (rad/sec)                              = "; OMEGAN
INT USING "& ##.##": "Galloping amplitude (feet)                               = "; A0
INT USING "& #.####": "Ratio of total vertical to static vertical force        = "; R
INT USING "& #.####": "Ratio of total horizontal to static horizontal force    = "; RH
INT USING "& #####.##": "Total end i vertical force (pounds)                  = "; WMAXI
INT USING "& #####.##": "Total end j vertical force (pounds)                  = "; WMAXJ
INT USING "& #####.##": "Total horizontal force (pounds)                      = "; HHMAX
INT USING "& #####.##": "Total end i tension after galloping (pounds)         = "; TENSIONI
INT USING "& #####.##": "Total end j tension after galloping (pounds)         = "; TENSIONJ
INT #2, : PRINT #2,
INT #2, "######################################################################"
INT #2, "                   GALLOPING CONDITIONS AND ANALYSIS                  "
INT #2, "######################################################################"
INT #2,
INT #2, "Number of hanging insulators per span                       = "; NJ
INT #2, "Number of galloping loops assumed                           = "; NL
INT #2, "Weight of each insulator (pounds)                           = "; WI
INT #2, "Length of each insulator (feet)                             = "; LI
INT #2, USING "& ###.##": "Sag used (feet)                                     = "; GSAG
INT #2, "Wind velocity (ft/sec)                                      = "; WIND
INT #2, USING "& ##.###": "Natural frequency (rad/sec)                         = "; OMEGAN
INT #2, USING "& ##.##": "Galloping amplitude (feet)                           = "; A0
INT #2, USING "& #.####": "Ratio of total vertical to static vertical force    = "; R
INT #2, USING "& #.####": "Ratio of total horizontal to static horizontal force = "; RH
INT #2, USING "& #####.##": "Total end i vertical force (pounds)              = "; WMAXI
INT #2, USING "& #####.##": "Total end j vertical force (pounds)              = "; WMAXJ
INT #2, USING "& #####.##": "Total horizontal force (pounds)                  = "; HHMAX
INT #2, USING "& #####.##": "Total end i tension after galloping (pounds)     = "; TENSIONI
INT #2, USING "& #####.##": "Total end j tension after galloping (pounds)     = "; TENSIONJ
CATE 23, 20: INPUT "Press <ENTER> to continue", A$
TO EDITMENU
OBLEM2:
 = WC + WICE
 = AREA * E
```

```
R = HP: VER = VP
TPRT=1
PRT = 0
RINT = 1
 MAINOPT$ = "3" THEN IPRINT = 0
IV = 1
SUB PCAFX
 MAINOPT$ = "2" THEN GOTO EDITMENU
OBLEM3:
PUT "ENTER: Ground elevation (feet) > ", GEL

The mid-point of the conductor is raised to
the ground level

LG = LSAGF
ENT = XLG
ENT2 = XLO - XLG
EL = (ET1 + YSAG) - GEL
COOR(2, 100) = YSAG - DEL
COOR(1, 100) = XSAG
 = 1
TAGE:
 = 100
 = M - 1
LG = LENT

'The left portion of the conductor is stretched on the ground

TAGE1:
LO = XLG
OR = XCOOR(1, M)
ER = XCOOR(2, M)
OSUB PCAFX
 = M + 1
 = N + 1
LG = LSAGF
RA1 = XLO - XLG
XCOOR(1, M) = XCOOR(1, N) - RA1
DEL = (ET1 + YSAG) - GEL
XCOOR(2, M) = YSAG - DEL
IF ABS(DEL) > .1 THEN GOTO STAGE1
XLF = XLO

'Force imbalance is checked for the last point touching the ground

STAGE2:
HOR = XCOOR(1, M)
VER = XCOOR(2, M)
XLO = XLF
GOSUB PCAFX
FHIR = ABS(FOC(3))
LRA1 = XCOOR(1, 100) - XCOOR(1, M)
```

```
A1 = LRA1 - (LENT - XLF)
RA1 = ABS(DRA1 * AE / LRA1)
H = ABS(FHIR - FHRA1)
 DFH >= 100 THEN
       XSTEP = .9 * ABS(DRA1)
SEIF DFH >= 5 THEN
       XSTEP = .3 * ABS(DRA1)
SE
       XSTEP = .05 * ABS(DRA1)
D IF
 FHIR > FHRA1 THEN
       XCOOR(1, M) = XCOOR(1, M) - XSTEP
SE
       XCOOR(1, M) = XCOOR(1, M) + XSTEP
D IF
RINT DFH
 DFH > 5 THEN GOTO STAGE2
POINT = XCOOR(1. M)
ANGLEI = ANGLEI
ANGLEJ = ANGLEJ
TI = TENI
TJ = TENJ
 = 100
 = M - 1

The right portion is stretched on the ground

LO = LENT + LENT2
LG = LENT
TAGE3:
LO = XLO - XLG
OR = HP - XCOOR(1, M)
ER = ET2 - GEL
OSUB PCAFX
 = M + 1
 = N + 1
LG = LSAGF
1R = XLG
COOR(1, M) = XCOOR(1, N) + A1R
EL = YSAG
F ABS(DEL) > .1 THEN GOTO STAGE3
LF = XLO

Horizontal force imbalance is checked for the last point touching the ground

TAGE4:
OR = HP - XCOOR(1, M)
ER = ET2 - GEL
LO = XLF
OSUB PCAFX
HRJ = ABS(FOC(1))
A1R = XCOOR(1, M) - XCOOR(1, 100)
```

```
R = LA1R - (LENT2 - XLF)
1R = ABS(DA1R * AE / LA1R)
2 = ABS(FHA1R - FHRJ)
DFH2 >= 200 THEN
      XSTEP = .9 * ABS(DA1R)
SEIF DFH2 >= 100 THEN
      XSTEP = .5 * ABS(DA1R)
SEIF DFH2 >= 50 THEN
      XSTEP = .1 * ABS(DA1R)
SEIF DFH2 >= 10 THEN
      XSTEP = .05 * ABS(DA1R)
SE
      XSTEP = .005 * ABS(DA1R)
D IF
FHRJ > FHA1R THEN
      XCOOR(1, M) = XCOOR(1, M) + XSTEP
SE
      XCOOR(1, M) = XCOOR(1, M) - XSTEP
D IF
PRINT DFH2
F DFH2 > 5 THEN GOTO STAGE4
POINT = XCOOR(1, M)
ANGLEI = ANGLEI
ANGLEJ = ANGLEJ
TI = TENI
TJ = TENJ

Location of the middle point is adjusted for the horizontal force
imbalance

MBAL(K) = ABS(FHRA1 - FHA1R)
IMBAL = IMBAL(2) - IMBAL(1)
F K = 1 THEN
      K = K + 1
      XCOOR(1, 100) = XCOOR(1, 100) + 1
      GOTO STAGE
ND IF
 = 1
RINT "IMBAL = "; IMBAL(1)
F ABS(IMBAL(1)) >= 20 THEN
      XCOOR(1, 100) = XCOOR(1, 100) - 1 / RIMBAL * 1 * IMBAL(1)
      GOTO STAGE
ELSEIF ABS(IMBAL(1)) > 10 THEN
      XCOOR(1, 100) = XCOOR(1, 100) - 1 / RIMBAL * .3 * IMBAL(1)
      GOTO STAGE
ELSEIF ABS(IMBAL(1)) > 1 THEN
      XCOOR(1, 100) = XCOOR(1, 100) - 1 / RIMBAL * .0001 * IMBAL(1)
      GOTO STAGE
ND IF
HA1 = .5 * (FHA1R + FHRA1)
RINT : PRINT
RINT "-----------------------------------------------------------------"
```

```
NT "          FORCES AND MISC FOR CABLE ON THE GROUND             "
NT "--------------------------------------------------------------"
NT USING FMT2$; "Dist. tower 1 to first point on ground (ft)  = "; LPOINT
NT USING FMT2$; "Dist. tower 1 to  last point on ground (ft)  = "; RPOINT
NT USING FMT2$; "ANGLEI  for left hanging portion (deg)       = "; LANGLEI
NT USING FMT2$; "ANGLEJ  for left hanging portion (deg)       = "; LANGLEJ
NT USING FMT2$; "TI for  left hanging portion (lbs)           = "; LTI
NT USING FMT2$; "TJ for  left hanging portion (lbs)           = "; LTJ
NT USING FMT2$; "ANGLEI  for right hanging portion (deg)      = "; RANGLEI
NT USING FMT2$; "ANGLEJ  for right hanging portion (deg)      = "; RANGLEJ
NT USING FMT2$; "TI for  right hanging portion (lbs)          = "; RTI
NT USING FMT2$; "TJ for  right hanging portion (lbs)          = "; RTJ
INT USING FMT2$; "Horiz  tension in cable on ground (lbs)      = "; FHA1
INT #2, : PRINT #2,
INT #2, "-------------------------------------------------------------"
INT #2, "          FORCES AND MISC FOR CABLE ON THE GROUND              "
INT #2, "-------------------------------------------------------------"
INT #2, USING FMT2$; "Dist tower 1 to first point on ground, ft = "; LPOINT
INT #2, USING FMT2$; "Dist tower 1 to last point on  ground, ft = "; RPOINT
INT #2,
INT #2, USING FMT2$; "ANGLEI for left hanging portion (deg)    = "; LANGLEI
INT #2, USING FMT2$; "ANGLEJ for left hanging portion (deg)    = "; LANGLEJ
INT #2,
INT #2, USING FMT2$; "TI for left hanging portion (lbs)        = "; LTI
INT #2, USING FMT2$; "TJ for left hanging portion (lbs)        = "; LTJ
INT #2,
INT #2, USING FMT2$; "ANGLEI for right hanging portion (deg)   = "; RANGLEI
INT #2, USING FMT2$; "ANGLEJ for right hanging portion (deg)   = "; RANGLEJ
INT #2,
INT #2, USING FMT2$; "TI for right hanging portion (lbs)       = "; RTI
INT #2, USING FMT2$; "TJ for right hanging portion (lbs)       = "; RTJ
INT #2,
INT #2, USING FMT2$; "Horiz. tension in cable on the ground (lbs) = "; FHA1
INT : PRINT
CATE 23, 20: INPUT "Press <ENTER> to continue", A$
TO MENU
*******
ITMENU:
*******
S
INT "*******************************"
INT "      EDIT MENU"
INT "*******************************"
INT "  A   ANALYZE (no more changes)"
INT ""
INT "  1   tower properties"
INT "  2   conductor properties"
 MAINOPT$ = "2" OR MAINOPT$ = "3" THEN
INT "  3   original conductor length"
SE
INT "  3   stringing conditions"
D IF
```

```
NT "  4   loading conditions"
NT ""
NT "  E   find galloping forces"
NT "      after analysis and/or EXIT"
NT "******************************"
NT
UT "ENTER: selection> ", OPT$
OPT$ = "A" OR OPT$ = "a" THEN
VP = ET2 - ET1
WICE = 3.14159 * 56 / 144 * ((DIAMC / 2 + RICE) ^ 2 - (DIAMC ^ 2 / 4))
AREAS = AREA - AREAA
E = ES * AREAS / AREA + EA * AREAA / AREA
DELTEMP = TEMPICE - TEMPS
PRINT #2, CHR$(12)
GOSUB PRINTCOND
IF MAINOPT$ = "2" THEN
  IF IEDIT = 2 THEN
      IPRINT = 0
      IDIV = 0
      GOTO ICELOAD
  ELSE
      GOTO PROBLEM2
  END IF
ELSE
END IF
IF IEDIT = 1 THEN
   IPRINT = 0
   IDIV = 0
   GOTO NEWCABLE
ELSEIF IEDIT = 2 THEN
   IPRINT = 0
   IDIV = 0
   GOTO ICELOAD
END IF
SEIF OPT$ = "1" THEN
 GOTO TOWERMENU
SEIF OPT$ = "2" THEN
 GOTO CONDMENU
SEIF OPT$ = "3" THEN
 IF MAINOPT$ = "2" OR MAINOPT$ = "3" THEN
   GOSUB ENTERXLO
   GXLO = XLO
 ELSE
   GOTO STRINGMENU
 END IF
SEIF OPT$ = "4" THEN
 GOTO LOADMENU
SEIF OPT$ = "E" OR OPT$ = "e" THEN
PUT "Do you want galloping loads? (Y/N)", GALOP$
 GALOP$ = "Y" OR GALOP$ = "y" THEN GOTO PROBLEM4
LOSE #2: END
SE
```

```
 BEEP: GOTO EDITMENU
D IF
TO EDITMENU
WERMENU:
S
INT "******************************"
INT "      TOWER MENU"
INT "******************************"
INT "  1   span between towers"
INT "  2   elev. tower i"
INT "  3   elev. tower j"
INT ""
INT "  E   EDIT MENU"
INT "******************************"
INT
PUT "ENTER: selection> ", OPT$
F OPT$ >= "1" AND OPT$ <= "3" THEN IEDIT = 1
F OPT$ = "1" THEN
  GOSUB ENTERHP
LSEIF OPT$ = "2" THEN
  GOSUB ENTERET1
LSEIF OPT$ = "3" THEN
  GOSUB ENTERET2
LSEIF OPT$ = "E" OR OPT$ = "e" THEN
  GOTO EDITMENU
LSE
  BEEP
ND IF
OTO TOWERMENU
ONDMENU:
LS
RINT "******************************"
RINT "      CONDUCTOR MENU"
RINT "******************************"
RINT "  1   conductor diameter"
RINT "  2   total conductor area"
RINT "  3   area of aluminum"
RINT "  4   E steel"
RINT "  5   E aluminum"
RINT "  6   weight conductor"
RINT "  7   coef. of exp. steel"
RINT "  8   coef. of exp. aluminum"
RINT ""
RINT "  E   EDIT MENU"
RINT "******************************"
RINT
NPUT "ENTER: selection> ", OPT$
F OPT$ >= "1" AND OPT$ <= "6" THEN IEDIT = 1
F OPT$ = "1" THEN
  GOSUB ENTERDIAMC
LSEIF OPT$ = "2" THEN
  GOSUB ENTERAREA
```

```
F OPT$ = "3" THEN
SUB ENTERAREAA
F OPT$ = "4" THEN
SUB ENTERES
F OPT$ = "5" THEN
SUB ENTEREA
IF OPT$ = "6" THEN
SUB ENTERWC
IF OPT$ = "7" THEN
SUB ENTERETS
IF OPT$ = "8" THEN
SUB ENTERETA
IF OPT$ = "E" OR OPT$ = "e" THEN
OTO EDITMENU

EEP
IF
 CONDMENU
NGMENU:

IT "******************************"
IT "      STRINGING MENU"
IT "******************************"
IT "  1   line tension"
IT "  2   temperature @ stringing"
IT ""
IT "  E   EDIT MENU"
IT "******************************"
IT
IT "ENTER: selection> ", OPT$
PT$ >= "1" AND OPT$ <= "2" THEN IEDIT = 1
PT$ = "1" THEN
GOSUB ENTERP
EIF OPT$ = "2" THEN
GOSUB ENTERTEMPS
EIF OPT$ = "E" OR OPT$ = "e" THEN
GOTO EDITMENU
E
EEP
 IF
O STRINGMENU
MENU:

NT "******************************"
NT "      LOAD MENU"
NT "******************************"
MAINOPT$ = "2" OR MAINOPT$ = "3" THEN
NT "  1   temprature change"
E
NT "  1   temperature for analysis"
 IF
NT "  2   radial ice thickness"
```

```
"  3   weight ice"
""
"  E   EDIT MENU"
"******************************"

"ENTER: selection> ", OPT$
OPT$ >= "1" AND OPT$ <= "3") AND IEDIT = 0) THEN IEDIT = 2
T$ = "1" THEN
SUB ENTERTEMPICE
F OPT$ = "2" THEN
SUB ENTERRICE
F OPT$ = "3" THEN
SUB ENTERWICE
F OPT$ = "E" OR OPT$ = "e" THEN
TO EDITMENU

EP
F
LOADMENU
**************************************************
LO:       ' determine original cable length
**************************************************
VEN:

= input value of horizontal tension
= horizontal projection
= vertical projection
= weight along cable
O = original cable length
 = area*modulus of elasticity
LD= load tolerence for convergence
SQR(HP * HP + VP * VP)
 = .0002 * S
ACT < .005 THEN FACT = .005
= 0  'NNN COUNTS THE NUMBER OF ITERATIONS
 = 0
 = 0
 = 0
 = 0
----------------------------------------------------
termine first guess for XLO based on inelastic cable
----------------------------------------------------
= ABS(HP)
S = ABS(P)
A = (WO * HOR) / (2 * HTENS)
BD = (EXP(AMBDA) - EXP(-AMBDA)) / 2
 (HP * HP * SHAMBD * SHAMBD) / (AMBDA * AMBDA) + VP * VP
 SQR(XL)
= (HTENS * XL * XL) / (AE * HP)
 XL - DXL
= XL
**
```

```
P1:
***
UB PCAFX
 ABS(FOC(1))
ABS(F - P) < PCLD THEN
RETURN
E
NNN = NNN + 1
IF NNN > 20 THEN
 PRINT "NO CONVERGENCE"
 END
ELSE
 IF (ABS(F) - ABS(P)) > 0 THEN
   XLOS = XLO
   FMAX = F
   IF (XLOM > 0 AND XLOS > 0) THEN
      XLO = XLOM + (XLOS - XLOM) * ((P - FMIN) / (FMAX - FMIN))
   ELSE
      XLO = XLO + FACT
   END IF
 ELSE
   XLOM = XLO
   FMIN = F
   IF (XLOM > 0 AND XLOS > 0) THEN
      XLO = XLOM + (XLOS - XLOM) * ((P - FMIN) / (FMAX - FMIN))
   ELSE
      XLO = XLO - FACT
   END IF
 END IF
END IF
GOTO STEP1
D IF
*******************************************************
AFX:
*******************************************************
 IDIV = 0  no coordinates calculated
 NEP  = 0  converges
 IPRINT = 0  no print
------------------
set constants
------------------
. = XLO
1 = .0000001
2 = .0000001
P = 0
ERA = 0
 CTEMP$ = "LOAD" THEN XL = XL * (1 + ET * DELTEMP)
RD = SQR(HOR * HOR + VER * VER)
OP = XL / CORD
 = HOR / XL
 = VER / XL
S1 = EP1 * ABS(H)
```

```
)2 = EP1 * ABS(V)
 EPS1 < EP2 THEN EPS1 = EP2
 EPS2 < EP2 THEN EPS2 = EP2
 = 0
 V > 0! THEN
 KK = 1
 V = -V
 H = -H
D IF
 = PROP
 = 1!
 = WO * XLO
 = WX / AE
 = WO
 = XL
 = V - D3 / 2
 D1 <= 1! THEN
 AMBDA = .18
LSE
 IF ABS(H) < 1E-20 THEN
   AMBDA = 1000000 'AMBDA IS ABOUT 4 TIMES SAG TO SPAN RATIO
 ELSE
   AMBDA = SQR(3 * (1 - 1 / (PROP * PROP)) / (H * H))
 END IF
ND IF
1 = H / (2 * AMBDA)
F AMBDA > 80 THEN
 COT = 1
LSE
 COT = (EXP(AMBDA) + EXP(-AMBDA)) / (EXP(AMBDA) - EXP(-AMBDA))
ND IF
2 = .5 * (1 + V * COT)
F1 = 0
F2 = 0
--------------------------------------
EWCYCLE:  ' start of cycle
--------------------------------------
1 = C1 - DF1
2 = C2 - DF2
I = SQR(C1 * C1 + C2 * C2 - 2 * C2 + 1)
J = SQR(C1 * C1 + C2 * C2)
 = C2 + TJ
F = TI - 1 + C2
F (1 - (1 - C2) / TI) <= .0001 THEN
 F = TI + 1 - C2
 FF = TJ - C2
ND IF
F FF < 1E-10 THEN FF = 1E-10
 = F / FF
F G < 1E-10 THEN G = 1E-10
L = LOG(G)
AH = DL + D3
```

```
= H - C1 * AAH
= D4 + D3 * (1 - C2) - TJ + TI
 = ABS(CA)
 = ABS(CB)
ITPRT = 1 THEN
RINT ITERA; ACA; " vs "; EPS1; ACB; " vs "; EPS2
 IF
(ACA <= EPS1 AND ACB <= EPS2) THEN GOTO ALLDONE
RA = ITERA + 1
ITERA > 14 THEN
RINT "FAILURE TO CONVERGE"; HOR, VER, ACA, ACB
EP = 1
ETURN
 IF
 = (1 - C2) / TI + C2 / TJ
 = -VAR - D3
 = -AAH + VAR
 = -C1 * (1 / TJ - 1 / TI)
T = A1 * B2 - A2 * A2
1 = (CA * B2 - CB * A2) / DET
2 = (A1 * CB - A2 * CA) / DET
TO NEWCYCLE
-----------------------------------------
LDONE:    ' converged - do cleanup
-----------------------------------------
 = C1 * (1 - 2 * KK)
 = C2 + KK * (1 - 2 * C2)
C(1) = -C1 * WX
C(3) = C1 * WX
C(4) = C2 * WX
C(2) = WX - FOC(4)
NI = (TI + KK * (TJ - TI)) * WX
NJ = (TJ + KK * (TI - TJ)) * WX
-----------------------------------------
letermine coordinates along cable element
-----------------------------------------
 IDIV = 0 THEN RETURN
1 = FOC(1) * (1 - 2 * KK)
2 = FOC(2) + KK * (FOC(4) - FOC(2))
 = H * XLO
 = V * XLO
 = TI * WX
 = TJ * WX
4 = W * XL - FO2
AFST = X + (FO4 * TJ + FO2 * TI + FO1 * FO1 * LOG(G)) / (2 * AE * W)
BXL = X / (NPTS - 1)
 = -SUBXL
AG = ABS(FO2 / W)
R MM = 1 TO NPTS
  XL = XL + SUBXL
  FO4 = W * XL - FO2
  FO3 = -FO1
```

```
    TI = SQR(FO1 * FO1 + FO2 * FO2)
    TJ = SQR(FO3 * FO3 + FO4 * FO4)
    F = FO4 + TJ
    FF = TI - FO2
    IF (1 - FO2 / TI) <= .0001 THEN
      F = TI + FO2
      FF = TJ - FO4
    END IF
    IF FF < 1E-10 THEN FF = 1E-10
    G = F / FF
    IF G < 1E-10 THEN G = 1E-10
    AAH = LOG(G) / W + D2 * XL / AE
    AH = -FO1 * AAH
    BV = D2 * (TJ * TJ - TI * TI) / (2 * AE * W) + (TJ - TI) / W
    MN = MM + (NPTS - 2 * MM + 1) * KK
    XCOOR(1, MN) = AH - H * KK
    XCOOR(2, MN) = BV - V * KK
    IF ABS(XL) > LSAG THEN
         XSAG = XCOOR(1, MN)
         YSAG = XCOOR(2, MN)
         LSAGF = ABS(LSAG - KK * XLO)
         LSAG = 100000
    END IF
NEXT MM
'---------------------------------------------------------------
'draw the cable configuration for cable not touching the ground
'---------------------------------------------------------------
CLS
IF MAINOPT$ <> "3" THEN
LINE (120, 1)-(639, 349), , B
PSET (140, 80)
XSCALE = 450 / HP
YSCALE = 250 / ABS(YSAG)
 FOR MN = 1 TO NPTS
   IF MN <> 1 THEN
    XORD = XSCALE * ABS((XCOOR(1, MN) - XCOOR(1, MN - 1)))
    YORD = -YSCALE * (XCOOR(2, MN) - XCOOR(2, MN - 1))
    LINE -STEP(XORD, YORD)
   ELSE
   END IF
 NEXT MN
LOCATE 4, 30: INPUT "Press <ENTER> to continue", A$
ELSE
END IF
'--------------------------------------
' determine angles at ends of cable
'--------------------------------------
PI = 3.1415926#
ANGLEI = ATN(FOC(2) / ABS(FOC(1))) * 180 / PI
ANGLEJ = ATN(FOC(4) / ABS(FOC(3))) * 180 / PI
'--------------------------------------
' print results if IPRINT<>0
```

```
---------------------------------
PRINT = 0 THEN RETURN
F
IT "------------------------------------------------------"
IT "               COORDINATES ALONG CABLE"
IT "------------------------------------------------------"
NT " POINT     X       Y        POINT     X         Y"
NT "------------------------------------------------------"
NT #2, : PRINT #2,
NT #2, "------------------------------------------------------"
NT #2, "               COORDINATES ALONG CABLE"
NT #2, "-------------------------------------------------------"
NT #2, " POINT     X         Y        POINT     X         Y"
NT #2, "------------------------------------------------------"
= NPTS \ 2 + 1
 i = 1 TO NP
 i + NP
i < NP THEN
RINT #2, USING FMT1$; i; XCOOR(1, i); XCOOR(2, i); J; XCOOR(1, J); XCOOR(2, J)
RINT USING FMT1$; i; XCOOR(1, i); XCOOR(2, i); J; XCOOR(1, J); XCOOR(2, J)
E
RINT #2, USING FMT1$; i; XCOOR(1, i); XCOOR(2, i)
RINT USING FMT1$; i; XCOOR(1, i); XCOOR(2, i)
 IF
XT i
ATE 23, 20: INPUT "Press <ENTER> to continue", A$
NG = ((XLAFST - X) / X) * 100
S
INT "-----------------------------------"
INT "      CABLE FORCES & MISC"
INT "-----------------------------------"
INT USING FMT2$; " Area (sq in)                                = "; AREA
INT USING FMT2$; " Elasticity Modulus (psi)          = "; E
INT USING FMT2$; " Weight (lbs per ft)               = "; WO
INT USING FMT2$; " Hor proj (ft)                     = "; HP
INT USING FMT2$; " Ver proj (ft)                     = "; VP
INT USING FMT2$; " Original length (ft)              = "; XLO
INT USING FMT2$; " Maximum sag from end I (ft)       = "; YSAG
INT USING FMT2$; " Hor force left (lbs)              = "; FOC(1)
INT USING FMT2$; " Hor force right (lbs)             = "; FOC(3)
INT USING FMT2$; " Ver force left (lbs)              = "; FOC(2)
INT USING FMT2$; " Ver force right (lbs)             = "; FOC(4)
INT USING FMT2$; " Tension end I (lbs)               = "; TI
INT USING FMT2$; " Tension end J (lbs)               = "; TJ
INT USING FMT4$; " Angle end I (deg)                 = "; ANGLEI
INT USING FMT4$; " Angle end J (deg)                 = "; ANGLEJ
INT USING FMT4$; " Length after stretching (ft)      = "; XLAFST
INT USING FMT3$; " Elongation                        = "; ELONG; "%"
INT USING FMT5$; " NO. of iterations                 = "; ITERA
INT #2, : PRINT #2,
INT #2, "-----------------------------------"
INT #2, "      CABLE FORCES & MISC"
```

```
PRINT #2, "-------------------------------------"
PRINT #2, USING FMT2$; " Area (sq in)                          = "; AREA
PRINT #2, USING FMT2$; " Elasticity Modulus (psi)              = "; E
PRINT #2, USING FMT2$; " Weight (lbs per ft)                   = "; WO
PRINT #2, USING FMT2$; " Hor proj (ft)                         = "; HP
PRINT #2, USING FMT2$; " Ver proj (ft)                         = "; VP
PRINT #2, USING FMT2$; " Original length (ft)                  = "; XLO
PRINT #2, USING FMT2$; " Maximum sag from end I (ft)           = "; YSAG
PRINT #2, USING FMT2$; " Hor force left (lbs)                  = "; FOC(1)
PRINT #2, USING FMT2$; " Hor force right (lbs)                 = "; FOC(3)
PRINT #2, USING FMT2$; " Ver force left (lbs)                  = "; FOC(2)
PRINT #2, USING FMT2$; " Ver force right (lbs)                 = "; FOC(4)
PRINT #2, USING FMT2$; " Tension end I (lbs)                   = "; TI
PRINT #2, USING FMT2$; " Tension end J (lbs)                   = "; TJ
PRINT #2, USING FMT4$; " Angle end I (deg)                     = "; ANGLEI
PRINT #2, USING FMT4$; " Angle end J (deg)                     = "; ANGLEJ
PRINT #2, USING FMT4$; " Length after stretching (ft)          = "; XLAFST
PRINT #2, USING FMT3$; " Elongation                            = "; ELONG; "%"
PRINT #2, USING FMT5$; " NO. of iterations                     = "; ITERA
LOCATE 23, 20: INPUT "Press <ENTER> to continue", A$
RETURN
'*******************************************************************
' SUBPROGRAMS FOR DATA ENTRY
'*******************************************************************
ENTERHP:
INPUT "ENTER: span between towers (feet) > ", HP: RETURN
'-------------------------------------------------------------------
ENTERET1:
INPUT "ENTER: attachment elevation at tower i (feet) > ", ET1: RETURN
'-------------------------------------------------------------------
ENTERET2:
INPUT "ENTER: attachment elevation at tower j (feet) > ", ET2: RETURN
'-------------------------------------------------------------------
ENTERDIAMC:
INPUT "ENTER: diameter of conductor (inches) > ", DIAMC: RETURN
'-------------------------------------------------------------------
ENTERAREA:
INPUT "ENTER: total area of conductor (in2) > ", AREA: RETURN
'-------------------------------------------------------------------
ENTERAREAA:
INPUT "ENTER: area of aluminum strands (in2) > ", AREAA: RETURN
'-------------------------------------------------------------------
ENTERES:
INPUT "ENTER: E of steel (psi)  > ", ES: RETURN
'-------------------------------------------------------------------
ENTEREA:
INPUT "ENTER: E of aluminum (psi)  > ", EA: RETURN
'-------------------------------------------------------------------
ENTERETS:
INPUT "ENTER: coef. of exp. steel (/deg F)  > ", ETS: RETURN
'-------------------------------------------------------------------
ENTERETA:
```

```
INPUT "ENTER: coef. of exp. aluminum (/deg F)  > ", ETA: RETURN
'-------------------------------------------------------------------
ENTERWC:
INPUT "ENTER: conductor weight (pounds per ft) > ", WC: RETURN
'-------------------------------------------------------------------
ENTERTEMPS:
INPUT "ENTER: temperature at stringing (deg. F) > ", TEMPS: RETURN
'-------------------------------------------------------------------
ENTERP:
INPUT "ENTER: line tension (pounds) >"; P: RETURN
'-------------------------------------------------------------------
ENTERTEMPICE:
IF MAINOPT$ = "2" OR MAINOPT$ = "3" THEN
  INPUT "ENTER: temprature change in deg F (use +/-) >", DELTEMP: RETURN
ELSE
END IF
INPUT "ENTER: temperature for this analysis (deg. F) > ", TEMPICE: RETURN
'-------------------------------------------------------------------
ENTERRICE:
INPUT "ENTER: radial thickness of ice (inches) > ", RICE: RETURN
'-------------------------------------------------------------------
ENTERWICE:
INPUT "ENTER: ice load (pounds/ft) >"; WICE: RETURN
'-------------------------------------------------------------------
ENTERXLO:
INPUT "ENTER: original conductor length (feet) > ", XLO: RETURN
'-------------------------------------------------------------------
ENTERNJ:
INPUT "ENTER: number of suspension insulators per span > ", NJ
RETURN
'-------------------------------------------------------------------
ENTERNL:
INPUT "ENTER: number of galloping loops per span > ", NL: RETURN
'-------------------------------------------------------------------
ENTERLI:
INPUT "ENTER: length of insulator (feet) > ", LI: RETURN
'-------------------------------------------------------------------
ENTERWI:
INPUT "ENTER: weight of insulator (pounds) > ", WI: RETURN
'-------------------------------------------------------------------
ENTERWIND:
INPUT "ENTER: wind velocity (ft/sec) > ", WIND: RETURN
'*******************************************************************
PRINTCOND:
'*******************************************************************
PRINT #2, : PRINT #2,
PRINT #2, "           LINE CONDITIONS FOR ANALYSIS "
PRINT #2, "-----------------------------------------------------"
PRINT #2, "Span between towers (feet)          = "; HP
PRINT #2, "Attachment elev. at tower i (feet) = "; ET1
PRINT #2, "Attachment elev. at tower j (feet) = "; ET2
PRINT #2, USING "& ###.##"; "Vert. projection of conductor (ft) = "; VP
```

```
T #2,
AINOPT$ = "1" THEN
   PRINT #2, "Line tension (pounds)              = "; P
   PRINT #2, "Temperature at stringing (deg. F)  = "; TEMPS
   PRINT #2, "Temperature for this analysis      = "; TEMPICE
   PRINT #2, "Temperature change                 = "; DELTEMP
IF
AINOPT$ <> "1" THEN
RINT #2, "Original conductor length (ft) = "; OXLO
IF
T #2,
T #2, "Diameter of conductor (inches)          = "; DIAMC
T #2, "Total area of conductor (in2)           = "; AREA
T #2, "Area of aluminum strands (in2)          = "; AREAA
T #2, USING FMT2$; "Area of steel strands (in2) = "; AREAS
T #2,
T #2, USING FMT2$; "E of steel (psi)           = "; ES
NT #2, USING FMT2$; "E of aluminum (psi)       = "; EA
NT #2, USING FMT2$; "Modified E (psi)          = "; E
NT #2, USING FMT6$; "Coef. of exp.of steel     = "; ETS; " per deg F "
NT #2, USING FMT6$; "Coef. of exp.of aluminum  = "; ETA; " per deg F "
NT #2, USING FMT6$; "Modified coef. of exp.    = "; ET; " per deg F "
NT #2,
NT #2, "Conductor weight (pounds per ft)   = "; WC
 A$ = "T" OR A$ = "t" THEN
RICE <> 0 THEN
  PRINT #2, "Radial thickness of ice (inches)   = ", RICE
 IF
NT #2, USING FMT2$; "Ice load (pounds/ft)       = "; WICE
URN
```

```
ARE SUB PLOTT (FILENAME$)
ARE SUB INSTRUCTIONS ()
ARE SUB SOLXLO (MEMNO%, ZH#, ZV#, ZAE#, ZWO#, ZXLO#, ZP#, PCLD#, FOC#())
ARE SUB GENDYD (NSPAN%, NCE%, NPE%, NCTE%)
ARE SUB PCAFX (MEMNO%, HOR#, VER#, AE#, WO#, XLO#, FOC#(), TENI#, TENJ#, NPTS%, XCOOR#(), IDIV%, IPRINT%, NEP%)
ARE SUB DITSIM (NCABLE%, NPOLE%, NCT%, NP1%, FILENAME$)
==== CABLE7 =====

AIN CALLING PROGRAM FOR DYNAMIC ANALYSIS

SPAN = NUMBER OF SPANS
SEG = MAXIMUM NUMBER OF DIVISIONS OF CONDUCTOR PER SPAN
UNIT = UNIT CODE (0=METRIC,1=AMERICAN UNITS)

ONDUCTOR MOVEMENT IS SHOWN UNLESS SPECIFIED, ICODE = 2
CODE = 0  PRINTS DISPLACEMENTS, FORCES + SUMMARY OF DATA ONTO A FILE
CODE = 1  PRINTS FORCES + SUMMARY OF DATA ONTO A FILE
CODE = 2  PRINTS SUMMARY OF DATA ONTO A FILE WITHOUT SHOWING THE CONDUCTOR MOVEMENT
CODE = 3  PRINTS SUMMARY OF DATA ONTO A FILE
CODE = 4  GENERATE DATA IN GENDYD ONLY, NO DYNAMIC ANALYSIS

H = HORIZONTAL LINE TENSION
CLD = FORCE TOLERANCE - INITIAL DATA
PS4 = FORCE TOLERANCE - DYNAMIC EQUILIBRIUM
   DT = TIME INTERVAL (SEC)
   TF = TIME FINAL (SEC)
INT = K DATA PRINTED AT EVERY K INTERVALS
INT = G CONDUCTOR DRAWN EVERY G INTERVALS

 CLS
  CLEAR , , 4000
 DEFDBL A-H, O-Z
 DEFINT I-N

THE GRAPHIC MODE IS SET TO VGA (640 * 480)
THE FILENAME SPECIFIED BY THE USER WILL BE THE BASE NAME FOR ALL THE FILES
RELATED TO THAT RUN. INCLUDE DRIVE SPECIFICATION TO CHANGE THE DEFAULT
DRIVE. THE EXTENSION FOR THE INPUT FILE MUST BE ".IN", THE OUTPUT FILE
CREATED WILL HAVE THE EXTENSION ".OUT". THE TWO FILES FOR USE BY THE
POST-PROCESSOR WILL HAVE THE EXTENSIONS PL1 AND PL2

  SCREEN 12, 1
  INPUT "ENTER: file name for the run >"; FILENAME$
  INPUT "Do you want the plots from a previous run (Y/N)", PLOT$
  IF PLOT$ = "Y" OR PLOT$ = "y" THEN GOTO PLOTS
  OPEN FILENAME$ + ".OUT" FOR OUTPUT AS #1
  OPEN FILENAME$ + ".IN" FOR INPUT AS #10
  PCLD = 1
  EPS4 = 10
  INPUT "ENTER: Problem title >", TITLE$
  PRINT #1, USING "TITLE : &"; TITLE$
  INPUT #10, NSPAN, NSEG, NUNIT, ICODE, KINT, GINT
```

```
INPUT #10, PH, PCL1, EPSF, DT, TF
IF PCL1 > 0 THEN PCLD = PCL1
IF EPSF > 0 THEN EPS4 = EPSF
MAXNSEG = NSEG

ERMINE ESTIMATE OF ARRAY DIMENSIONS

 = NUMBER OF CABLE ELEMENTS
 = NUMBER OF DEGREES OF FREEDOM
 = NUMBER OF CABLE ELEMENT TYPES

   NCE = NSPAN + NSPAN * NSEG
   NPE = NCE * 2 + NSPAN
   NCT = NSPAN * 2

IERATE DYNAMIC DATA

CALL GENDYD(NSPAN, NCE, NPE, NCT)
IF ICODE = 4 THEN GOTO 200
CLOSE #2
OPEN "TEMP1.DAT" FOR INPUT AS #2
INPUT #2, NCABLE, NPOLE, NCT, NP, NP1, NSTAT, NSTM
IPOLE = NPOLE  'NPOLE is the number of unfixed poles
IF NPOLE > 0 THEN GOTO 10
NPOLE = 1

NAMIC ANALYSIS OF A PLANE TRANSMISSION LINE SYSTEM

ALL DITSIM(NCABLE, NPOLE, NCT, NP1, FILENAME$)
OCATE 18, 30: INPUT "PRESS <ENTER> TO CONTINUE"; A$
S:
CALL PLOTT(FILENAME$)
END
```

```
UB DITSIM (NCABLE, NPOLE, NCT, NP1, FILENAME$)
IIS SUBROUTINE DOES A SIMULATION OF A ONE-LINE, ONE-PLANE
ANSMISSION LINE SYSTEM AFTER A CONDUCTOR BREAKAGE

E ALGORITHM IS AN ITERATIVE STEP-BY-STEP INTEGRATION
SUMING LINEAR ACCELERATION OVER THE TIME INTERVAL

ITSIM REQUIRES THE USE OF FILES TEMP1.DAT AND TEMP2.DAT
ILES *.PL1 AND *.PL2 ARE USED FOR SAVING DATA REQUIRED
Y SUBROUTINE PLOTT FOR CREATING THE TIME PLOTS
 IS THE BASENAME SPECIFIED BY THE USER

DIM AMASS(NP1), FILA(NP1), ALPHA(NP1), XS(NP1), XE(NP1), XDS(NP1)
DIM XDE(NP1), XDDS(NP1), XDDE(NP1)
DIM FI(NP1)
DIM CH(NCABLE), CV(NCABLE)
DIM DAMP(NCABLE), INPE(NCABLE, 4), INDT(NCABLE), INDS(NCABLE)
DIM AET(NCT), WOT(NCT), XLOT(NCT), AK(NPOLE), NPP(NPOLE)
DIM SAV(501, 14)
DIM FORR(4), ISTM(8)
DIM ZFOC(4)
DIM ZCOOR(2, 30)
DIM VMAX(13, 2), VMIN(13, 2), PLT1(8000)
SHARED NUNIT, KINT, GINT, ICODE, ITC1, ITC2, IPOLE, NSTM, NFILES, NCNT1
SHARED DT, PCLD, PH, TF, EPS4, HCMAX, V11, INPE, INDT, INDS, NPP, MAXNSEG, NINS
3$ = "&--------------------------------------------------------------------------------&"
4$ = "&                    MAXIMUM AND MINIMUM VALUES OF TENSIONS AND DISPLACEMENT&"
5$ = "&                                                   &MAXIMUM              &MINIMUM"
6$ = "&            1ST TOWER INSULATOR TENSION= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
7$ = "&             1ST SPAN CONDUCTOR TENSION= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
8$ = "&            2ND TOWER INSULATOR TENSION= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
9$ = "&             1ST TOWER HORIZONTAL FORCE= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
0$ = "&               1ST TOWER VERTICAL FORCE= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
6B$ = "&             1ST SPAN CONDUCTOR TENSION= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
7B$ = "&            2ND TOWER INSULATOR TENSION= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
9B$ = "&             1ST TOWER HORIZONTAL FORCE= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
0B$ = "&               1ST TOWER VERTICAL FORCE= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
1$ = "&      1ST TOWER HORIZONTAL DISPLACEMENT= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
2$ = "&      2ND TOWER HORIZONTAL DISPLACEMENT= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
3$ = "& 1ST TOWER INSULATOR HOR. DIS. (LOWER END)= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
4$ = "& 1ST TOWER INSULATOR VERT. DIS.(LOWER END)= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
5$ = "&  2ND TOWER INSULATOR HOR.DIS.(LOWER END)= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
6$ = "& 2ND TOWER INSULATOR VERT. DIS.(LOWER END)= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
7$ = "&VERT. DISPLACEMENT AT MIDSPAN OF CONDUCTOR= #.####^^^^ &AT ##.### &SEC #.####^^^^ &AT ##.### &SEC"
8$ = "&FAILURE TO CONVERGE IN PCAFX AT T= ###.######"
9$ = "&CHECK DATA AT ERROR PRINT OUT, INFORMATION BELOW, AND ERROR MESSAGE RECOMMENDATIONS IN USER MANUAL&"
3$ = "&FAILURE TO MEET FORCE CONVERGENCE CRITERIA OF ####.## &AT TIME ##.#### &WITH TIME INTERVAL= #.####"
11$ = "&                                                                   RECOMMENDED&"
12$ = "&  CABLE                  WEIGHT/                  FREQ       PERIOD       DT&"
13$ = "& ELEMENT        AE       LENGTH      LENGTH      (1/SEC)     (SEC)       (SEC)&"
14$ = "######## #.####^^^^ #.####^^^^ #.####^^^^ #.####^^^^ #.####^^^^ #.####^^^^"
15$ = "&THE RECOMMENDED MAXIMUM TIME INTERVAL, DT= ##.###### &- ##.###### &SECONDS--(CABLE ELEMENT ### &CONTROLS)"
```

```
$ = "&THE RECOMMENDED FORCE TOLERANCE= #.####^^^^"
$ = "&PLEASE CONSULT RECOMMENDATIONS IN USER MANUAL&"
$ = "&      IMBALANCE   IMBALANCE   ABSOLUTE    ALLOWED&"
$ = "& DOF     FORCES    LIN. ACC. DIFFERENCE  TOLERENCE&"
$ = "#### #.####^^^^ #.####^^^^ #######.### #######.###"
$ = "#### #.####^^^^ #.####^^^^ #######.### #######.### &EXCEEDS TOLERENCE"
0$ = "##.#####"
0A$ = "#########.###"
1$ = "#.###^^^^ #.###^^^^ #.###^^^^ #.###^^^^ #.###^^^^ #.###^^^^ #.###^^^^ #.###^^^^ #.###^^^^ #.###^^^^"
3$ = "##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ####
#"
4$ = "##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####"
5$ = "&                         DISPLACEMENTS FROM DYNAMIC ANALYSIS"
6$ = "&                      HORIZ        VERT         HORIZ        VERT        HORIZ        VERT&"
7$ = "&             HORIZ   LOWER END   LOWER END     MIDSPAN     MIDSPAN    LOWER END   LOWER END
9$ = "&            TOWER 1  INSULATOR 1  INSULATOR 1   CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2     T
10$ = "&  TIME       "
06B$ = "&                       HORIZ        VERT        HORIZ        VERT&"
07B$ = "&              HORIZ    MIDSPAN      MIDSPAN    LOWER END    LOWER END        HORIZ&"
09B$ = "&             TOWER 1  CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2      TOWER 2&"
10B$ = "&  TIME       "
08$ = "####.###"
08A$ = "#########.###"
10A$ = "&X- ## &         "
11$ = "&          HORIZ        VERT          HORIZ        VERT        HORIZ        VERT&"
12$ = "&        LOWER END   LOWER END     MIDSPAN     MIDSPAN    LOWER END   LOWER END        HORIZ&"
13$ = "&       INSULATOR 1  INSULATOR 1    CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2      TOWER 2&"
11B$ = "&         HORIZ        VERT        HORIZ        VERT&"
12B$ = "&        MIDSPAN      MIDSPAN    LOWER END    LOWER END        HORIZ&"
13B$ = "&       CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2      TOWER 2&"
15$ = "&        LOWER END   LOWER END     MIDSPAN     MIDSPAN    LOWER END   LOWER END&"
16$ = "&       INSULATOR 1  INSULATOR 1   CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2&"
15B$ = "&         MIDSPAN      MIDSPAN    LOWER END    LOWER END&"
16B$ = "&        CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2&"
18$ = "&        HORIZ    LOWER END   LOWER END     MIDSPAN     MIDSPAN    LOWER END   LOWER END&"
19$ = "&       TOWER 1  INSULATOR 1  INSULATOR 1   CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2&"
18B$ = "&        HORIZ    MIDSPAN      MIDSPAN    LOWER END    LOWER END&"
19B$ = "&       TOWER 1  CONDUCTOR    CONDUCTOR  INSULATOR 2  INSULATOR 2&"
20$ = "&      TENSIONS IN CONDUCTOR AND INSULATORS FROM DYNAMIC ANALYSIS&"
21$ = "&                                              HORIZONTAL    VERTICAL&"
22$ = "&          TENSION       TENSION     TENSION       FORCE        FORCE&"
23$ = "&  TIME    INSULATOR 1    CONDUCTOR  INSULATOR 2  INSULATOR 1  INSULATOR 1&"
21B$ = "&                                HORIZONTAL    VERTICAL&"
22B$ = "&           TENSION     TENSION       FORCE        FORCE&"
23B$ = "&  TIME     CONDUCTOR  INSULATOR 2  CONDUCTOR    CONDUCTOR&"
66$ = " ######.### ######.### ######.### ######.### ######.### ######.### ######.### ######.### "

NCNT1   COUNTER FOR STORAGE OF DATA ON FILES
KKK    COUNTER FOR PRINTING DATA

SAVE THE SCREEN WITH THE CONDUCTOR DRAWN IN GENDYD
AND ADD THE TILTLES FOR PLOTTING INSULATOR LOAD VS
```

```
' TIME ON THE SCREEN
'
 GET (140, 10)-(601, 275), PLT1
 IF ICODE <> 2 THEN
     LOCATE 4: PRINT : "ELAPSED TIME"
     IF VI1 <> 0 THEN
        LOCATE 12: PRINT : "INSULATOR"
     ELSE
        LOCATE 12: PRINT : "CONDUTOR"
     END IF
     LOCATE 13: PRINT : "ANGLE PER"; KINT
     LOCATE 14: PRINT : "TIME INTERVAL"
     LOCATE 15: PRINT : "FROM HORIZONTAL"
     IF VI1 <> 0 THEN
        LOCATE 23: PRINT : "INSULATOR"
     ELSE
        LOCATE 23: PRINT : "CONDUCTOR"
     END IF
     LOCATE 24: PRINT : "TENSION PER"; KINT
     LOCATE 25: PRINT : "TIME INTERVAL"
  ELSE
  END IF
'
' OPEN FILE TO STORE DATA FOR PLOTTING
'
 OPEN FILENAME$ + ".PL1" FOR OUTPUT AS #6
 OPEN FILENAME$ + ".PL2" FOR OUTPUT AS #7
'
' INITIALIZE CONSTANTS
'
  PI = 3.14159
  NP = NP1 - 1
  EPS = .001
  D1 = DT * DT / 2
  D2 = D1 * DT / 3
  T = 0
  KPR$ = "0"
  IF ICODE > 1 THEN KPR$ = "1"
  KSAV$ = "0"
  KNPOL$ = "0"
  NKK = KINT
  KKK = NKK - 1
  NRT = 0
  KSTOP1 = 500
  IF IPOLE = 0 THEN KNPOL$ = "1"
  NFILES = 0
  IDIV = 0
  CLOSE #3
  OPEN "TEMP2.DAT" FOR OUTPUT AS #3
  IF ICODE <> 2 THEN
   XSCALE = 450 / HCMAX
   YSCALE = 300 / 150
```

```
V = 1

IF

ALIZE ARRAYS

I = 1 TO NP1
(I) = 0
(I) = 0
PHA(I) = 0
S(I) = 0
T I
(NP1) = 0

FROM FILE TEMP1.DAT THE DATA GENERATED IN GENDYD

I = 1 TO NCT
PUT #2, AET(I), WOT(I), XLOT(I)
T I
I = 1 TO NCABLE
UT #2, CH(I), CV(I), INDT(I), INDS(I)
J = 1 TO 4
UT #2, INPE(I, J)
T J
UT #2, DAMP(I)
T I
KNPOL$ = "1" GOTO 551
I = 1 TO NPOLE
UT #2, NPP(I), AK(I)
T I
R I = 1 TO NP
UT #2, AMASS(I), FI(I), XDDS(I)
T I
I = 1 TO NSTM
UT #2, ISTM(I)
T I
NT #1, USING D5020$; SPACE$(0)
NINS = 0 THEN
RINT #1, USING D5021$; SPACE$(0)
RINT #1, USING D5022$; SPACE$(0)
RINT #1, USING D5023$; SPACE$(0)
E
RINT #1, USING D5021B$; SPACE$(0)
RINT #1, USING D5022B$; SPACE$(0)
RINT #1, USING D5023B$; SPACE$(0)
IF

ICODE <> 2 THEN PSET (140, 50)

EASE COUNTERS EACH TIME INTERVAL

= KKK + 1
```

```
KKK < NKK THEN GOTO 1002
 = 0
.V$ = "0"
O 103
SAV$ = "1"
O 105

IT1 = NCNT1 + 1
NCNT1 <= KSTOP1 THEN GOTO 105
IT1 = 1
O 5801


 PORTION OF THE PROGRAM DOES AN ITERATIVE LINEAR
ELERATION ROUTINE ON EACH DOF

PUTE END OF INTERVAL VALUES OF DISPLACEMENT, VELOCITY,
 ACCELERATION
ELERATION IS LINEAR OVER TIME INTERVAL-ALPHA (CONSTANT)
IT = 0
OR I = 1 TO NP
DDE(I) = XDDS(I) + ALPHA(I) * DT
DE(I) = XDS(I) + ALPHA(I) * D1 + XDDS(I) * DT
E(I) = XS(I) + XDS(I) * DT + ALPHA(I) * D2 + XDDS(I) * D1
EXT I

ERMINE THE IMBALANCE OF FORCES ON EACH LUMPED MASS
NEW POSITION
L IMBALANCE FORCE ARRAY (FI)

OR I = 1 TO NP1
I(I) = 0
EXT I
F KNPOL$ = "1" GOTO 135

 FORCES FROM TOWER SUPPORTS

OR I = 1 TO NPOLE
PPI = NPP(I)
I(NPPI) = FI(NPPI) - XE(NPPI) * AK(I)
NEXT I
IS = 0
LI = 0

ERMINE THE FORCES ON THE CABLE SEGMENTS DUE TO THE
PLACEMENTS OF THE ENDS

LI = ILI + 1
PE1 = INPE(ILI. 1)
PE2 = INPE(ILI, 2)
PE3 = INPE(ILI. 3)
PE4 = INPE(ILI, 4)
```

```
   ZH = XE(NPE3) - XE(NPE1)
   ZV = XE(NPE4) - XE(NPE2)
   ZH = CH(ILI) + ZH
   ZV = CV(ILI) + ZV
   MN = ILI
   INCT = INDT(MN)
   ZAE = AET(INCT)
   ZWO = WOT(INCT)
   ZXLO = XLOT(INCT)
   IF ZXLO <> 0 THEN
      CALL PCAFX(ILI, ZH. ZV, ZAE, ZWO, ZXLO, ZFOC(), ZTENI, ZTENJ, 2, ZCOOR(), IDIV, 0, NE)
   ELSE
      ZH = 0
      ZV = 0
      ZFOC(1) = 0
      ZFOC(2) = 0
      ZFOC(3) = 0
      ZFOC(4) = 0
      ZTENI = 0
      ZTENJ = 0
      ZCOOR(1, 1) = 0
      ZCOOR(1, 2) = 0
      ZCOOR(2, 1) = 0
      ZCOOR(2, 2) = 0
      NE = 0
   END IF
   IF NE = 0 THEN GOTO 350
   NRT = 2
   GOTO 600
350 FOR I = 1 TO 4
   FORR(I) = ZFOC(I)
360 NEXT I
   TEN = ZTENI
'
' STORE THE VALUES OF TENSION
'
   IF KSAV$ = "1" THEN GOTO 1401
   IIS = INDS(ILI)
   IF IIS = 0 THEN GOTO 1401
   NIS = NIS + IIS
   SAV(NCNT1, NIS) = TEN
   IF ILI > 2 THEN GOTO 1401
   IF NINS = 0 AND ILI = 2 THEN GOTO 1401
   SAV(NCNT1, 4) = FORR(3)
   SAV(NCNT1, 5) = -FORR(2)
   IF SAV(NCNT1. 4) <> 0 THEN
     ANG = ATN(SAV(NCNT1, 5) / SAV(NCNT1, 4)) * 180 / PI
   ELSE
     ANG = 90
   END IF
'
' ADD CABLE FORCES TO IMBALANCE ARRAY
```

```
'
1401 FOR J = 1 TO 4
   NPEJ = INPE(ILI, J)
   FI(NPEJ) = FI(NPEJ) - FORR(J)
150 NEXT J
'
' ADD DAMPING FORCES TO IMBALANCE ARRAY
'
   C = DAMP(ILI)
   DVH = XDE(NPE3) - XDE(NPE1)
   DVV = XDE(NPE4) - XDE(NPE2)
   HOR = ZH
   VER = ZV
   C1 = HOR * HOR
   C2 = HOR * VER
   C3 = VER * VER
   IF C1 <> 0 OR C3 <> 0 THEN
      C4 = C / (C1 + C3)
   ELSE
   END IF
   DH = C4 * (DVH * C1 + DVV * C2)
   DV = C4 * (DVH * C2 + DVV * C3)
   FI(NPE1) = FI(NPE1) + DH
   FI(NPE2) = FI(NPE2) + DV
   FI(NPE3) = FI(NPE3) - DH
   FI(NPE4) = FI(NPE4) - DV
'
' DRAW THE CONDUCTOR AND THE INSULATORS OF THE FIRST SPAN
' FOR EVERY GINT TIME INTERVALS
'
   IF ICODE <> 2 AND ABS(GCHK) < .000001 THEN
    IF KAC$ = "1" AND ILI < MAXNSEG + 3 THEN
       XORD = XSCALE * (ZCOOR(1, 2) - ZCOOR(1, 1))
       YORD = -YSCALE * (ZCOOR(2, 2) - ZCOOR(2, 1))
       IF ILI = MAXNSEG + 2 THEN
         YORD = YSCALE * (ZCOOR(2, 2) - ZCOOR(2, 1))
         XORD = -XSCALE * (ZCOOR(1, 2) - ZCOOR(1, 1))
       ELSE
       END IF
       IF ILI = 1 THEN
         VIEW SCREEN (121, 1)-(638, 299)
         CLS 1
         PUT (140, 10), PLT1, OR
         PSET (140 + XSCALE * XE(ILI), 50)
       ELSE
       END IF
       IF ILI = 1 OR ILI = MAXNSEG + 2 THEN
         LINE -STEP(XORD, YORD), 4
       ELSE
         LINE -STEP(XORD, YORD), 3
       END IF
    ELSE
```

```
 END IF
 ELSE
 END IF
1 IF ILI < NCABLE THEN GOTO 136

ECK BUFFER FOR SPECIAL LETTER IF FIND "O" OR "o" FREEZE THE SCREEN

$ = INKEY$
F S$ = "O" OR S$ = "o" THEN CALL INSTRUCTIONS

OMPARE IMBALANCE FROM LINEAR ACCELERATION CALCULATION
 TO IMBALANCE FROM FORCES

 FOR I = 1 TO NP
 FILA(I) = XDDE(I) * AMASS(I)
)2 NEXT I
 KAC$ = "1"
5 FOR I = 1 TO NP
 IF ABS(FILA(I) - FI(I)) < EPS4 THEN GOTO 2101
 KAC$ = "0"
)1 NEXT I
 IF KAC$ = "1" GOTO 230
 NIT = NIT + 1
 IF NIT = 8 THEN GOTO 290

DETERMINE THE NEW CONSTANT FOR THE LINEAR ACCELERATION OVER THE
TIME INTERVAL IF CONVERGENCE CRITERIA ARE NOT MET

 FOR I = 1 TO NP
 ALPHA(I) = (FI(I) / AMASS(I) - XDDS(I)) / DT
0 NEXT I
 GOTO 115

AFTER CONVERGENCE CRITERIA ARE MET
ASSIGN NEW XS,XDS,XDDS FOR THE START OF THE NEXT INTERVAL

0 FOR I = 1 TO NP
  XDDS(I) = XDDE(I)
  XDS(I) = XDE(I)
  XS(I) = XE(I)
0 NEXT I

STORE DISPLACEMENTS

 IF KSAV$ = "1" GOTO 2501
  FOR I = 1 TO NSTM
   J = ISTM(I)
   K = I + 5
   SAV(NCNT1, K) = XS(J)
45 NEXT I
501
```

```
LOT LOAD VS DISPLACEMENT UNDER THE CONDUCTOR SHAPE
OR EVERY GINT TIME INTERVALS

  T = T + DT
  GCHK = CINT((T / DT) / GINT) - (T / DT) / GINT
  IF ICODE <> 2 AND KSAV$ = "1" THEN
      LOCATE 6: PRINT USING "###.### &"; T; "SEC"
      LOCATE 17: PRINT USING "###.## &"; ANG; "  DEG"
      LOCATE 27: PRINT USING "#####.###"; SAV(NCNT1, 1)
    IF NUNIT = 0 THEN LOCATE 28: PRINT ; "NEWTONS"
    IF NUNIT = 1 THEN LOCATE 28: PRINT ; "LBS"
    VIEW SCREEN (120, 300)-(639, 475)
       PSET (140 + T * 450 / TF, 450 - SAV(NCNT1, 1) * 150 / (ABS(PH) * 2.5))
  ELSE
  END IF

PRINT THE DATA STORED IN SAV
BEGIN NEXT TIME INTERVAL IF T < TF

  IF (KSAV$ = "1") THEN GOTO 280
   SAV(NCNT1, 14) = T
  IF KPR$ = "1" THEN GOTO 280
  PRINT #1, USING D5000$; SAV(NCNT1, 14);
  FOR I = 1 TO 5
   IF I <> 3 THEN PRINT #1, USING D5000A$; SAV(NCNT1, I);
  NEXT I
  PRINT #1, USING "&"; SPACE$(0)
80
  IF T > TF THEN GOTO 600
  GOTO 90

DATA PRINTED IF NON-CONVERGENCE IN ITERATIVE PORTION

0 NRT = 1
  GOTO 600

STORE DATA IN SAV ON FILE TEMP2.DAT AND RETURN TO ALGORITHM

001
  NFILES = NFILES + 1
  FOR NI = 1 TO 500
   FOR NJ = 1 TO 14
    PRINT #3, SAV(NI, NJ),
   NEXT NJ
  IF SAV(NI, 4) <> 0 THEN
    ANG = ATN(SAV(NI, 5) / SAV(NI, 4)) * 180 / PI
  ELSE
    ANG = 90
  END IF
   PRINT #6, USING D6666$; SAV(NI, 14); SAV(NI, 1); SAV(NI, 4); SAV(NI, 5); SAV(NI, 7); SAV(NI, 8); SAV(NI, 10); SAV(NI, 6)

NG
  NEXT NI
```

```
GOTO 105

STORE DATA AND PRINT RESULTS
THIS IS WHERE THE FINAL VALUES OF SAV ARE SAVED ONTO A FILE


NFILES = NFILES + 1
FOR NI = 1 TO NCNT1
 FOR NJ = 1 TO 14
  PRINT #3, SAV(NI, NJ),
 NEXT NJ
IF SAV(NI, 4) <> 0 THEN
  ANG = ATN(SAV(NI, 5) / SAV(NI, 4)) * 180 / PI
ELSE
  ANG = 90
END IF
 PRINT #6, USING D6666$; SAV(NI, 14); SAV(NI, 1); SAV(NI, 4); SAV(NI, 5); SAV(NI, 7); SAV(NI, 8); SAV(NI, 10); SAV(NI, 6

5
NEXT NI

PRINT DISPLACEMENTS IF ICODE = 0

IF ICODE <> 0 THEN GOTO 625
PRINT #1, USING D5005$; SPACE$(0)
IF NSTM <> 8 THEN GOTO 601
IF NINS = 0 THEN
   PRINT #1, USING D5006$; SPACE$(0)
   PRINT #1, USING D5007$; SPACE$(0)
   PRINT #1, USING D5009$; SPACE$(0)
   PRINT #1, USING D5010$; SPACE$(0);
ELSE
   PRINT #1, USING D5006B$; SPACE$(0)
   PRINT #1, USING D5007B$; SPACE$(0)
   PRINT #1, USING D5009B$; SPACE$(0)
   PRINT #1, USING D5010B$; SPACE$(0);
END IF
FOR I = 1 TO NSTM
IF ISTM(I) <> 0 THEN PRINT #1, USING D5010A$; SPACE$(0); ISTM(I); SPACE$(0);
NEXT I
PRINT #1, USING "&"; SPACE$(0)
GOTO 605
01 IF ITC1 = 1 THEN GOTO 603
IF ITC2 = 0 THEN GOTO 602
IF NINS = 0 THEN
   PRINT #1, USING D5011$; SPACE$(0)
   PRINT #1, USING D5012$; SPACE$(0)
   PRINT #1, USING D5013$; SPACE$(0)
   PRINT #1, USING D5010$; SPACE$(0);
ELSE
   PRINT #1, USING D5011B$; SPACE$(0)
   PRINT #1, USING D5012B$; SPACE$(0)
   PRINT #1, USING D5013B$; SPACE$(0)
```

```
      PRINT #1, USING D5010B$; SPACE$(0);
   END IF
   FOR I = 1 TO NSTM
   IF ISTM(I) <> 0 THEN PRINT #1, USING D5010A$; SPACE$(0); ISTM(I); SPACE$(0);
   NEXT I
   PRINT #1, USING "&"; SPACE$(0)
   GOTO 605
602 IF NINS = 0 THEN
      PRINT #1, USING D5011$; SPACE$(0)
      PRINT #1, USING D5015$; SPACE$(0)
      PRINT #1, USING D5016$; SPACE$(0)
      PRINT #1, USING D5010$; SPACE$(0);
   ELSE
      PRINT #1, USING D5011B$; SPACE$(0)
      PRINT #1, USING D5015B$; SPACE$(0)
      PRINT #1, USING D5016B$; SPACE$(0)
      PRINT #1, USING D5010B$; SPACE$(0);
   END IF
   FOR I = 1 TO NSTM
   IF ISTM(I) <> 0 THEN PRINT #1, USING D5010A$; SPACE$(0); ISTM(I); SPACE$(0);
   NEXT I
   PRINT #1, USING "&"; SPACE$(0)
   GOTO 605
603 IF NINS = 0 THEN
      PRINT #1, USING D5006$; SPACE$(0)
      PRINT #1, USING D5018$; SPACE$(0)
      PRINT #1, USING D5019$; SPACE$(0)
      PRINT #1, USING D5010$; SPACE$(0);
   ELSE
      PRINT #1, USING D5006B$; SPACE$(0)
      PRINT #1, USING D5018B$; SPACE$(0)
      PRINT #1, USING D5019B$; SPACE$(0)
      PRINT #1, USING D5010B$; SPACE$(0);
   END IF
   FOR I = 1 TO NSTM
   IF ISTM(I) <> 0 THEN PRINT #1, USING D5010A$; SPACE$(0); ISTM(I); SPACE$(0);
   NEXT I
   PRINT #1, USING "&"; SPACE$(0)
605
   K1 = 5 + NSTM
   CLOSE #3
   OPEN "TEMP2.DAT" FOR INPUT AS #3
   NN = 500
   FOR I = 1 TO NFILES
   IF I = NFILES THEN NN = NCNT1
   FOR NI = 1 TO NN
    FOR NJ = 1 TO 14
     INPUT #3, SAV(NI, NJ)
    NEXT NJ
   NEXT NI
   FOR J = 1 TO NN
    PRINT #1, USING D5008$; SAV(J, 14);
```

```
    FOR K = 6 TO K1
      IF NINS = 0 THEN
        PRINT #1, USING D5008A$; SAV(J, K);
      ELSEIF ITC1 = 1 THEN
        IF K <> 7 AND K <> 8 THEN PRINT #1, USING D5008A$; SAV(J, K);
      ELSEIF ITC1 = 0 THEN
        IF K <> 6 AND K <> 7 THEN PRINT #1, USING D5008A$; SAV(J, K);
      END IF
    NEXT K
    PRINT #1, USING "&"; SPACE$(0)
   NEXT J
620 NEXT I
625 CLOSE #3
   OPEN "TEMP2.DAT" FOR INPUT AS #3
'
' DETERMINE THE RANGE OF TENSIONS AND DISPLACEMENTS
'
   J = 1
   K1 = 5 + NSTM
   FOR I = 1 TO 13
   VMAX(I, J) = 0
   VMIN(I, J) = 1000000
672 NEXT I
   CLOSE #3
   OPEN "TEMP2.DAT" FOR INPUT AS #3
   NN = 500
   FOR J = 1 TO NFILES
   IF J = NFILES THEN NN = NCNT1
    FOR NI = 1 TO NN
     FOR NJ = 1 TO 14
      INPUT #3, SAV(NI, NJ)
     NEXT NJ
    NEXT NI
   FOR K = 1 TO NN
   FOR I = 1 TO K1
   P = SAV(K, I)
   IF P < VMAX(I, 1) THEN GOTO 675
   VMAX(I, 1) = P
   VMAX(I, 2) = SAV(K, 14)
675 IF P > VMIN(I, 1) THEN GOTO 680
   VMIN(I, 1) = P
   VMIN(I, 2) = SAV(K, 14)
680 NEXT I
   NEXT K
   NEXT J
   PRINT #1, USING D683$; SPACE$(0)
   PRINT #1, USING D684$; SPACE$(0)
   PRINT #1, USING D683$; SPACE$(0)
   PRINT #1, USING D685$; SPACE$(0)
   PRINT #1, USING D683$; SPACE$(0)
   IF NINS = 0 THEN
     PRINT #1, USING D686$; SPACE$(0); VMAX(1, 1); SPACE$(0); VMAX(1, 2); SPACE$(0); VMIN(1, 1); SPACE$(0); VMIN(1,
```

```
SPACE$(0)
      PRINT #1, USING D687$; SPACE$(0); VMAX(2, 1); SPACE$(0); VMAX(2, 2); SPACE$(0); VMIN(2, 1); SPACE$(0); VMIN(2, 2);
SPACE$(0)
      PRINT #1, USING D688$; SPACE$(0); VMAX(3, 1); SPACE$(0); VMAX(3, 2); SPACE$(0); VMIN(3, 1); SPACE$(0); VMIN(3, 2);
SPACE$(0)
      PRINT #1, USING D689$; SPACE$(0); VMAX(4, 1); SPACE$(0); VMAX(4, 2); SPACE$(0); VMIN(4, 1); SPACE$(0); VMIN(4, 2);
SPACE$(0)
      PRINT #1, USING D690$; SPACE$(0); VMAX(5, 1); SPACE$(0); VMAX(5, 2); SPACE$(0); VMIN(5, 1); SPACE$(0); VMIN(5, 2);
SPACE$(0)
   ELSE
      PRINT #1, USING D686B$; SPACE$(0); VMAX(1, 1); SPACE$(0); VMAX(1, 2); SPACE$(0); VMIN(1, 1); SPACE$(0); VMIN(1, 2);
SPACE$(0)
      PRINT #1, USING D687B$; SPACE$(0); VMAX(2, 1); SPACE$(0); VMAX(2, 2); SPACE$(0); VMIN(2, 1); SPACE$(0); VMIN(2, 2);
SPACE$(0)
      PRINT #1, USING D689B$; SPACE$(0); VMAX(4, 1); SPACE$(0); VMAX(4, 2); SPACE$(0); VMIN(4, 1); SPACE$(0); VMIN(4, 2);
SPACE$(0)
      PRINT #1, USING D690B$; SPACE$(0); VMAX(5, 1); SPACE$(0); VMAX(5, 2); SPACE$(0); VMIN(5, 1); SPACE$(0); VMIN(5, 2);
SPACE$(0)
   END IF
   I = 6
   IF ITC1 = 1 THEN I = 7
   IF NINS = 0 THEN PRINT #1, USING D693$; SPACE$(0); VMAX(I, 1); SPACE$(0); VMAX(I, 2); SPACE$(0); VMIN(I, 1); SPACE$(0);
VMIN(I, 2); SPACE$(0)
   I = I + 1
   IF NINS = 0 THEN PRINT #1, USING D694$; SPACE$(0); VMAX(I, 1); SPACE$(0); VMAX(I, 2); SPACE$(0); VMIN(I, 1); SPACE$(0);
VMIN(I, 2); SPACE$(0)
   I = I + 2
   PRINT #1, USING D697$; SPACE$(0); VMAX(I, 1); SPACE$(0); VMAX(I, 2); SPACE$(0); VMIN(I, 1); SPACE$(0); VMIN(I, 2); SPACE$

   I = I + 1
   PRINT #1, USING D695$; SPACE$(0); VMAX(I, 1); SPACE$(0); VMAX(I, 2); SPACE$(0); VMIN(I, 1); SPACE$(0); VMIN(I, 2); SPACE$

   I = I + 1
   PRINT #1, USING D696$; SPACE$(0); VMAX(I, 1); SPACE$(0); VMAX(I, 2); SPACE$(0); VMIN(I, 1); SPACE$(0); VMIN(I, 2); SPACE$

   IF ITC1 = 0 THEN GOTO 681
   PRINT #1, USING D691$; SPACE$(0); VMAX(6, 1); SPACE$(0); VMAX(6, 2); SPACE$(0); VMIN(6, 1); SPACE$(0); VMIN(6, 2); SPACE$

681 IF ITC2 = 0 THEN GOTO 682
   I = I + 1
   PRINT #1, USING D692$; SPACE$(0); VMAX(I, 1); SPACE$(0); VMAX(I, 2); SPACE$(0); VMIN(I, 1); SPACE$(0); VMIN(I, 2); SPACE$

682 PRINT #1, USING D683$; SPACE$(0)
'
' WRITE ERROR MESSAGES IF CONVERGENCE FAILURE
'
    IF NRT = 0 THEN GOTO 800
    IF NRT = 1 THEN GOTO 702
    PRINT #1, USING D698$; SPACE$(0); T
    PRINT #1, USING D699$; SPACE$(0)
    GOTO 704
702 PRINT #1, USING D703$; SPACE$(0); EPS4; SPACE$(0); T; SPACE$(0); DT
704
    TOL = .001 * ABS(PH)
    PRINT #1, USING D711$; SPACE$(0)
    PRINT #1, USING D712$; SPACE$(0)
    PRINT #1, USING D713$; SPACE$(0)
```

```
DTM = 1
FOR IA = 1 TO NCABLE
I = INDT(IA)
AEWXL = AET(I) / (WOT(I) * XLOT(I) * XLOT(I))
G = 32.2
IF NUNIT = 1 THEN GOTO 705
G = G * .30481
FREQ = SQR(AEWXL * G)
FREQ = FREQ / (PI * 2)
PER = 1 / FREQ
DTREC = .01 * PER
PRINT #1, USING D714$; IA; AET(I); WOT(I); XLOT(I); FREQ; PER; DTREC
IF DTREC > DTM THEN GOTO 710
DTM = DTREC
IDT = IA
NEXT IA
DTM2 = 5 * DTM
PRINT #1, USING D715$; SPACE$(0); DTM; SPACE$(0); DTM2; SPACE$(0); IDT; SPACE$(0)
IF NRT = 2 THEN GOTO 800
PRINT #1, USING D716$; SPACE$(0); TOL
PRINT #1, USING D717$; SPACE$(0)
PRINT #1, USING D718$; SPACE$(0)
PRINT #1, USING D719$; SPACE$(0)
FOR I = 1 TO NP
TFC = ABS(FILA(I) - FI(I))
IF TFC > EPS4 THEN GOTO 725
PRINT #1, USING D720$; I; FILA(I); FI(I); TFC; EPS4
GOTO 730
PRINT #1, USING D721$; I; FILA(I); FI(I); TFC; EPS4; SPACE$(0)
NEXT I
PRINT #7, NUNIT, TF, PH, VI1, NFILES, NCNT1, VMAX(1, 1), VMAX(7, 1), VMAX(8, 1), VMIN(10, 1), VMAX(6, 1), NINS
CLOSE #7
END SUB
```

```
 SUB GENDYD (NSPAN, NCE, NPE, NCTE)
'
' THIS SUBROUTINE GENERATES THE CABLE PROPERTY DATA FOR A DYNAMIC ANALYSIS
' OF A POLE/INSULATOR/CONDUCTOR SYSTEM DUE TO A BROKEN CONDUCTOR
'
' DATA IS STORED FOR USE BY THE MAIN PROGRAM ON FILE TEMP1.DAT
' GENDYD USES SCRATCH FILES TEMP2.DAT, TEMP3.DAT FOR TEMPORARY STORAGE
'
' INDS=ARRAY CONTAINING CODE TO PRINT TENSION IN DYNAMIC ANAL
' INDT=ARRAY CONTAINING CABLE ELEMENT TYPE
' INPE=ARRAY CONTAINING CABLE ELEMENT DEGREES OF FREEDOM
' NPP=ARRAY CONTAINING THE DOF FOR POLE/TOWER
' DAMP=ARRAY CONTAINING DAMPING CONSTANT FOR EACH CABLE ELEMENT
' AMASS=MASS FOR EACH DEGREE OF FREEDOM
' FI=INITIAL FORCE IMBALANCE FOR EACH DOF
' XDDS=INITIAL ACCELERATION FOR EACH DOF
' NSTAT=NUMBER OF CABLE ELEMENT TENSIONS TO BE PRINTED IN DYN ANAL
' NSTM=NUMBER OF DISPLACEMENTS TO BE PRINTED DURING DYN ANAL
' ISTM=DEGREES OF FREEDOM FOR PRINTED DISPLACEMENTS
' VI=LENGTH OF INSULATOR
' HC=HORIZONTAL PROJECTION OF CONDUCTOR
' VC=VERTICAL PROJECTION OF CONDUCTOR
' WOI=WEIGHT OF INSULATOR
' WOC=WEIGHT/LENGTH OF CONDUCTOR
' AEC=AREA TIMES MODULUS OF ELASTICITY FOR CONDUCTOR
' AEI=AREA TIMES MODULUS OF ELASTICITY FOR INSULATOR
' NSEG=NUMBER OF CABLE ELEMENTS FOR DIVIDING CONDUCTOR
' AKT=POLE OR TOWER STIFFNESS
' AM=POLE MASS FOR DOF AT INSULATOR ATTACHMENT
' AET=AE FOR EACH CABLE ELEMENT TYPE
' AEWXT=AE/WX FOR EACH CABLE ELEMENT TYPE
' WOT=WEIGHT/LENGTH FOR EACH CABLE ELEMENT TYPE
' WXT=WEIGHT FOR EACH CABLE ELEMENT TYPE
' XLOT=LENGTH FOR EACH CABLE ELEMENT TYPE
' CD=PERCENT OF CRITICAL DAMPING/100
'           (PROGRAM USES 20 PERCENT)
' PH=HORIZONTAL LINE TENSION
'  (VERTICAL LOAD AT BREAK IS THE SAME AS FOR THE 1ST SPAN)
' PCLD=LOAD TOLERENCE -- CONVERGENCE CRITERIA
' NPT=POLE TYPE
' NCE=ESTIMATE OF THE NUMBER OF CABLE ELEMENTS
' NPE=ESTIMATE OF THE NUMBER OF DOF
' NCTE=ESTIMATE OF THE NUMBER OF CABLE ELEMENT TYPES

' IIS=0  TENSION NOT PRINTED DURING DYNAMIC ANALYSIS
' IIS=1  TENSION PRINTED DURING DYNAMIC ANALYSIS

' NUNIT=0    METRIC UNITS(KILOGRAMS FORCE -- METERS)
' NUNIT=1 AMERICAN UNITS(POUNDS -- FEET)

 DIM XLOT(NCTE), AET(NCTE), WOT(NCTE)
 DIM PVER(NSPAN), AMPOL(NSPAN), AK(NSPAN), NPP(NSPAN)
```

```
DIMM(30, 2), XCOOR(2, 30), FOC(4)
AMASS(NPE), FI(NPE), XDDS(NPE)
CH(NCE), CV(NCE), INPE(NCE, 4), INDT(NCE), DAMP(NCE)
AEWXT(NCTE), WXT(NCTE)
INDS(NCE)
ISTM(8)
ED NUNIT, KINT, ICODE, ITC1, ITC2, IPOLE, NSTM, HCMAX
ED DT, PCLD, PH, TF, EPS4, MAXNSEG, VI1, NINS
= "&-------------------------------------------------------------------------------------------------------"
= "&      INPUT DATA FOR SUBROUTINE GENDYD"
= "&              DATA UNITS= FEET -- POUNDS"
= "&              DATA UNITS=METERS -- KILOGRAMS-FORCE"
= "&LOAD TOLERANCE (GENDYD)= ###.### UNITS-FORCE"
= "&             NO. OF SPANS= ###"
= "&          EXT. HOR. LOAD= ######.##"
= "& PERCENT OF CRITICAL DAMP= ######.##"
= "&I------------------CONDUCTOR DATA-------------------I-------INSULATOR DATA-------I-----TOWER/POLE DATA--------I"
= "&       HORIZ    VERT   WEIGHT PER             NUMBER"
= "&SPAN    PROJ    PROJ  UNIT LENGTH     AE    ELEMENTS   LENGTH   WEIGHT     AE    TYPE    MASS    STIFFNESS"
= "####. ####. ####. ####. ####. #########. #########. ##### ##### #########. #########."
= "##### ######.## #####.## ######.## ##############. ####### ######.## #####.## #########. ###### #####.## #########.

= "&-------------------------------------------------------------------------------------------------------"
= "&LOAD TOLERANCE (DITSIM)= ###.### &UNITS-FORCE"
= "&                                          CABLE ELEMENTS FOR DYNAMIC ANALYSIS"
= "& STATIC DYN DEGREES OF FREEDOM"
= "&     NO  NO NPE1 NPE2 NPE3 NPE4      H         V         AE        AE/WX      WO       XLO     WX=WO*XLO     MASS
IS NCT"
$ = "& C ## ####"
$ = "#####"
$ = "######.### #####.### #.###^^^^^ #.###^^^^^ #####.## ######.##### ######.##### #####.### #.###^^^^^ #### ####"
$ = "&I ## ####"
$ = "#####"
$ = "######.### #####.### #.###^^^^^ #.###^^^^^ #####.## ######.##### ######.##### #####.### ##.###^^^^^ #### ####"
= "&ERROR---NPD IS GREATER THAN NPD1--REVISE MAIN"
= "&DYNAMIC CABLE SYSTEM - INITIAL CONDITIONS"
= "&  DOF     MASS  IMBALANCE  ACCELERATION&"
= "##### #####.#### #####.#### #.####^^^^^^"
= "&SUMMARY OF PARAMETERS FOR DYNAMIC ANALYSIS"
= "&       NO. OF POLES(DYNAMIC)= ###"
= "&      NO. OF CABLES(DYNAMIC)= ###"
= "&                        NP= ###"
= "&                       NP1= ###"
= "&                          CABLES FOR DYNAMIC ANALYSIS -- CHECK FORCES"
= "&N NPE1 NPE2 NPE3 NPE4        FO1       FO2       FO3       FO4     H        V     TEN I     TEN J"
$ = "###"
$ = "#####"
$ = "#####.##"
$ = "######.### #######.### #######.## #######.##"
= "&             TIME FINISH TF= ###.######"
= "&           TIME INTERVAL DT= ###.######"
= "&           NO. OF INTERVALS= #####"
= "&           DATA PRINTED EVERY #####   &INTERVALS"
```

```
G743$ = "&-----------------------------------------------------------------------------------------"
G744$ = "&---------------------------------------"
'
' INITIALIZE ARRAYS AND CONSTANTS
'
  PCLM = PCLD
  NCABLE = NSPAN
  NINSUL = NSPAN
  NPOLE = NSPAN
  NP = NPE
  NPD1 = NPE
  CD = .2
  EPS = .0001
  NINS = 0
 FOR I = 1 TO NP
  AMASS(I) = 0
 NEXT I
 FOR I = 1 TO NINSUL
  PVER(I) = 0
 NEXT I
  UMASS = 32.2
  IF NUNIT = 0 THEN UMASS = UMASS * .30481
  NINT = TF / DT
'
' PRINT GENERAL PROGRAM DATA
'
  PRINT #1, USING G701$; SPACE$(0)
  IF NUNIT = 0 THEN GOTO 51
  PRINT #1, USING G702$; SPACE$(0)
  GOTO 6
51 PRINT #1, USING G703$; SPACE$(0)
6  PRINT #1, USING G704$; SPACE$(0); PCLD; SPACE$(0)
  PRINT #1, USING G714$; SPACE$(0); EPS4; SPACE$(0)
  PRINT #1, USING G705$; SPACE$(0); NSPAN
  PRINT #1, USING G706$; SPACE$(0); PH
  C = CD * 100
  PRINT #1, USING G707$; SPACE$(0); C
'
' READ AND PRINT CABLE/INSULATOR/POLE DATA FOR A TRANSMISSION LINE SYSTEM
'  (ONE PLANE-ONE LINE)
'
' STORE CONDUCTOR DATA ON FILE TEMP1.DAT
'
  OPEN "TEMP1.DAT" FOR OUTPUT AS #2
  OPEN "TEMP2.DAT" FOR OUTPUT AS #3
  OPEN "TEMP3.DAT" FOR OUTPUT AS #4
  PRINT #1, USING G699$; SPACE$(0)
  PRINT #1, USING G708$; SPACE$(0)
  PRINT #1, USING G709$; SPACE$(0)
  PRINT #1, USING G710$; SPACE$(0)
  PRINT #1, USING G699$; SPACE$(0)
  PH = -PH
```

```
  FOR I = 1 TO NSPAN
  INPUT #10, VI, HC, VC, WOI, WOC, AEI, AEC, NSEG, NPT, AKT, AM
  PRINT #1, USING G712$; I; HC; VC; WOC; AEC; NSEG; VI; WOI; AEI; NPT; AM; AKT
'
' IF THE LENGTH OF THE FIRST INSULATOR, VI1, IS ZERO, THIS INSULATOR
' IS NOT INCLUDED IN THE NUMBERING OF THE DEGRRES OF FREEDOM
'
  IF I = 1 THEN VI1 = VI
  IF VI1 = 0 THEN NINS = 1
  IF I = 1 THEN HCMAX = HC
  HC = ABS(HC)
  XLO = HC
  IIS = 0
  IF I <> 1 THEN GOTO 21
   IIS = 1
   NNSEG = NSEG
21
   PRINT #2, HC, VC, AEC, WOC, XLO, NSEG, IIS
'
' STORE INSULATOR DATA ON FILE TEMP2.DAT
'
  NSEG = 1
  VI = -VI
  XLO = ABS(VI)
  HI = 0
  IF XLO <> 0 THEN
     WOI = WOI / XLO
  ELSE
     WOI = 0
  END IF
  IIS = 0
  IF I <= 2 AND XLO <> 0 THEN IIS = 1
  PRINT #3, HI, VI, AEI, WOI, XLO, NSEG, IIS, I, NPT
'
'  STORE POLE/TOWER DATA
'
  AMPOL(I) = AM
  AK(I) = AKT
  IF I <> 1 THEN GOTO 25
  NNP1 = NPT
25 IF I <> 2 THEN GOTO 30
  NNP2 = NPT
30 NEXT I
  PRINT #1, USING G699$; SPACE$(0)
  IDIV = 0
'
' SET PROGRAM UP FOR DRAWING THE CONDUCTOR (ICODE <> 2)
'
   IF ICODE <> 2 THEN
    CLS 0
    LINE (120, 0)-(639, 475), , B
    LINE (120, 300)-(639, 300)
```

```
    PSET (140, 50)
    XSCALE = 450 / HCMAX
    YSCALE = 300 / 150
    IDIV = 1
   ELSE
   END IF
'
' DETERMINE THE DEGREES OF FREEDOM FOR THE DISPLACEMENTS WHICH ARE TO BE
' PRINTED DURING THE DYNAMIC ANALYSIS
'
   ITC1 = 0
   ITC2 = 0
   IF NNP1 = 0 THEN GOTO 31
   ISTM(1) = 1
   IF NINS = 0 THEN ISTM(2) = 2
   IF NINS = 0 THEN ISTM(3) = 3
   ISTM(4) = NNSEG + ISTM(2)
   ISTM(5) = ISTM(4) + 1
   ISTM(6) = 2 * NNSEG + ISTM(2)
   ISTM(7) = ISTM(6) + 1
   ITC1 = 1
   NSTM = 7
   IF NNP2 = 0 THEN GOTO 32
   ISTM(8) = ISTM(7) + 1
   ITC2 = 1
   NSTM = 8
   GOTO 32
31 IF NINS = 0 THEN ISTM(1) = 1
   IF NINS = 0 THEN ISTM(2) = 2
   ISTM(3) = NNSEG + ISTM(1)
   ISTM(4) = ISTM(3) + 1
   ISTM(5) = 2 * NNSEG + ISTM(1)
   ISTM(6) = ISTM(5) + 1
   NSTM = 6
   IF NNP2 = 0 THEN GOTO 32
   ISTM(7) = ISTM(6) + 1
   ITC2 = 1
   NSTM = 7
32
'
' RESTORE INSULATOR DATA AFTER CONDUCTOR DATA ON FILE TEMP1.DAT
'
   CLOSE #3
   OPEN "TEMP2.DAT" FOR INPUT AS #3
   FOR I = 1 TO NSPAN
   INPUT #3, H, V, AE, WO, XLO, IC, IIS, J, NPT
   PRINT #2, H, V, AE, WO, XLO, IC, IIS, J, NPT
   NEXT I
'
' COMPUTE THE CONDUCTOR LENGTHS TO MATCH PROBLEM GEOMETRY
' AND MATERIAL PROPERTIES
'
```

```
    CLOSE #2, #3
    OPEN "TEMP1.DAT" FOR INPUT AS #2
    OPEN "TEMP2.DAT" FOR OUTPUT AS #3
    N = 0
    FOR II = 1 TO NCABLE
    INPUT #2, H, V, AE, WO, XLO, IC, IIS
    IF XLO <> 0 THEN
      CALL SOLXLO(II, H, V, AE, WO, XLO, PH, PCLM, FOC())
    ELSE
      H = 0
      V = 0
    END IF
    PRINT #3, H, V, AE, WO, XLO, IC, IIS
'
'   COMPUTE LOADING ON NEXT CONDUCTORS AND INSULATORS
'
    N = N + 1
    N1 = N + 1
    PH = -FOC(3)
    PVER(N) = PVER(N) - FOC(2)
    IF II <> 1 THEN GOTO 34
    PVER(N) = PVER(N) - FOC(2)
34
    IF N1 > NSPAN THEN GOTO 35
    PVER(N1) = PVER(N1) - FOC(4)
35 NEXT II
'
' COMPUTE INSULATOR VERTICAL DIMENSION
'   (ASSUMES THAT H=0)
'
    FOR I = 1 TO NINSUL
    INPUT #2, H, V, AE, WO, XLO, IC, IIS, NPOL, NPT
    TJ = ABS(PVER(I))
    TI = ABS(WO * XLO - PVER(I))
    IF WO <> 0 THEN
      V = (TJ * TJ - TI * TI) / (2 * AE * WO) + (TJ - TI) / WO
    ELSE
      V = 0
    END IF
    PRINT #4, H, V, AE, WO, XLO, IC, IIS, NPOL, NPT
42 NEXT I
'
'   DIVIDE CONDUCTORS AND INSULATORS INTO CABLE SEGMENTS,
'     AND NUMBER THE DEGREES OF FREEDOM
'
    CLOSE #2, #3, #4
    OPEN "TEMP2.DAT" FOR INPUT AS #3
    OPEN "TEMP3.DAT" FOR INPUT AS #4
    NCABD = 0
    NSTAT = 0
    NCT = 0
    NC = 0
```

```
   NP = 0
   PRINT #1, USING G719$; SPACE$(0)
   PRINT #1, USING G713$; SPACE$(0)
   PRINT #1, USING G720$; SPACE$(0)
   PRINT #1, USING G721$; SPACE$(0)
   PRINT #1, USING G713$; SPACE$(0)
'
' DIVIDE INSULATORS INTO M SEGMENTS
'  M=1 ASSUMED FOR ALL INSULATORS
'
   FOR II = 1 TO NINSUL
    INPUT #4, H, V, AE, WO, XLO, NSEG, IIS, NPOL, NPT
    NPO = NPOL
    IF NSEG = 1 THEN GOTO 65
    NPTS = NSEG + 1
    AH = H
    AV = V
    AAE = AE
    AXLO = XLO
    AWO = WO
    IF AXLO <> 0 THEN
       CALL PCAFX(II, AH, AV, AAE, AWO, AXLO, FOC(), TENI, TENJ, NPTS, XCOOR(), 1, 0, N)
    ELSE
       AH = 0
       AV = 0
       XCOOR(1, 1) = 0
       XCOOR(1, 2) = 0
       XCOOR(2, 1) = 0
       XCOOR(2, 2) = 0
    END IF
    FOR I = 1 TO NSEG
    J = I + 1
    DIMM(I, 1) = XCOOR(1, J) - XCOOR(1, I)
    DIMM(I, 2) = XCOOR(2, J) - XCOOR(2, I)
64  NEXT I
    GOTO 66
65  DIMM(1, 1) = H
    DIMM(1, 2) = V
66
'
'  DETERMINE THE MASS/SEGMENT FOR THE INSULATOR
'
    XLOS = XLO / NSEG
    XMASS = WO * XLOS / UMASS
    NSTAT = NSTAT + IIS
    NCABD = NCABD + NSEG
'
'  DETERMINE THE BOUNDARY CONDITIONS FOR NUMBERING THE DOF
'
    NCOND = 1
    IF II = 1 THEN NCOND = 0   'for the first insul the DOF at I are given
    MT = 0
```

```
   MN = II
   NECJ = 2
   IF NPT = 0 THEN NPOLE = NPOLE - 1
68 NECI = NPT
   W = WO
   XLO = XLOS
   LM = 1
   GOTO 300
70
'
'  DIVIDE CONDUCTORS INTO NSEG SEGMENTS
'
   INPUT #3, H, V, AE, WO, XLO, NSEG, IIS
   IF NSEG = 1 THEN GOTO 73
   NPTS = NSEG + 1
   AH = H
   AV = V
   AAE = AE
   AXLO = XLO
   AWO = WO
   IF AXLO <> 0 THEN
      CALL PCAFX(II, AH, AV, AAE, AWO, AXLO, FOC(), TENI, TENJ, NPTS, XCOOR(), 1, 0, N)
   ELSE
      AH = 0
      AV = 0
      XCOOR(1, 1) = 0
      XCOOR(1, 2) = 0
      XCOOR(2, 1) = 0
      XCOOR(2, 2) = 0
   END IF
   FOR I = 1 TO NSEG
   J = I + 1
   DIMM(I, 1) = XCOOR(1, J) - XCOOR(1, I)
   DIMM(I, 2) = XCOOR(2, J) - XCOOR(2, I)
72 NEXT I
   GOTO 74
73
   DIMM(1, 1) = H
   DIMM(1, 2) = V
74
'
'  DETERMINE THE MASS/SEGMENT FOR CONDUCTORS
'
   XLOS = XLO / NSEG
   XMASS = WO * XLOS / UMASS
   NSTAT = NSTAT + IIS
   NCABD = NCABD + NSEG
'
'  DETERMINE THE BOUNDARY CONDITIONS FOR NUMBERING THE DOF
'
   NCOND = 0
   MT = 1
```

```
1  MN = II
   NECI = 2
   IF II < NINSUL THEN GOTO 75
   NECJ = 0
   GOTO 80
5  NECJ = 2
)
   W = WO
   XLO = XLOS
   LM = 2
00

    NECI=NECJ=NPT=0 FIXED HORIZONTAL AND VERTICAL SUPPORT
    NECI=NECJ=NPT=1 FIXED VERTICAL AND FREE HORIZONTAL SUPPORT
    NECI=NECJ=    2 FREE HORIZONTAL AND FREE VERTICAL

    NCOND=0     STARTING VALUES FOR I END ARE GIVEN
    NCOND=1     STARTING VALUES FOR J END ARE GIVEN

    MT=0   INSULATOR
    MT=1   CONDUCTOR


    ASSIGN THE NUMBER OF DEGREE OF FREEDOM BY KNOWN END CONDITION

305  IF NCOND <> 0 THEN GOTO 325

 NUMBER DOF FOR THE 1ST SPAN INSULATORS AND ALL CONDUCTORS

   IS1 = IIS
   I = 1
   KK = 1 + NECI
   ON KK GOTO 310, 311, 312

 I END IS FIXED, J END IS FREE

310  N1 = NPD1
     N2 = NPD1
     IF XLO <> 0 THEN
        N3 = NP + 1
        N4 = NP + 2
        NP = NP + 2
      ELSE
        N3 = N1
        N4 = N2
        NP = NP + 0
     END IF
     GOTO 314

  I END IS FIXED VERTICALLY AND J END FREE
```

```
11  N1 = NP + 1
    N2 = NPD1
    IF XLD <> 0 THEN
       N3 = NP + 2
       N4 = NP + 3
       NP = NP + 3
    ELSE
       N3 = N1
       N4 = N2
       NP = NP + 1
    END IF
'
'   IF ELEMENT IS AN INSULATOR STORE THE MASS FOR POLE/TOWER
'   IF FREE FOR HORIZONTAL MOVEMENT
'
    IF MT = 1 THEN GOTO 314
       NPP(NPO) = N1
       AMASS(N1) = AMASS(N1) + AMPOL(NPO)
    GOTO 314
'
'  I END IS FREE AND J END IS FREE, I END DOF IS ALREADY KNOWN
'
312  N1 = NPH
     N2 = NPV
     IF XLD <> 0 THEN
        N3 = NP + 1
        N4 = NP + 2
        NP = NP + 2
     ELSE
        N3 = N1
        N4 = N2
        NP = NP + 0
     END IF
'
'   ESTABLISH THE FOLLOWING ELEMENT I END DOF NUMBERS
'
314  IF NSEG > 1 THEN GOTO 317
    NPH = N3
    NPV = N4
    IF NECJ = 2 THEN GOTO 315
    N4 = NPD1
    NP = NP - 1
    IF NECJ = 1 THEN GOTO 315
    N3 = NPD1
    NP = NP - 1
'
' NUMBER THE CABLE ELEMENT AND STORE CABLE ELEMENT H AND V PROJ
'
315 NC = NC + 1
    CH(NC) = DIMM(1. 1)
    CV(NC) = DIMM(1. 2)
    LN = 1
```

```
   GOTO 400
17 NC = NC + 1
   CH(NC) = DIMM(1, 1)
   CV(NC) = DIMM(1, 2)
   LN = 2        'NSEG>1
   GOTO 400
'
 NUMBER THE DOF FOR THE INTERMEDIATE ELEMENTS OF THE
   CONDUCTOR DIVIDED IN NSEG SEGMENTS
'
18 IS1 = 0
   IF NSEG = 2 THEN GOTO 321
   JJ = 1
19 JJ = JJ + 1
   N1 = N3
   N2 = N4
   IF XLO <> 0 THEN
      N3 = NP + 1
      N4 = NP + 2
      NP = NP + 2
   ELSE
      N3 = N1
      N4 = N2
      NP = NP + 0
   END IF
'
'  NUMBER THE CABLE ELEMENT AND STORE THE CABLE ELEMENT H AND V PROJ
'
   NC = NC + 1
   CH(NC) = DIMM(JJ, 1)
   CV(NC) = DIMM(JJ, 2)
   LN = 3
   GOTO 400
'
' DETERMINE THE DOF FOR THE LAST ELEMENT OF CONDUCTOR
'  DIVIDED INTO NSEG ELEMENTS
'
320 IF JJ < NSEG - 1 THEN GOTO 319
321 I = NSEG
'
'  J END OF CONDUCTOR FIXED
'
   N1 = N3
   N2 = N4
   IF XLO <> 0 THEN
      N3 = NPD1
      N4 = NPD1
   ELSE
      N3 = N1
      N4 = N2
   END IF
   IF NECJ = 0 THEN GOTO 322
```

```
    J END OF CONDUCTOR FREE

    IF XLO <> 0 THEN
       N3 = NP + 1
       N4 = NP + 2
       NP = NP + 2
    ELSE
       N3 = N1
       N4 = N2
       NP = NP + 0
    END IF
'
'  NUMBER CABLE ELEMENT AND STORE H AND V PROJECTION
'
322 NC = NC + 1
    LN = 4
    CH(NC) = DIMM(I, 1)
    CV(NC) = DIMM(I, 2)
323 NPH = N3
    NPV = N4
    GOTO 400
'
'  ASSIGN DOF NUMBERS FOR INSULATORS OTHER THAN 1ST SPAN
'
325
    IS1 = IIS
    M = NSEG
    I = 1
    KK = 1 + NECI
    ON KK GOTO 330, 331
'
'   I END IS FIXED, J END IS FREE AND VALUES ARE KNOWN
'
330 N1 = NPD1
    N2 = NPD1
    IF XLO <> 0 THEN
       N3 = NP + (M - 1) * 2 - 1
       N4 = N3 + 1
       NP = NP + (M - 1) * 2
    ELSE
       N3 = N1
       N4 = N2
       NP = NP + (M - 1) * 2
    END IF
    GOTO 333
'
'   I END IS FIXED VERTICALLY, J END IS FREE AND VALUES ARE KNOWN
'
331 N1 = NP + (M - 1) * 2 + 1
    N2 = NPD1
    IF XLO <> 0 THEN
```

```
      N3 = N1 - 2
      N4 = N1 - 1
      NP = NP + (M - 1) * 2 + 1
   ELSE
      N3 = N1
      N4 = N2
      NP = NP + (M - 1) * 2
   END IF
'
'  STORE MASS FOR POLE/TOWER
'
  NPP(NPO) = N1
  AMASS(N1) = AMASS(N1) + AMPOL(NPO)
'
' ESTABLISH THE FOLLOWING ELEMENT I END DOF NUMBERS
'    NUMBER THE CABLE ELEMENT AND STORE H AND V PROJECTION
'
333 NPH = N3
   NPV = N4
   NC = NC + 1
   CH(NC) = DIMM(I, 1)
   CV(NC) = DIMM(I, 2)
   LN = 5
   GOTO 400
'
'  NUMBER THE REMAINING ELEMENTS FOR INSULATOR WITH NSEG.GT.1
'
334 IF M = 1 THEN GOTO 340
   IS1 = 0
   JJ = 1
335 JJ = JJ + 1
   N1 = NPH
   N2 = NPV
   IF XLO <> 0 THEN
      N3 = N1 - 2
      N4 = N1 - 1
   ELSE
      N3 = N1
      N4 = N2
   END IF
   NPH = N3
   NPV = N4
   NC = NC + 1
   CH(NC) = DIMM(JJ, 1)
   CV(NC) = DIMM(JJ, 2)
   LN = 6
   GOTO 400
336
   IF JJ < M THEN GOTO 335
340 ON LM GOTO 70, 501
400
'
```

```
'   SET UP PROPERTY ARRAYS BY CABLE TYPE
'
    IF NCT <> 0 THEN GOTO 402
401 NCT = NCT + 1
    AET(NCT) = AE
    WOT(NCT) = W
    XLOT(NCT) = XLO
    WX = WOT(NCT) * XLOT(NCT)
    IF AET(NCT) <> 0 OR WX <> 0 THEN
       AEWX = AET(NCT) / WX
    ELSE
    END IF
    AEWXT(NCT) = AEWX
    WXT(NCT) = WX
    J = NCT
    GOTO 404
402 J = 0
    FOR I = 1 TO NCT
    IF ABS(XLO - XLOT(I)) > EPS THEN GOTO 403
    IF ABS(W - WOT(I)) > EPS THEN GOTO 403
    J = I
403 NEXT I
    IF J = 0 THEN GOTO 401
'
'  SET UP THE INDEX FOR CABLE TYPE, STATISTICS AND DOF
'
404 INDT(NC) = J
    INDS(NC) = IS1
    INPE(NC, 1) = N1
    INPE(NC, 2) = N2
    INPE(NC, 3) = N3
    INPE(NC, 4) = N4
'
'   BUILD THE MASS AND DAMPING ARRAYS
'
    C = 2 * CD * SQR(AE * W / UMASS)
    DAMP(NC) = C
    FOR I = 1 TO 4
    NPEI = INPE(NC, I)
    AMASS(NPEI) = AMASS(NPEI) + XMASS / 2
410 NEXT I
    N = INDT(NC)
    M1 = INDS(NC)
    IF MT = 0 THEN GOTO 420
'
'  PRINT NEW CABLE ELEMENT PROPERTIES
'
    PRINT #1, USING G722A$; SPACE$(0); MN; NC;
    FOR J = 1 TO 4
    PRINT #1, USING G722B$; INPE(NC, J);
    NEXT J
    PRINT #1, USING G722C$; CH(NC); CV(NC); AET(N); AEWXT(N); WOT(N); XLOT(N); WXT(N); XMASS; DAMP(NC); M1; N
```

```
   GOTO 425
20 PRINT #1, USING G723A$; SPACE$(0); MN; NC;
   FOR J = 1 TO 4
   PRINT #1, USING G723B$; INPE(NC, J);
   NEXT J
   PRINT #1, USING G723C$; CH(NC); CV(NC); AET(N); AEWXT(N); WOT(N); XLOT(N); WXT(N); XMASS; DAMP(NC); M1; N
25
   ON LN GOTO 340, 318, 320, 340, 334, 336
01 NEXT II
   LOCATE 24, 20: INPUT "Press <ENTER> to continue", A$

  CHECK DATA AND FORCES

   PRINT #1, USING G713$; SPACE$(0)
   IF NP < NPD1 THEN GOTO 550
   PRINT #1, USING G726$; SPACE$(0)
   GOTO 999
550
   NP1 = NP + 1
   FOR I = 1 TO NP1
   FI(I) = 0
555 NEXT I
   PRINT #1, USING G736$; SPACE$(0)
   PRINT #1, USING G743$; SPACE$(0)
   PRINT #1, USING G737$; SPACE$(0)
   PRINT #1, USING G743$; SPACE$(0)
   NCABLE = NC
560 FOR I = 1 TO NCABLE
   N = INDT(I)
   AH = CH(I)
   AV = CV(I)
   AAE = AET(N)
   AWO = WOT(N)
   AXLO = XLOT(N)
   IF AXLO <> 0 THEN
      CALL PCAFX(I, AH, AV, AAE, AWO, AXLO, FOC(), TENI, TENJ, 2, XCOOR(), IDIV, 0, N)
   ELSE
     AH = 0
     AV = 0
     XCOOR(1, 1) = 0
     XCOOR(1, 2) = 0
     XCOOR(2, 1) = 0
     XCOOR(2, 2) = 0
   END IF
'
' DRAW THE CONDUCTOR AND THE INSULATORS OF THE FIRST SPAN
'
    IF ICODE <> 2 AND I < MAXNSEG + 3 THEN
        XORD = XSCALE * ABS(XCOOR(1, 2) - XCOOR(1, 1))
        YORD = -YSCALE * (XCOOR(2, 2) - XCOOR(2, 1))
        IF I = MAXNSEG + 2 THEN
          YORD = YSCALE * (XCOOR(2, 2) - XCOOR(2, 1))
```

```
        XORD = -XSCALE * ABS(XCOOR(1, 2) - XCOOR(1, 1))
      ELSE
      END IF
      IF I = 1 OR I = MAXNSEG + 2 THEN
        LINE -STEP(XORD, YORD), 4
      ELSE
        LINE -STEP(XORD, YORD)
      END IF
  ELSE
  END IF
  PRINT #1, USING G738A$; I;
  FOR J = 1 TO 4
  PRINT #1, USING G738B$; INPE(I, J);
  NEXT J
  FOR J = 1 TO 4
  PRINT #1, USING G738C$; FOC(J);
  NEXT J
  PRINT #1, USING G738D$; CH(I); CV(I); TENI; TENJ
'
' COMPUTE THE INITIAL FORCE IMBALANCE FOR EACH DOF
'
  FOR J = 1 TO 4
  IF INPE(I, J) >= NP1 THEN INPE(I, J) = NP1
  NPEJ = INPE(I, J)
  FI(NPEJ) = FI(NPEJ) - FOC(J)
570 NEXT J
'
' COMPUTE THE INITIAL ACCELERATION FOR EACH DOF
'
  NEXT I
  PRINT #1, USING G743$; SPACE$(0)
  FOR I = 1 TO NP
  XDDS(I) = FI(I) / AMASS(I)
585 NEXT I
  PRINT #1, USING G744$; SPACE$(0)
  PRINT #1, USING G727$; SPACE$(0)
  PRINT #1, USING G744$; SPACE$(0)
  PRINT #1, USING G728$; SPACE$(0)
  PRINT #1, USING G744$; SPACE$(0)
  FOR I = 1 TO NP
  PRINT #1, USING G729$; I; AMASS(I); FI(I); XDDS(I)
587 NEXT I
  PRINT #1, USING G744$; SPACE$(0)
590 OPEN "TEMP1.DAT" FOR OUTPUT AS #2
'
'  STORE DATA ON DISK FILE TEMP1.DAT
'
  PRINT #2, NCABLE, NPOLE; NCT; NP; NP1; NSTAT; NSTM
  FOR I = 1 TO NCT
  PRINT #2, AET(I); WCT(I); XLOT(I)
591 NEXT I
  FOR I = 1 TO NCABLE
```

```
    PRINT #2, CH(I), CV(I), INDT(I), INDS(I);
    FOR J = 1 TO 4
    PRINT #2, INPE(I, J);
    NEXT J
    PRINT #2, DAMP(I)
592 NEXT I
    IF NPOLE = 0 THEN GOTO 594
    FOR I = 1 TO NPOLE
    PRINT #2, NPP(I); AK(I)
593 NEXT I
594 FOR I = 1 TO NP
    PRINT #2, AMASS(I), FI(I), XDDS(I)
595 NEXT I
    FOR I = 1 TO NSTM
    PRINT #2, ISTM(I)
    NEXT I
    PRINT #1, USING G730$; SPACE$(0)
    PRINT #1, USING G731$; SPACE$(0); NPOLE
    PRINT #1, USING G732$; SPACE$(0); NCABLE
    PRINT #1, USING G734$; SPACE$(0); NP
    PRINT #1, USING G735$; SPACE$(0); NP1
    PRINT #1, USING G739$; SPACE$(0); TF
    PRINT #1, USING G740$; SPACE$(0); DT
    PRINT #1, USING G741$; SPACE$(0); NINT
    PRINT #1, USING G742$; SPACE$(0); KINT; SPACE$(0)
    GOTO GEND
999 END
GEND:
    END SUB


SUB INSTRUCTIONS
LOCATE 18, 30: INPUT "PRESS <ENTER> TO CONTINUE"; A$
LOCATE 18, 30: PRINT "                                        "
END SUB
```

```
SUB PCAFX (MEMNO, HOR, VER, AE, WO, XLO, FOC(), TENI, TENJ, NPTS, XCOOR(), IDIV, IPRINT, NEP)
'  COMPUTES THE FORCES ON CABLE ELEMENTS
'
'   HOR=HORIZONTAL PROJECTION OF CABLE ELEMENT
'   VER=VERTICAL PROJECTION OF CABLE ELEMENT
'   AE=AREA TIMES MODULUS OF ELASTICITY
'   WO=WEIGHT OF CABLE ELEMENT PER UNIT LENGTH
'   XLO=UNSTRETCHED CABLE ELEMENT LENGTH
'    FOC=CABLE FORCES
'   TENI=CABLE TENSION AT THE I END
'   TENJ=CABLE TENSION AT THE J END
'   NPTS=NUMBER OF COORDINATE POINTS ALONG THE CABLE ELEMENT
'   XCOOR=COORDINATES OF NPTS POINTS ALONG THE CABLE ELEMENT
'   WX=WO*XLO
'   C1=FOC(3)/WX
'   C2=FOC(4)/WX
'   EP1=CONVERGENCE CRITERIA
'   EP2=CONVERGENCE CRITERIA
'  ITERA= NUMBER OF ITERATIONS
'  IDIV=0  OMIT STEPS LISTED BELOW
'  IDIV=1 COORDINATES OF NPTS POINTS ON CABLE ARE DETERMINED
'          ELASTIC STRETCHED AND THE ANGLE OF CABLE ENDS
'   IPRINT=0    NO PRINTING
'   IPRINT=1    PRINTS XCOOR,FOC,ELASTIC STRETCHING
P383$ = "&         SUMMARY FOR CABLE NO. ####"
P384$ = "&POINT ### &X= #####.#### &T= #####.####"
P385$ = "&F1= ##.#####^^^^^ &F2= ##.#####^^^^^ &F3= ##.#####^^^^^ &F4= ##.#####^^^^^"
P385A$ = "&TI= ##.#####^^^^^ &TJ= ##.#####^^^^^"
P386$ = "&  ANGLE ELOW HORIZONTAL IN DEGREES AT I= ####. &AT J= ####."
P387$ = "&  LENGTH AFTER ELASTIC STRETCHING= #####.##"
P388$ = "&  ELONGATION= ###.#### &PERCENT  NO. OF ITERATIONS= ####"
P401$ = "&FAILURE TO CONVERGE IN PCAFX FOR MEMBER NO ####"
P402$ = "&AE= ##.####^^^^^ &WO= ##.####^^^^^ &XLO= ##.#####^^^^^"
P403$ = "&HOR= ##.####^^^^^ &VER= ##.####^^^^^ &ACA= ##.####^^^^^ &ACB= ##.####^^^^^"
'
' INITIALIZE CONSTANTS
'
     EP1 = .0000001
     EP2 = .0000001
     NEP = 0        'converges
     ITERA = 0
     CORD = HOR * HOR + VER * VER
     CORD = SQR(CORD)
     PROP = XLO / CORD
     H = HOR / XLO
     V = VER / XLO
     EPS1 = EP1 * ABS(H)
     EPS2 = EP1 * ABS(V)
     IF EPS1 < EP2 THEN EPS1 = EP2
     IF EPS2 < EP2 THEN EPS2 = EP2
'
'  INTERCHANGE ORIGIN AND END OF CABLE IF V IS POSITIVE
```

```
'
40   KK = 0
     IF V <= 0 THEN GOTO 45
     KK = 1
     V = -V
     H = -H
45
     D1 = PROP
     D2 = 1
55  WX = WO * XLO
    D3 = WX / AE
    W = WO
    X = XLO
    D4 = V - D3 / 2
'
'  INITIALIZE LAMBDA AND DETERMINE STARTING VALUES
'
1001 AMBDA = 1000000
    IF D1 <= 1 THEN GOTO 130
    IF ABS(H) < 1E-20 THEN GOTO 140
    AMBDA = SQR(3 * (1 - 1 / (PROP * PROP)) / (H * H))
    GOTO 140
130 AMBDA = .18
140 C1 = H / (2 * AMBDA)
    IF AMBDA > 80 THEN
    COT = 1
    ELSE
    COT = (EXP(AMBDA) + EXP(-AMBDA)) / (EXP(AMBDA) - EXP(-AMBDA))
    END IF
    C2 = .5 * (1 + V * COT)
180 DF1 = 0
    DF2 = 0
'
'   APPLY CORRECTIONS TO C1 AND C2
'
2001 C1 = C1 - DF1
    C2 = C2 - DF2
    TI = SQR(C1 * C1 + C2 * C2 - 2 * C2 + 1)
    TJ = SQR(C1 * C1 + C2 * C2)
    F = C2 + TJ
    FF = TI - 1 + C2
    IF (1 - (1 - C2) / TI) > .0001 THEN GOTO 210
    F = TI + 1 - C2
    FF = TJ - C2
210 IF FF < 1E-10 THEN FF = 1E-10
    G = F / FF
    IF G < 1E-10 THEN G = 1E-10
'
'  COMPUTE VALUES OF H AND V
'    CALCULATE MISCLOSURE VECTOR AND CHECK CONVERGENCE
'
    DL = LOG(G)
```

```
    AAH = DL + D3
    CA = H - C1 * AAH
    CB = D4 + D3 * (1 - C2) - TJ + TI
    ACA = ABS(CA)
    ACB = ABS(CB)
    IF ACA <= EPS1 AND ACB <= EPS2 THEN GOTO 250
    ITERA = ITERA + 1
    IF ITERA > 14 THEN GOTO 1400
'
'    DETERMINE CORRECTION TERMS
'
    VAR = (1 - C2) / TI + C2 / TJ
    B2 = -VAR - D3
    A1 = -AAH + VAR
    A2 = -C1 * (1 / TJ - 1 / TI)
    DET = A1 * B2 - A2 * A2
    DF1 = (CA * B2 - CB * A2) / DET
    DF2 = (A1 * CB - A2 * CA) / DET
    GOTO 2001
'
'   DETERMINE FORCES AND LENGTH AFTER CONVERGENCE
'
250
    C1 = C1 * (1 - 2 * KK)
    C2 = C2 + KK * (1 - 2 * C2)
    FOC(1) = -C1 * WX
    FOC(3) = C1 * WX
    FOC(4) = C2 * WX
    FOC(2) = WX - FOC(4)
    TENI = (TI + KK * (TJ - TI)) * WX
    TENJ = (TJ + KK * (TI - TJ)) * WX
    IF IDIV = 0 THEN GOTO 500
'
'   DETERMINE THE COORDINATES OF NPTS POINTS ALONG THE CABLE,
'    THE ELASTIC STRETCHING, AND THE ANGLE OF THE CABLE ENDS
'
    FO1 = FOC(1) * (1 - 2 * KK)
    FO2 = FOC(2) + KK * (FOC(4) - FOC(2))
    H = H * XLO
    V = V * XLO
    TI = TI * WX
    TJ = TJ * WX
    FO4 = W * XLO - FO2
'
'  COMPUTE THE ELASTIC STREICHING
'
    XLAFST = X + (FO4 * TJ + FO2 * TI + FO1 * FO1 * LOG(G)) / (2 * AE * W)
'
'   DETERMINE THE COORDINATES
'
    SUBXL = X / (NPTS - 1)
    XL = -SUBXL
```

```
    FOR MM = 1 TO NPTS
    XL = XL + SUBXL
    F04 = W * XL - F02
    F03 = -F01
    TI = SQR(F01 * F01 + F02 * F02)
    TJ = SQR(F03 * F03 + F04 * F04)
    F = F04 + TJ
    FF = TI - F02
    IF (1 - F02 / TI) > .0001 THEN GOTO 1320
    F = TI + F02
    FF = TJ - F04
1320 IF FF < 1E-10 THEN FF = 1E-10
    G = F / FF
    IF G < 1E-10 THEN G = 1E-10
    AAH = LOG(G) / W + D2 * XL / AE
    AH = -F01 * AAH
    BV = D2 * (TJ * TJ - TI * TI) / (2 * AE * W) + (TJ - TI) / W
3301 MN = MM + (NPTS - 2 * MM + 1) * KK
    XCOOR(1, MN) = AH - H * KK
    XCOOR(2, MN) = BV - V * KK
3401 NEXT MM
'
'   COMPUTE THE ANGLES
'
    PI = 3.1415926#
    IF ABS(FOC(1)) = 0 OR ABS(FOC(3) = 0) THEN
      ANGLEI = 90
      ANGLEJ = 90
    ELSE
      ANGLEI = ATN(FOC(2) / ABS(FOC(1))) * 180 / PI
      ANGLEJ = ATN(FOC(4) / ABS(FOC(3))) * 180 / PI
    END IF
    IF IPRINT = 0 THEN GOTO 500
'
'  PRINT THE COORDINATES, ANGLES, FORCES, STRETCHING
'
   PRINT #1, USING P383$; SPACE$(0); MEMNO
    FOR I = 1 TO NPTS
    PRINT #1, USING P384$; SPACE$(0); I; SPACE$(0); XCOOR(1, I); SPACE$(0); XCOOR(2, I)
345 NEXT I
    PRINT #1, USING P385$; SPACE$(0); FOC(1); SPACE$(0); FOC(2); SPACE$(0); FOC(3); SPACE$(0); FOC(4)
    PRINT #1, USING P385A$; SPACE$(0); TENI; SPACE$(0); TENJ
    PRINT #1, USING P386$; SPACE$(0); ANGLEI; SPACE$(0); ANGLEJ
    PRINT #1, USING P387$; SPACE$(0); XLAFST
    ELONG = ((XLAFST - X) / X) * 100
    PRINT #1, USING P388$; SPACE$(0); ELONG; SPACE$(0); ITERA
    GOTO 500
1400
    PRINT #1, USING P401$; SPACE$(0); MEMNO
    PRINT #1, USING P402$; SPACE$(0); AE; SPACE$(0); WO; SPACE$(0); XLO
    PRINT #1, USING P403$; SPACE$(0); HOR; SPACE$(0); VER; SPACE$(0); ACA; SPACE$(0); ACB
    NEP = 1
```

END SUB

```
UB PLOTT (FILENAME$)

  THIS SUBROUTINE WORKS AS A POST-PROCESSOR
  IT PLOTS THE TIME HISTORIES OF FORCE AND DISPLACEMENTS
  FOR THE FIRST SPAN OF THE LINE
  THE INPUT DATA FOR THE PLOTS ARE READ FROM *.PL1 AND *.PL2
' * IS THE BASE NAME SPECIFIED BY THE USER

)IM SAV(501, 8) AS SINGLE, VMAX(13, 2) AS SINGLE, VMIN(13, 2)  AS SINGLE
/IEW
'
' READ THE VALUES FOR THE BOUNDARIES OF THE AXES FROM *.PL2
' DETERMINE THE SCALE TO BE USED FOR THE PLOTS
'
)PEN FILENAME$ + ".PL2" FOR INPUT AS #7
INPUT #7, NUNIT, TF, PH, VI1, NFILES, NCNT1, VMAX(1, 1), VMAX(7, 1), VMAX(8, 1), VMIN(1
CLOSE #7
DMAX = VMAX(8, 1)
IF VMAX(7, 1) > VMAX(8, 1) THEN DMAX = VMAX(7, 1)
IF NINS <> 0 THEN DMAX = VMAX(6, 1)
DOPLOT:
CLOSE #6
OPEN FILENAME$ + ".PL1" FOR INPUT AS #6
CLS 0
PRINT "****************************************"
PRINT "        MENU"
PRINT "****************************************"
IF NINS = 0 THEN
   PRINT " 1  PLOT INSULATOR TENSION VS TIME"
   PRINT ""
   PRINT " 2  PLOT HORIZONTAL COMPONENT OF"
   PRINT "    INSULATOR TENSION VS TIME"
   PRINT ""
   PRINT " 3  PLOT VERTICAL COMPONENT OF"
   PRINT "    INSULATOR TENSION VS TIME"
   PRINT ""
   IF ICODE = 0 THEN PRINT " 4  PLOT HORIZONTAL DISPLACEMENT"
   IF ICODE = 0 THEN PRINT "    OF LOWER END OF INSULATOR ONE"
   IF ICODE = 0 THEN PRINT ""
   IF ICODE = 0 THEN PRINT " 5  PLOT VERTIAL DISPLACEMENT"
   IF ICODE = 0 THEN PRINT "    OF LOWER END OF INSULATOR ONE"
   IF ICODE = 0 THEN PRINT ""
   PRINT " 6  PLOT INSULATOR ANGLE FROM "
   PRINT "    HORIZONTAL VS TIME"
   PRINT ""
ELSE
   PRINT " 1  PLOT CONDUCTOR TENSION VS TIME"
   PRINT ""
   PRINT " 2  PLOT HORIZONTAL COMPONENT OF"
   PRINT "    CONDUCTOR TENSION VS TIME"
   PRINT ""
   PRINT " 3  PLOT VERTICAL COMPONENT OF"
```

```
    PRINT "    CONDUTOR TENSION VS TIME"
    PRINT ""
    IF ICODE = 0 THEN PRINT " 4  PLOT HORIZONTAL DISPLACEMENT"
    IF ICODE = 0 THEN PRINT "    OF TOWER ONE"
    IF ICODE = 0 THEN PRINT ""
    PRINT " 6  PLOT INSULATOR ANGLE FROM "
    PRINT "    HORIZONTAL VS TIME"
    PRINT ""
END IF
IF ICODE = 0 THEN PRINT " 7  PLOT CONDUCTOR MIDSPAN VERTICAL"
IF ICODE = 0 THEN PRINT "    DISPLACEMENT VS TIME"
IF ICODE = 0 THEN PRINT ""
PRINT " E  END PLOT"
PRINT "*************************"
INPUT "ENTER: selection > ", OPT$
IF OPT$ = "E" OR OPT$ = "e" THEN GOTO EPLOT
CLS 0
'
' PLOT THE GRAPHS
'
IF VMAX(1, 1) <> 0 THEN PSCALE = 350 / (ABS(VMAX(1, 1)))
IF ABS(DMAX) <> 0 THEN PDSCALE = 350 / (ABS(DMAX))
CSCALE = 350 / (ABS(VMIN(10, 1)))
ASCALE = 350 / 100
TSCALE = 500 / TF
IF OPT$ = "1" THEN
  IF NINS = 0 THEN
    IF NUNIT = 0 THEN LOCATE 30, 15: PRINT ; "INSULATOR TENSION, newtons, VS TIME, seconds"
    IF NUNIT = 1 THEN LOCATE 30, 15: PRINT ; "INSULATOR TENSION, lbs, VS TIME, seconds"
  ELSE
    IF NUNIT = 0 THEN LOCATE 30, 15: PRINT ; "CONDUCTOR TENSION, newtons, VS TIME, seconds"
    IF NUNIT = 1 THEN LOCATE 30, 15: PRINT ; "CONDUCTOR TENSION, lbs, VS TIME, seconds"
  END IF
ELSEIF OPT$ = "2" THEN
  IF NINS = 0 THEN
     IF NUNIT = 0 THEN LOCATE 30, 15: PRINT ; "X-COMPONENT INSULATOR TENSION, newtons, VS TIME, seconds"
     IF NUNIT = 1 THEN LOCATE 30, 15: PRINT ; "X-COMPONENT INSULATOR TENSION, lbs, VS TIME, seconds"
  ELSE
     IF NUNIT = 0 THEN LOCATE 30, 15: PRINT ; "X-COMPONENT CONDUCTOR TENSION, newtons, VS TIME, seconds"
     IF NUNIT = 1 THEN LOCATE 30, 15: PRINT ; "X-COMPONENT CONDUCTOR TENSION, lbs, VS TIME, seconds"
  END IF
ELSEIF OPT$ = "3" THEN
   IF NINS = 0 THEN
      IF NUNIT = 0 THEN LOCATE 30, 15: PRINT ; "Y-COMPONENT INSULATOR TENSION, newtons, VS TIME, seconds"
      IF NUNIT = 1 THEN LOCATE 30, 15: PRINT ; "Y-COMPONENT INSULATOR TENSION, lbs, VS TIME, seconds"
   ELSE
      IF NUNIT = 0 THEN LOCATE 30, 15: PRINT ; "Y-COMPONENT CONDUCTOR TENSION, newtons, VS TIME, seconds"
      IF NUNIT = 1 THEN LOCATE 30, 15: PRINT ; "Y-COMPONENT CONDUCTOR TENSION, lbs, VS TIME, seconds"
   END IF
ELSEIF OPT$ = "4" THEN
   IF NINS = 0 THEN
     IF NUNIT = 0 THEN LOCATE 30, 5: PRINT ; "X-COMPONENT INSULATOR END DISPLACEMENT, meters, VS TIME, secon
```

```
      IF NUNIT = 1 THEN LOCATE 30, 5: PRINT ; "X-COMPONENT INSULATOR END DISPLACEMENT, feet, VS TIME, seconds"
    ELSE
      IF NUNIT = 0 THEN LOCATE 30, 5: PRINT ; "TOWER ONE HORIZONTAL DISPLACEMENT, meters, VS TIME, seconds"
      IF NUNIT = 1 THEN LOCATE 30, 5: PRINT ; "TOWER ONE HORIZONTAL DISPLACEMENT, feet, VS TIME, seconds"
    END IF
ELSEIF OPT$ = "5" THEN
    IF NUNIT = 0 THEN LOCATE 30, 5: PRINT ; "Y-COMPONENT INSULATOR END DISPLACEMENT, meters, VS TIME, seconds"
    IF NUNIT = 1 THEN LOCATE 30, 5: PRINT ; "Y-COMPONENT INSULATOR END DISPLACEMENT, feet, VS TIME, seconds"
ELSEIF OPT$ = "6" THEN
    IF NINS = 0 THEN
      LOCATE 30, 15: PRINT ; "INSULATOR ANGLE FROM HORIZON, deg, VS TIME, seconds"
    ELSE
      LOCATE 30, 15: PRINT ; "CONDUCTOR ANGLE FROM HORIZON, deg, VS TIME, seconds"
    END IF
ELSEIF OPT$ = "7" THEN
    IF NUNIT = 0 THEN LOCATE 30, 10: PRINT ; "CONDUCTOR MIDSPAN VERTICAL DISPLACEMENT, meters, VS TIME, seconds"
    IF NUNIT = 1 THEN LOCATE 30, 10: PRINT ; "CONDUCTOR MIDSPAN VERTICAL DISPLACEMENT, feet, VS TIME, seconds"
ELSE
END IF
IF OPT$ = "6" THEN
  LOCATE 7, (10 + TF * TSCALE) / 640 * 80: PRINT USING "##.##"; TF
ELSE
  LOCATE 28, (10 + TF * TSCALE) / 640 * 80: PRINT USING "##.##"; TF
  LOCATE 28, 6: PRINT USING "##.##"; 0
END IF
IF OPT$ = "4" OR OPT$ = "5" THEN
   LOCATE (400 - DMAX * PDSCALE) / 350 * 25, 1: PRINT USING "###.#"; DMAX
ELSEIF OPT$ = "6" THEN
   LOCATE (400 - 100 * ASCALE) / 350 * 25, 1: PRINT USING "###.#"; 10
ELSEIF OPT$ = "7" THEN
   LOCATE (400 - ABS(VMIN(10, 1)) * CSCALE) / 350 * 25, 1: PRINT USING "###.#"; ABS(VMIN(10, 1))
ELSE
   LOCATE (400 - VMAX(1, 1) * PSCALE) / 350 * 25, 1: PRINT USING "######.#"; VMAX(1, 1)
END IF
IF OPT$ = "6" THEN
   LOCATE 26, 1: PRINT USING "###.#"; -90
ELSE
   LOCATE 26, 1: PRINT USING "##.##"; 0
END IF
IF OPT$ <> "6" THEN
  LINE (65, 400)-(65 + TF * 450 / TF, 400)
ELSE
  LINE (65, 400 - 90 * ASCALE)-(65 + TF * 450 / TF, 400 - 90 * ASCALE)
END IF
IF OPT$ = "4" OR OPT$ = "5" THEN
   LINE (65, 400)-(65, 400 - DMAX * PDSCALE)
ELSEIF OPT$ = "6" THEN
   LINE (65, 400)-(65, 400 - 100 * ASCALE)
ELSEIF OPT$ = "7" THEN
   LINE (65, 400)-(65, 400 - ABS(VMIN(10, 1)) * CSCALE)
ELSE
   LINE (65, 400)-(65, 400 - VMAX(1, 1) * PSCALE)
```

```
ND IF
OR I = 1 TO 10
  PT = 65 + (TF * 450 / TF) / 10 * I
  IF OPT$ <> "6" THEN
    LINE (PT, 400)-(PT, 397)
  ELSE
    LINE (PT, 400 - 90 * ASCALE)-(PT, 400 - 90 * ASCALE - 3)
  END IF
  IF OPT$ = "4" OR OPT$ = "5" THEN
     PF = 400 - DMAX * PDSCALE / 10 * I
  ELSEIF OPT$ = "6" THEN
     PF = 400 - 100 * ASCALE / 10 * I
  ELSEIF OPT$ = "7" THEN
     PF = 400 - ABS(VMIN(10, 1)) * CSCALE / 10 * I
  ELSE
     PF = 400 - VMAX(1, 1) * PSCALE / 10 * I
  END IF
  LINE (65, PF)-(68, PF)
NEXT I
NN = 500
FOR I = 1 TO NFILES
IF I = NFILES THEN NN = NCNT1
FOR NI = 1 TO NN
       IF OPT$ = "1" THEN
          INPUT #6, SAV(NI, 1), SAV(NI, 2), SAV(NI, 3), SAV(NI, 4), SAV(NI, 5), SAV(NI, 6), SAV(NI, 7), SAV(NI, 8), ANG
          PTENS = SAV(NI, 2)
          PSET (65 + SAV(NI, 1) * 450 / TF, 400 - PTENS * PSCALE)
       ELSEIF OPT$ = "2" THEN
          INPUT #6, SAV(NI, 1), SAV(NI, 2), SAV(NI, 3), SAV(NI, 4), SAV(NI, 5), SAV(NI, 6), SAV(NI, 7), SAV(NI, 8), ANG
          PTENS = SAV(NI, 3)
          PSET (65 + SAV(NI, 1) * 450 / TF, 400 - PTENS * PSCALE)
       ELSEIF OPT$ = "3" THEN
          INPUT #6, SAV(NI, 1), SAV(NI, 2), SAV(NI, 3), SAV(NI, 4), SAV(NI, 5), SAV(NI, 6), SAV(NI, 7), SAV(NI, 8), ANG
          PTENS = ABS(SAV(NI, 4))
          PSET (65 + SAV(NI, 1) * 450 / TF, 400 - PTENS * PSCALE)
       ELSEIF OPT$ = "4" THEN
          INPUT #6, SAV(NI, 1), SAV(NI, 2), SAV(NI, 3), SAV(NI, 4), SAV(NI, 5), SAV(NI, 6), SAV(NI, 7), SAV(NI, 8), ANG
          IF NINS = 0 THEN
            PDISP = SAV(NI, 5)
          ELSE
            PDISP = SAV(NI, 8)
          END IF
          PSET (65 + SAV(NI, 1) * 450 / TF, 400 - PDISP * PDSCALE)
       ELSEIF OPT$ = "5" THEN
          INPUT #6, SAV(NI, 1), SAV(NI, 2), SAV(NI, 3), SAV(NI, 4), SAV(NI, 5), SAV(NI, 6), SAV(NI, 7), SAV(NI, 8), ANG
          PDISP = SAV(NI, 6)
          PSET (65 + SAV(NI, 1) * 450 / TF, 400 - PDISP * PDSCALE)
       ELSEIF OPT$ = "6" THEN
          INPUT #6, SAV(NI, 1), SAV(NI, 2), SAV(NI, 3), SAV(NI, 4), SAV(NI, 5), SAV(NI, 6), SAV(NI, 7), SAV(NI, 8), ANG
          PSET (65 + SAV(NI, 1) * 450 / TF, 400 - 90 * ASCALE - ANG * ASCALE)
       ELSEIF OPT$ = "7" THEN
          INPUT #6, SAV(NI, 1), SAV(NI, 2), SAV(NI, 3), SAV(NI, 4), SAV(NI, 5), SAV(NI, 6), SAV(NI, 7), SAV(NI, 8), ANG
```

```
    PSET (65 + SAV(NI, 1) * 450 / TF, 400 - ABS(SAV(NI, 7)) * CSCALE)
  ELSE
  END IF
IEXT NI
:XT I
: 1, 20: INPUT "PRESS <ENTER> TO CONTINUE"; A$
)OPLOT

JB
```

```
 SUB SOLXLO (MEMNO, ZH, ZV, ZAE, ZWO, ZXLO, ZP, PCLD, FOC())
'
'    THIS SUBROUTINE DETERMINES THE VALUE OF XLO TO MATCH
'    SPECIFIED CABLE FORCES AND GEOMETRY
'
'   PCLD=LOAD TOLERENCE FOR CONVERGENCE
'      H=HORIZONTAL PROJECTION OF CABLE ELEMENT
'      V=VERTICAL PROJECTION OF CABLE ELEMENT
'     WO=WEIGHT OF CABLE PER UNIT LENGTH
'     AE=AREA TIMES MODULUS OF ELASTICITY
'    XLO=UNSTRETCHED CABLE ELEMENT LENGTH
'    Z PREFIX IS VARIABLE IN SINGLE PRECISION
     DIM XCOOR(2, 30)

S200$ = "&NO CONVERGENCE IN SOLXLO FOR CABLE NO. ### &WITH P= #####.### &CHECK LOAD AND DATA"
S210$ = "#.####^^^^,#.####^^^^,#.####^^^^,#.####^^^^,#.####^^^^,#.####^^^^,#.####^^^^,#.####^^
'
'  INITILIZE DATA
'
      P = ZP
      H = ZH
      V = ZV
      WO = ZWO
      XLO = ZXLO
      AE = ZAE
      B = SQR(H * H + V * V)
      FACT = .0002 * B
      IF FACT < .005 THEN FACT = .005
      NNN = 0
      XLOS = 0
      XLOM = 0
      FMAX = 0
      FMIN = 0
'
'   DETERMINE A FIRST GUESS FOR XLO BASED ON THE CATENARY
'   EQUATIONS FOR AN INELASTIC CABLE
'
     HOR = ABS(H)
     HTENS = ABS(P)
     AMBDA = (WO * HOR) / (2 * HTENS)
     SHAMBD = (EXP(AMBDA) - EXP(-AMBDA)) / 2
     XL = (H * H * SHAMBD * SHAMBD) / (AMBDA * AMBDA) + V * V
     XL = SQR(XL)
     DXL = (HTENS * XL * XL) / (AE * H)
     XL = XL - DXL
     XLO = XL
'
'   USING ITERATIVE ALGORITHM, REFINE VALUE OF XLO TO
'   INCLUDE ELASTIC STRETCHING
'
1
    IF XLO <> 0 THEN CALL PCAFX(MEMNO, H, V, AE, WO, XLO, FOC(), T1, TJ, 2, XCOOR(), 0, 0, N)
```

```
 = FOC(1)
 ABS(F - P) <= POLD THEN GOTO 5
IN = NNN + 1
 NNN > 20 THEN GOTO 100
 (ABS(F) - ABS(P)) > 0 THEN GOTO 12
.OM = XLO
IIN = F
 (XLOM > 0 AND XLOS > 0) THEN GOTO 3
.O = XLO - FACT
)TO 1
.OS = XLO
1AX = F
F (XLOM > 0 AND XLOS > 0) THEN GOTO 3
.O = XLO + FACT
OTO 1
.O = XLOM + (XLOS - XLOM) * ((P - FMIN) / (FMAX - FMIN))
OTO 1
XLO = XLO
OTO 301
 = -P
RINT #1, USING S200$; SPACE$(0); MEMNO; SPACE$(0); P; SPACE$(0)
RINT #1, USING S210$; FMIN; FMAX; XLO; ZXLO; F; XLOS; XLOM; FACT
ND
ND SUB
```