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Evaluation of long-term performance of cold in-place recycled asphalt roads

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Evaluation of long-term performance of cold in-place recycled asphalt roads

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ABSTRACT

Asphalt pavements deteriorate over time. Typically three to five years following construction, reflected cracks, one of the primary forms of distress in hot-mix asphalt overlays of flexible pavements, may be observed. When rolled downed, reflected cracks affect ride quality. In addition, reflected cracks allow the penetration of water into the pavement and the base. The water causes the asphalt mix to deteriorate and the base to soften. Consequently the service life of pavements is reduced. Cold In-Place Recycling (CIR) provides an economical rehabilitation method that mitigates crack reflection by pulverizing the asphalt pavement surface, thus destroying the old crack pattern in the recycled layer. However, recycled roads have inconsistent performance. Several years after recycling, some roads are still in excellent condition with only a few minor cracks while extensive cracking and rutting were observed on other roads. These opposite behaviors can be observed on roads that were constructed in the same county, by the same contractor in the same construction season. Thus the difference in performance is probably not from such factors as weather, equipment, contractors' experiences, and construction procedures. Rather, other factors become more prominent in affecting pavement performance, such as: age of the recycled pavement; traffic volume; support conditions; and aged engineering properties of the CIR materials.

This dissertation investigates how aged engineering properties of the CIR materials and other factors affect pavement performance. Twenty-four sample roads were selected to represent various ages, traffic volumes, and support conditions in a geographically balanced sampling in Iowa. Pavement Condition Index (PCI) ratings were collected using an automated pavement distress digital image collection and analysis system. Engineering properties of CIR materials were examined through field and lab tests. Statistical analyses were conducted to descript the relationships between the pavement performance and the prominent factors. The conclusions and recommendations were presented in this dissertation.

CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

Asphalt pavements deteriorate over time due to traffic and environmental effects. In order to keep an asphalt pavement at a certain acceptable level of serviceability, highway agencies need to select an appropriate rehabilitation method among three common alternatives. The three common alternatives are: thick or thin hot mix asphalt (HMA) overlay, asphalt pavement recycling, and reconstruction [1]. Without rehabilitation, pavements can deteriorate at a faster rate and ultimately cost much more to maintain than pavements maintained with proper rehabilitation.

Studies have shown that transverse and longitudinal cracks in asphalt pavements overlaid with one or two inches of HMA will reflect through the overlay within two to four years [2]. In addition, while the costs of pavement construction have increased significantly in recent years, available funding has actually decreased. As a result, there exists a national trend away from overlay and reconstruction to recycling of existing distressed pavements. The trend has been strengthened by the fact that there are more than a million miles of roads in the United States with asphalt surface courses over granular bases, and thus there are a substantial number of opportunities for asphalt pavement recycling.

Asphalt pavement recycling is not a new concept. The technique was initially developed in 1915, and it started gaining its popularity since 1975 because it offers reduced costs; geometric preservation; and conservation of aggregates, binders, and energy [3].

There are several methods to recycle asphalt pavements. One promising and cost-effective recycling method is Cold In-Place Recycling (CIR). This dissertation focuses on the performance evaluation of cold in-place recycled asphalt pavements.

1.2 Problem Statement

While the performance of cold in-place recycled roads is generally good, there is some inconsistency. Several years after recycling, some roads are in excellent condition, while more cracking and rutting is observed on other roads. These differing behaviors can be observed on roads constructed in the same county by the same contractor in the same construction season. Thus, the difference in performance is probably not from such factors as weather, equipment, contractor experience, and construction procedures. Rather, other factors more prominently affect pavement performance, such as:

1. Age of the recycled pavement,
2. Cumulative traffic volume,
3. Support conditions, and
4. Aged engineering properties of the CIR materials.

1.3 Purpose of the Study

The objective of this dissertation is to answer the following questions concerning CIR performance:

1. What affects do traffic, age, and support conditions have on pavement performance?

2. How can these affects be explained by aged engineering properties of the CIR materials and other factors?

3. What changes should be made with regard to design, material selection, and construction in order to improve the performance of future recycled roads?

1.4 Scope of the Study

This dissertation provides a summary of the results of a comprehensive program of performing field distress surveys, field testing and laboratory testing for 24 cold in-placed recycled asphalt roads constructed from 1986 to 2004 at various locations throughout the state of Iowa. Of these 24 projects, 18 projects were selected from a sample of roads in a previous research project (HR-392) [4]. Six projects were selected from newly constructed CIR projects in Iowa after 1999.

1.5 Organization of the Dissertation

This dissertation has five chapters. Chapter One provides the general introduction and objectives of this study. Chapter Two consists of the detailed literature review of studies pertinent to Cold In-Place Recycling of asphalt pavements. Chapter Three includes the methodology of the study. Chapter Four presents statistical analyses and results. Final conclusions and recommendations are summarized in Chapter Five.

CHAPTER 2. LITERATURE REVIEW

2.1 Background

Recycling existing pavement materials for pavement rehabilitation is not a new concept. The technique was initially developed in 1915 [5], and it has gained more popularity since 1975 based on the following:

- Inflation of construction costs and reduced funding for transportation facilities.
- More than one million miles of asphalt roads in the United States need to be rehabilitated. Hence, there are substantial opportunities for recycling.
- Although obtaining aggregates for pavement construction generally is not a problem in the United States, some agencies are concerned about the depletion of aggregate supplies and high costs of extraction and hauling.
- Agencies need to consider zoning restrictions when dumping waste materials. Rather than remove and dump old pavement materials, many agencies are solving this problem by recycling them.
- The asphalt binder contained in existing pavement is a valuable resource. Because of factors such as oxidation, the aged asphalt may have lost some of its original properties, but when combined with new asphalt it can again serve as an effective binder [6]. The reuse of aged asphalt may reduce the amount of new asphalt required for pavement reconstruction.

Recycling of existing pavement materials for rehabilitation purposes offered an effective solution to these problems. Specifically, recycling offered the following major potential benefits compared with conventional techniques:

- Reduced costs,
- Preservation of existing pavement geometries,
- Conservation of aggregates and binders,
- Preservation of the environment, and
- Energy conservation.

Because recycling appeared promising from a wide variety of viewpoints, a number of agencies, including the National Cooperative Highway Research Program (NCHRP) [7, 8], Federal Highway Administration (FHWA) [9-15], Corps of Engineers (for the Air Force) [16], and U.S. Navy [17], sponsored recycling research and implementation studies. Early research and implementation efforts led to the categorization of four types of pavement recycling:

- Surface recycling,
- Cold recycling,
- Hot recycling, and
- Portland cement concrete pavement recycling.

The scope of this dissertation is limited to Cold In-Place Recycling (CIR) with bituminous binders.

2.2 Cold In-Place Recycling

Cold In-Place Recycling (CIR) is defined as a rehabilitation technique in which the existing pavement materials are reused in place [18]. The materials are mixed in-place without the application of heat. In CIR, a portion of the asphalt layer, normally between 75 to 100 mm (3 to 4 in) is used to produce a base course for generally low-to-medium traffic volume highways. The steps in CIR consist of preparation of construction area, milling the existing pavement, addition of recycling agent and/or new materials, laydown, compaction, and placement of surface course. The addition of new aggregates may not be necessary in some projects.

2.2.1 Benefits

The benefits of using CIR include [8, 19-21]:

- Significant pavement structural improvements may be achieved without changes in horizontal and vertical geometry and without shoulder reconstruction.
- All types and degrees of pavement distress can be treated.
- Reflection cracking normally is eliminated if the depth of recycling is adequate.
- Pavement ride quality can be improved.
- Hauling costs can be minimized.

- The old pavement profile, crown, and cross slope may be improved.
- High production rates are possible.
- Engineering costs are low.
- Aggregate and asphalt binder are conserved.
- Energy is conserved.
- Air quality problems resulting from dust, fumes, and smoke are minimized.
- It is a cost-effective solution for a number of situations.
- Frost susceptibility may be improved.
- Pavement widening operations can be accommodated.
- It is environmentally desirable, because disposal problems are eliminated.

2.2.2 Problem Areas

Identified problem areas with CIR include [8, 19]:

- Curing is required for strength gain,
- The rate of strength gain and the speed of construction are dependent to climatic conditions, including temperature and moisture, and
- Placement of a wearing surface is required.

Considering the above identified benefits and problem areas, CIR has been mostly used on low-to-medium traffic volume highways as a base course.

2.3 Extent of Use

A nationwide survey of CIR was conducted in early 1987 for ARRA [20]. 24 states indicated use of CIR, 5 states indicated that they have placed only experimental test sections, and the remaining 21 states do not use cold recycling. Based on the ARRA survey [20], county roads and secondary highways composed equal proportions of CIR projects (31 percent of responses each). City street projects account for 19 percent and primary and Interstate highways compose 12 and 7 percent shares, respectively [20].

The survey indicates that CIR had been used for all types of roads and structural section components. However, some agencies restrict its use. Twenty percent of the ARRA reporting agencies restrict CIR to rural areas; an additional 20 percent limit use to roads with low traffic volumes. Most agencies limit the use of CIR to base courses (95 percent). Of these base course projects, 12 percent placed fog, sand, or slurry seals as surfaces; 33 percent of the projects were surfaced with aggregate chip seals; and 50 percent were surfaced with an asphalt concrete. Three states use CIR for shoulder reconstruction on Interstate highways [20].

2.4 Construction Methods

A wide variety of equipment and sequence of operations have been used for CIR. A typical CIR sequence consists of nine operations [3]:

- Pavement sizing,
- Addition of new aggregate,

- Addition of new asphalt/recycling agent,
- Mixing,
- Laydown,
- Aeration,
- Compaction,
- Curing, and
- Application of wearing surface.

Many of these operations are operated by a single train. Addition of new aggregate may not be necessary on some projects.

Epps [3] summarized the construction method using a single-pass equipment train: "Several contractors have developed a single-pass equipment train capable of full-depth and partial-depth CIR. Large quantities of pavement can be recycled daily. The equipment train usually consists of a cold-milling machine, portable crusher, travel-plant mixer, and laydown machine. The oversized material from the milling operation is sized by the small portable screen and crusher unit. The cold-milling machine's conveyor discharges the recycled asphalt pavement (RAP) into the crusher unit, which passes it over a screen with large sieve sizes. The particular sieve size will depend on the job specifications. The material retained on the screen is rerouted to the roll unit for crushing and then back to the screen. Eventually, 100 percent of the RAP will pass through the screen and onto another conveyor where it can be weighed before being deposited into a pugmill or a paver. The screen and crusher unit can also be fitted with a pugmill and asphalt feeder system for mixing. The recycled mix can then be windrowed directly behind the mixer." This dissertation focuses on the partial-depth CIR technology.

2.5 Performance

A comprehensive nationwide source of information on performance of CIR pavement is not available. The general performance data reported by states that have constructed a number of projects indicate that performance has been mostly good or very good, particularly with respect to cracking [3]. A summary of information from California, Indiana, Iowa, Kansas, Maine, Nevada, New Mexico, New York, Oregon, and Pennsylvania is provided below.

California

In an evaluation study of thirteen cold recycled asphalt pavements constructed between 1979 and 1983, about 70 percent of the projects were found to have good performance [22]. The poor performance of the rest of the projects was attributed to incomplete mix design and nonuniform distribution of the binder.

Indiana

Roughness, deflection, and visual evaluation made after one year of construction (1986) indicated better performance for a CIR mix section compared to a conventional resurfaced pavement [23]. Transverse reflection cracks and longitudinal cracks were found in the conventional HMA pavement but not in the cold recycled mix section.

Iowa

CIR started in Iowa in 1986 when Clinton County recycled County Road E50 near Andover. A study carried out in 1998 reviewed the performance of CIR pavements. The performance was rated both quantitatively and qualitatively. The study found that most roads were performing well; cold-recycled asphalt is effective in mitigating reflective cracks; the service life of recycled pavements is predicted to be 15~26 years [24].

Kansas

Kansas [25] reports pavements containing cold-recycled asphalt concrete exhibit less reflective cracking if the remaining original mat is the proper thickness. If the original mat is too thin, it does not provide a solid base and the equipment can break through into the base, which is often unstable. If the remaining original mat is too thick, it will initiate new reflective cracks at the location of the old cracks.

Maine

Deflection, rut depth, ride quality, and a crack study have been performed on recycled pavements in Maine [26]. Based on three years of performance, CIR has virtually eliminated reflective cracking problems and has helped to solve frost problems.

Nevada

Examination of cores and surveys of visual conditions performed after seven years of service revealed areas of bleeding and minor cracking in one cold recycled project [3]. A large portion of the project was found to have no distress. The authors mention that the bleeding was probably caused by improper seal coat design and quality control. Examination of another three year old project revealed no distress other than joint raveling [3].

New Mexico

A total of 120 CIR projects have been constructed in New Mexico since 1984. A recent performance evaluation of 45 projects located throughout New Mexico [2] shows that all of the pavements are providing acceptable performance levels. Pavement condition surveys have indicated that these pavements will far exceed their assumed service life of 10 years. More than 90 percent of the projects were found to be in excellent condition, and the rest were in fair to good condition. Comparison of density of cores obtained at the time of construction and at the time of evaluation indicated no significant change in air voids.

New York

A total of four CIR projects were constructed in New York from 1990 to 1992. The four rural road projects total 57 lane miles, with an average traffic volume range of 500 to 4,300 vehicles per day. All the projects were reported to be performing extremely well in 1992 [27].

Oregon

Results from evaluation of 52 CIR pavements indicated that 47 of the projects had good or very good performance, and only five had poor performance [28-31].

Pennsylvania

The Pennsylvania Department of Transportation had completed about 90 cold-mix recycling projects by the end of 1985 [32]. Experience with these projects indicates a need for obtaining optimum moisture content in the RAP material so that the emulsified asphalt can be dispersed effectively in the mix. Other findings are as follows:

1) Recycled mixtures are usually susceptible to damage from moisture intrusion and abrasion by traffic.
2) The placement of a surface is necessary to avoid raveling and potholing.
3) Projects carrying a significant amount of heavy truck traffic should not be selected for cold recycling.
4) Cold recycling should not be attempted if the existing road has inadequate drainage.

2.6 Support Condition

To better understand how pavement layers affect CIR pavement performance, an investigation of the resilient moduli of these layers is recommended [33]

The support condition of a pavement can be assessed in various ways. A standard penetration test (SPT) is the most common strength test conducted in the field [34]. Jahren et al [35] developed a testing method using dynamic cone penetrometer (DCP) to assess subgrade stability before recycling. Several studies indicated that a more comprehensive approach is to use the Falling Weight Deflectometer (FWD) data [36-40]. Guidelines for collecting and processing FWD deflection data are available elsewhere [41]. Some backcalculation software packages can be easily obtained to process FWD measurements and provide estimates of the moduli of the pavement layers [42].

Recently artificial neural networks (ANN) have been used to evaluate flexible pavement layer moduli [43-45]. However, an ANN algorithm of CIR pavements was not found in the literature review.

2.7 Engineering Properties of CIR Mixtures

The following engineering properties of CIR mixtures are deemed to be important factors that affect CIR pavement performance.

Air void (V_a)

Air voids decrease with increasing binder content and time. Initial values ranged from about 10 to 15 percent [3, 29]. Other studies showed that the compacted mixture internal void content ranges between 12 and 15% [3, 46, 47].

Croteau and Lee's study [48] showed that with similar air voids, CIR mixtures had significantly greater fatigue lives than standard HMA mixtures. This indicated that a CIR mixture may behave more like an open graded mixture rather than a dense graded mixture

[49]. Open graded mixtures are known to provide more fatigue resistance but less stiffness in comparison to densely graded HMA mixtures [50].

Resilient modulus

Resilient moduli were obtained on cores from seven projects in Oregon. These results showed that resilient modulus values in the range of 150,000 to 600,000 psi were obtained. Resilient moduli are also affected by the stiffness of RAP asphalt [29, 30].

Indirect Tensile (IDT) Strength

A strong correlation between rutting potential and IDT strength was found by Anderson et al.[51]. In another study, indirect tensile testing has been used to specify maximum cracking temperatures for CIR projects [52].

Lauter's study indicated that indirect tensile strength increases for all samples as the temperature decreases [53].

Halim [54, 55] showed that during compaction, the top layer will crack due to the influence of the relative rigidity of the underlying layer. Furthermore, Halim showed that as the stiffness of the layer immediately under the layer that is being compacted increases, the number of construction induced cracks increases. Applying this concept to the CIR process, it suggests that as the CIR material is being compacted on top of the subgrade, very few construction cracks are induced. After compaction of this layer, a hot asphalt overlay is placed at approximately 130°C (266°F). The temperature sensitive CIR layer has very little strength at high temperatures. Thus, compaction of the HMA layer occurs over a layer that is relatively less stiff, again causing few construction induced cracks that were induced by construction.

Aggregate

Aggregate quality is important in crack resistance. Aggregates with low absorption, high abrasion resistance, and high tensile strength have a greater resistance to cracking [56].

2.8 Economics

CIR has proved to be a cost effective method of pavement rehabilitation. When properly selected, CIR is usually more economical than the conventional rehabilitation methods. A review of the FHWA Demonstration Project 39 reports [3] indicates the following component costs for CIR operations:

- Materials – 46.6 percent,
- Equipment – 29.7 percent, and
- Labor – 23.7 percent.

The main economic advantage that recycling offers is in material cost savings. The majority of the material costs are associated with new binder. The addition of new aggregate will increase recycling costs.

Studies [57] showed that the representative cost of CIR varies from approximately $1.71/m^2 ($1.37/yd^2) to $9.87/m^2 ($7.90/yd^2) depending upon many factors such as depth of recycling, equipment type, and thickness of overlay. The initial savings have varied from 6 to 67 percent.

It should be noted that recycling costs have changed over the years because of continual developments in the recycling technology and equipment.

2.7 Summaries

A review of current literature shows that savings up to 67 percent can be achieved by using CIR. In addition to the material and construction cost savings, significant amount of cost savings can be realized by the reduced interruptions in traffic flow when compared with conventional rehabilitation techniques. Recycling can be used to rejuvenate a pavement or correct mix deficiency and conserve material and energy — these benefits are not available with the conventional paving techniques. In addition, CIR projects are sometimes placed in a classification that does not require the major changes in road geometry that are sometimes required to bring roads up to the latest design standards. By comparison, a reconstruction project may require more such changes that would increase the cost.

In the CIR process, existing in-place materials are mixed with recycling agents and/or new or reclaimed materials without the application of heat. The method can be used to eliminate a variety of distresses such as rutting, cracks, and irregularities.

The CIR process can be carried out by using an equipment train that includes machinery to perform the complete process, including milling, crushing, screening of the RAP, and mixing. The mix requires aeration before compaction to reduce the excess fluid content by evaporation. Although CIR mix produces a stable surface, a wearing surface consisting of hot mix asphalt or a seal coat is normally required because the recycled surface is not adequately resistant to abrasion by traffic and intrusion by moisture.

2.8 Glossary

- **Recycling** – reuse of existing materials to produce new materials.
- **Recycling agent** – organic materials with chemical and physical characteristics selected to restore aged asphalt to desired specifications.
- **Rehabilitation** – work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway including shoulders, to a condition of structural or functional adequacy.
- **Fog seal** – a method of adding asphalt to an existing pavement surface to improve sealing or waterproofing, prevent further stone loss by holding aggregate in place, or simply improve the surface appearance.
- **Sand seal** – a thin asphalt surface treatment constructed by spraying a bituminous binding agent and immediately spreading and rolling a thin fine aggregate (i.e. sand or screenings) cover.
- **Slurry seal** – a petroleum-based emulsion product, mixed with fine aggregate rock, blended on-site in a large truck, and then applied evenly across the entire surface of an asphalt street.
- **Raveling** – wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder.

CHAPTER 3. METHODOLOGY

3.1 Overview

Cold In-Place Recycling (CIR) provides an economical rehabilitation strategy that mitigates crack reflection by pulverizing the asphalt pavement surface, thus destroying the old crack pattern in the recycled layer. In 1998, the Iowa Department of Transportation (DOT) and Iowa Highway Research Board initiated an evaluation of the performance of CIR asphalt cement concrete roads (HR-392) [4]. Research results from 18 sample roads showed that CIR retarded the development of transverse cracking (reflected cracks). Additionally, CIR roads within the state of Iowa and with an annual average daily traffic (AADT) of less than 2,000 were predicted to have an average service life of 15 to 26 years.

However, recycled roads have inconsistent performance. This study is to investigate how aged engineering properties of the CIR materials, traffic volume, and other factors affect pavement performance. The flow chart of methodology of this study is shown in Figure 3.1.

3.2 Data Collection and Processing

For this study researchers investigated performance of 24 CIR roads, including 18 roads from the previous research [4] and 6 newly recycled pavements. The researchers conducted a geographically balanced sampling in Iowa, such that the 24 roads were selected to represent various geographic regions of the state, project age, traffic levels and support

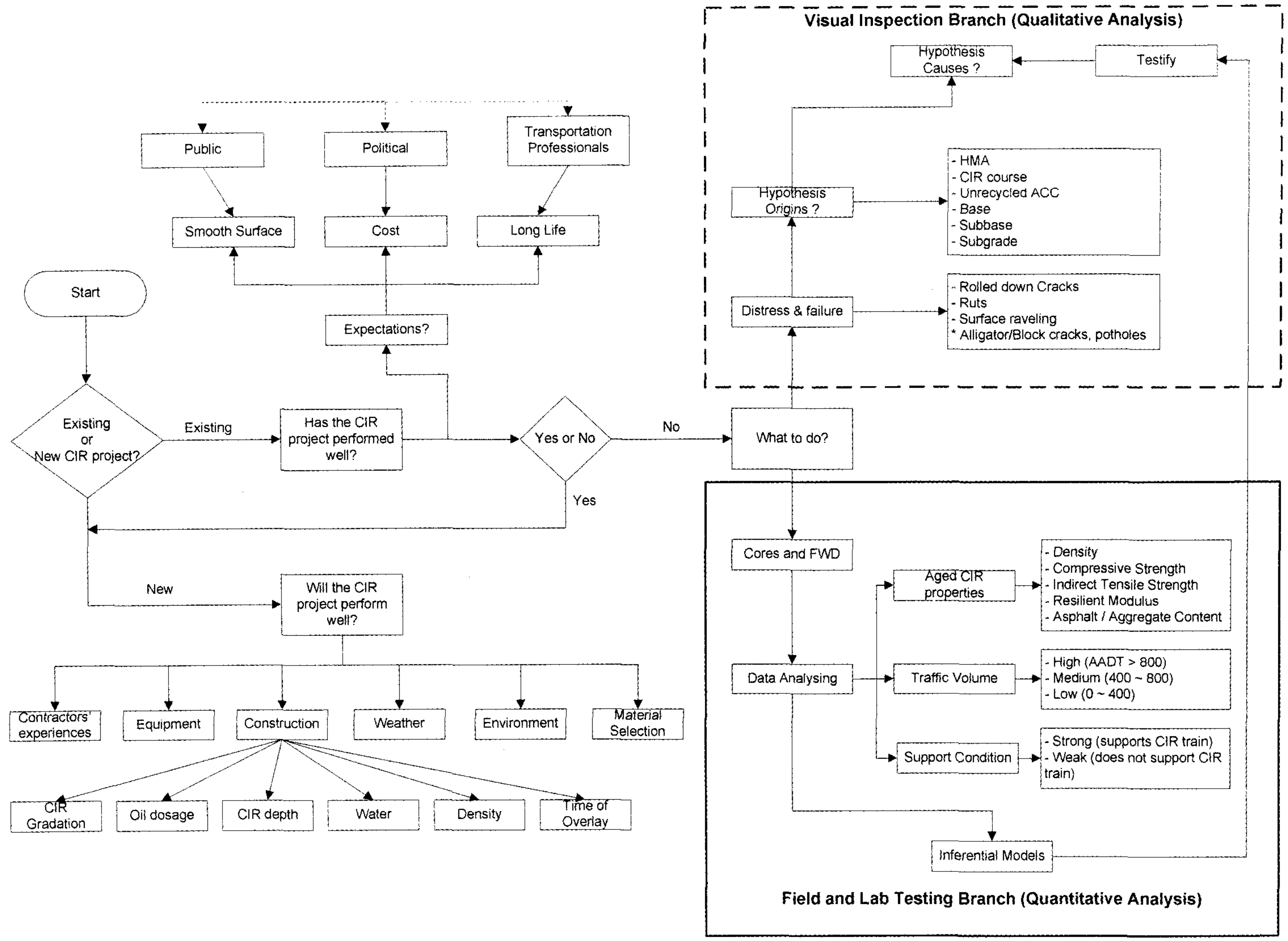


Figure 3.1 Flow chart of the study

conditions. In order to evaluate the pavement performance, the following data of each road was collected, processed and analyzed based on the same standard as the previous research [4].

- Qualitative and quantitative distress data
  - Appearance of pavements and rideability
  - Length of longitudinal/transverse cracks
  - Width of longitudinal/transverse cracks
  - Area of rutting/alligator crack/block crack/edge crack/patching
- Support conditions as inferred by pavement deflections
- Engineering properties of CIR materials obtained by coring asphalt samples and conducting lab tests

The collection and processing of the abovementiond data are described in the following sections.

3.2.1 Interviews

The writer interviewed construction superintendents, foremen, laborers, county engineers, and material suppliers who were working on the following CIR projects in the summer of 2004. These projects were:

- P-33 in Webster County,
- IA-175 in Hardin County,

- County Road 299 in Hardin County,
- S-14 in Story County, and
- S-27 in Story County.

The writer observed the construction procedures, recorded productivities, and interviewed construction personnel to identify prominent issues that the contractors faced on the job sites. Although this information was not used in the data analyses, it provided context for understanding possible interactions amongst CIR pavement performance, mix design, construction methods, and materials.

3.2.2 Survey

In 1998, pavement distress surveys of 18 sample roads were conducted, and the present serviceability index (PSI) and pavement condition index (PCI) of each road were calculated. Then, the performance of CIR pavements were evaluated [4]. In 2004, researchers obtained the same types of data from the 18 roads under new conditions. It is of particular interest to analyze the performance of pavements in 1998 and the performance of the same pavements in 2004. It is expected that this longitudinal study will enable researchers to describe pavement performance patterns and changes over time and better understand factors that lead to good or poor performance. One of the most important assumptions for a longitudinal study is that factors, other than those considered in the study, should remain the same or have minimum changes over time. This helps researchers narrow down the selection of factors and focus on several factors that are deemed to be important.

For example, it is assumed that the percentage of truck traffic, a factor that increases the rate of pavement deterioration, remained constant from 1998 to 2004.

In order to find out whether or not factors other than those studied had significantly changed, the writer sent out a questionnaire (Appendix A) to all of the eight jurisdictions that maintained the roads. The survey inquired about the levels of traffic (including truck traffic), support condition, and other new changes that may have occurred since 1998. Table 3.1 summarizes the results of the survey. After reviewing the results, the researchers decided that none of the changes on these 18 roads were large enough to invalidate the assumption that there were no important changes during the time of the longitudinal study.

3.2.3 Pavement Distress Survey

The pavement distress survey in this study was conducted by researchers at the University of Iowa. Complete details of this effort are presented elsewhere [58]. A summary is presented in the following narrative. The following data was collected for the pavement survey:

- Length of longitudinal/transverse cracks,
- Width of longitudinal/transverse cracks, and
- Area of rutting/alligator crack/block crack/edge crack/patching.

Most of the distress survey was conducted using an Automated Image Collection System (AICS). The AICS system consists of an off-the-shelf area scan digital video camera mounted on a vehicle, a Data Management Interface (DMI), and a portable computer with an image processing board. The digital camera is able to capture images of the pavement surface at a predetermined interval controlled by the DMI while the vehicle is traveling at highway speed during daytime hours. The images are then stored in the computer for further processing.

Because the AICS system cannot capture pavement profile, rutting was measured manually using a portable rutting gauge. The rutting was measured in both inner and outer wheel paths in two lanes at every 15.24 meters (50 ft) from each 457.2-meter (1,500-ft) long test section. If at one location, the rutting is deeper than 6.35 mm (¼ inch), 7 m2 (75 ft2) of rutting area is recorded. Seven square meter (75 ft2) is calculated by multiplying wheel path width, 457 mm (1.5 ft), by the interval between rut depth measurements, 15.24 meters (50 ft). A typical test section is 457.2-meter (1,500-ft) long. Thus the sum of rutting area is divided by 15 to obtain an average rutting area (ft2) per 100-ft station. The locations of each test section can be found in Appendix B.

Table 3.1 Summary of the questionnaire results

County	Road	Support/Drainage Condition	Traffic Volume	Truck	New changes since 1996
Boone	E-52	Same as others	310~390 VPD (Vehicle Per Day)	5~10%	No
Boone	198th	Poor drainage	130 VPD	5%	No
Butler	T-16	80% of all the paved roads has been recycled in the past 14 years.	This road has a little higher percentage of truck traffic than the normal county road since it connects Highway 3 and Highway 57.		No
Cerro Gordo	B-43	Fairly good support and drainage. Planning to widen shoulders and overlay this road in 2005	300~700 VPD	10%, no unusual amount of truck traffic	No
Cerro Gordo	S.S	Poor drainage in certain areas. Shoulders are eroding and deteriorating. Road needs to be widened.	1,140~4,200 VPD (High traffic in summer due to Clear Lake resort traffic)	< 9%	No
Clinton	E-50	PCC roads in Clinton County have edge drains but HMA roads don't. This section of road is well drained due to the hilly terrain.	AADT=540 (2002 data). A large dairy operation is located nearby and generates a significant amount of milk and waste product hauling.	Slightly higher than 9%	No
Clinton	Z-30	HMA roads don't have edge drains like PCC roads do in Clinton County. This road located in flat terrain and the overall drainage is fair	AADT=910 (2002 data)	9%	No

Table 3.1 (continued)

County	Road	Support/Drainage Condition	Traffic Volume	Truck	New changes since 1996
Hardin	D-35	This section is comparable to other sections of roads in Hardin County.	D-35 has served as a short-cut for Highway 20 traffic, and during the period between completing Highway 20 to Iowa 65 and Highway 14. Therefore, traffic volumes were running in the neighborhood of 1,500 VPD with an abnormally high secondary road percentage of trucks.	was high	The road condition has remained fairly stable since 1996. The traffic volume now has dropped to the normal 600 VPD since the opening of new US20 last August.
Muscatine	F-70	Good/average	AADT=1250 (2002 data)	N/A	No
Muscatine	G-28	Fair/average	AADT= 960~1100 (2002 data)	N/A	No
Muscatine	Y-14	Poor/very poor	AADT=1160~1490 (2002 data)	N/A	No
Tama	E-66	E66 road lays in an area that is generally flatter than other roads and that we occasionally have trouble with culverts being plugged and water running over the road. This is caused by debris and by drainage that is flat from the road south to the river. But the bulk of the road is drained reasonably well, with good ditches.	Same as before	Same as before	No

Table 3.1 (continued)

County	Road	Support/Drainage Condition	Traffic Volume	Truck	New changes since 1996
Tama	V-18	Same as others	Same as before	Same as before	No
Winnebago	R-34	Support and drainage are about the same as most of the other paved roads in the county.	270~490 VPD	About 9%	Cracks are routed and sealed. It is scheduled for an ACC overlay in 2009.
Winnebago	R-60	Drainage is similar to most of our paved roads. Support is somewhat less due to possible problems with an underlying peat layer in some areas of the roadway.	540 VPD, Truck traffic has decreased since the coop elevator closed in Scarville.	About 7%	We have routed and sealed cracks. We are planning an ACC overlay in 2008.

Since the captured digital images contain visual information of distresses, the following factors can be quantitatively determined using a computer software package, named Manual Image Analysis System (MIAS) [59]:

- Length of the longitudinal/transverse cracking (average, inch per 100-ft station),
- Width of the longitudinal/transverse cracking (largest number in one test section, inch),
- Area of alligator/block/edge cracking (average, ft^2 per 100-ft station), and
- Area of patching (average, ft^2 per 100-ft station).

As shown in Figure 3.2 and Figure 3.3, the longitudinal/transverse crack can be traced using a pen tool, and the length of the crack can be calculated; the area of alligator cracking can be measured using a polygon tool. The width of cracks can also be measured from the enlarged image.

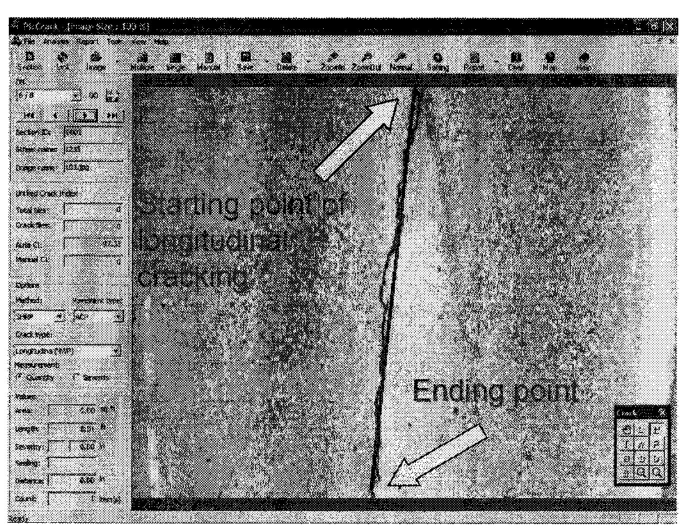


Figure 3.2 Length and width measurement of distresses using MIAS [58]

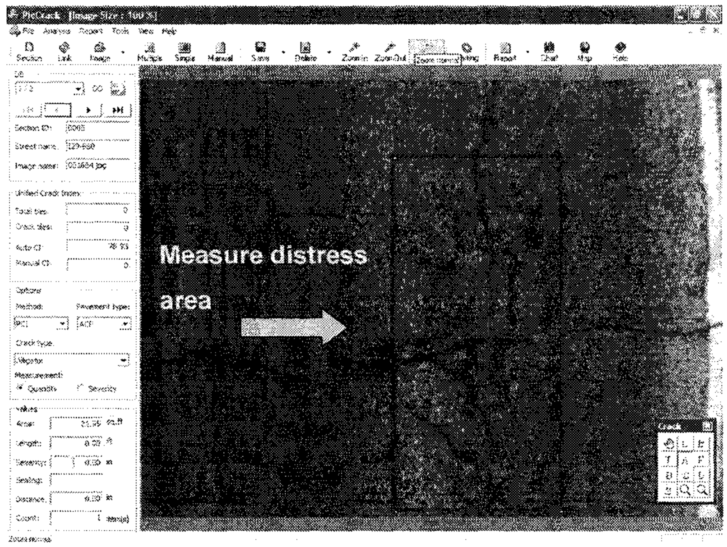


Figure 3.3 Area measurement of distresses using MIAS [58]

The research team at University of Iowa collected and processed the pavement distress data, and then calculated pavement condition index (PCI, according to a method established by U. S. Army Corps of Engineers [60]) and present serviceability index (PSI, by American Association of State Highway Transportation Officials [61]). In this study, PCI was used to represent performance of CIR pavements because PSI is subjective in nature.

PCI was calculated using MicroPaver, a software package developed by the Construction Engineering Research Laboratory of the U. S. Army Corps of Engineers [62].

The summary of the pavement distress data is shown in Table 3-2 through Table 3-4. In the tables, “First” represents data collected from the previous study [60], “Second” represents data collected in the current study.

Table 3.2 Distress survey of old test sections (per 100 feet)

Road	Longitudinal (ft)		Transverse (ft)		Alligator (ft^2)		Block (ft^2)	
	First	Second	First	Second	First	Second	First	Second
Boone 198th	27	21	5	24	50	240	0	0
Boone E52	0	42	19	25	0	0	0	0
Butler T16	0	1	8	11	0	0	0	0
Calhoun IA175	0	47	10	22	0	191	0	6
Cerro Gordo B43	105	162	41	167	0	0	232	14
Cerro Gordo SS	31	31	44	49	0	149	14	0
Clinton E50	16	172	51	64	0	136	0	0
Clinton Z30	0	452	16	61	0	30	0	43
Greene IA144	33	61	64	109	0	385	0	13
Guthrie IA4	0	0	6	25	0	0	0	0
Hardin D35	0	37	83	85	0	30	180	0
Muscatine F70	0	34	0	7	0	0	0	0
Muscatine G28	8	257	21	73	0	0	19	9
Muscatine Y14	34	173	70	248	0	24	0	274
Tama V18	0	1	9	12	0	0	0	0
Winnebago R34	2	31	89	64	0	0	0	0
Winnebago R60	0	0	0	0	0	0	2200	2200

Table 3.3 Distress survey of old test sections (con't) (per 100 feet)

Road	Rutting (ft^2)		Edge (ft)		Patching (ft^2)	
	First	Second	First	Second	First	Second
Boone 198th	80	140	4	4	0	0
Boone E52	0	0	28	31	0	0
Butler T16	0	0	0	32	0	0
Calhoun IA175	0	55	0	4	0	0
Cerro Gordo B43	25	5	0	0	0	0
Cerro Gordo SS	5	0	0	0	0	2
Clinton E50	30	60	0	42	0	84
Clinton Z30	0	0	0	0	0	0
Greene IA144	60	65	0	36	0	0
Guthrie IA4	0	0	0	0	0	0
Hardin D35	5	20	0	4	0	0
Muscatine F70	0	5	0	4	0	0
Muscatine G28	0	10	0	1	0	65
Muscatine Y14	25	45	0	5	0	153
Tama V18	0	0	0	4	0	0
Winnebago R34	0	10	0	0	0	0
Winnebago R60	0	10	0	0	0	0

Table 3.4 Distress survey of new test sections (per 100 feet)

Road	Longitudinal (ft)	Transverse (ft)	Alligator (ft^2)	Block (ft^2)	Rutting (ft^2)	Edge (ft)	Patching (ft^2)
Carroll N58	0	0	0	0	0	0	0
Carroll N. of Breda	0	7	0	0	0	3	0
Delaware US20	52	0	10	0	0	0	0
Harrison IA44	0	1	0	0	0	0	0
Jackson US61	0	0	2	0	35	0	0
Montgomery IA48	0	0	0	0	0	0	0
Story S14	0	0	0	0	0	0	0
Story S27	0	0	0	0	0	0	0

3.2.4 Support Condition

3.2.4.1 Evaluating the Support Condition Using FWD

As mentioned in Chapter 1, the support condition of asphalt pavements is one of the prominent factors that affect the pavement performance. In order to understand procedures for evaluating the support conditions, a better understanding of pavement structure and evaluation technologies is necessary.

3.2.4.2 Pavement Structure

A pavement structure (Figure 3.4) that includes CIR is a flexible pavement because the total pavement structure deflects under traffic loads. Like other typical flexible pavements, a CIR pavement structure consists of several material layers. They are:

1. Surface layer,
2. Base layer,
3. Subbase layer, and
4. Subgrade layer.

The surface layer support the tire loads; provides smoothness, rut resistance, noise control, friction and drainage; and prevents surface water penetration. For a CIR pavement, the surface layer usually has three sub-layers: a wearing course, a CIR layer, and a layer of original HMA pavement that was not recycled.

The base layer provides additional load distribution, contributes to drainage and frost resistance. This layer is usually constructed with unbound aggregate.

The subbase layer functions similar as the base layer. It consists of materials that are of lower quality materials in comparison to that of the base layer.

The subgrade layer has the lowest load carrying capacity. It consists of the least expensive materials, typically the existing soil upon which the pavement structure is placed. The subgrade layer provides structural support for all the materials above it.

For the purpose of backcalcuating Falling Weight Deflectometer (FWD) measurements (described in detail in the later section) to infer pavement support conditions, a three-layer pavement structure (Figure 3.4) was defined. The three layers are:

1. HMA layer,
2. CIR layer, and
3. FND layer.

The FND layer, meaning the foundation layer, consists of all material layers beneath the CIR layer, working as a structural support for layers above.

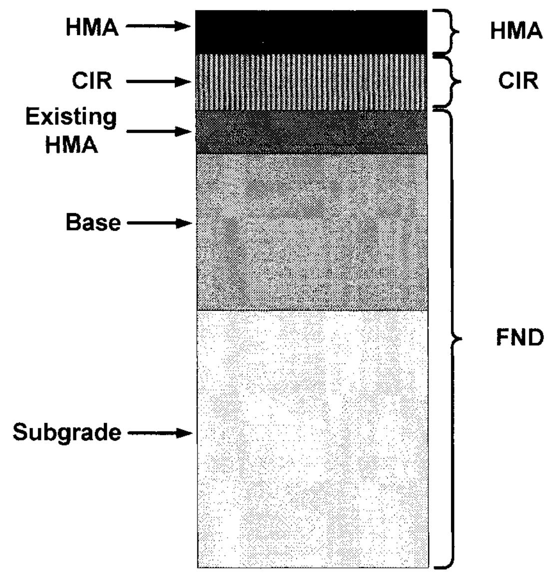


Figure 3.4 Pavement structure

3.2.4.4 Available Methods for Evaluating the Pavement Structure

The pavement structure can be evaluated using the following methods.

Dynamic Cone Penetrometer (DCP)

According to the literature, the first documented DCP, also known as the Scala penetrometer, was developed in 1956 in South Africa in response to the need for a simple and rapid device for the performance of subgrade soils [63-67]. The DCP was not extensively used in the United States in the early 1980's [68]. However, in the last few years, some state transportation authorities have shown considerable interests in the use of the DCP for several reasons [69, 70]. First, the DCP is adaptable to many types of evaluations. Second, there are few currently available rapid evaluation techniques. Third, the DCP is portable, and cost effective.

The DCP consists of a steel rod with a steel cone attached to one end driven into the pavement structure or subgrade using a sliding hammer (Figure 3.5). Material strength is measured by the penetration (usually in millimeters or inches) per hammer blow.

Although the DCP has been used widely in the United States, it has some disadvantages:

1. It takes significant amount of physical efforts to operate the DCP. In addition, data collection is time consuming (Figure 3.6).
2. Moisture content, gradation, density, and plasticity can cause large variability in DCP rest results [71, 72].
3. Some of the existing strength relationships are only applicable to certain subgrade material types and conditions. All cases are not covered.

Engineers have recognized that the magnitude and shape of pavement deflection is a function of traffic, pavement structural section, temperature, and moisture [73, 74]. Therefore, many characteristics of a HMA pavement can be determined by measuring its deflection in response to load, nondestructively. Several devices had been developed which can simulate the timing and amplitude of a moving wheel load, and provide pavement vertical deflection [75-78]. These devices are introduced in the following sections.

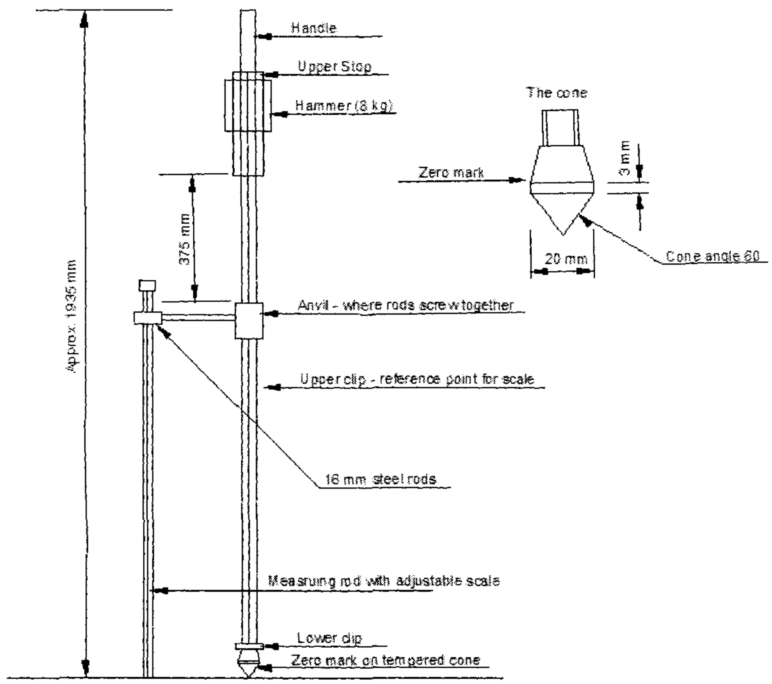


Figure 3.5 DCP scheme

Figure 3.6 DCP operation

(http://www.mrr.dot.state.mn.us/images/research/DCP/Manual1.jpg)

Static Deflection Measurements

Static tests use a stationary, nontime-variant force to simulate the wheel load.

The Benkelman Beam

In 1953, A. C. Benkelman of the U.S. Bureau of Public Roads (now known as the Federal Highway Administration) designed the Benkelman Beam. The beam was first used at the WASHO Road Test [79], and was used extensively at the ASSHTO Road Test [40]. The beam measures the deflection between the two rear tires on a dump truck with a standard axle load (Figure 3.7). The load is applied or removed slowly, over a period of several seconds, which results in deflections. To obtain accurate readings with the beam, the deflection region of a pavement must be limited to a radius of less than 8 feet around the loading point. Otherwise, the support system for the beam is in the deflection basin, resulting in a measurement that under-represents the actual deflection.

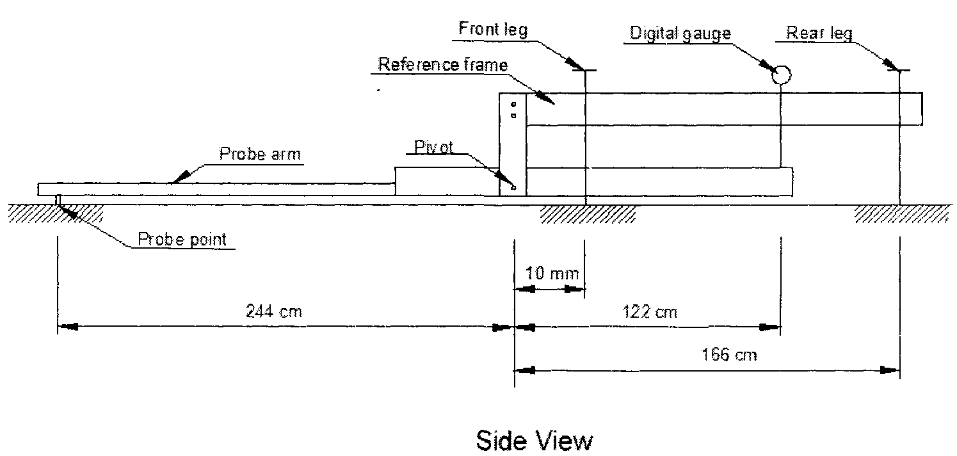


Figure 3.7 Benkelman Beam scheme

The Dynamic Deflection Testing

Another class of deflection testing methods uses a dynamic force to generate pavement deflections.

The Dynaflect

The Dynaflect was first introduced in 1964 by the Lane-Wells Company [78]. The Dynaflect is a trailer-mounted device that uses two eccentric rotating masses to generate a vertical force (Figure 3.8). This dynamic force is then applied to the pavement through two steel wheels. The deflections induced by this force are measured with five sensors.

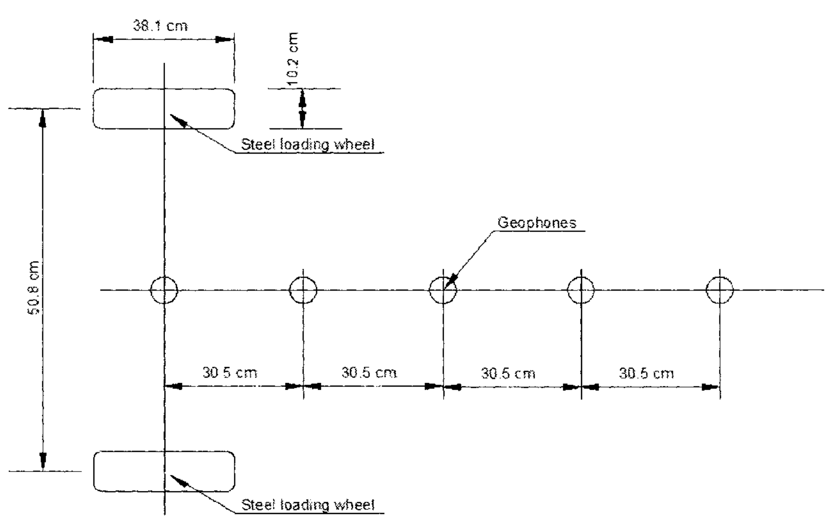


Figure 3.8 Dynaflect scheme

The Road Rater

The Road Rater functions in a manner that is similar to that of the Dynaflect in that it is trailer-mounted, and it applies dynamic forces to the pavement, and it measures the deflections with an array of sensors. The Road Rater uses a hydraulic system to raise and lower a mass in order to generate the vertical force. The frequency and magnitude of the dynamic force can be adjusted on the Road Rater (Figure 3.9).

Figure 3.9 The Road Rater
(http://www.labellemarvin.com/testing.html)

The Falling Weight Deflectometer (FWD)

The FWD was first developed in Europe, and is now widely used in the United States. In 1966, Isada [80] reported the application of a falling mass device to measure the strength of flexible pavements in the United States. From France and Denmark, Bonitzer [81] and Bohn et al [82] described the use of a FWD. Since then, further development efforts have improved the FWD. Computerized data collection was added in 1981. Full computer control of FWD operation was available in 1982. The current models of the FWD are able to display and record the time history of the load pulse, along with air and pavement temperature measurement, electronic distance measurement, and global positioning system (GPS).

The FWD can either be mounted in a vehicle or on a trailer and is equipped with a weight and several velocity transducer sensors (Figure 3.10, 3.11, and 3.12). To perform a test, the vehicle is stopped and the loading plate (weight) is positioned over the desired location. The sensors are then lowered to the pavement surface, and the weight is dropped; this produces a dynamic impulse load that simulates a moving wheel load (typically lasting 25 to 30 ms), and the surrounding pavement vertical deflection is recorded with velocity transducers (seven or more). These are mounted on a bar and automatically lowered to the pavement surface with the loading plate.

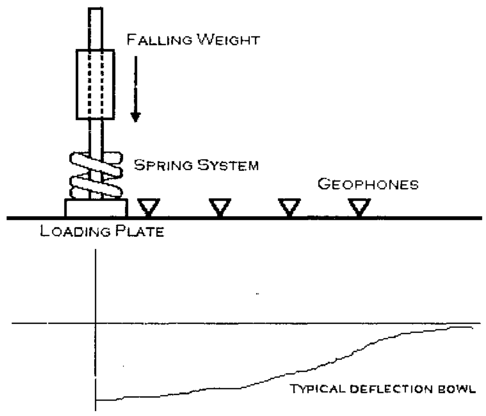


Figure 3.10 FWD scheme

(http://www.civil.port.ac.uk/projects/hmaint/struct.htm)

Figure 3.11 FWD equipment

(http://www.creig.gci.ulaval.ca/appareillage/document_view)

The resulting deflections form a shallow basin in the pavement. The depth and shape of the "deflection basin" is used to calculate the material properties of the pavement layers (Figure 3.10). These properties are used to estimate the stress and strain conditions within the pavement structure under the current and expected future traffic conditions. The magnitude of these stresses and strains are used to estimate the resilient moduli of the pavement and support layers. This information, in turn, is used to evaluate whether the pavement can meet its expected design criteria.

Advantages of using the FWD are that it provides (a) non-destructive evaluation, (b) high productivity (up to 60 test points per hour), (c) realistic pavement loading levels, (d) rapid data acquisition and the ability to develop a deflection basin, and (e) that is can be applied to many type of pavement.

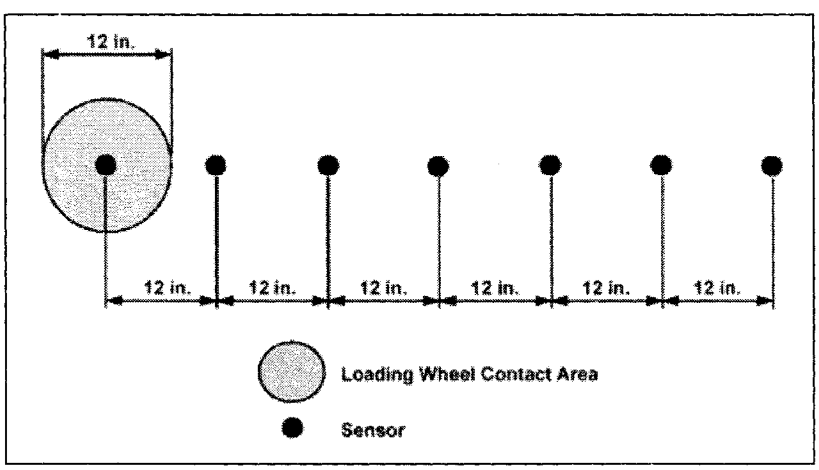


Figure 3.12 Typical location of loading plate and deflection sensors

(http://www.asnt.org/publications/materialseval/basics/jul04basics/jul04basics.htm)

Note: The Federal Highway Administration's long term pavement performance study specifies deflection sensor spacing at 0, 0.2, 0.3, 0.5, 0.6, 0.9 and 1.5 m (0, 8, 12, 18, 24, 36 and 60 in.) for its testing programs.

However, initial costs for the FWD equipment are higher and the equipment is more complex in comparison to abovementioned methods. In addition, there are three main source of errors associated with the FWD test [40]. Actions may be taken to reduce these errors, shown in Table 3.5 below.

Table 3.5 Main errors and remedy actions with the FWD test

Type of Errors	Remedy Actions
Seating Errors	Applying one or two drops in order to seat the sensors
Random Deflection Errors	Take multiple readings and average the result
Systematic Errors	Calibrate the device every time before use

It is difficult to compare the advantages and disadvantages amongst the various devices because each of the devices applies a different type of force and frequency to the pavement. Also the pavement and subgrade conditions differ from site to site; thus the responses are different. Therefore, the summaries (Table 3.6, 3.7, and 3.8) below are limited to the mechanistic differences between the various testing methods.

Table 3.6 Forces Applied to the Pavement by Various Testing Methods

Deflection Testing Method	Type of Force	Force Level	Frequency Range	Force Measurement Method
Benkelman Beam	Static	23-45 KN (5-10 kip)	9 Hz	Dead Weight on Wheels
Dynaflect	Dynamic	8/9 KN (2 kip) peak-to-peak	8 Hz	Inertial
Road Rater	Dynamic	2.2-3.6 KN (0.5-8 kip) peak-to-peak	5-70 Hz	Load Cell
FWD	Dynamic	4.45-156 (1-35 kip) KN	0-60 Hz	Load Cell

Table 3.7 Deflection Measurement Methods Used by Various Testing Methods

Deflection Testing Method	Deflection Reference	Deflection Measured at Point of Force Applications?	Number of Sensors
Benkelman Beam	Elevation Datum	Yes	1
Dynaflect	Inertial	No	>= 5
Road Rater	Inertial	Yes	>= 5
FWD	Inertial	Yes	>= 7

Table 3.8 Summary of Efficiency of Deflection Measurement Methods

Deflection Testing Method	Crew Size	Maximum Daily Production
Benkelman Beam	3	50-100 test locations
Dynaflect	1-2	100-400 test locations
Road Rater	1-2	100-400 test locations
FWD	1-2	100-300 test locations

3.2.4.4 Evaluation of the Support Condition in This Research Project

The FWD was chosen to evaluate the support condition (ASTM D4694-96), because it is the support condition measurement device that is commonly in use by the Iowa DOT as explained in the next paragraph.

The Iowa DOT has used several devices to evaluate the pavement performance. The Benkelman Beam was initially used, and then it was replaced by the Road Rater in 1985. The Road Rater has been used to collect the structural strength data for the network level since then. Recently The Iowa DOT has been phasing out the use of the Road Rater, and moving toward the use of the FWD. The reasons are that: a) the technology of the Road Rater has become obsolete, and b) the manufacture of the Road Rater, Foundation Mechanics, does not provide technical support for the Road Rater because its product line has moved into the FWD products. Even though the FWD has lower productivity than the Road Rater, it provides results that are much more reliable to Iowa DOT engineers. However, because appropriate data analyzing software has not been fully developed as of this writing, the FWD is used primarily for project level investigations in Iowa.

For this research project, the Special Investigation team of Iowa DOT used a FWD machine (the model name is JILS-20, manufactured by Foundation Mechanics, Inc.) to conduct the FWD tests on 24 roads on the following dates. As shown in Table 3.9 (sorted by the testing date) and Table 3.10 (sorted by road names).

Table 3.9 Dates of FWD tests (sorted by the testing date)

Date of Testing	Number of Roads Tested	Roads
12/13/04	6	Boone 198th, Boone E52, Muscatine F70, Muscatine G28, Muscatine Y14, Tama V18
12/14/04	6	Cerro Gordo B43, Clinton E50, Clinton Z30, Delaware US20, Jackson US61, Winnebago R34
12/15/04	6	Cerro Gordo South Shore, Calhoun IA175, Carroll N of Breda, Harrison IA44, Montgomery IA48, Winnebago R60
03/30/05	3	Bulter T16, Hardin D35, Story S14
03/31/05	3	Carroll N58, Greene IA144, Guthrie IA4

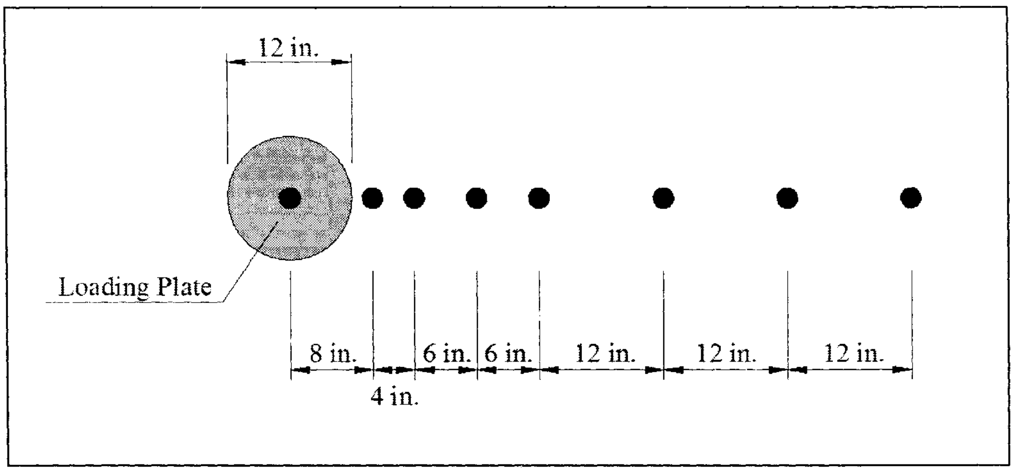
The FWD measurements were taken in the winter, even though it is not the best season to conduct these tests (in the winter, the base and subgrade are frozen and become stiffer than they are in the warmer weather, thus moduli measured in the winter are higher than the normal working moduli). This was because winter was the only time that the FWD was available to perform the tests for this research project. The Iowa DOT engineers and equipment are usually occupied during warmer months with other projects, such as conducting the network level pavement surveys (covering the entire system every three to five years).

Table 3.10 Dates of FWD tests (sorted by road names)

Road	FWD date
Boone 198th	12/13/2004
Boone E52	12/13/2004
Bulter T16	3/30/2005
Calhoun IA175	12/15/2004
Carroll N58	3/31/2005
Carroll Nof Breda	12/15/2004
Cerro Gordo B43	12/14/2004
Cerro Gordo SS	12/15/2004
Clinton E50	12/14/2004
Clinton Z30	12/14/2004
Delaware US20	12/14/2004
Greene IA144	3/31/2005
Guthrie IA4	3/31/2005
Hardin D35	3/30/2005
Harrison IA44	12/15/2004
Jackson US61	12/14/2004
Montgomery IA48	12/15/2004
Muscatine F70	12/13/2004
Muscatine G28	12/13/2004
Muscatine Y14	12/13/2004
Story S14	3/30/2005
Tama V18	12/13/2004
Winnebago R34	12/14/2004
Winnebago R60	12/15/2004

The sensor layout of the FWD of this research project is illustrated in Figure 3.13.

Figure 3.13 Sensor layout for the FWD used in this study



The JILS-20 was operated over a 1,500 feet-long section of each test road. The loading plate was dropped every 100 feet, and the deflections from 8 sensors were collected. There were total of 16 drops on each road. Figure 3.14 shows the locations of cores. An example of raw FWD data is shown in Figure 3.15.

Figure 3.14 Locations of cores

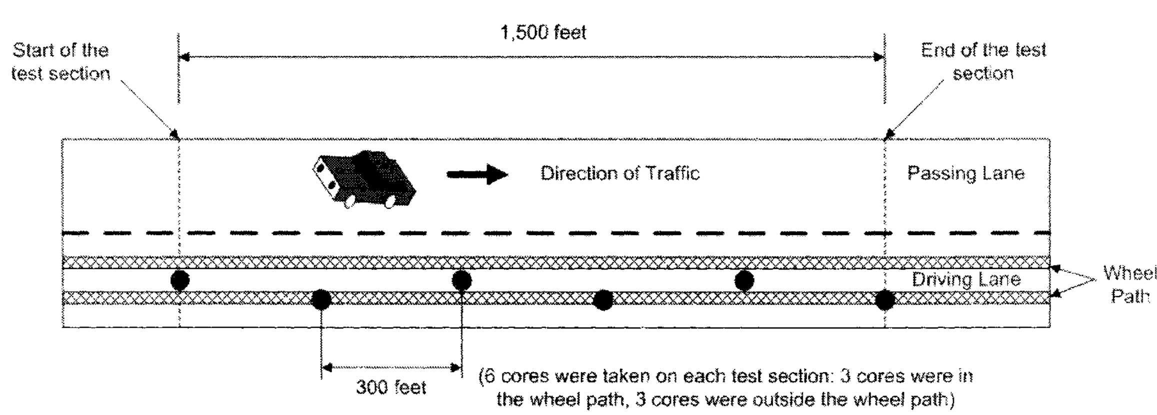


Figure 3.15 FWD raw data

```
boone198.DAT - Notepad
File  Edit  Format  View  Help
Date-Time: 12-13-2004  8:36: 9
Sensors: 096011F04  096012F04  096013F04  096014F04  096015F04  096016F04  096017F04  096018F04  096019F04
weight/spring: 3
Location: boone co
Temp: 10
Operator:
Comments:
1 1   0.000 1  9.14 14.12 12.74 11.24  9.39  7.79  5.34  3.51  2.57 10.93  21.2
GPS Position: Latitude =     Longitude =
Note:
2 1 105.000 1  8.81 13.35 12.39 11.15  9.48  7.96  5.44  3.57  2.43 10.84  20.9
GPS Position: Latitude =     Longitude =
Note:
3 1 211.000 1  9.35 15.91 14.26 12.30  9.94  7.90  5.04  3.16  2.37 11.82  20.9
GPS Position: Latitude =     Longitude =
Note:
4 1 304.000 1  9.42 12.68 11.75 10.26  8.39  6.75  4.38  2.81  2.15  9.45  21.2
GPS Position: Latitude =     Longitude =
Note:
5 1 402.000 1  9.27 15.28 14.84 12.82 10.26  8.03  5.00  3.09  2.44 11.74  21.2
GPS Position: Latitude =     Longitude =
Note:
6 1 503.000 1  9.20 13.40 13.30 11.83  9.93  8.18  5.50  3.53  2.64 11.41  21.2
GPS Position: Latitude =     Longitude =
Note:
```

Most part of the data is self-explanatory, except the highlighted date lines. They are explained below:

```
Date-Time: 12-13-2004  8:36: 9
Sensors: 096011F04  096012F04  096013F04  096014F04  096015F04  096016F04  096017F04  096018F04  096019F04
weight/spring: 3
Location: boone co
Temp: 10
Operator: bad
Comments:
1 1   0.000 1  9.14 14.12 12.74 11.24  9.39  7.79  5.34  3.51  2.57 10.93  21.2
GPS Position: Latitude =     Longitude =
Note:
```

Where:

Temp: Air Temperature, °F,

1: Test #,

1: Lane index. 1=Driving Lane, 2=Passing Lane,

0.000: Test Location (ft),

1: Direction index. 1=Northbound or Eastbound, 2=Southbound or Westbound,

9.14: Actual load (kips),

14.12 – 10.93: Deflections from sensors, and

21.2: Temperature of pavement surface, °F.

The raw data file generated by the JILS-20 cannot be read by the various computer packages that can process FWD data. Therefore, it must be converted into a more common file format, such as *.fwd. A converter that was developed by Gary Sanati of Foundation Mechanics, Inc. resolved this issue by converting the JILS file into a *.fwd format. The user interface of the converter is shown below in Figure 3.16.

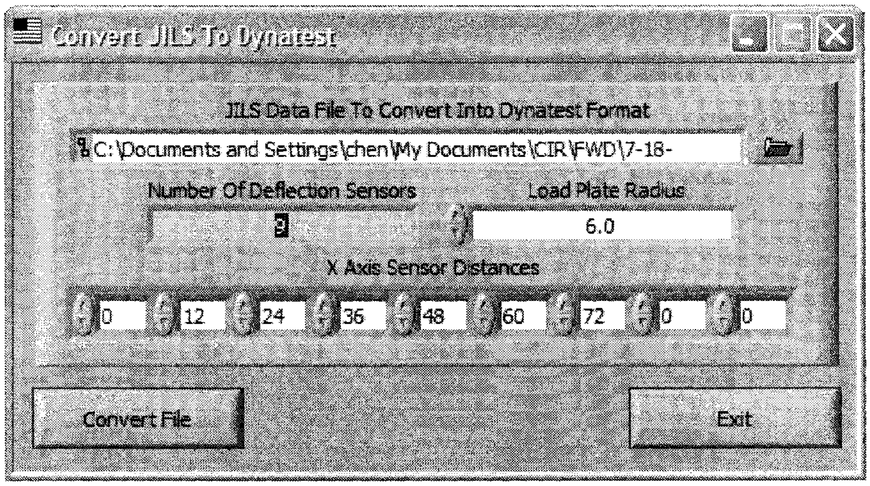


Figure 3.16 FWD raw data converter

Several computer packages were tested for processing the converted data. The packages include: ELMOD (Dynatest) [83], MichBack (Michigan DOT) [84], BACKFAA(The Federal Aviation Administration) [85], FWDAREA (Washington DOT) [86], and PCASE (U. S. Army Corps of Engineers) [87].

Only FWDAREA could recognize the converted file correctly. The other packages could not read the file. However, FWDAREA failed to normalize the weight of the load plate.

Artificial Neural Networks (ANN) have been used to predict the support condition of various types of pavements. Researchers at Iowa State University developed an ANN algorithm for flexible pavements in Iowa [45]. This algorithm was used to analyze the FWD data for this project, however, the results were counter-intuitive. One reason was that the algorithm was not designed for the CIR structure pavement specifically. The second reason was that this algorithm requires accurate input of all layer thickness. In some cases where accurate measures of actual thickness was not available, an approximated thickness was used; this approximation may have compromised the results.

BACKFAA was then chosen to analyze the FWD raw data because its consideration of layer thickness and the user' control of error level. Figure 3.17 shows the interface of the software. This program attempts to match the calculated deflection curve with the actual deflection curve by minimizing the mean square errors. The program required manual input of the FWD deflections, and the results were satisfactory.

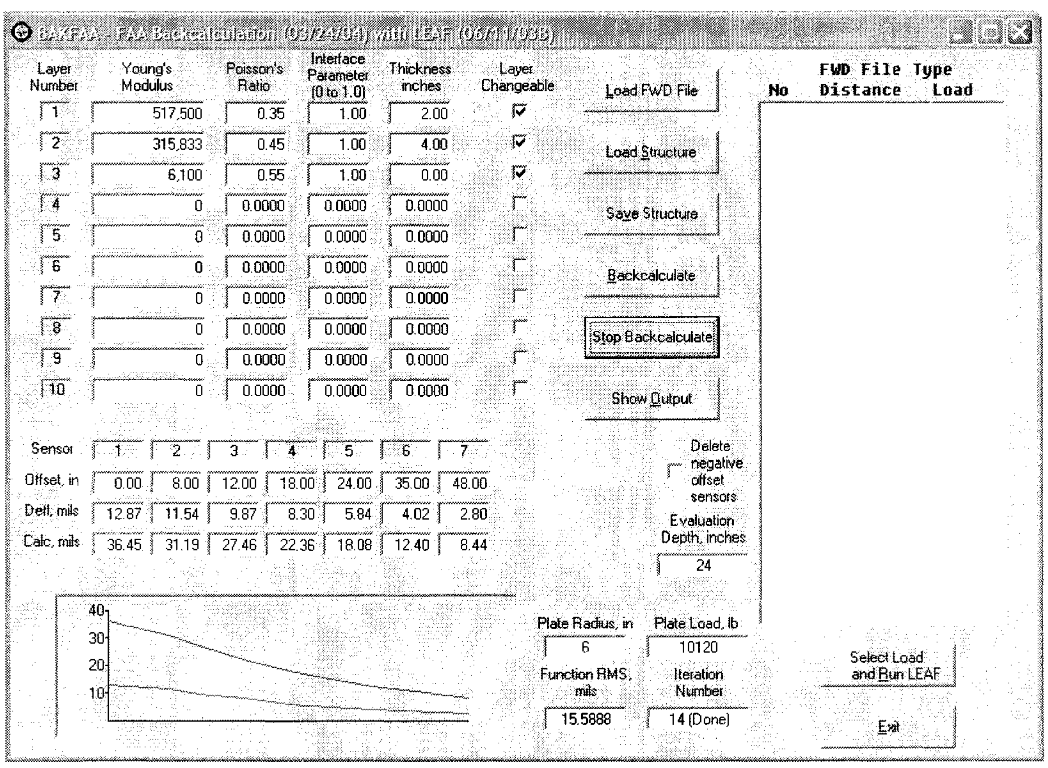


Figure 3.17 BACKFAA interface

Dr. Hosin "David" Lee from University of Iowa suggested the following initial inputs for BACKFAA (Table 3.11). A summary of the results is provided in Appendix E.

Table 3.11 Initial inputs for BACKFAA

Layer	Young's Modulus (psi)	Poisson's Ratio
HMA	450,000	0.35
CIR	250,000	0.40
FND	5,000	0.45

3.2.5 Laboratory Test Methodology

The first draft for this section was developed by Sunghwan Kim, a graduate student at Iowa State University who was included in the project team for the laboratory investigation portion of the study. The author edited the draft and included it in this dissertation.

For each selected road, six cores (4" in diameter) were typically taken by an Iowa DOT special investigation crew. The total number of cores were 182, including 8 cores for two sections and cores that were taken from both lanes of one test section (Figure 3.18). These cores were transported to Iowa State University's asphalt laboratory where laboratory tests were conducted. The laboratory testing effort was divided into three phases:

1. Mixture properties testing,
2. Asphalt binder properties testing, and
3. Aggregate properties testing.

Preliminary issues

In order to develop a protocol for the lab testing, the research project steering committee (Table 3.12) discussed the objectives and questions that required answers for each testing phase are summarized in Table 3.13.

Figure 3.18 Locations of FWD tests

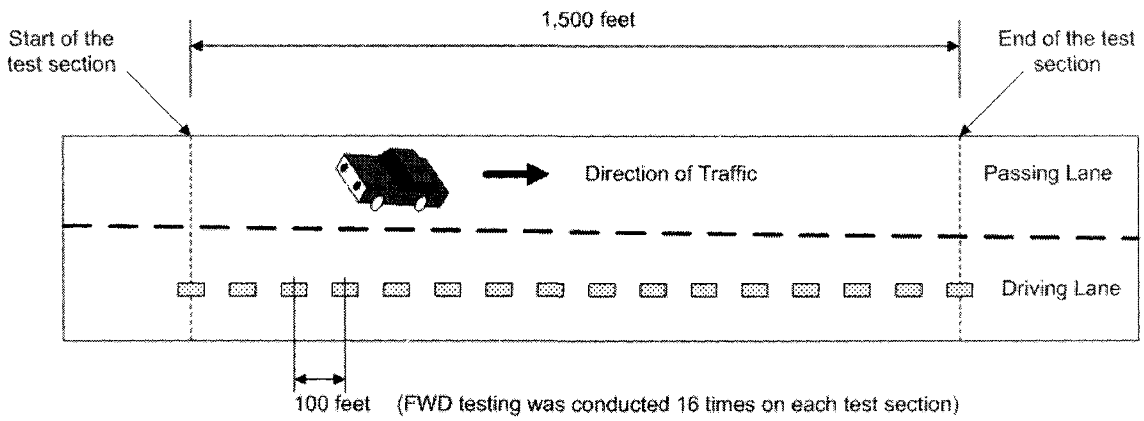


Table 3.12 Research project steering committee

Name	Title	Organization
Larry Mattusch	County Engineer	Scott County
Tom Stoner	County Engineer	Harrison County
Bob Nady	Consultant	Construction Materials Testing
Michael Heitzman	Bituminous Materials, Engineer	Iowa Department of Transportation (DOT)
Mike Kvach	Executive Vice President	Asphalt Paving Association of Iowa (APAI)
Hosin "David" Lee	Professor	University of Iowa
Charles Jahren	Professor	Iowa State University
Don Chen	Researcher	Iowa State University

Table 3.13 Questions considered in each testing phase

Phase	Question
1. Mixture properties test	• Which performance tests will be conducted? • What specimen size will be used for mixture performance test? • How will volumetric properties be measured?
2. Binder properties test	• What methods will be used for separating binder from aggregate? • Which types of binder tests will be conducted?
3. Aggregate property test	• Which aggregate properties tests will be conducted?

Laboratory testing protocol

The laboratory testing process is illustrated in the flowchart (Figure 3.19). ASTM, AASHTO, or other material testing protocols were followed whenever possible. For discussion purposes, laboratory work can be broken down into seven distinct steps as shown below.

1. Calibration of test equipment needed to conduct the proposed laboratory test;
2. Sample preparation for mixture performance test (Cutting);
3. Bulk specific gravity (G_{mb});
4. Conditioning, mixture performance test, taking pictures of broken faces (IDT);
5. Theoretical maximum specific gravity (G_{mm});
6. Extraction of binder from mixture;
7. Aggregate property tests; and
8. Binder property tests.

Test equipment calibration

After the laboratory test protocol was selected, the required equipment was calibrated with the assistance of the Iowa DOT bituminous materials engineer and the engineer's staff. The measurement calibration for each piece of required equipment is listed in Table 3.14.

Sample preparation for mixture performance test

The core samples of CIR material were uniform in diameter (4 inches matching the core bit inside diameter), but non-uniform in height. CIR samples, that were not two inches in height were cut to that height because the mixture performance test required two inch by four inch samples. Pictures were taken of all samples before they were cut. To identify the CIR layer, each core was rolled on a lab table and marked at the place where the contact between layers were observed. The thickness of the HMA surface layer and CIR base layer in each sample was measured for FWD analysis. All of samples were transferred to the Iowa DOT concrete lab and the samples were uniformly cut with a saw. During the cutting procedure, each sample was fully sprayed with water; therefore, samples were dried before measuring bulk specific gravity (G_{mb}).

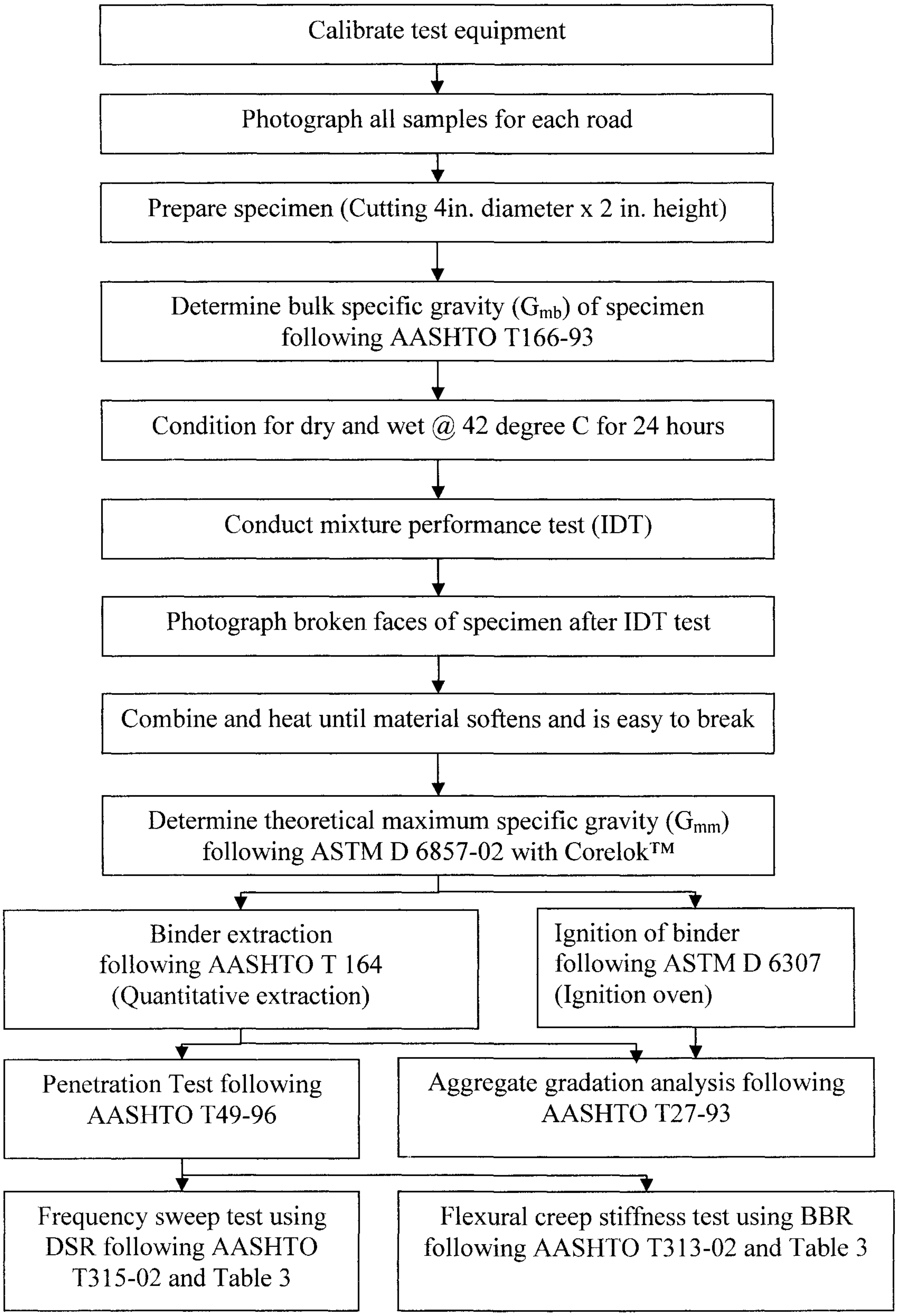


Figure 3.19 Flow Chart of Laboratory Testing

Table 3.14 The measurements calibrated at each equipment

Equipment	Measurements calibrated
Scale	Mass
Thermometer	Temperature
Dynamic shear rheometer (DSR)	Temperature, Viscosity
Bending beam rheometer (BBR)	Temperature, force, deflection and compliance
Indirect tensile test apparatus	Force
Ignition oven	Binder content

Bulk specific gravity

The dried samples were transferred to Iowa State University asphalt laboratory where the bulk specific gravity (G_{mb}) was obtained following AASHTO T166-93. Each dried sample was placed on a scale to measure the weight, then it was immersed in a water bath at 25 ± 1°C for 4 ± 1 minute and weighted while suspended in the water bath to obtain the immersed weight. The samples were then taken from the water bath, rolled on damp towel, and placed on a scale to measure the surface dry weight. The bulk specific gravity was calculated using three measuring parameters (the weight of dry sample, the weight of sample in water bath, and the weight of surface – dry sample in air). After obtaining the $G_{mb,}$ each sample was dried to remove moisture absorbed during the test procedure.

Conditioning, mixture performance test, and visual inspection

Samples for each road were divided into two groups to investigate possible moisture damage effects. One group of samples were measured after dry conditioning, and the other group was measured after wet conditioning. To ensure the temperature inside of the samples during the mixture performance test was 40° C, which was intended to represent the average CIR base layer temperature during a summer day in Iowa, the dry conditioned group was placed in a temperature controller setting at 42° C (two degrees higher than the intended test temperature for the anticipated loss of temperature during the test). The wet conditioned group was placed in a water bath with temperature set at 42° C for 24 hours. The number of CIR specimens from each road that survived the cutting process varied due to the differing severity of deterioration from sample to sample. The number of mixture performance test specimens for each group was determined by the number of samples that survived the cutting process (Table 3.15).

Table 3.15 The number of mixture performance test specimens for each group

Number of specimens obtained through cutting	Wet (40°C, 24 hr)	Dry (40°C, 24hr)
6	3	3
5	3	2
4	4	0
<4	<4	0

The Indirect Tensile Test was selected as the mixture performance test for this project because it measures tensile stress that the specimen can resist, this is one of the critical responses in a CIR base layer. The Indirect Tensile Test is known to be a good indicator of possible moisture damage that may exist in the samples. Tensile strength and flow value was obtained following ASTM D4123 - 82 and AASHTO T245-94.

Pictures of the broken faces of specimens were taken after the IDT test was performed. The broken faces of specimens provided a visual indication of moisture damage: if the specimens broke through the aggregate, a good bond was indicated and moisture damage was not suspected. If the specimens broke through the bond between the aggregate and the binder, a poor bond was suspected due to moisture damage.

Theoretical maximum specific gravity

The CIR specimens and residual CIR material for each road were combined to obtain the required sample size for the theoretical maximum specific gravity test. The combined CIR material from each road was placed in a pan and heated at 135°C (275°F) until the material was soft enough to be broken manually. After the combined CIR material was broken, it was cooled to room temperature. The theoretical maximum specific gravity determination followed ASTM D6857-02 using the CoreLok ™ procedure. ASTM D6857-02 requires that each sample to be sealed inside a plastic bag and then immersed in a water bath with a cut in the plastic bag. The mass of the immersed sample was then recorded. The theoretical maximum specific gravity was calculated using two parameters (the mass of dry sample and the mass of immersed sample). After obtaining the theoretical maximum specific gravity the sample was dried before the next test was conducted.

Binder and aggregate extraction from mixture

The binder was burned from the aggregate using the ignition oven method (ASTM D6307-98) and the quantitative extraction method (AASHTO T164 -01). The binder content of the mixture can be obtained through the two test methods previously mentioned, however; there are some differences with regard to the remaining material between the two methods. The ignition oven method has the advantage of convenience; however, only the aggregate remains after the test because the binder is completely incinerated. The quantitative extraction method has the advantage of not destroying the binder or aggregate during the test. Samples from each road were broken into two groups to be tested using these two methods. For the quantitative extraction method, more than 2,000g of mixture is required. Samples from each road were transferred to the Iowa DOT bituminous laboratory where the quantitative extraction was performed. The remaining sample was used to conduct the ignition oven test in order to determine the binder content.

Aggregate property test

An aggregate gradation analysis (AASHTO T27-93) was conducted to identify the aggregate properties. Aggregate properties test such as coarse aggregate angularity, fine aggregate angularity and aggregate specific gravity were considered, but excluded during the original planning stage of this laboratory investigation. This decision was made because there was a concern that these properties of the aggregate might have changed during prior sampling and testing steps. An aggregate gradation sample for each road was obtained after the ignition oven burned the asphalt binder from the mixture. After completing gradation analysis (AASHTO T27-93), the aggregate was visually inspected and classified as one of these types: crushed limestone, crushed gravel, or natural gravel.

Binder properties tests

The binder in CIR material is a combination of old binder in existing asphalt pavement and emulsified or foamed binder added during construction. This combination of materials types complicates the determination of binder properties. Three test methods were used – an empirical method and two rheological test methods were used. The penetration test (AASHTO T49-96) was undertaken as the empirical test method. A frequency sweep test using dynamic shear rheometer (DSR) and flexural creep stiffness test using bending beam rheometer (BBR) were undertaken as the rheological test methods at intermediate temperatures and at low temperatures, respectively. The frequency sweep test was conducted according to AASHTO T315-02 and the flexural creep stiffness test was conducted according to AASHTO T313-02. A more detailed temperature and frequency test protocol as seen in Table 3.16 was suggested to reflect Iowa climatic condition.

Table 3.16 Test protocol for DSR and BBR

	DSR (Frequency Sweep Test)	**BBR (Flexural Creep Stiffness Test)**
Spindle Size	8mm (the small one)	N/A
Shear strain	2 %	N/A
Temperature (degree C)	20,25,30,35,40,45,50	-12,-18,-24,-30 ,-36
Frequency (Hz)	0.1,0.3,0.5,0.9,1.6,2.9, 5.1, 9.2,16.6,30.1	N/A
Time (Sec)	N/A	8,15,30,60,120

Table 3.17 shows the number of cores and the number of replications of each test.

This chapter has summarized the data collection, materials characterization, and methodologies that were used in this study. The summary of collected data can be found in Appendix C.

Table 3.17 Number of cores and replications

Road	# of cores	Gmb	IDTwet	IDTdry	Gmm	Gradation	Extraction	Penetration
Boone 198th	8	12	6	6	2	1	1	1
Boone E52	8	8	4	4	2	1	1	1
Bulter T16	6	6	3	3	2	1	1	1
Calhoun IA175	6	3	3	0	2	1	1	1
Carroll N58	6	6	3	3	2	1	1	1
Carroll N of Breda	6	4	4	0	2	1	1	1
Cerro Gordo B43	6	5	3	2	2	1	1	1
Cerro Gordo S. Shore	6	4	4	0	2	1	1	1
Clinton E50	6	6	3	3	2	1	1	1
Clinton Z30	6	6	3	3	2	1	1	1
Delaware US20	6	6	3	3	2	1	1	1
Greene IA144	6	5	3	2	2	1	1	1
Guthrie IA4	6	2	2	0	2	1	1	1
Hardin D35	6	6	3	3	2	1	1	1
Harrison IA44	6	6	3	3	2	1	1	1
Jackson US61	6	4	4	0	2	1	1	1
Montgomery IA48	6	7	4	3	2	1	1	1
Muscatine F70	6	4	0	2	2	1	1	1
Muscatine G28 WB	6	4	4	0	2	1	1	1
Muscatine G28 EB	6	4	4	0	2	1	1	1
Muscatine Y14 NB	6	6	3	3	2	1	1	1
Muscatine Y14 SB	6	5	3	2	2	1	1	1
Story S14 NB	6	6	3	3	2	1	1	1
Story S14 SB	6	2	2	0	2	1	1	1
Tama V18 A	6	6	3	3	2	1	1	1
Tama V18 B	6	8	4	4	2	1	1	1
Winnebago R34 A	6	2	2	0	2	1	1	1
Winnebago R34 B	6	2	2	0	2	1	1	1
Winnebago R60	6	3	3	0	2	1	1	1
Total	**178**	**148**	**91**	**55**	**58**	**29**	**29**	**29**

CHAPTER 4. EVALUATION OF LONG-TERM PERFORMANCE OF COLD IN-PLACE RECYCLED ROADS

4.1 Data

In this study, data were obtained from the Iowa DOT and county engineers, the pavement distress survey, falling weight deflectometer (FWD) tests, and lab tests. As described below.

4.1.1 General data

Project Age is defined as the number of years that the project has been recycled. For county roads, this information was provided by county engineers; for state highways, this information was provided by the Iowa DOT.

Traffic is represented by Average Annual Daily Traffic (AADT) of the test section. AADT can be found from the transportation maps at the Iowa DOT's web site [88]. 24 sample roads were divided into to two groups according to traffic volume. As follows:

- Low traffic roads (AADT < 800), and
- High traffic roads (AADT > 800).

Most county roads were low traffic roads. One state highway, IA 44 in Harrison County, was in level 1 because of its traffic level of 770 AADT was less than the cutoff value of 800. All other State and U.S. Highways and some county roads with high traffic volume were in the high traffic roads category. Table 4-1 shows how the roads were divided into the two different traffic levels.

Table 4.1 Traffic Level of sample roads

Road	Traffic (AADT)	Traffic Level
Boone 198th	130	Low
Carroll N of Breda	190	Low
Carroll N58	340	Low
Boone E52	390	Low
Winnebago R34	400	Low
Cerro Gordo B43	450	Low
Clinton E50	540	Low
Winnebago R60	550	Low
Tama V18	570	Low
Bulter T16	610	Low
Story S14	740	Low
Harrison IA44	770	Low
Clinton Z30	890	High
Hardin D35	930	High
Muscatine G28	1,100	High
Cerro Gordo SS	1,140	High
Muscatine F70	1,250	High
Muscatine Y14	1,490	High
Calhoun IA175	1,255	High
Greene IA144	1,315	High
Guthrie IA4	1,518	High
Montgomery IA48	1,866	High
Delaware US20	4,900	High
Jackson US61	5,842	High

The cumulative traffic volume, the product of the age and the traffic volume of a CIR road, was considered as one of the factors in this study.

$$\text{Cumulative traffic} = \text{Age} * \text{Traffic volume}$$

4.1.2 Pavement Distress Survey

The pavement distress survey was conducted by the researchers at University of Iowa. Pavement condition index (PCI) [62] and present serviceability index (PSI) [89] were collected.

In this study, PSI was obtained by a subjective measurement of the rideability and appearance of the road as determined by two raters. Because PSI is subjective in nature, it was not used as an index of pavement performance.

Relative PCI, the difference between the observed PCI and the expected PCI, was used to represent which CIR pavements are performing especially well and which are performing especially poorly.

$$\text{Relative PCI} = \text{Observed PCI} - \text{Expected PCI}$$

The observed PCI was obtained from the pavement distress survey described in Chapter 3. The expected PCI was calculated based on a statistical relationship (as described below) between the observed PCI and age. Large positive values of relative PCI value indicate that the CIR road has performed better than expected.

Expected PCI

A linear regression analysis was performed to determine the expected PCI. The response in this analysis is observed PCI of all 24 CIR roads. The independent variable is age. The response and the independent variable were analyzed separately for each traffic level.

Figure 4.1 shows the output of a polynomial regression of observed PCI versus age. The middle line represents the regression line, the lines next to the regression line represent 95 percent confidence interval, and the outside lines represent 95 percent prediction interval. The expected PCI can be calculated from the regression equations that were determined by the regression lines (black lines). The regression equations are:

- All CIR roads: *Expected PCI = 96.97 - 0.0067*Age* ^{3}

Figure 4.1 All 24 CIR roads: Observed PCI vs. Age

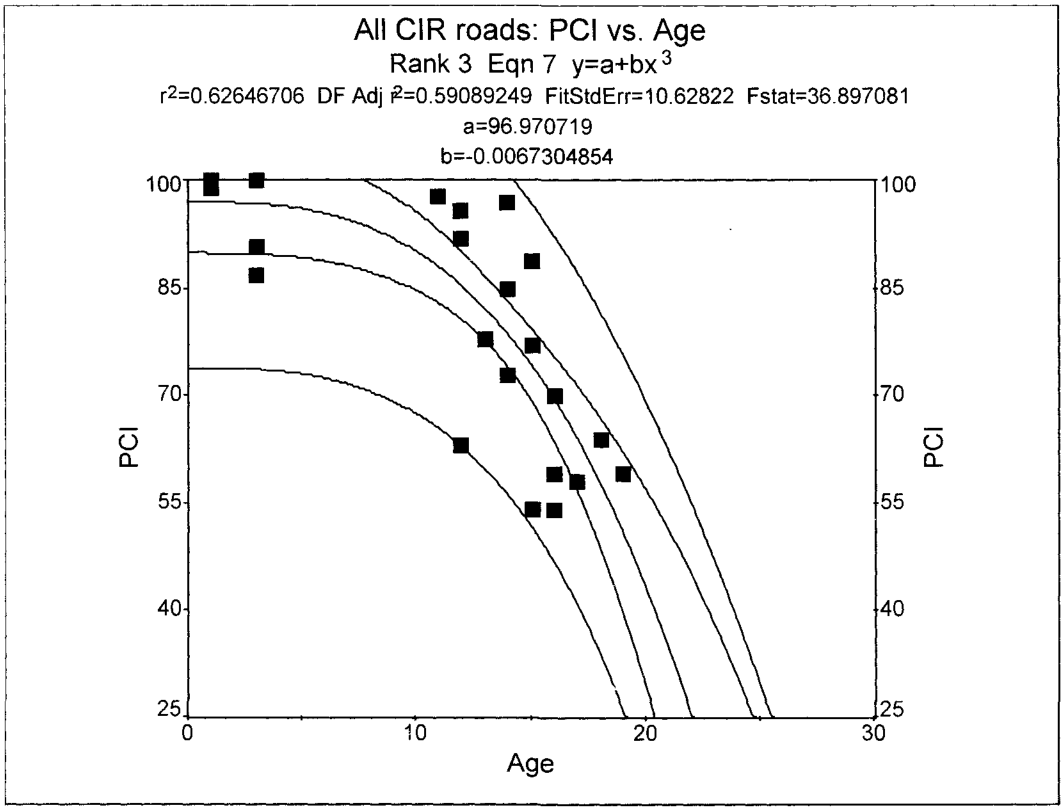


Table 4.2 below shows the summary of PCI.

Table 4.2 The summary of PCI

Road	Age	Traffic	Observed PCI	Expected PCI (all)	Relative PCI (all)
Boone198th	17	130	58	64	-6
CarrollNofBreda	1	190	99	97	2
CarrollN58	3	340	100	97	3
BooneE52	14	390	85	79	6
WinnebagoR34	15	400	89	74	15
CerroGordoB43	16	450	59	69	-10
ClintonE50	19	540	59	51	8
WinnebagoR60	15	550	77	74	3
TamaV18	14	570	97	79	18
BulterT16	12	610	96	85	11
StoryS14	1	740	100	97	3
HarrisonIA44	3	770	100	97	3
ClintonZ30	16	890	70	69	1
HardinD35	13	930	78	82	-4
MuscatineG28	14	1100	73	79	-6
CerroGordoSS	15	1140	54	74	-20
MuscatineF70	12	1250	92	85	7
CalhounIA175	12	1255	63	85	-22
GreeneIA144	16	1315	54	69	-15
MuscatineY14	18	1490	64	58	6
GuthrieIA4	11	1518	98	88	10
MontgomeryIA48	3	1866	100	97	3
DelawareUS20	3	4900	91	97	-6
JacksonUS61	3	5842	87	97	-10

4.1.3 Falling Weight Deflectometer (FWD) Tests

As described in Section 3.2.4, FWD tests were conducted on 24 sample roads. Extreme deflections caused by errors listed in Table 3.5 were excluded from the study. For each drop, the resilient modulus of three layers (HMA, CIR, and FND layer) were calculated. Then the average resilient modulus was used to represent stiffness of the pavement layers. Table 4.3 summarizes the resilient moduli.

Table 4.3 Summary of the resilient moduli

Road	HMA Modulus (ksi)	CIR Modulus (ksi)	FND Modulus (ksi)
Boone198th	700	1,100	15
CarrollNofBreda	4,300	3,000	11
CarrollN58	4,500	2,800	15
BooneE52	1,300	1,100	12
WinnebagoR34	6,300	4,400	17
CerroGordoB43	11,400	9,900	25
ClintonE50	3,600	2,800	15
WinnebagoR60	13,100	14,500	21
TamaV18	2,000	1,500	19
BulterT16	600	500	10
StoryS14	1,200	700	15
HarrisonIA44	7,300	5,100	19
ClintonZ30	5,300	6,100	23
HardinD35	1,300	900	10
MuscatineG28	1,800	1,700	21
CerroGordoSS	12,600	10,100	25
MuscatineF70	1,500	1,000	25
CalhounIA175	10,500	10,800	21
GreeneIA144	1,000	800	13
MuscatineY14	1,200	1,000	13
GuthrieIA4	1,900	700	20
MontgomeryIA48	3,600	2,100	24
DelawareUS20	6,500	5,200	66
JacksonUS61	18,400	11,900	33

4.1.4 Lab Tests

Various lab tests were conducted and the following data were collected:

- Bulk specific gravity (G_{mb}) and theoretical maximum specific gravity (G_{mm}) of CIR specimen – these gravities were used to calculate air void (V_a, %) of the CIR mixture [90]. Thus only V_a was considered in the study. G_{mb} and G_{mm} values can be found in Appendix C.

- Indirect tensile (IDT) strength of wet and dry CIR specimen (psi) – only the indirect tensile strength of wet CIR specimen (IDT_{wet} strength) was included in the analysis, even though some IDT_{dry} tests were conducted. The reason was that the researchers desired the opportunity to investigate the potential effect of the stripping on CIR pavement performance, and IDT_{wet} strength is a good indicator of possible stripping. Therefore, the best specimens, those closer to the standard specimen, 4" in diameter and 2" in height, were used to conduct IDT_{wet} specimen tests. The remaining specimens were used to conduct IDT_{dry} specimen tests. Although this procedure better enabled researchers to investigate possible stripping issues, the side effect was that IDT_{dry} strengths of some specimens were lower than their IDT_{wet} strength, possibly because of interior specimen quality. IDT_{wet} and IDT_{dry} strength can be found in Appendix C.

  In one case (Muscatine F70), an IDT_{wet} strength test was not conducted because the specimen disintegrated during wet conditioning.

- Pictures of broken faces of wet CIR specimen after indirect tensile tests – researchers expected that these pictures might be used to visually detect possible stripping issues. However, when researchers actually examined the photos after testing, they were unable to determine whether or not stripping might have been an issue.
- Aggregate gradation of CIR mixture – the gradation (fine or coarse aggregate) was not considered in the study because it was adjusted by contractors according to ASTM D 6307, thus it was nearly the same for all CIR roads. Immediately after milling, the RAP gradations may vary from one road to another. However, the recycling equipment adjusts the final gradation that meets the DOT specification during the crushing and screening process. If constructed properly, the final gradation should be nearly the same for all CIR roads. All 24 CIR roads in this study had graduations that would be considered to be open-graded by an asphalt mix designer. Aggregate gradations can be found in Appendix D.
- The depth of penetration of CIR binder (0.1 mm or dmm, Appendix C) – The depth was obtained from the penetration test that was undertaken as an empirical test method to measure the consistency of asphalt binder. Some penetration readings were close to zero. It was possibly because the binder was overheated during the extraction process. The results were not included in the statistical analysis.
- Complex shear modulus (G*, Pa) – G* was obtained from the dynamic shear rheometer (DSR) test. G* has two portions: the elastic portion and the viscous

portion (Figure 4.2). In order to resist rutting, the complex shear modulus elastic portion should be large. In order to resist fatigue cracking, the complex shear modulus viscous portion should be small. Phase angles in this study range from 50 to 70 degree. Since this is a relatively small range, phase angles were not considered in the study. Since PCI was affected by rutting and cracking, G* is considered in the study (Table 4.4).

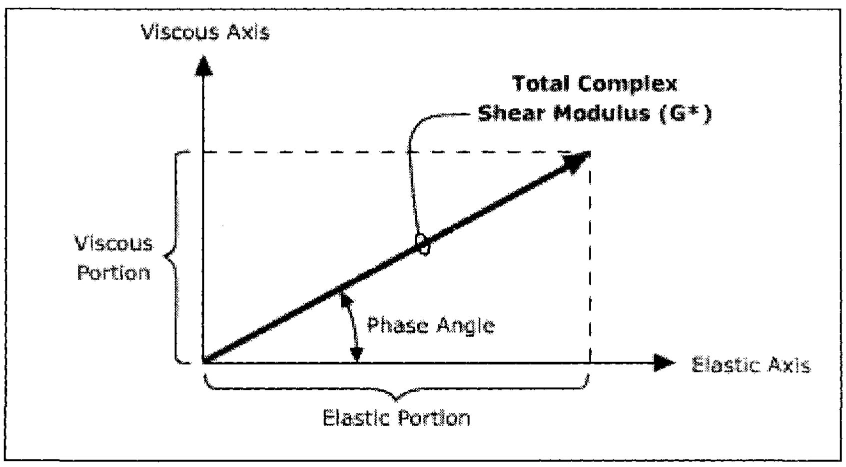


Figure 4.2 Complex shear modulus component

(http://training.ce.washington.edu/WSDOT/)

- Flexural creep stiffness (S(t)) – S(t) was obtained from the bending beam rheometer (BBR) test. S(t) represents asphalt binder stiffness after two hours of loading at low temperatures where the chief failure mechanism is thermal cracking. In this study, BBR samples were tested at -12°C, -18°C, and -24°C, respectively. The m-value indicates the rate of change of the stiffness, S(t), over time. One of the committee members recommended that S(t) and m-value obtained from tests at -18°C were considered in the study (Table 4.4).

- Type of aggregate – In this study, three types of aggregate were identified in the CIR layer (Table 4.4). They are: limestone, crushed gravel, and gravel. Among 24 projects, 34% used limestone, 40% used crushed gravel, and the rest of 26% used gravel. The type of aggregate was a variable that was considered in the statistical analysis. Since this variable was a nominal variable, in order to be processed by most of commonly available Flexural statistical software packages (for example, SAS), three different types were converted from nominal (qualitative) variables into quantitative variables. As shown below:

    - Limestone → 1,
    - Crushed gravel → 2,
    - Gravel → 3.

4.1.5 Summary of data

The data that were initially considered in the study are shown in Table 4.4. Summary statistics are shown in Table 4.5.

Table 4.4 Summary of data (sorted by Traffic)

Road	Age (year)	Traffic (AADT)	Cumulative Traffic	Observed PCI	Expected PCI	Relative PCI
Boone198th	17	130	2210	58	64	-6
CarrollNofBreda	1	190	190	99	97	2
CarrollN58	3	340	1020	100	97	3
BooneE52	14	390	5460	85	79	6
WinnebagoR34	15	400	6000	89	74	15
CerroGordoB43	16	450	7200	59	69	-10
ClintonE50	19	540	10260	59	51	8
WinnebagoR60	15	550	8250	77	74	3
TamaV18	14	570	7980	97	79	18
BulterT16	12	610	7320	96	85	11
StoryS14	1	740	740	100	97	3
HarrisonIA44	3	770	2310	100	97	3
ClintonZ30	16	890	14240	70	69	1
HardinD35	13	930	12090	78	82	-4
MuscatineG28	14	1100	15400	73	79	-6
CerroGordoSS	15	1140	17100	54	74	-20
MuscatineF70	12	1250	15000	92	85	7
CalhounIA175	12	1255	13805	63	85	-22
GreeneIA144	16	1315	19725	54	69	-15
MuscatineY14	18	1490	26820	64	58	6
GuthrieIA4	11	1518	15180	98	88	10
MontgomeryIA48	3	1866	5598	100	97	3
DelawareUS20	3	4900	14700	91	97	-6
JacksonUS61	3	5842	17526	87	97	-10

Table 4.4 (continued)

Road	HMA Modulus (ksi)	CIR Modulus (ksi)	FND Modulus (ksi)	Va (%)	IDTwet (psi)	G* (kpa)	S(t) (Mpa)	m-value	Aggregate
Boone198th	700	1,100	15	6.5	19.4	200	204	0.29	3
CarrollNofBreda	4,300	3,000	11	11.3	12.3	1,700	681	0.18	3
CarrollN58	4,500	2,800	15	9.5	18.5	200	229	0.32	2
BooneE52	1,300	1,100	12	9.7	25.9	2,100	410	0.2	3
WinnebagoR34	6,300	4,400	17	13.3	23.7	2,000	745	0.18	2
CerroGordoB43	11,400	9,900	25	11.5	17.6	1,000	603	0.2	1
ClintonE50	3,600	2,800	15	12.7	28.8	1,900	678	0.18	1
WinnebagoR60	13,100	14,500	21	13.4	19.7	4,100	962	0.16	2
TamaV18	2,000	1,500	19	9.2	24	300	348	0.27	2
BulterT16	600	500	10	9.3	19.9	800	442	0.22	2
StoryS14	1,200	700	15	8.5	15.4	500	454	0.22	2
HarrisonIA44	7,300	5,100	19	4.5	28.7	300	285	0.27	2
ClintonZ30	5,300	6,100	23	11.1	43.47	1,300	655	0.21	1
HardinD35	1,300	900	10	8.3	43.47	800	494	0.21	3
MuscatineG28	1,800	1,700	21	11.1	16.5	1,200	532	0.21	1
CerroGordoSS	12,600	10,100	25	10.8	28	300	391	0.23	1
MuscatineF70	1,500	1,000	25	13.2		200	404	0.24	3
CalhounIA175	10,500	10,800	21	9.5	17.1	800	429	0.21	2
GreeneIA144	1,000	800	13	6.6	17.7	200	436	0.24	2
MuscatineY14	1,200	1,000	13	14.3	26.4	1,300	533	0.21	1
GuthrieIA4	1,900	700	20	11.8	24.2	1,500	651	0.18	3
MontgomeryIA48	3,600	2,100	24	5.8	25.6	200	319	0.25	1
DelawareUS20	6,500	5,200	66	7.6	16.3	200	318	0.27	2
JacksonUS61	18,400	11,900	33	9.8	9.6	400	583	0.2	1

Table 4.5 Summary statistics (Range (Mean/Standard Deviation)**)**

	Number of roads	Va (%)	IDTwet (psi)	G* (1000KPa)
Overall	24	4.5 ~ 14.3 (10/2.6)	9.6 ~ 43.5 (22.7/8.4)	0.2 ~ 4.1 (1.0/0.9)
Low Traffic Roads (AADT < 800)	12	4.5 ~ 13.4 (10/2.7)	12.3 ~ 28.8 (21.2/5.1)	0.2 ~ 4.1 (1.2/1.2)
High Traffic Roads (AADT > 800)	12	5.8 ~ 14.3 (10/2.6)	9.6 ~ 43.4 (24.4/10.9)	0.2 ~ 1.5 (0.7/0.5)
Roads with poor performance (Relative PCI < 0)	9	6.5 ~ 11.5 (9.1/1.9)	9.6 ~ 43.5 (20.6/9.8)	0.2 ~ 1.2 (0.6/0.4)
Roads with better performance (Relative PCI > 0)	15	4.5 ~ 14.3 (10.5/2.8)	12.2 ~ 43.5 (24.1/7.4)	0.2 ~ 4.1 (1.2/1.1)
Low Traffic / poor performance Roads	2	6.5 ~ 11.5 (9.0/3.5)	17.6 ~ 19.4 (18.8/1.2)	0.2 ~ 1.0 (0.6/0.6)
Low Traffic / better performance Roads	10	4.5 ~ 13.4 (10.2/2.7)	12.2 ~ 28.8 (21.7/5.5)	0.2 ~ 4.1 (1.4/1.2)
High Traffic / poor performance Roads	7	6.6 ~ 11.1 (9.1/1.7)	9.6 ~ 43.5 (21.2/11.2)	0.2 ~ 1.2 (0.6/0.4)
High Traffic / better performance Roads	5	5.8 ~ 14.3 (11.2/3.3)	24.2 ~ 43.5 (29.9/9.1)	0.2 ~ 1.5 (0.9/0.7)

4.2 Statistical Analysis and Results

Statistical analyses were performed to evaluate CIR pavement performance, which was represented by relative PCI. The independent variables that were initially considered in the analyses were listed below. The correlation matrix was developed and variance inflation factors (VIF) were calculated in order to reduce or eliminate multicollinearity among variables. The 24 CIR roads were first considered as one group, and then the 24 roads were divided into two groups. One group consisted of roads with higher traffic volume (AADT>800); another group consisted of roads with lower traffic volume (AADT<800). Within each group, a descriptive method and a mathematical method were applied to develop a first-order model (in which each of the independent variables appears, but there are no cross-product terms or terms in powers of the independent variables). Then a more complicated model with higher-degree terms was developed for all 24 CIR roads. The first-order models were developed in this study because their results are easy to interpret and thus may be preferred by practitioners. The results of analyses are presented in this section.

Independent variables that were initially considered are:

1. Cumulative traffic,
2. Resilient modulus of the HMA layer (psi),
3. Resilient modulus of the CIR layer (psi),
4. Resilient modulus of the FND layer (psi),
5. Indirect tensile strength of the mixture (wet samples) (psi),
6. Air voids (V_a,%),

7. Complex shear modulus (G*, KPa),

8. Flexural creep stiffness (S(t), MPa),

9. m-value, and

10. Types of aggregate.

4.2.1 Multicollinearity in Multiple Regressions

Multicollinearity exists when two independent variables are highly correlated and both convey essentially the same information. In this case, neither may contribute significantly after the other one is included in the model. Multicollinearity presents challenges in attempting to understand how the various variables impact the response. An important variable might be excluded from the final model because of its smaller significance. In order to remove multicollinearity, a correlation matrix was developed. The matrix consists of correlation coefficients that indicate the strength of the linear relationships between each pair of variables. Among pairs of independent variables with higher correlation coefficients, if one of the variables does not seem logically essential to the model, removing it may reduce or eliminate multicollinearity. Another more sophisticated way of diagnosing multicollinearity is to examine the variance inflation factors (VIF). VIF measures the amount that the variance (square of the standard error) of a coefficient is increased because of multicollinearity. If the VIF is 1, there is no multicollinearity. If it is very large, such as 10 or more, multicollinearity is a serious concern. Table 4.6 through 4.8 show the correlation matrix of all 24 CIR traffic roads/low traffic roads/high traffic roads, respectively. Table 4.9 shows the VIF values of the variables that were initially considered in this study.

Correlations that are higher than 0.80 are highlighted in the correlation matrices. Variables with high VIF values (VIF > 7) are highlighted (Table 4.9). The following variables were removed from the study since they had a larger correlation with other variables and a high VIF value. In addition, they were relatively irrelevant to the response compared with other variables.

- The HMA modulus was removed from the study since it is highly correlated with the CIR modulus. The HMA modulus was removed instead of the CIR modulus because this study was undertaken to investigate the material properties of the CIR layer, not the HMA layer.
- The m-value was removed from this study because of its high correlation with S(t). In addition, m-value is derived from S(t) – it is the rate of changes in S(t) over the loading time. Thus the decision was made to retain the original variable rather than the derived variable.

Table 4.6 Correlation matrix – all 24 CIR roads

	Cumulative Traffic	Relative PCI	HMA Modulus	CIR Modulus	FND Modulus	Va	IDTwet	G	S	m	Aggre-gate
Cumulative Traffic	1.00	-0.31	0.14	0.14	0.25	0.31	0.15	-0.03	0.18	-0.24	-0.42
Relative PCI	-0.31	1.00	-0.44	-0.45	-0.29	0.30	0.25	0.36	0.22	-0.11	0.13
HMA Modulus	0.14	-0.44	1.00	0.95	0.43	0.18	-0.26	0.14	0.31	-0.23	-0.40
CIR Modulus	0.14	-0.45	0.95	1.00	0.39	0.25	-0.19	0.29	0.39	-0.28	-0.37
FND Modulus	0.25	-0.29	0.43	0.39	1.00	-0.14	-0.22	-0.21	-0.12	0.19	-0.26
Va	0.31	0.30	0.18	0.25	-0.14	1.00	0.02	0.70	0.76	-0.68	-0.24
IDTwet	0.15	0.25	-0.26	-0.19	-0.22	0.02	1.00	0.08	0.04	-0.05	-0.02
G	-0.03	0.36	0.14	0.29	-0.21	0.70	0.08	1.00	0.84	-0.75	0.11
S	0.18	0.22	0.31	0.39	-0.12	0.76	0.04	0.84	1.00	-0.89	-0.12
m	-0.24	-0.11	-0.23	-0.28	0.19	-0.68	-0.05	-0.75	-0.89	1.00	0.05
Aggregate	-0.42	0.13	-0.40	-0.37	-0.26	-0.24	-0.02	0.11	-0.12	0.05	1.00

Table 4.7 Correlation matrix – low traffic roads

	Cumulative Traffic	Relative PCI	HMA Modulus	CIR Modulus	FND Modulus	Va	IDTwet	G*	S	m-value	Aggregate
Cumulative Traffic	1.00	0.49	0.26	0.33	0.32	0.53	0.51	0.46	0.47	-0.45	-0.57
Relative PCI	0.49	1.00	-0.32	-0.31	-0.25	0.26	0.51	0.14	0.13	-0.14	-0.07
HMA Modulus	0.26	-0.32	1.00	0.97	0.77	0.42	-0.03	0.54	0.61	-0.37	-0.44
CIR Modulus	0.33	-0.31	0.97	1.00	0.74	0.45	-0.07	0.64	0.66	-0.42	-0.37
FND Modulus	0.32	-0.25	0.77	0.74	1.00	0.13	0.12	0.11	0.24	-0.03	-0.57
Va	0.53	0.26	0.42	0.45	0.13	1.00	-0.13	0.74	0.85	-0.74	-0.34
IDTwet	0.51	0.51	-0.03	-0.07	0.12	-0.13	1.00	0.05	-0.12	0.05	-0.26
G*	0.46	0.14	0.54	0.64	0.11	0.74	0.05	1.00	0.88	-0.81	-0.02
S	0.47	0.13	0.61	0.66	0.24	0.85	-0.12	0.88	1.00	-0.91	-0.29
m-value	-0.45	-0.14	-0.37	-0.42	-0.03	-0.74	0.05	-0.81	-0.91	1.00	0.17
Aggregate	-0.57	-0.07	-0.44	-0.37	-0.57	-0.34	-0.26	-0.02	-0.29	0.17	1.00

Table 4.8 Correlation matrix – high traffic roads

	Cumulative Traffic	Relative PCI	HMA Modulus	CIR Modulus	FND Modulus	Va	IDTwet	G	S	m-value	Aggregate
Cumulative Traffic	1.00	0.04	-0.02	-0.03	-0.17	0.65	-0.20	0.27	0.32	-0.24	-0.16
Relative PCI	0.04	1.00	-0.52	-0.61	-0.10	0.39	0.40	0.58	0.43	-0.25	-0.01
HMA Modulus	-0.02	-0.52	1.00	0.95	0.38	0.00	-0.39	-0.39	-0.05	-0.05	-0.35
CIR Modulus	-0.03	-0.61	0.95	1.00	0.35	0.04	-0.29	-0.32	-0.07	-0.03	-0.35
FND Modulus	-0.17	-0.10	0.38	0.35	1.00	-0.25	-0.40	-0.42	-0.40	0.57	-0.09
Va	0.65	0.39	0.00	0.04	-0.25	1.00	0.13	0.78	0.65	-0.66	-0.20
IDTwet	-0.20	0.40	-0.39	-0.29	-0.40	0.13	1.00	0.35	0.25	-0.15	0.18
G	0.27	0.58	-0.39	-0.32	-0.42	0.78	0.35	1.00	0.80	-0.77	0.14
S	0.32	0.43	-0.05	-0.07	-0.40	0.65	0.25	0.80	1.00	-0.87	0.08
m-value	-0.24	-0.25	-0.05	-0.03	0.57	-0.66	-0.15	-0.77	-0.87	1.00	-0.20
Aggregate	-0.16	-0.01	-0.35	-0.35	-0.09	-0.20	0.18	0.14	0.08	-0.20	1.00

Table 4.9 VIF values of independent variables

Variables	VIF
Intercept	0.00
Traffic (AADT)	4.33
Cumulative Traffic	4.24
HMA Modulus (ksi)	19.18
CIR Modulus (ksi)	19.36
FND Modulus (ksi)	1.84
Va (%)	3.09
IDTwet (psi)	1.33
G* (KPa)	7.34
S (t) (MPa)	9.31
m-value	7.21
Aggregate	1.41

4.2.2 Model Selection

The goal of the statistical analyses was to find an appropriate model for this study to explain the pavement performance. Two methods, a descriptive method and a mathematical method, were used to perform the model selection.

Descriptive method: The scatter plot of individual variables versus relative PCI under different traffic level were developed (Figure 4.3 through 4.5). The linear regression line of each variable was projected onto the scatter plot. A variable with a steeper regression line contributes more significantly than the one with a flatter regression line. Therefore, the variables that have relatively steeply sloping regression line are the candidate variables that might be included in the final model. The following individual variables were deemed to be candidate variables:

- For all CIR roads: IDT_{wet}, Cumulative traffic, V_a;
- For low traffic roads (AADT<800): IDT_{wet}, Cumulative traffic, CIR modulus;
- For high traffic roads (AADT<800): IDT_{wet}, V_a, CIR modulus.

Since large variances existed in some variables (for example, IDT_{wet} and V_a), and linear regression lines were not sufficient to explain these variations, the determination of which variables should be included in the final model was accomplished by using a mathematical method.

Figure 4.3 Scatter plot of all 24 CIR roads

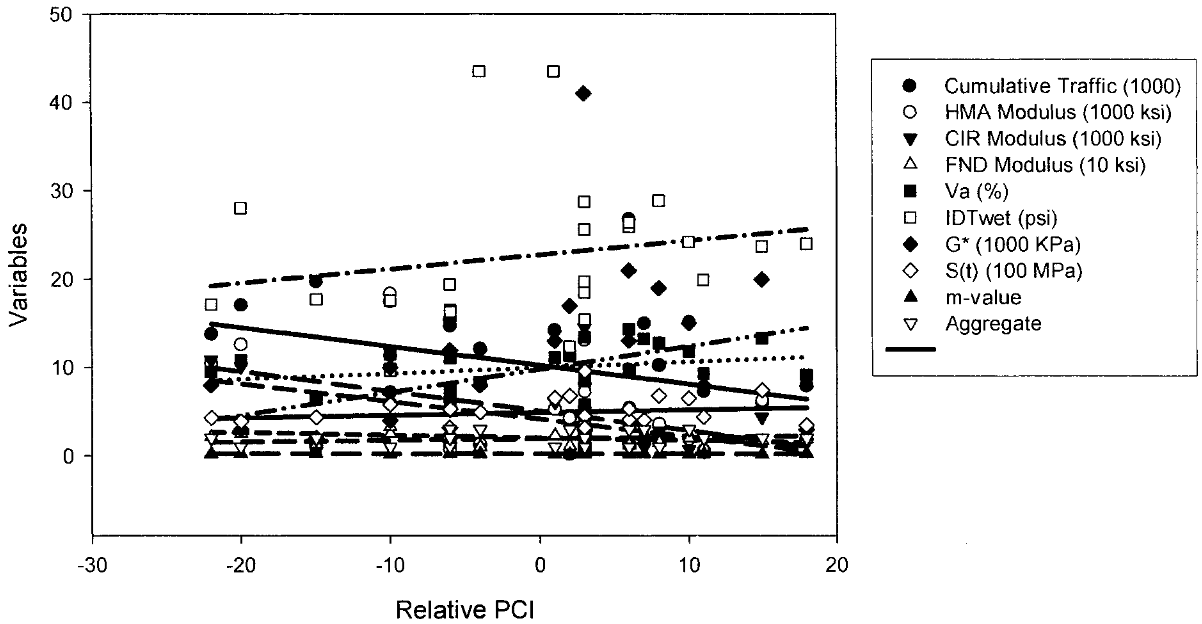


Figure 4.4 Scatter plot of Low traffic roads (AADT<800)

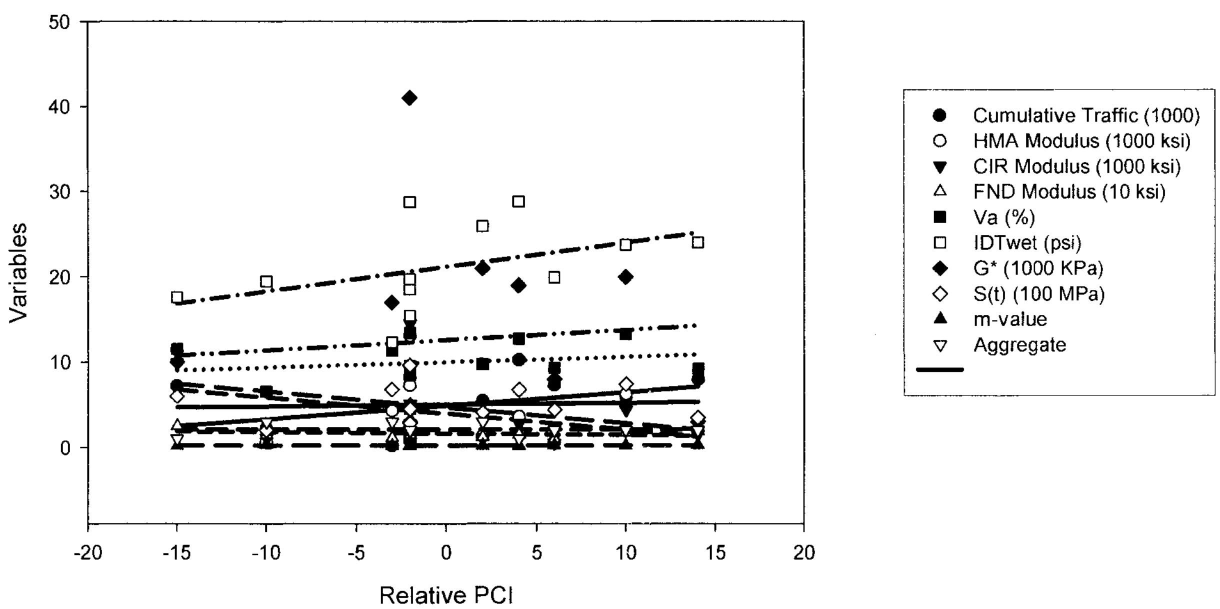
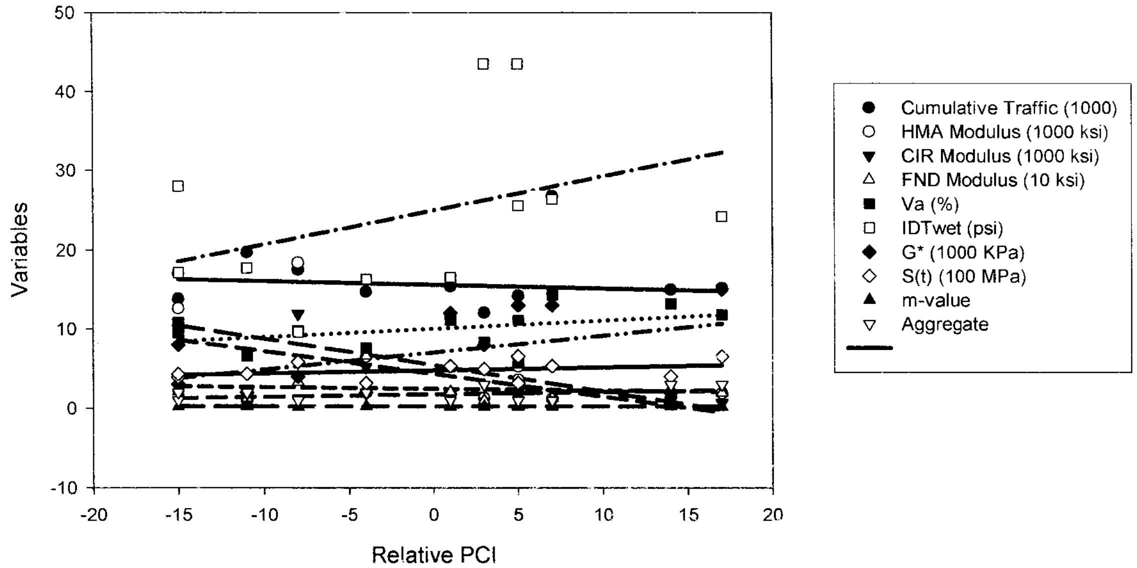


Figure 4.5 Scatter plot of high traffic roads (AADT>800)



Mathematical method: Four selection methods in SAS software package [91] were used to conduct the model selection. They are:

- FORWARD selection. This method starts with no variables in the model and adds variables. Significance level for entry into model is 0.05.

- BACKWARD elimination. This method starts with all variables in the model and deletes variables. Significance level for staying in model is 0.1.

- STEPWISE regression. This is similar to the FORWARD method except that variables already in the model do not necessarily stay there. Significance level for entry into model is 0.15, and significance level for staying in model is 0.15.

- RSQUARE finds a specified number of models with the highest R^2 in a range of model sizes (number of variables in the model). Model size of 4 was used.

First-order models

SAS outputs (Appendix G) of these methods indicated that the following variables should be used in order to obtain an appropriate model:

- For all CIR roads: Cumulative traffic, CIR modulus, and V_a;
- For low traffic roads (AADT < 800): IDT_{wet}, CIR modulus, and V_a; and
- For high traffic roads (AADT > 800): Cumulative traffic, CIR modulus, and V_a.

Higher-order model

Residual analyses were conducted in order to find which of the independent variables require higher order terms (Figure 4.6). Residuals are differences between observed PCI and expected PCI obtained from the regression model. Plotting the residuals from a first-order model (straight line linear terms only) against each independent variable often reveals further structure in the data that can be used to improve the regression model. For example, a noticeable curve in a linear regression of the residual plot reflects the possibility that a higher-order term would improve the fitness of the model. A scatterplot of the response against an independent variable can reveal the curve if it exists. However, the curved relationship is more evident in a residual plot.

The statistical software package, S-PLUS [92], was used to conduct the residual analyses. The plots (residuals of relative PCI versus independent variables) indicated that a noticeable curve existed in the residual plot of relative PCI versus FND modulus, V_a, IDT_{wet}, and G*. Therefore, these three independent variables require a higher order terms.

TableCurve 2D [93], another statistical software, was used to find the appropriate higher-order terms. The results are shown as follows:

- FND modulus → $(\text{FND modulus})^2$,
- $V_a \rightarrow (V_a)^3$,
- $IDT_{wet} \rightarrow (IDT_{wet})^{-2}$, and
- $G^* \rightarrow (G^*)^{-2}$.

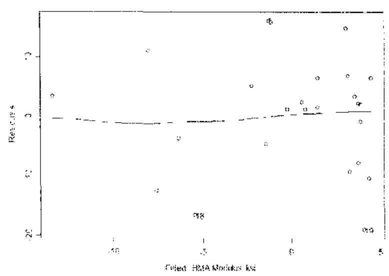
SAS outputs (Appendix G) of model selection methods indicated that the following variables should be used in order to obtain an appropriate model:

- For all CIR roads: Cumulative traffic, CIR modulus, and V_a.

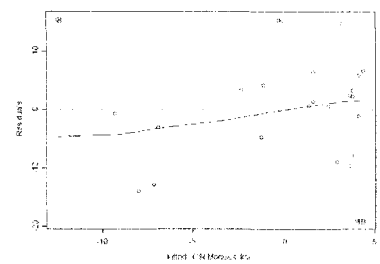
A dummy variable "Volume" was defined as follows and was included in the regression so that a comparison between low traffic roads and high traffic roads may be made.

- If Traffic < 800, then Volume = 0, and
- If Traffic > 800, then Volume = 1.

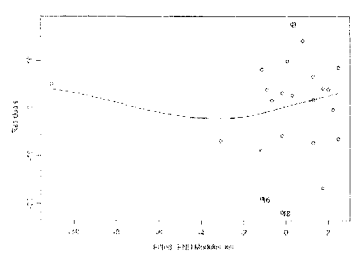
Figure 4.6 Residuals vs. independent variables



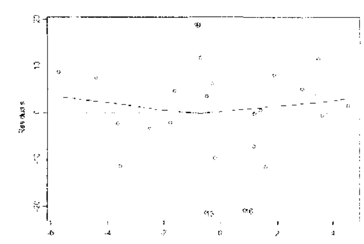
HMA modulus



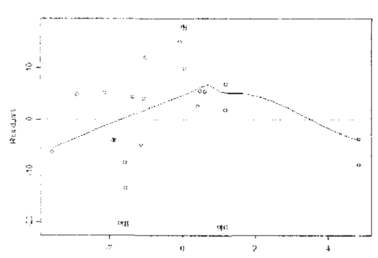
CIR modulus



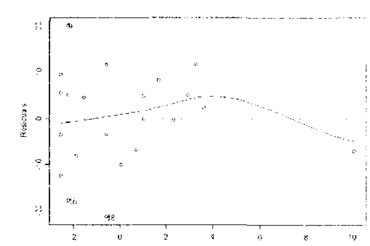
FND modulus



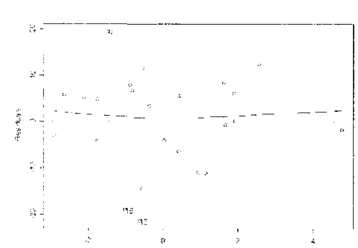
Va



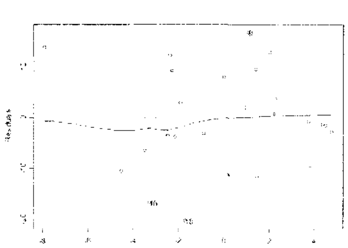
IDTwet



G*



S(t)



Cumulative traffic

4.2.3 Multiple Regression and Results

In order to appropriately apply the multiple regression technique and interpret its results, the following two concepts should be understood:

- The $\mathbf{R^2}$ value of a model is an indicator of how well the model fits the data. In other words, it describes how much variation in the response is being explained by the independent variables. R^2 can take on any value between 0 and 1, with values closer to 1 indicating that the model explains a greater proportion of variance. For example, an R^2 value of 0.8234 means that the model explains 82.34% of the total variation in the data.

- **P-value** of an independent variable indicates the probability that the relationship between an independent variable and the response obtained in a statistical analysis is due to chance rather than due to a true relationship between the two. For example, a p-value of 0.01 means there is a 1 in 100 chance the relationship occurred by chance. Therefore, if the p-value is small, an analyst would be confident to conclude that the relationship obtained is "real." A p-value of 0.05 or less is the commonly used standard to determine that a relationship between variables is significant.

  P-value of a model is the probability of rejecting the hypothesis that all variables are 0 except for the intercept if the hypothesis is true. A small p-value (less than 0.05) indicates that the effects in the model have significant impact on the response.

First-order models

The results from multiple regression analyses are shown in Table 4.10 through 4.12.

Table 4.10 Regression results for low traffic roads

F = 4.01, p-value = 0.052 (not significant at 0.05 level)
$R^2 = 0.60$, $R^2_{adj} = 0.45$

Term	Estimate	P-value	Significance
Intercept	-25.06	0.051	No
IDT_{wet}	0.87	0.040	Yes
V_a	1.73	0.051	No
CIR modulus	-1.02	0.066	No

The regression model for low traffic roads is:

Relative PCI = -25.06 + 0.87 IDTwet + 1.73* Va - 1.02* CIR modulus*

Table 4.11 Regression results for high traffic roads

F = 5.59, p-value = 0.023 (significant at 0.05 level)
$R^2=0.68$, $R^2_{adj} = 0.56$

Term	Estimate	P-value	Significance
Intercept	-12.23	0.25	No
CIR modulus	-1.59	0.0017	Yes
V_a	2.85	0.032	Yes
Cumulative Traffic	-0.00085	0.18	No

The regression model for high traffic roads is:

Relative PCI = -12.23 - 1.59 CIR modulus + 1.73* Va*

*- 0.00085*Cumulative Traffic*

Table 4.12 Regression results for all 24 CIR roads

F = 8.12, p-value = 0.001 (significant at 0.05 level)
R^2=0.55, R^2_{adj} = 0.48

Term	Estimate	P-value	Significance
Intercept	-10.37	0.13	No
V_a	2.45	0.0021	Yes
CIR modulus	-1.38	0.0027	Yes
Cumulative Traffic	-0.00026	0.015	Yes

The regression model for all 24 CIR roads is:

Relative PCI = -10.37 + 2.45 Va - 1.38* CIR modulus*

*- 0.00026*Cumulative Traffic*

Higher-order model

Regression results are shown in Table 4.13.

Table 4.13 Regression results from the higher-order model

F = 7.39, p-value = 0.0009 (significant at 0.05 level)
R^2=0.61, R^2_{adj} = 0.53

Term	Estimate	P-value	Significance
Intercept	1.39	0.73	No
CIR modulus	-1.31	0.0016	Yes
V_a^3	0.0065	0.012	Yes
Cumulative Traffic	-0.00035	0.43	No
Volume (0)	2.53	0.37	No

The regression model for all 24 CIR roads is:

$$Relative\ PCI = 1.39 + 0.0065 * V_a^3 - 1.31 * CIR\ modulus$$

$$- 0.00035 * Cumulative\ Traffic + 2.53 * Volume\ (0)$$

The higher-order model of all 24 CIR roads (with the dummy variable Volume) can be used to compare the effect of traffic levels on the relative PCI. Two other higher-order models (without the dummy variable Volume) were developed for low and high traffic roads, respectively, which can be used to conduct a comparison with the corresponding first-order models for the two traffic level roads. The results of the analysis using the two higher-order models (without the dummy variable Volume) can be found in Appendix G.

Overall fitness of the models

First-order models: The results (Table 4.10 through 4.12) show that the p-value of the model are 0.052, 0.023, and 0.001, respectively, for low traffic roads, high traffic roads, and all 24 CIR roads. This indicates that the effects of the selected variables in the *High Traffic* model and the *All CIR Roads* model had significant impact on the relative PCI at 0.05 level. The effects of the selected variables in the *Low Traffic* model were not significant; this suggests that other variables such as environmental factors might prominently affect pavement performance. R^2 are 0.60, 0.68, and 0.55, R^2_{adj} are 0.45, 0.56, and 0.48, respectively.

For low traffic roads, CIR modulus and V_a were not significant at 0.05 level, IDT_{wet} was significant; for high traffic roads, CIR modulus and V_a were significant at 0.05 level, but

Cumulative Traffic was not significant; and for all 24 CIR roads, CIR modulus, V_a, and Cumulative Traffic were significant at 0.05 level.

Higher-order model: The results (Table 4.13) shows that the p-value of the model is 0.009. This indicates that the effects of the selected variables in the model had significant impact on the relative PCI at 0.05 level. R^2 is 0.61.

CIR modulus and V_a^3 were significant at 0.05 level, Cumulative Traffic was not significant. When other variables remain the same, Volume changing from 0 to 1 (traffic changes from less than 800 AADT to more than 800 AADT) reduces relative PCI by 2.53.

Cumulative traffic

Repeated traffic loads are usually considered to be one of the major causes of rutting and fatigue/reflection cracking, the distresses that often impair pavement performance. The results show that cumulative traffic, even though not significant, negatively impacted pavement performance of high traffic CIR roads; it significantly impaired pavement performance of all CIR roads

Modulus of the CIR layer

In a typical flexible pavement structure, material layers are usually arranged in order of descending load bearing capacity with the highest load bearing capacity material on the top and the lowest load bearing capacity material on the bottom. Therefore, the surface course (typically an HMA layer) is the stiffest (as measured by resilient modulus). The underlying layers are less stiff. Serving as the base of the HMA surface course, the CIR layer should not only be stiff enough to provide adequate pavement strength, but also be flexible enough to allow the total pavement structure to deflect under repeated traffic loading. This study showed that the stiffness the CIR layer significantly affects performance of all 24 CIR roads and high traffic roads, and that a CIR road with a more elastic CIR layer performed better. This finding confirmed Halim's studies [54, 55] in that serving as a stress-relieving layer, the relative less stiff CIR layer will reduce cracks on the HMA layer.

Indirect tensile strength of wet samples (IDT_{wet})

IDT_{wet} is often used to evaluate water susceptibility of mixtures. A high number typically indicates that a good performance is expected. The results showed that IDT_{wet} significantly and positively affected pavement performance of low traffic roads.

Air voids (V_a)

In this study, air voids are voids between the aggregate particles in the compacted CIR layer that are filled with air. The results showed that V_a was significant and positively impacted pavement performance at 0.05 level for high traffic roads and overall performance, and it was not significant at for low traffic roads.

4.3 Rolled-down Cracking and Rutting

A rolled-down crack is a high severity crack, with the edges that are rolled down by traffic and possible existence of water in the base. Rolled-down cracking and rutting are major factors that affect the smoothness and safety of CIR pavements. Therefore, researchers attempted to investigate which CIR material prosperities are associated with rolled-down cracking and rutting.

The researchers' used their own judgment to decide whether or not the cracks were rolled down on 17 of the sample roads that were recycled more than 10 years ago. Based on the distress survey data (Chapter 3), the existence of rutting was determined. Table 4.14 shown the CIR material properties and the status of rolled-down cracking and rutting of 17 CIR roads.

Nominal logistic regression was conducted because the responses are nominal variables. As shown below:

- Rolled-down Cracking | yes = 1, Rolled-down Cracking | no = 0,
- Rutting | yes = 1, Rutting | no = 0.

Table 4.14 Rolled-down cracking and rutting status of 17 CIR roads

Road	Rolled-down Crack	Rutting	Va	IDTwet	G*	Aggregate	Traffic
Boone198	No	Yes	6.54	19.38	0.2	Gravel	130
BooneE52	Yes	No	9.73	25.87	2.1	Gravel	390
BulterT16	No	No	9.32	19.88	0.8	CrushedGravel	610
CGB43	Yes	Yes	11.52	17.63	1.0	Limestone	450
CGSS	Yes	No	10.81	28.02	0.3	Limestone	1,140
CalhounIA175	Yes	Yes	9.53	17.06	0.8	CrushedGravel	1,255
ClintonE50	Yes	Yes	12.74	28.82	1.9	Limestone	540
ClintonZ30	Yes	No	11.11	43.47	1.3	Limestone	890
GreeneIA144	Yes	Yes	6.57	17.66	0.2	CrushedGravel	1,315
GuthrieIA4	Yes	No	11.78	24.16	1.5	Gravel	1,518
HardinD35	Yes	Yes	8.26	43.47	0.8	Gravel	930
MuscatineF70	No	Yes	13.20		0.2	Gravel	1,250
MuscatineG28	Yes	Yes	11.07	16.5	1.2	Limestone	1,100
MuscatineY14	Yes	Yes	14.30	26.4	1.3	Limestone	1,490
TamaV18	No	No	9.18	24.03	0.3	CrushedGravel	570
WinnebagoR34	Yes	Yes	13.29	23.72	2.0	CrushedGravel	400
WinnebagoR60	No	Yes	13.42	19.74	4.1	CrushedGravel	550

Results of regression are in Table 4.15 and 4.16.

Table 4.15 Regression results for rolled-down cracking

F = 1.14, p-value = 0.37 (not significant at 0.05 level)
$R^2 = 0.22$, R^2 adj = 0.03

	Estimate	P-value	Significance
Intercept	-0.38	0.58	No
V_a	0.096	0.17	No
G*	-0.18	0.27	No
IDT_{wet}	0.014	0.34	No

Table 4.16 Regression results for rutting

F = 0.43, p-value = 0.73 (not significant at 0.05 level)
$R^2 = 0.10$, R^2 adj = -0.13

	Estimate	P-value	Significance
Intercept	0.92	0.27	No
IDT_{wet}	-0.016	0.34	No
G*	0.073	0.69	No
V_a	0.0015	0.98	No

In this study, for technology transfer purpose, a new term Importance was defined as: Importance = 1 – P-value. Figure 4.7 and 4.8 indicate effect of material properties on Rolled-down cracking and rutting, ordered by Importance.

Figure 4.7 Importance of variables (rolled-down cracking)

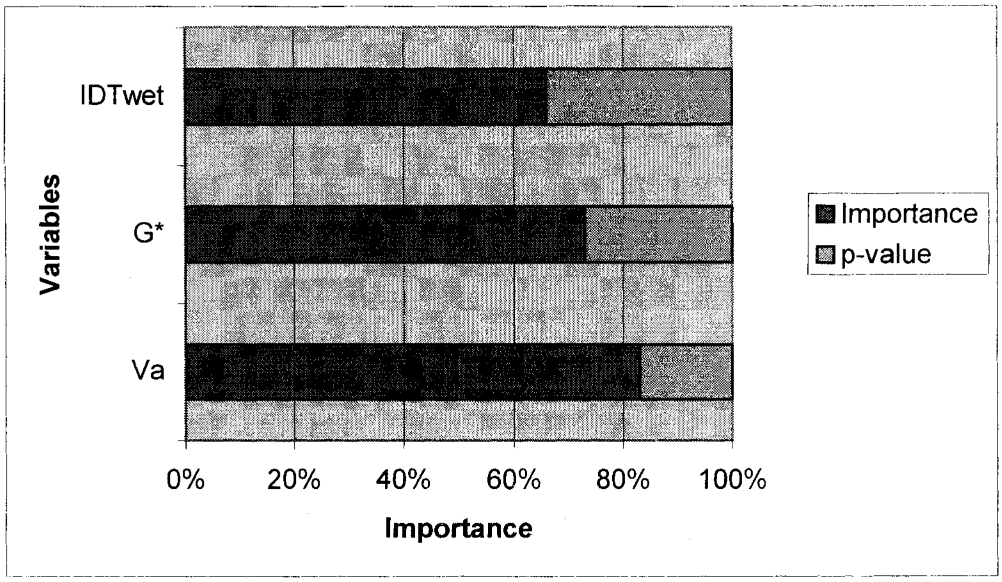
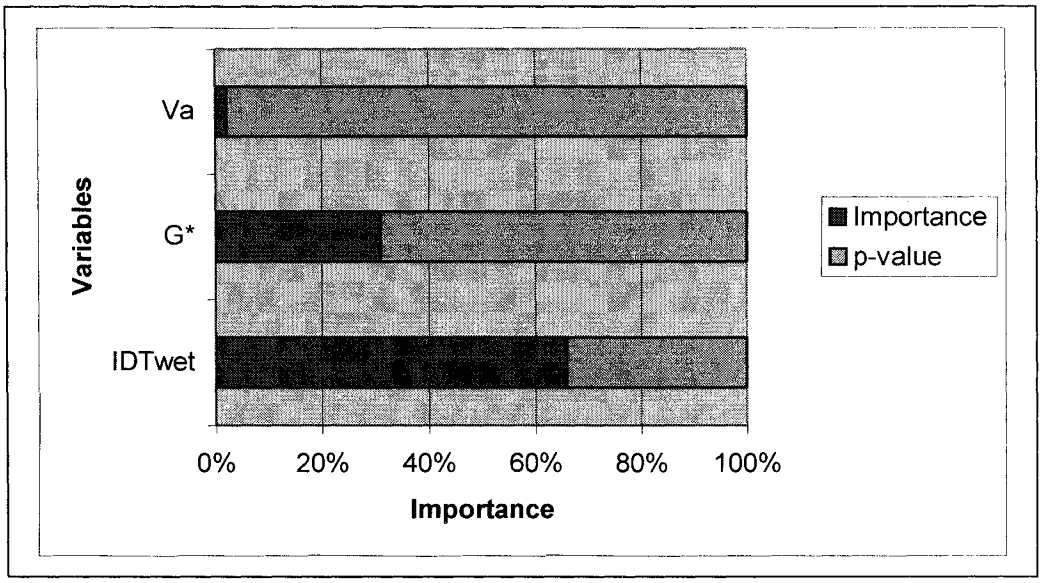


Figure 4.8 Importance of variables (rutting)



Since all the variables in the nominal logistic regression were not significant, it seems that factors other than what was considered in the study should be included in order to explain rolled-down cracking and rutting.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

A comprehensive investigation of CIR pavement performance, including distress surveys, field and lab testing, and statistical analyses, was conducted. twenty-four CIR roads with various traffic levels and support conditions that were constructed from 1986 to 2004 at various locations throughout the state of Iowa were studied. It was found that amongst the variables in this study, the modulus of the CIR layer, and the air voids (V_a) of CIR asphalt binder were the most important factors affecting CIR pavement performance for high traffic roads in the first-order model and in the higher-order model for all 24 CIR roads. The IDT_{wet} significantly affected pavement performance in the first-order model for low traffic roads. The impact of each of the factors was studied through statistical analyses. The conclusions are presented, as follows:

1. The results of this study support the theory that the CIR layer acts as a stress-relieving layer. Therefore, within the range of the data analyzed, a smaller value of CIR modulus (more viscoelastic) and a higher value of V_a of the CIR layer (more porous) indicates that better performance is expected.
2. Within the range of the data analyzed, a higher value of IDT_{wet} significantly and positively affected pavement performance of low traffic roads in the first-order model.
3. Variables other than those selected, such as environmental factors, may affect performance of low traffic CIR roads.
4. Higher amount of cumulative traffic is associated with lower relative pavement performance in the models for High traffic roads and all 24 CIR roads.

5. Material properties (IDT_{wet}, V_a, and G*) could not explain the occurrence of rolled-down cracking and rutting, according to the statistical analysis.

The following recommendations were made from this study:

- A larger sample size (about 50) is recommended for a future study. More cores and FWD tests on each road are also necessary to reduce the variance in the response variable, relative PCI.
- This study investigated the overall CIR pavement performance, which was affected by both the HMA and/or the CIR layer. A study with a larger sample size will contain sufficient information to distinguish these two effects. Therefore, a regression analysis between part of the response (relative PCI) that is affected solely by the CIR layer, and the independent variables might provide more conclusive findings. However, it would certainly be challenging to isolate what part of the response is related to the CIR layer.
- Phase angles need to be considered in the future study to account for the elasticity and viscosity of asphalt binders.
- In the current study, the variables that were considered did not explain the causes of rolled-down cracking and rutting. A further study is needed.

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Finally, special thanks are due to my wife, Haiqing, and my family for their constant encouragement and support.

APPENDIX A. QUESTIONNAIRE TO COUNTY ENGINEERS

County: **Road:**

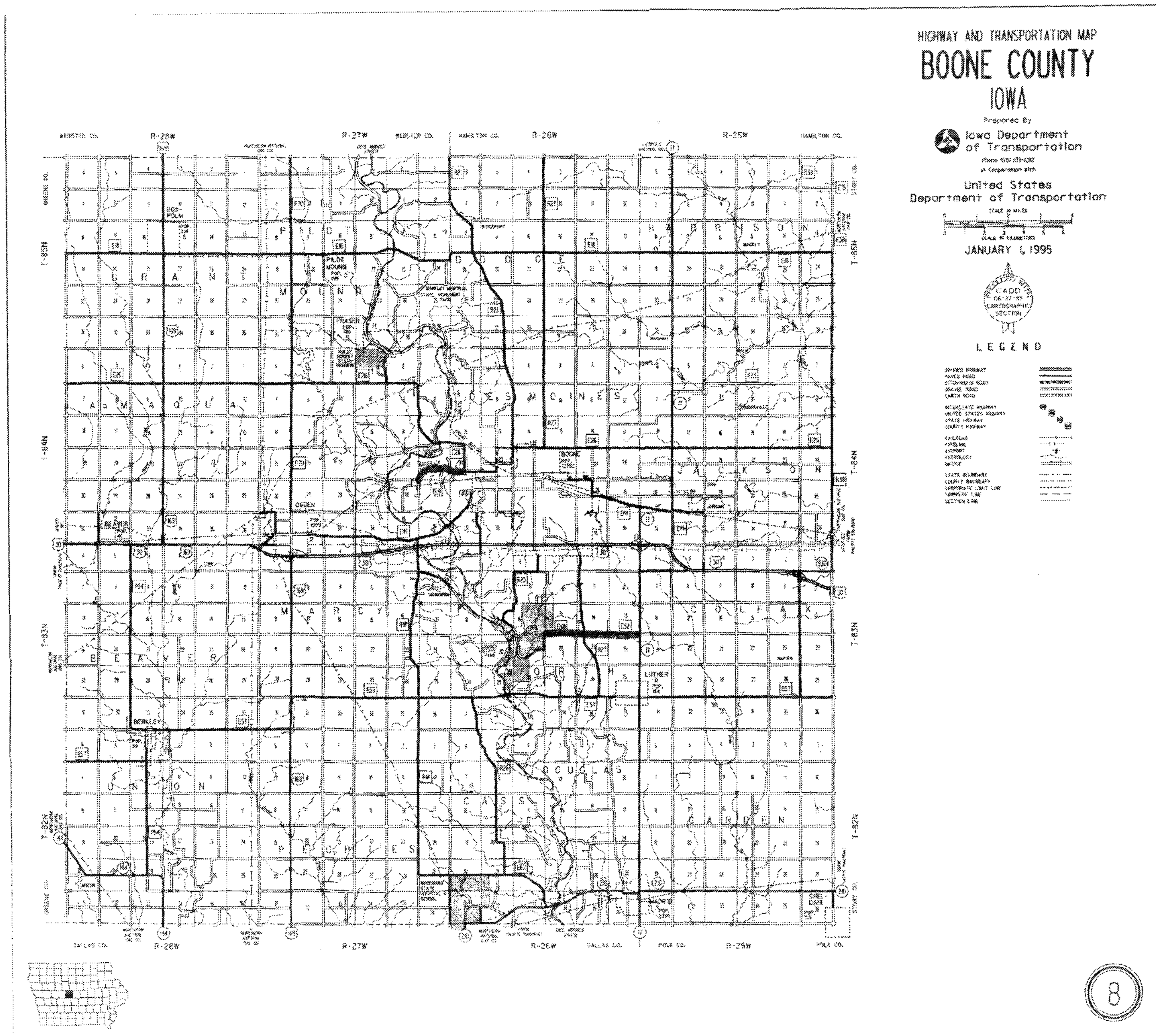
1. What are the current support and drainage conditions for this section compared to other roads in your jurisdiction?

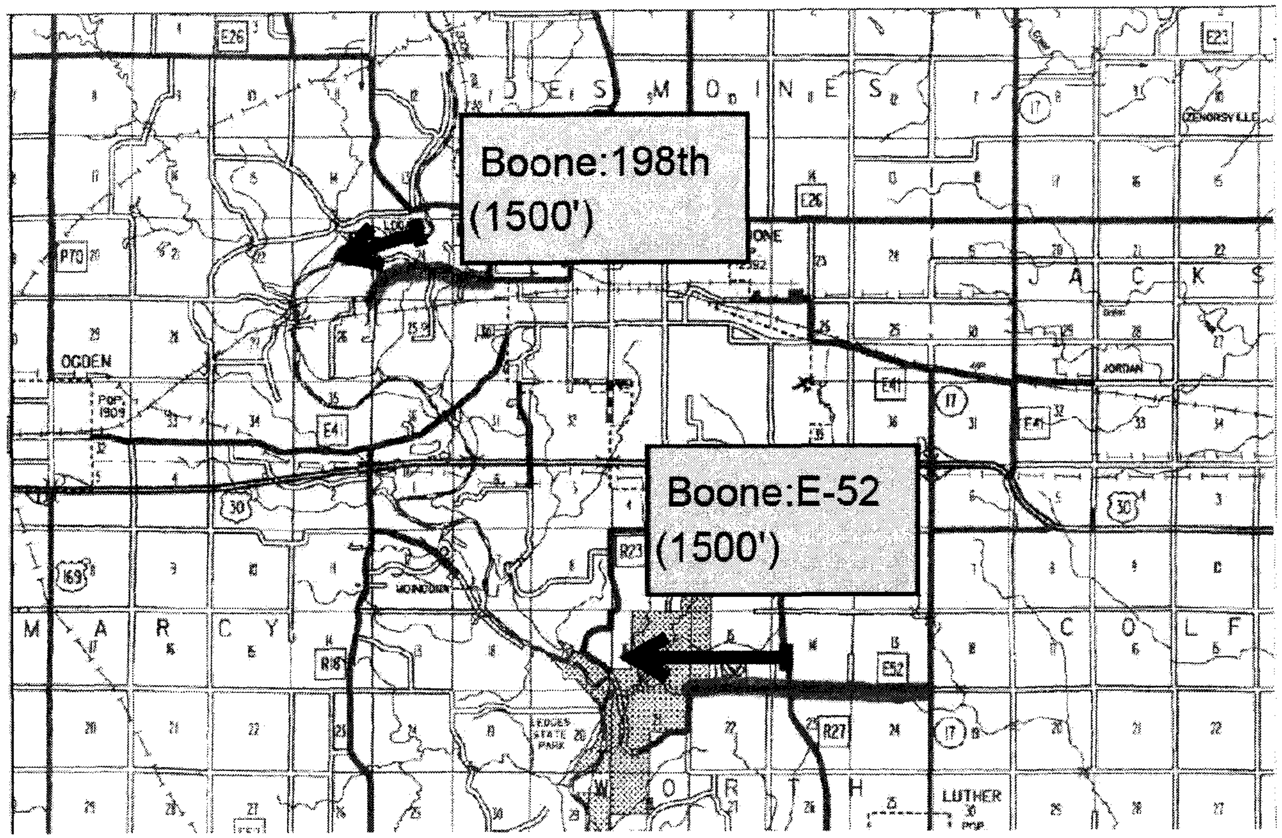
2. Could you please provide updated traffic information, including the proportion of truck traffic? Is there anything noteworthy about the truck traffic? Are there any specific truck traffic generators (e.g., elevator, quarry, industry, etc) that we should be aware of?

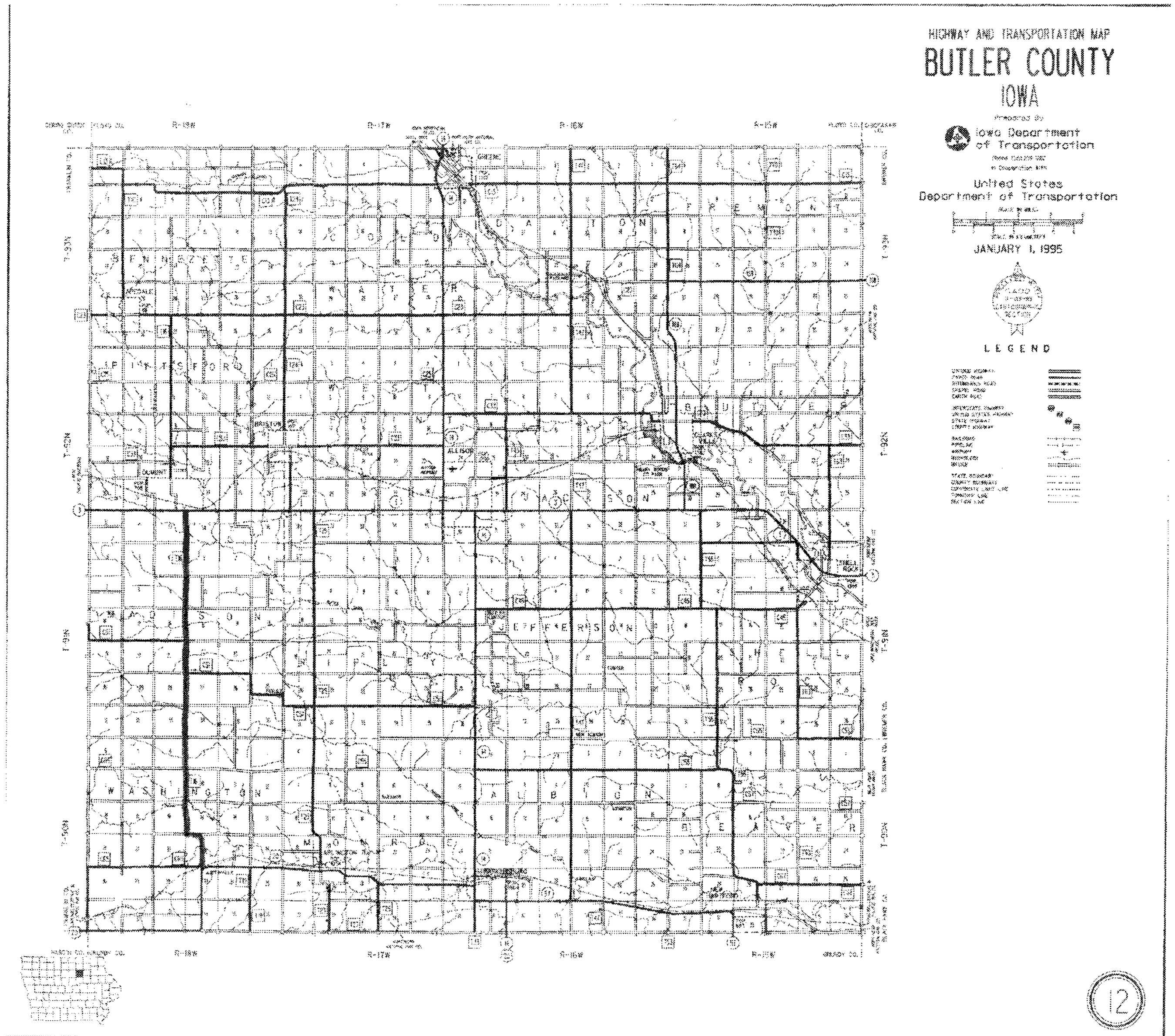
3. Last time we examined this road in 1996. Since then, have there been any other changes to these road or traffic that we should be aware of?

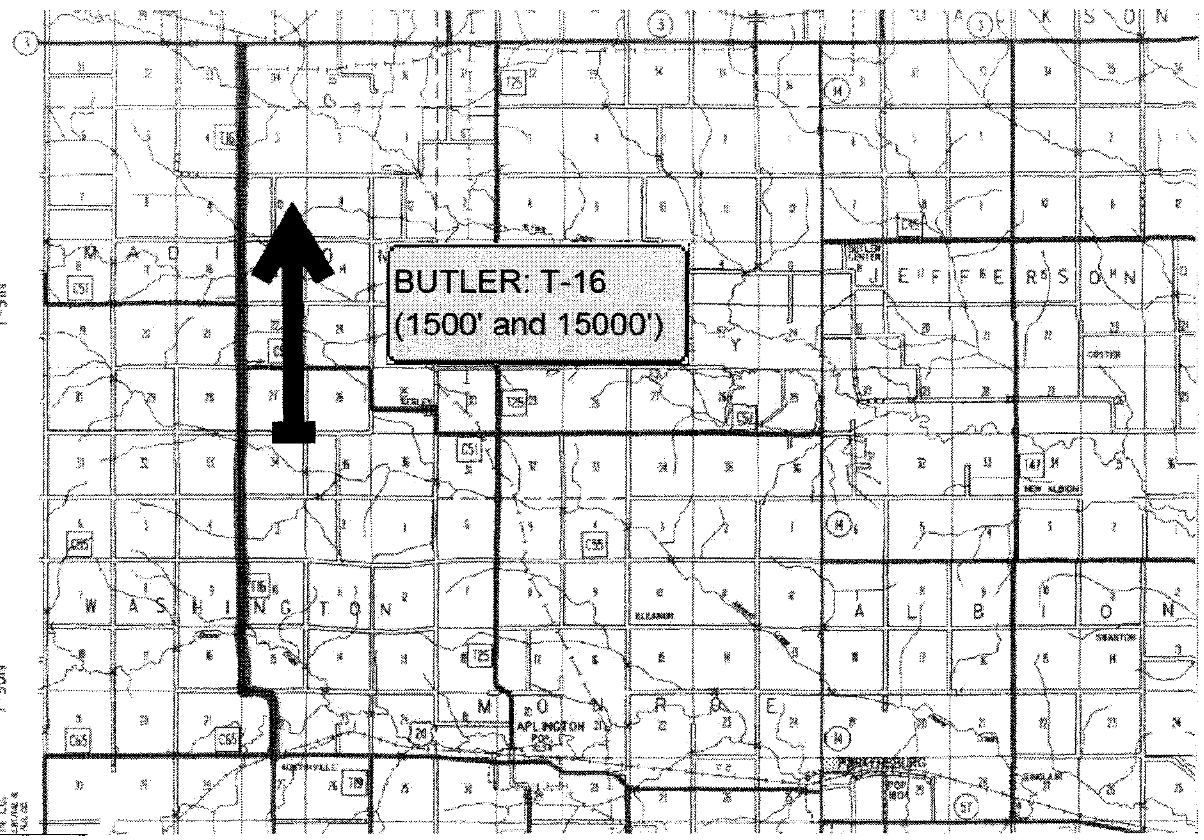
* Please return the questionnaire in the provided envelope.

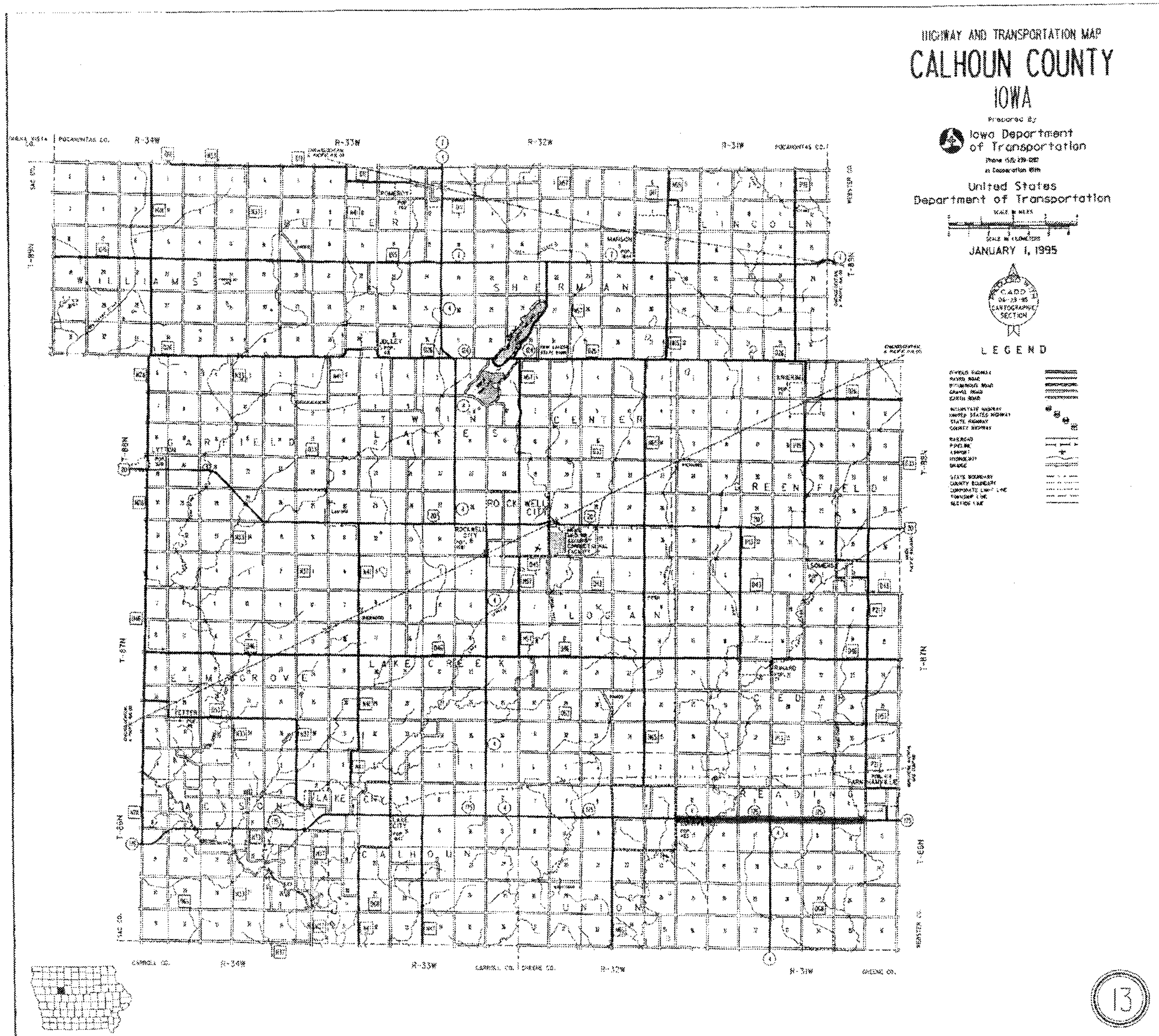
APPENDIX B. LOCATIONS OF SAMPLE ROADS

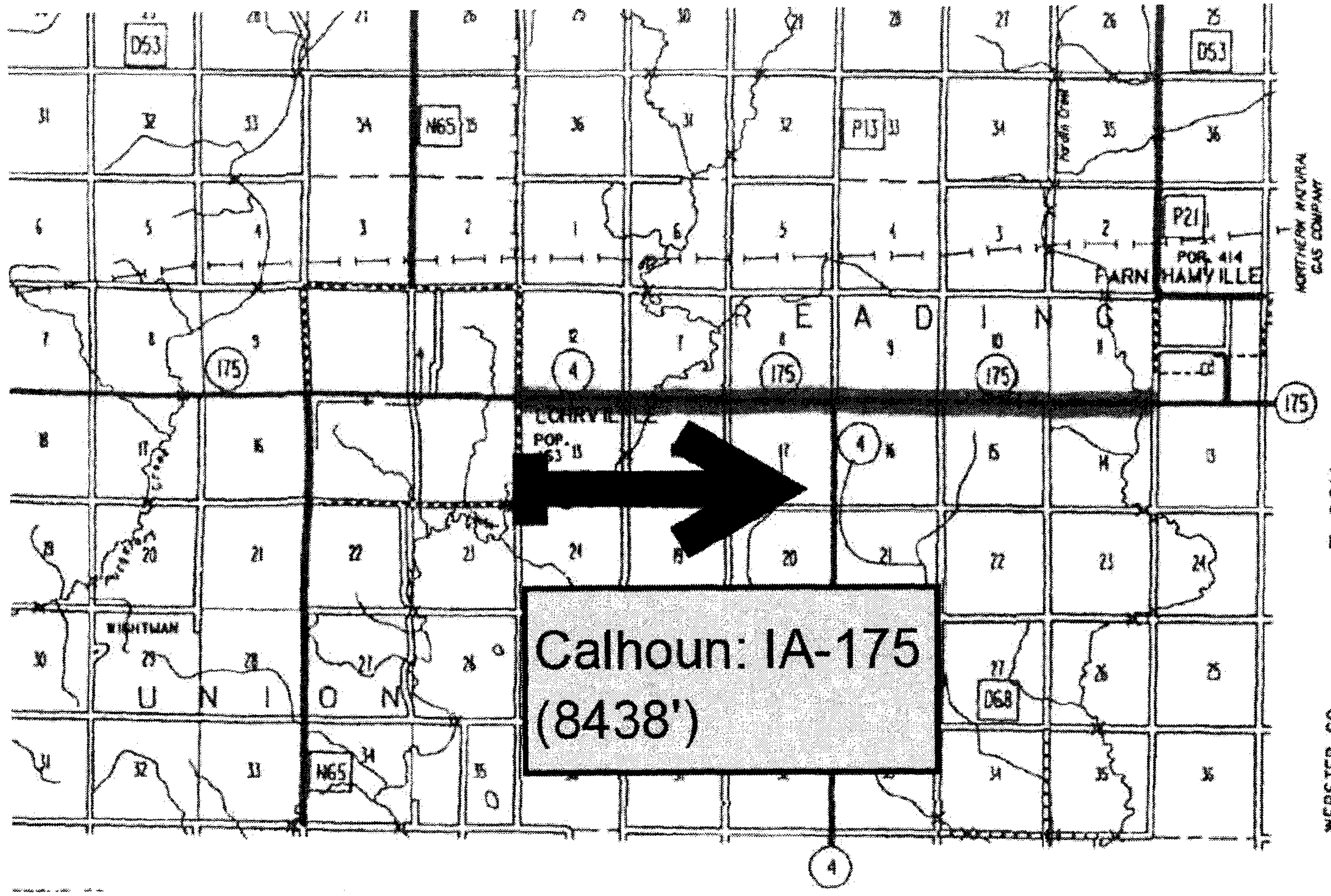

HIGHWAY AND TRANSPORTATION MAP
BOONE COUNTY
IOWA
Prepared By
Iowa Department of Transportation
In Cooperation With
United States Department of Transportation
JANUARY 1, 1995
LEGEND
8

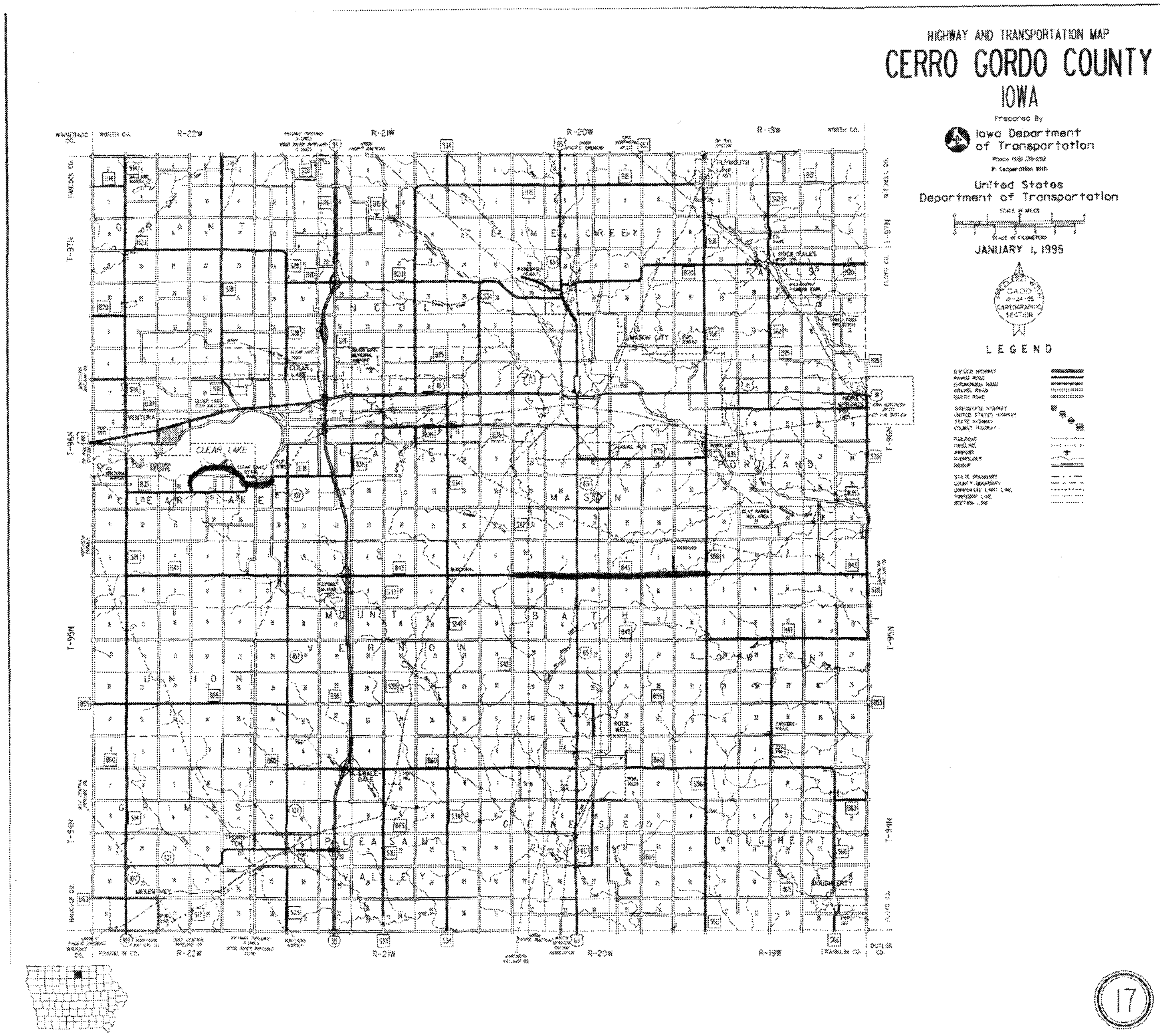

Boone:198th
(1500')
Boone:E-52
(1500')
OGDEN
LUTHER
E26
E41
E52
R27
R23
P70

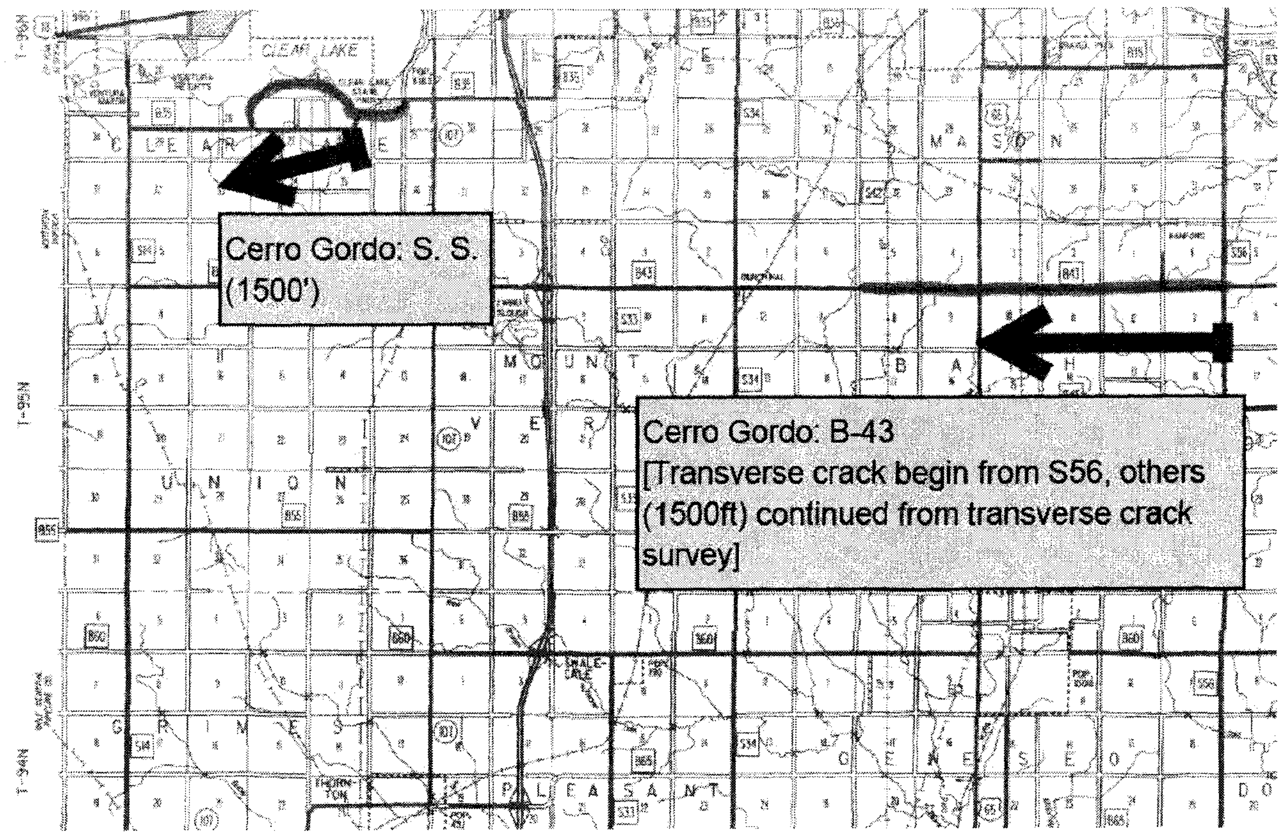

HIGHWAY AND TRANSPORTATION MAP
BUTLER COUNTY
IOWA
Prepared by
Iowa Department of Transportation
United States
Department of Transportation
JANUARY 1, 1995
LEGEND
12

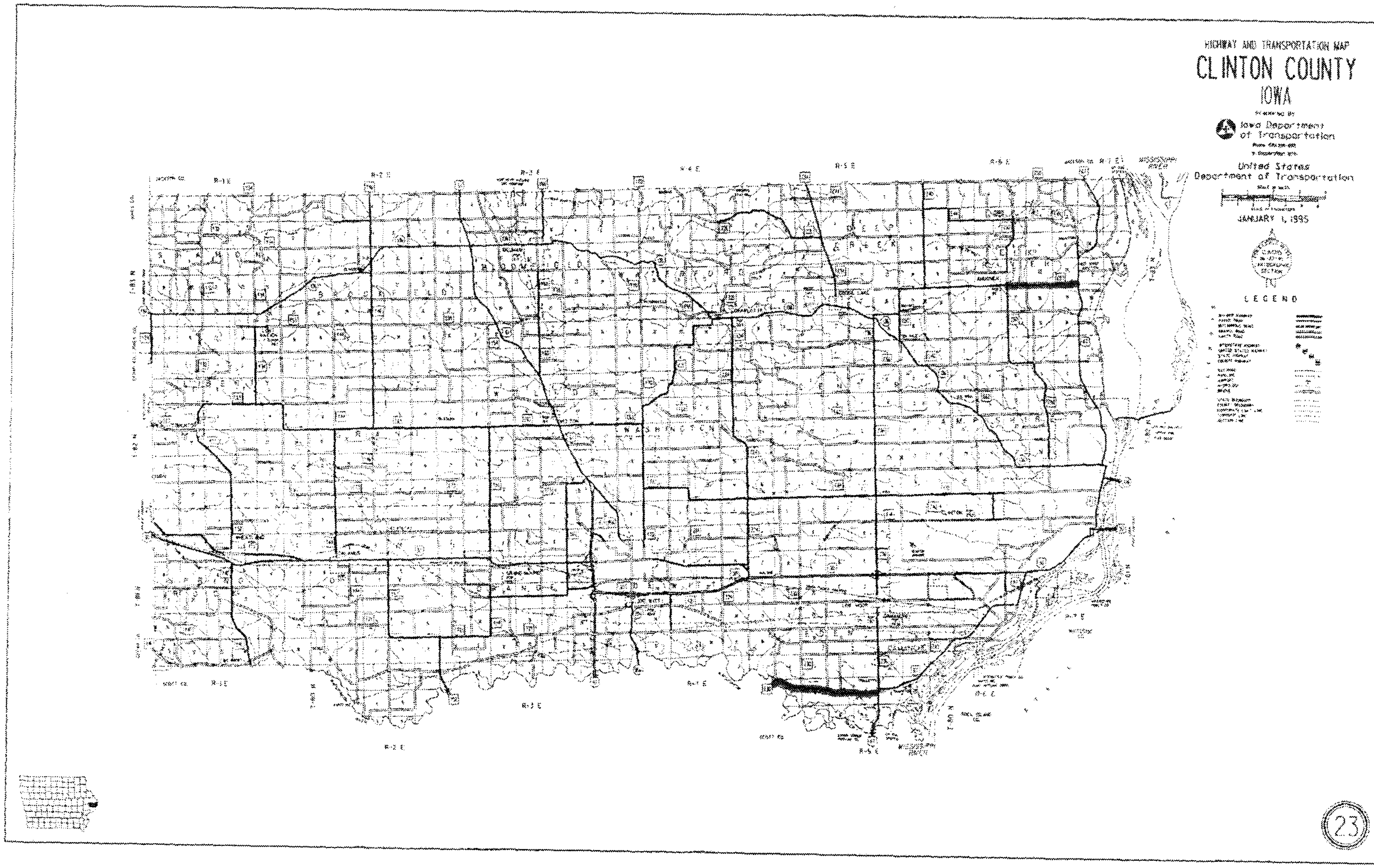

BUTLER: T-16
(1500' and 15000')
T-91N
T-90N
JEFFERSON
WASHINGTON
ALBION
MONROE
APLINGTON


HIGHWAY AND TRANSPORTATION MAP
CALHOUN COUNTY
IOWA
Prepared By
Iowa Department of Transportation
in Cooperation With
United States Department of Transportation
JANUARY 1, 1995
LEGEND
R-34W
R-33W
R-32W
R-31W
T-89N
T-88N
T-87N
T-86N
POCAHONTAS CO.
CARROLL CO.
GREENE CO.
SAC CO.
WEBSTER CO.
ROCKWELL CITY
LAKE CITY
LYTTON
SOMERS
MANSON
JOLLEY
13

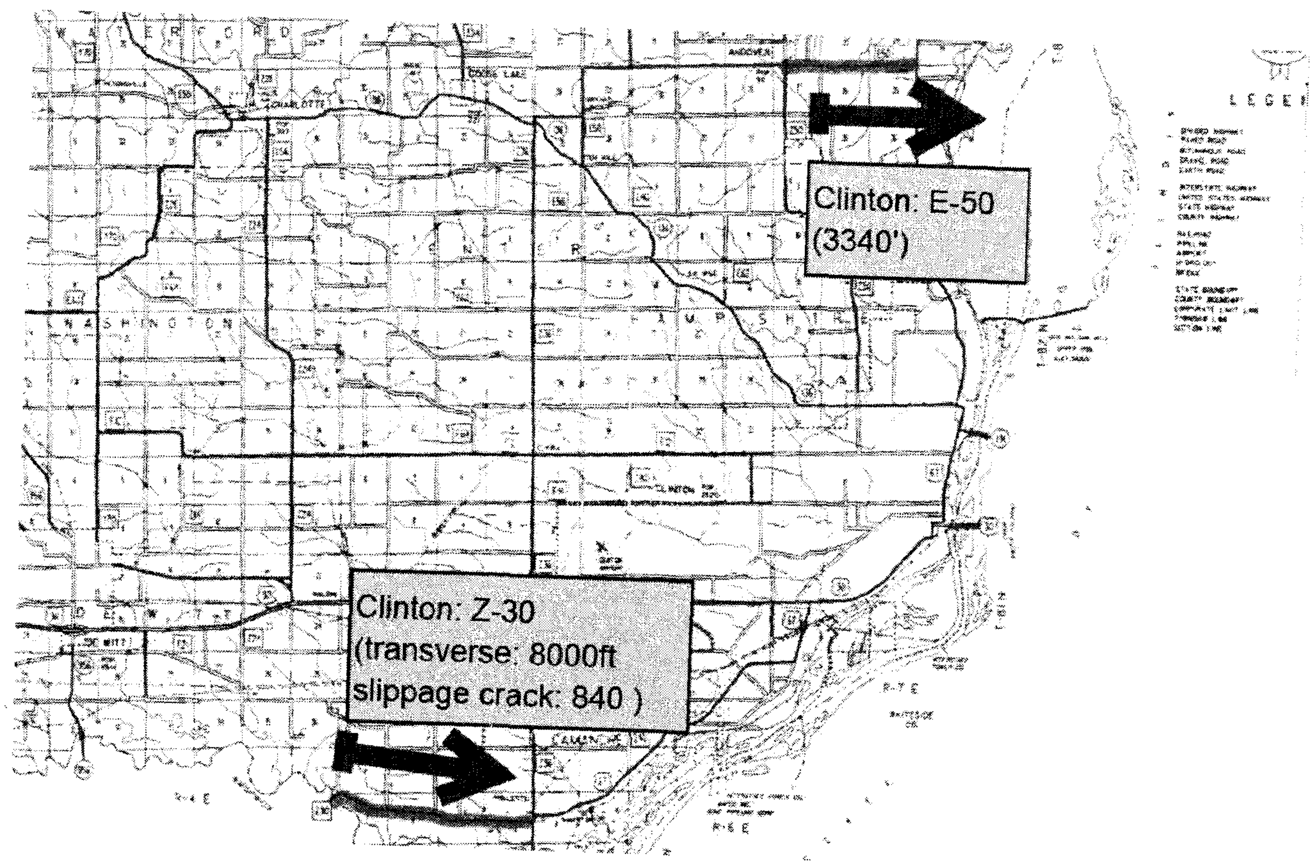

Calhoun: IA-175
(8438')
READING
UNION
FARNHAMVILLE
POP. 414
WIGHTMAN
NORTHERN NATURAL GAS COMPANY
T-86N
WEBSTER CO.
D53
N65
P13
P21
D68
175
4

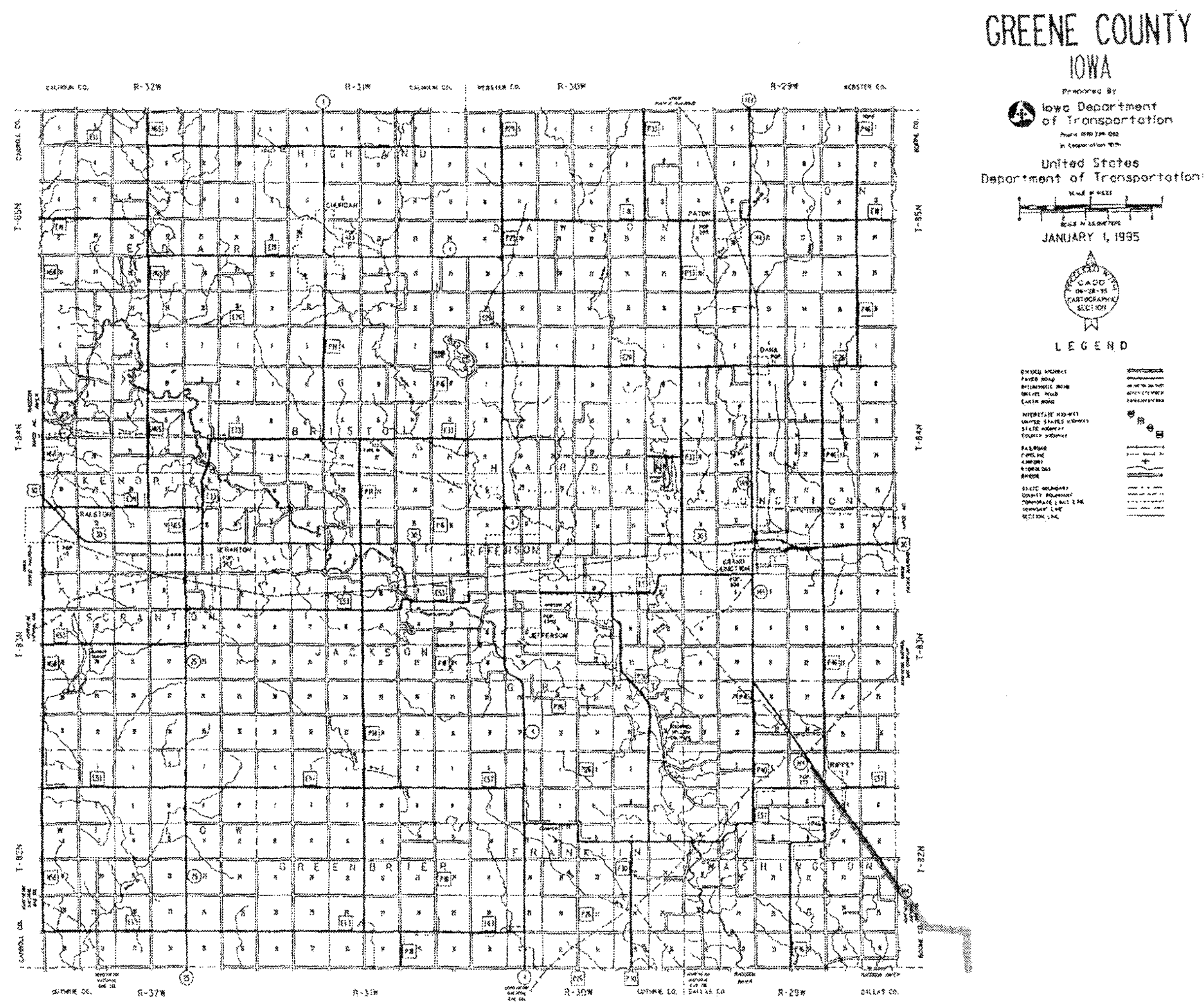

HIGHWAY AND TRANSPORTATION MAP
CERRO GORDO COUNTY
IOWA
Prepared By
Iowa Department of Transportation
In Cooperation With
United States Department of Transportation
JANUARY 1, 1995
LEGEND
CLEAR LAKE
MASON CITY
17


Cerro Gordo: S. S.
(1500')
Cerro Gordo: B-43
[Transverse crack begin from S56, others (1500ft) continued from transverse crack survey]

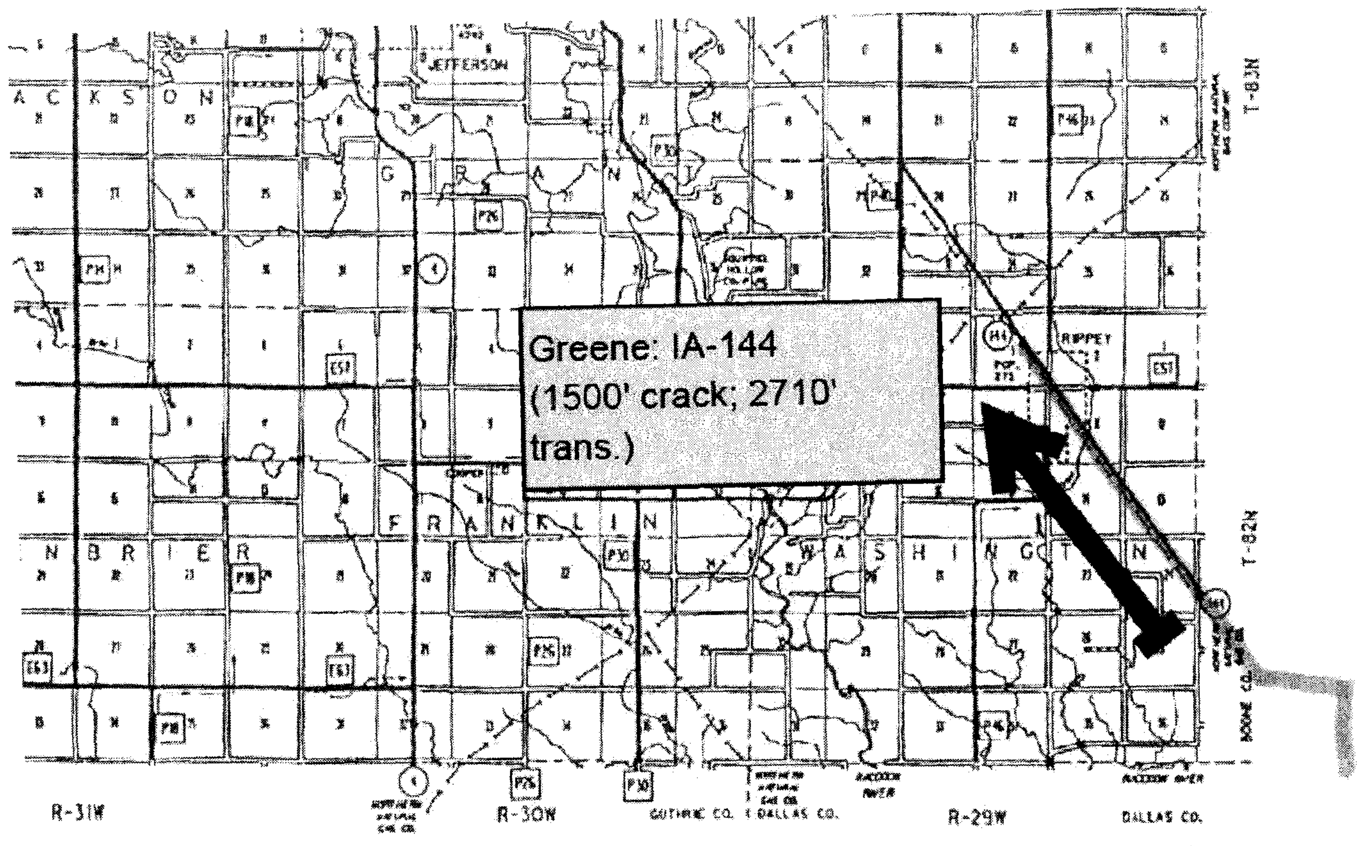


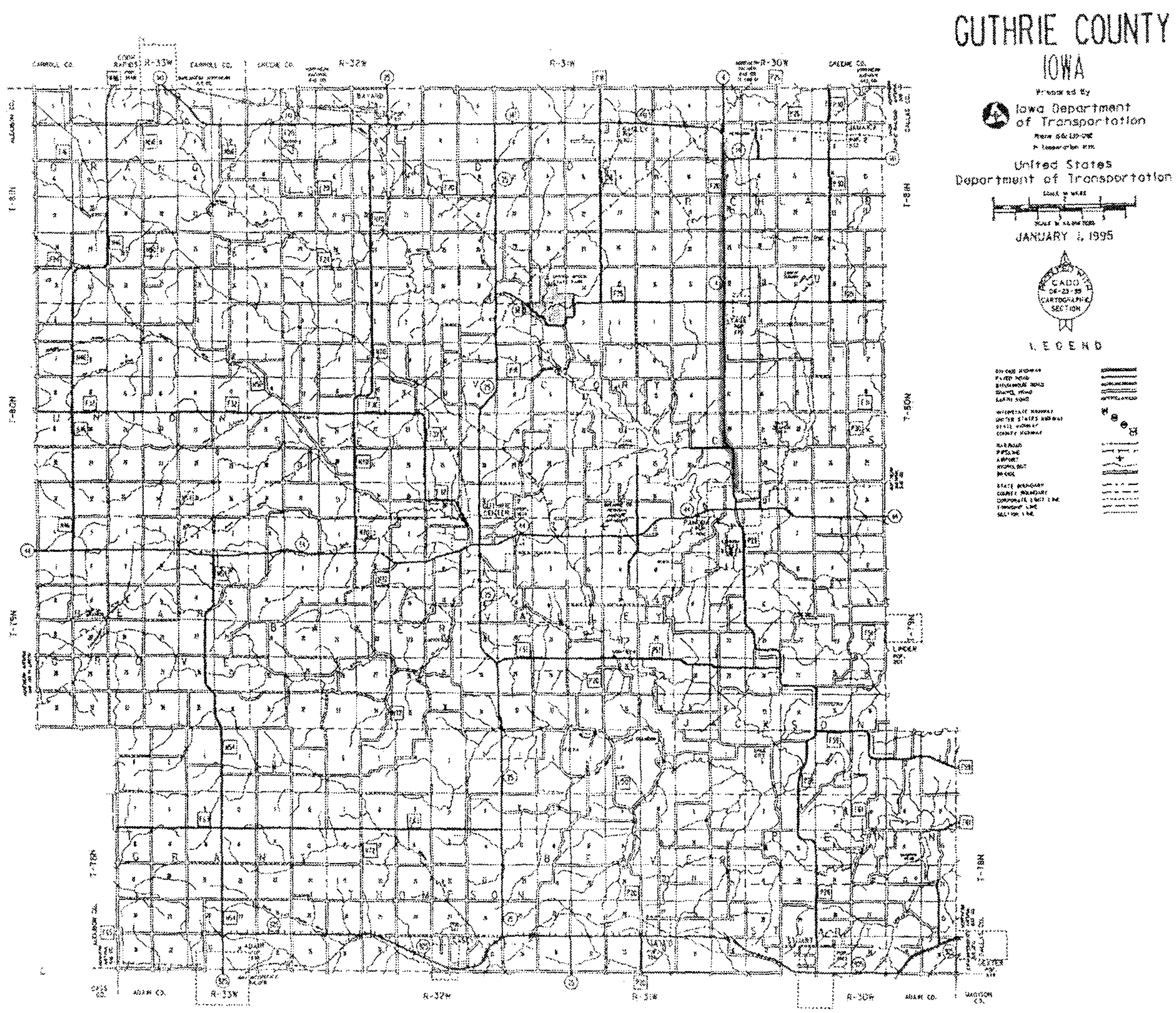
HIGHWAY AND TRANSPORTATION MAP
CLINTON COUNTY
IOWA
Iowa Department of Transportation
United States Department of Transportation
JANUARY 1, 1995
LEGEND
23

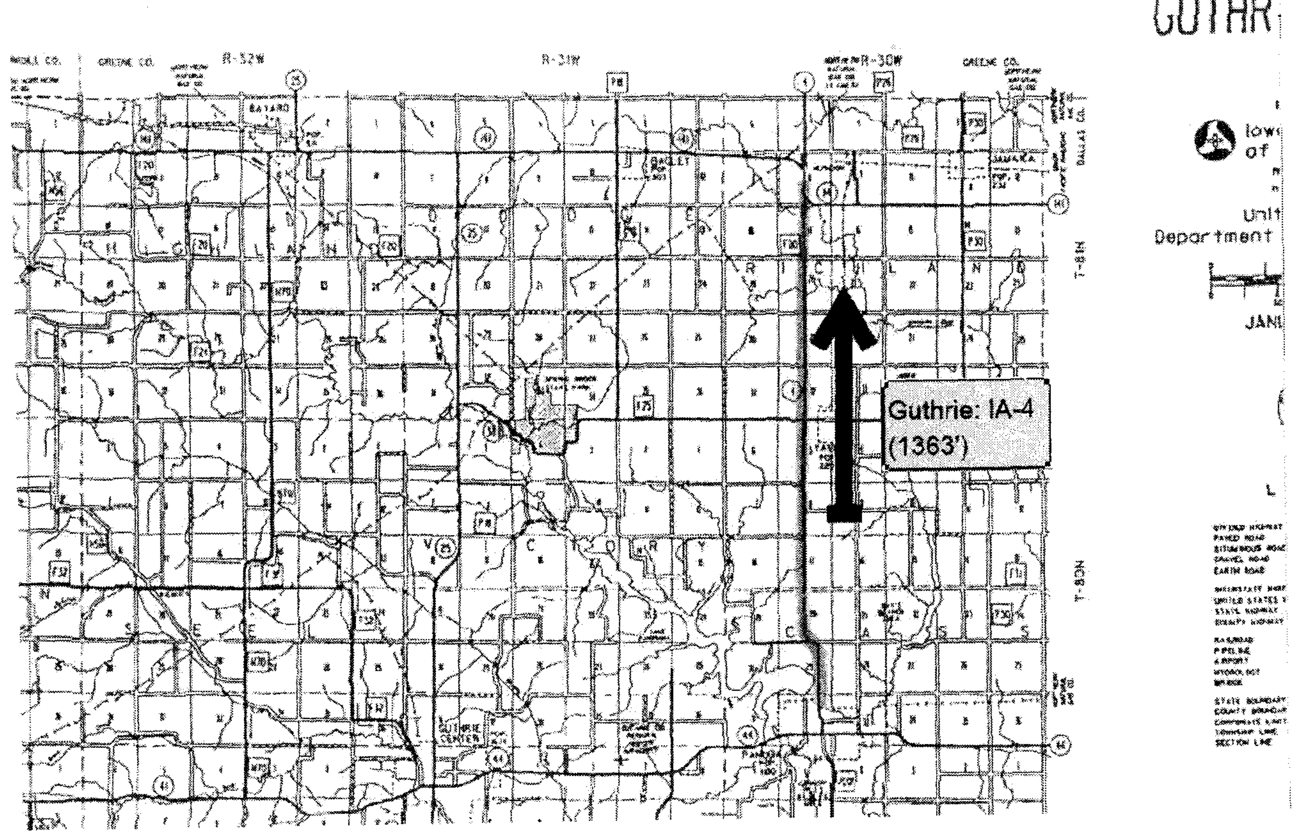

Clinton: E-50
(3340')
Clinton: Z-30
(transverse: 8000ft
slippage crack: 840)


GREENE COUNTY
IOWA
Iowa Department of Transportation
United States
Department of Transportation
JANUARY 1, 1995
LEGEND
R-32W
R-31W
R-30W
R-29W
T-85N
T-84N
T-83N
T-82N
JEFFERSON
GRAND JUNCTION
PATON
CHURDAN
RALSTON
SCRANTON
RIPPEY
HIGHLAND
DAWSON
BRISTOL
JUNCTION
JACKSON
GREENBRIER
FRANKLIN
WASHINGTON

136


Greene: IA-144
(1500' crack; 2710'
trans.)
JEFFERSON
G R A N T
F R A N K L I N
W A S H I N G T O N
RIPPEY
T-83N
T-82N
R-31W
R-30W
R-29W
GUTHRIE CO.
DALLAS CO.
BOONE CO.


GUTHRIE COUNTY
IOWA
Prepared By
Iowa Department of Transportation
United States Department of Transportation
JANUARY 1, 1995
LEGEND


GUTHR
Guthrie: IA-4
(1363')
R-32W
R-31W
R-30W
T-81N
T-80N
GUTHRIE CENTER
BAYARD
BAGLEY
JAMAICA
Department

HIGHWAY AND TRANSPORTATION MAP

HARDIN COUNTY

IOWA

Prepared by

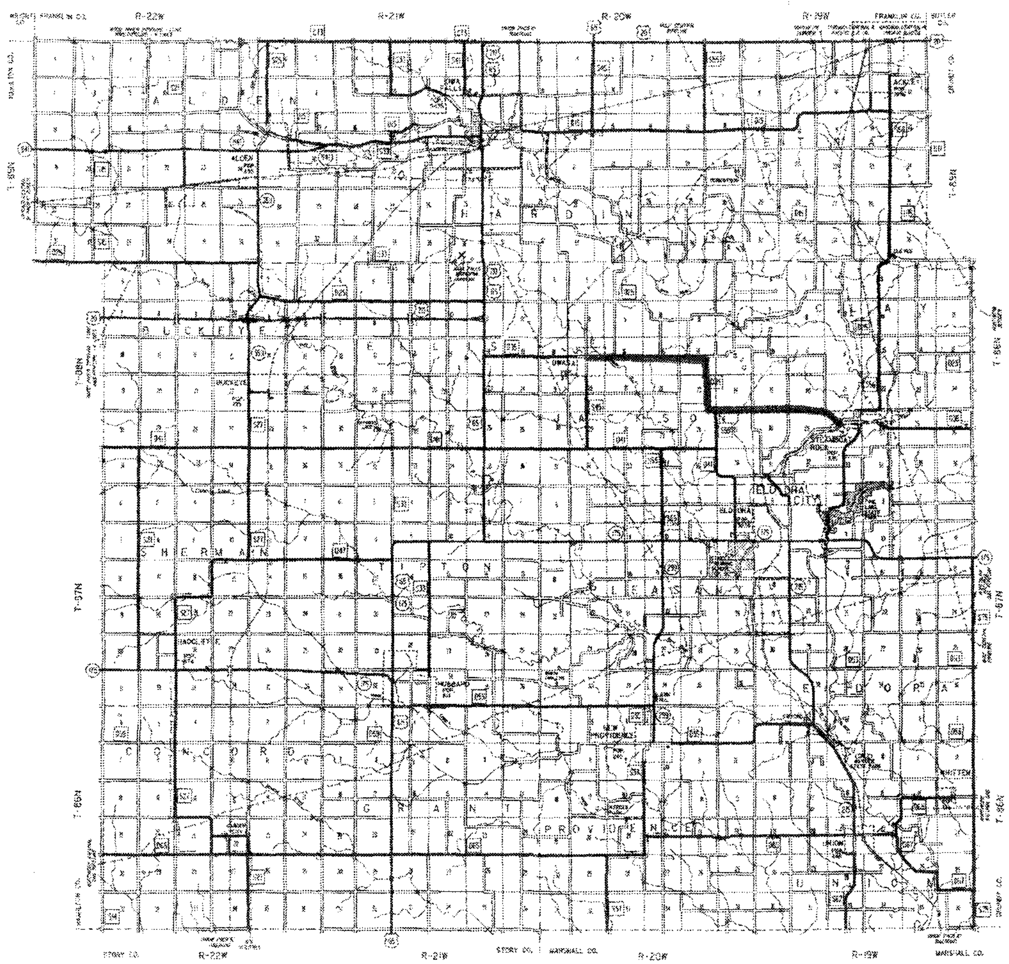
Iowa Department of Transportation

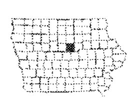
In cooperation with

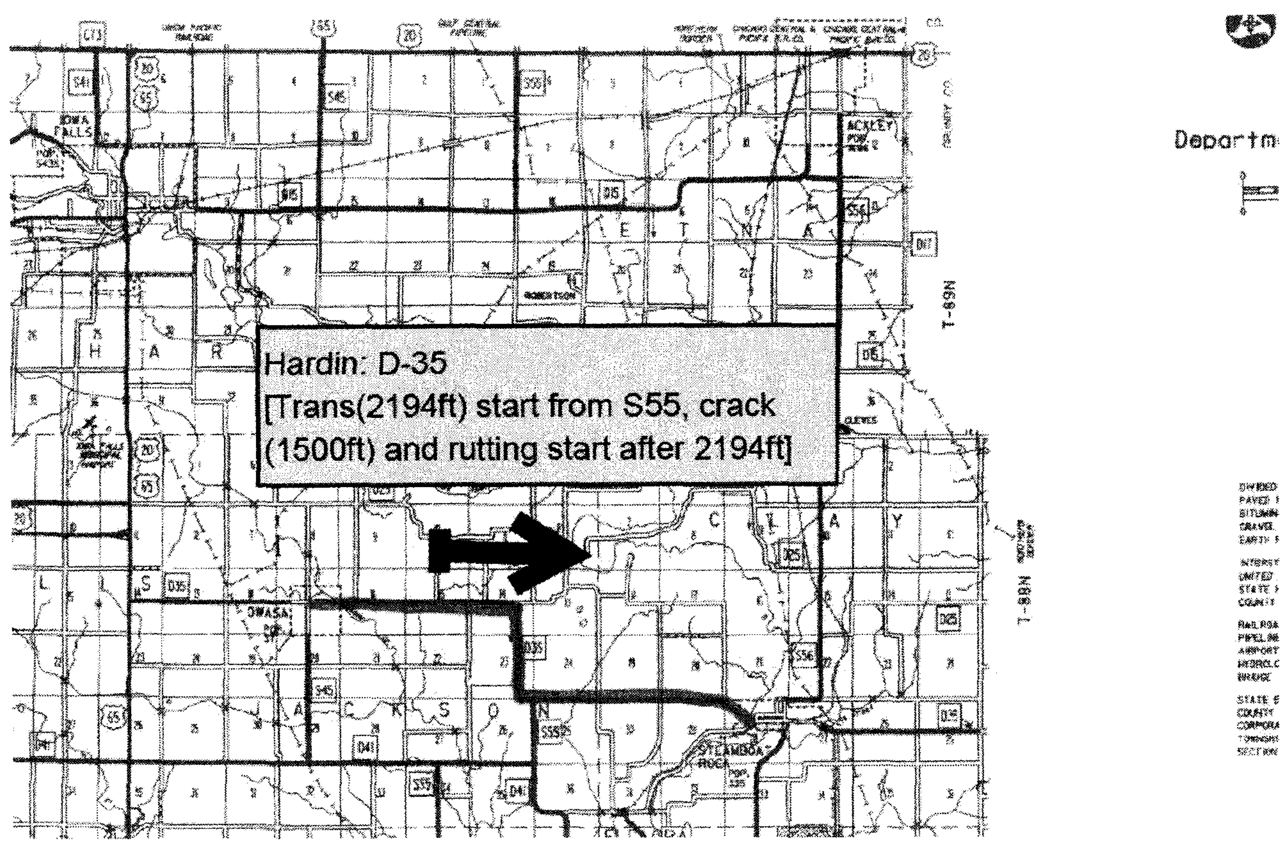
United States Department of Transportation

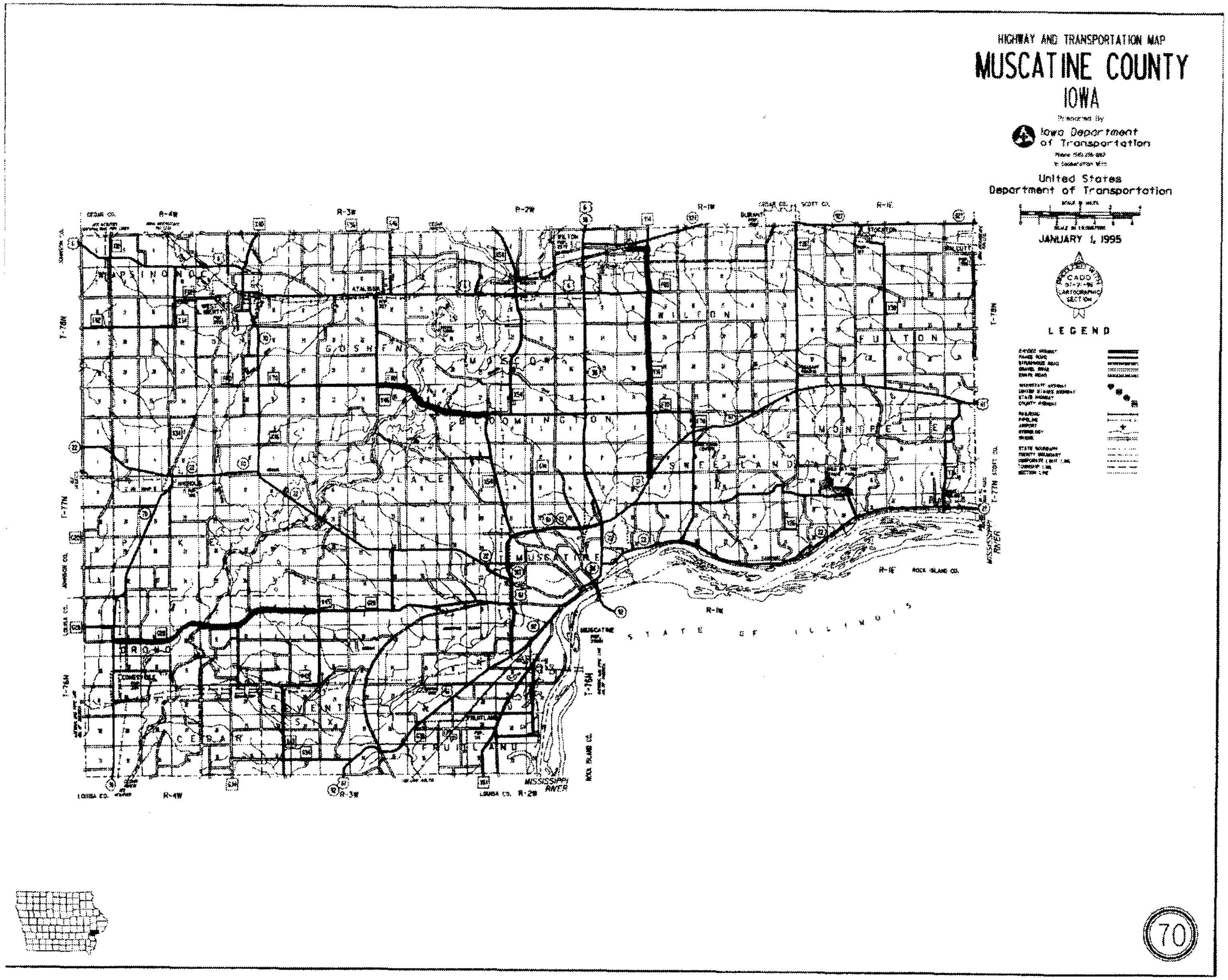
JANUARY 1, 1995

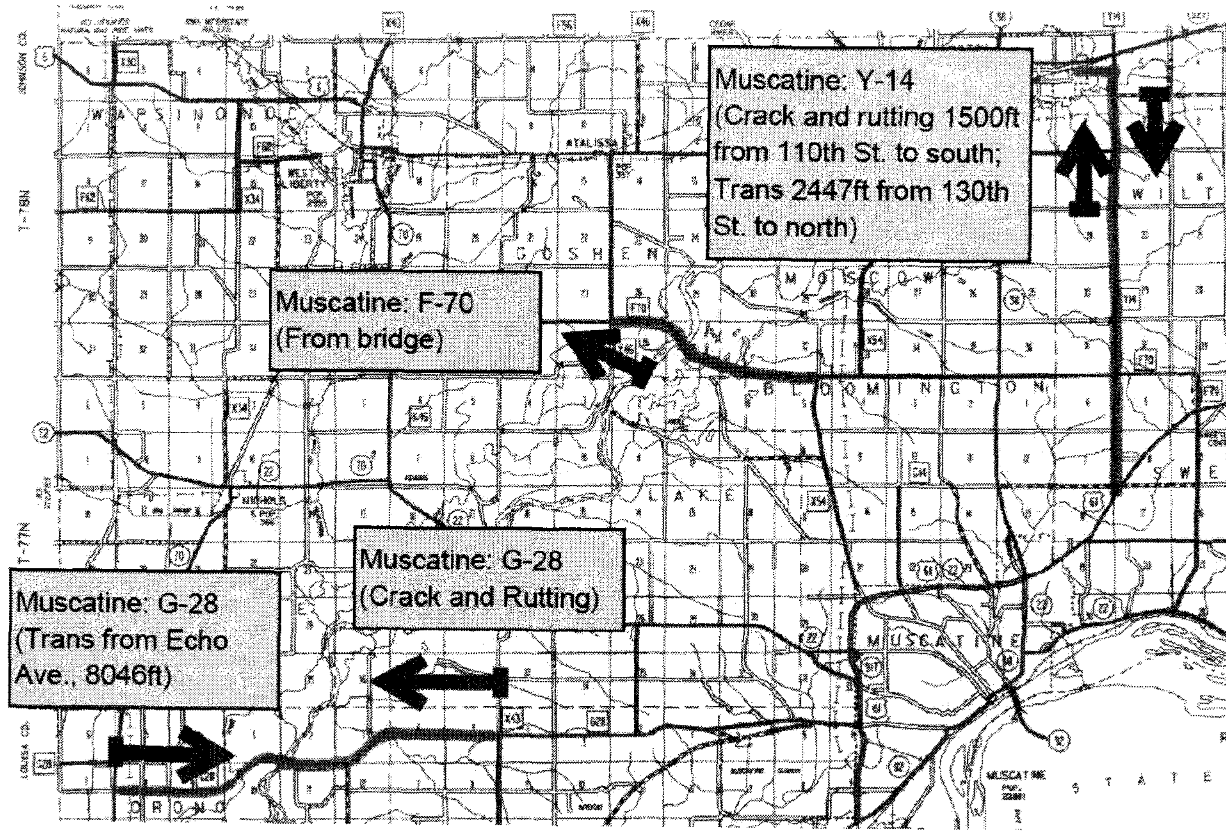
LEGEND

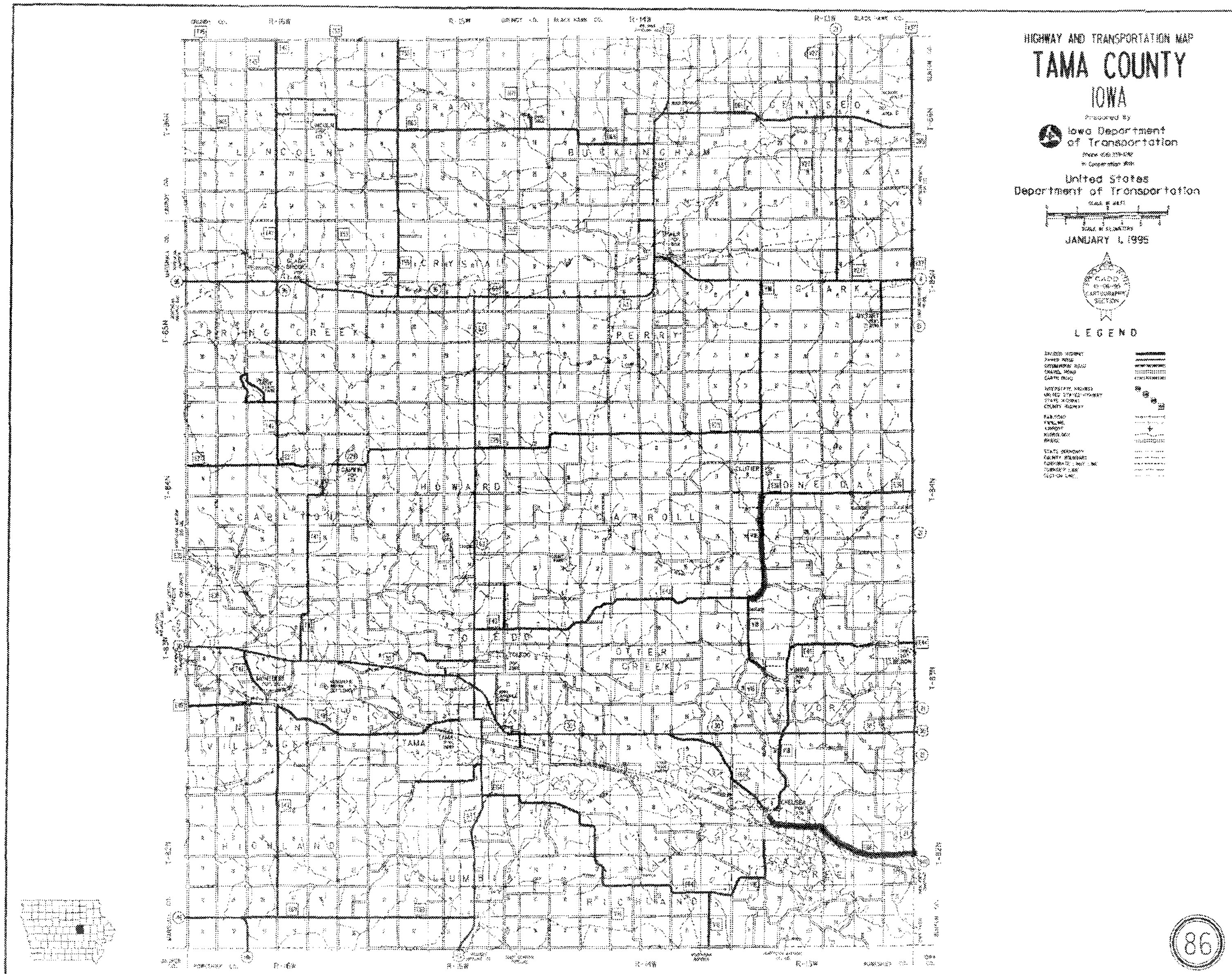


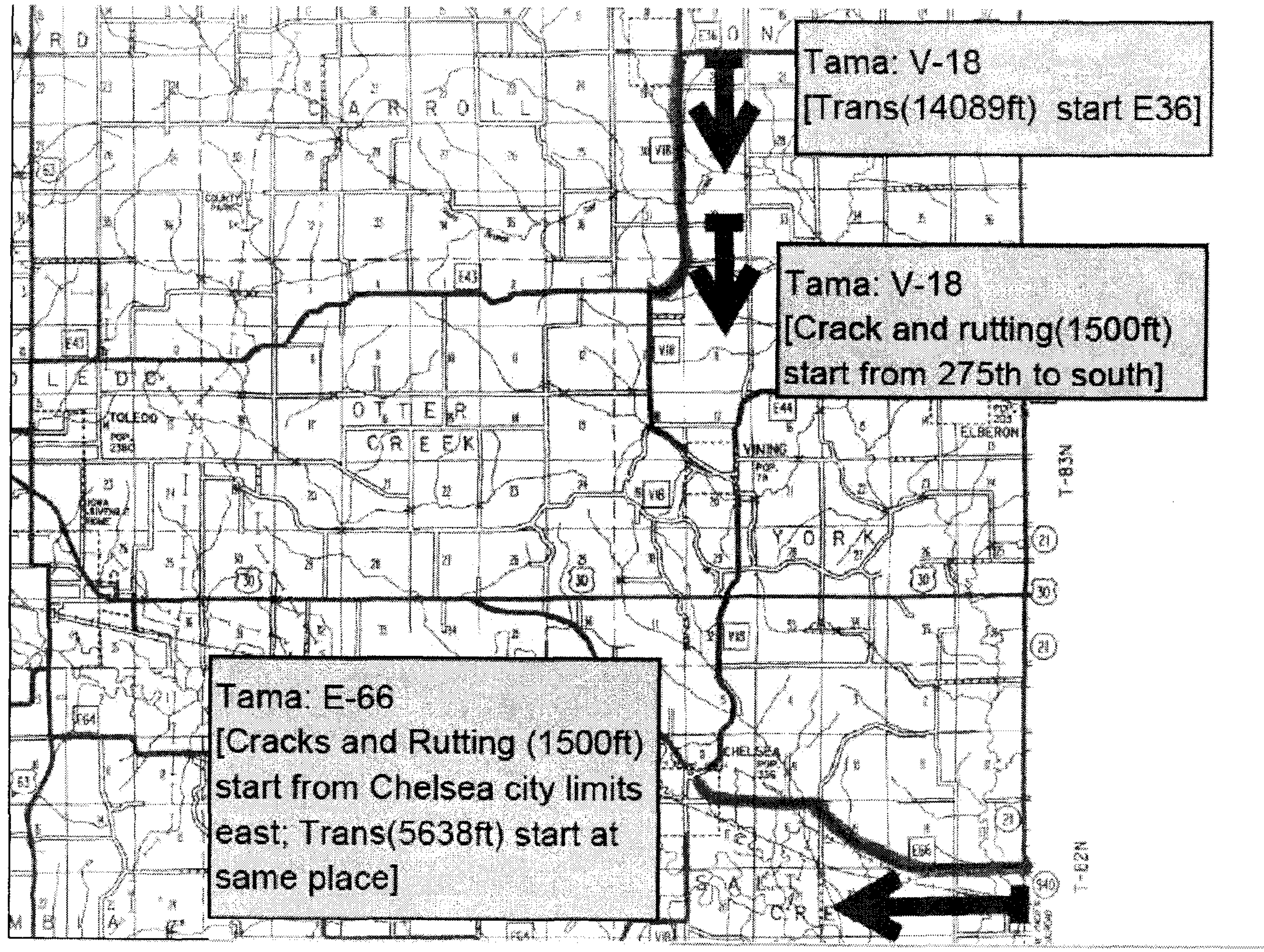



Hardin: D-35
[Trans(2194ft) start from S55, crack
(1500ft) and rutting start after 2194ft]
Departm


HIGHWAY AND TRANSPORTATION MAP
MUSCATINE COUNTY
IOWA
Iowa Department of Transportation
United States Department of Transportation
JANUARY 1, 1995
LEGEND
MUSCATINE
MONTPELIER
FULTON
GOSHEN
CEDAR
STATE OF ILLINOIS
MISSISSIPPI RIVER
70


Muscatine: Y-14
(Crack and rutting 1500ft from 110th St. to south; Trans 2447ft from 130th St. to north)
Muscatine: F-70
(From bridge)
Muscatine: G-28
(Crack and Rutting)
Muscatine: G-28
(Trans from Echo Ave., 8046ft)
MUSCATINE


HIGHWAY AND TRANSPORTATION MAP
TAMA COUNTY
IOWA
Produced By
Iowa Department
of Transportation
United States
Department of Transportation
JANUARY 1, 1995
LEGEND
GRANT
GENESEO
LINCOLN
BUCKINGHAM
CRYSTAL
CLARK
SPRING CREEK
PERRY
HOWARD
ONEIDA
CARLTON
CARROLL
TOLEDO
OTTER CREEK
YORK
INDIAN VILLAGE
TAMA
HIGHLAND
COLUMBIA
RICHLAND
86


Tama: V-18
[Trans(14089ft) start E36]
Tama: V-18
[Crack and rutting(1500ft)
start from 275th to south]
Tama: E-66
[Cracks and Rutting (1500ft)
start from Chelsea city limits
east; Trans(5638ft) start at
same place]
CARROLL
OTTER
CREEK
YORK
TOLEDO
VINING
ELBERON
CHELSEA
T-83N
T-82N

HIGHWAY AND TRANSPORTATION MAP

WINNEBAGO COUNTY

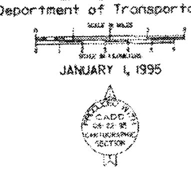
IOWA

Prepared by

Iowa Department of Transportation

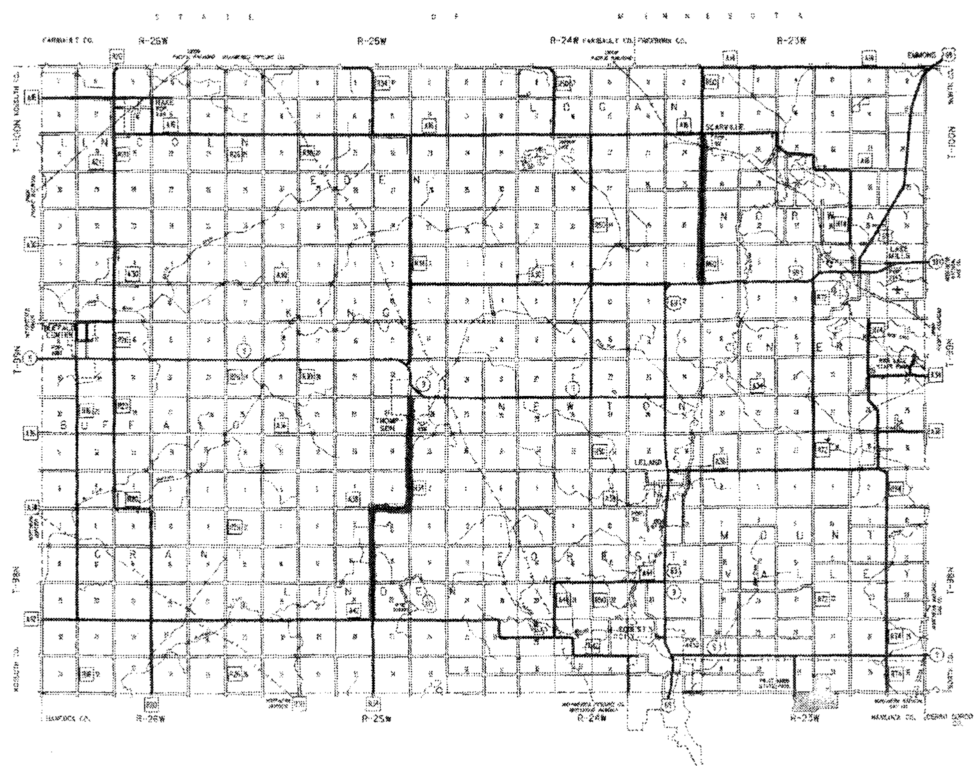
In Cooperation With

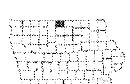
United States Department of Transportation



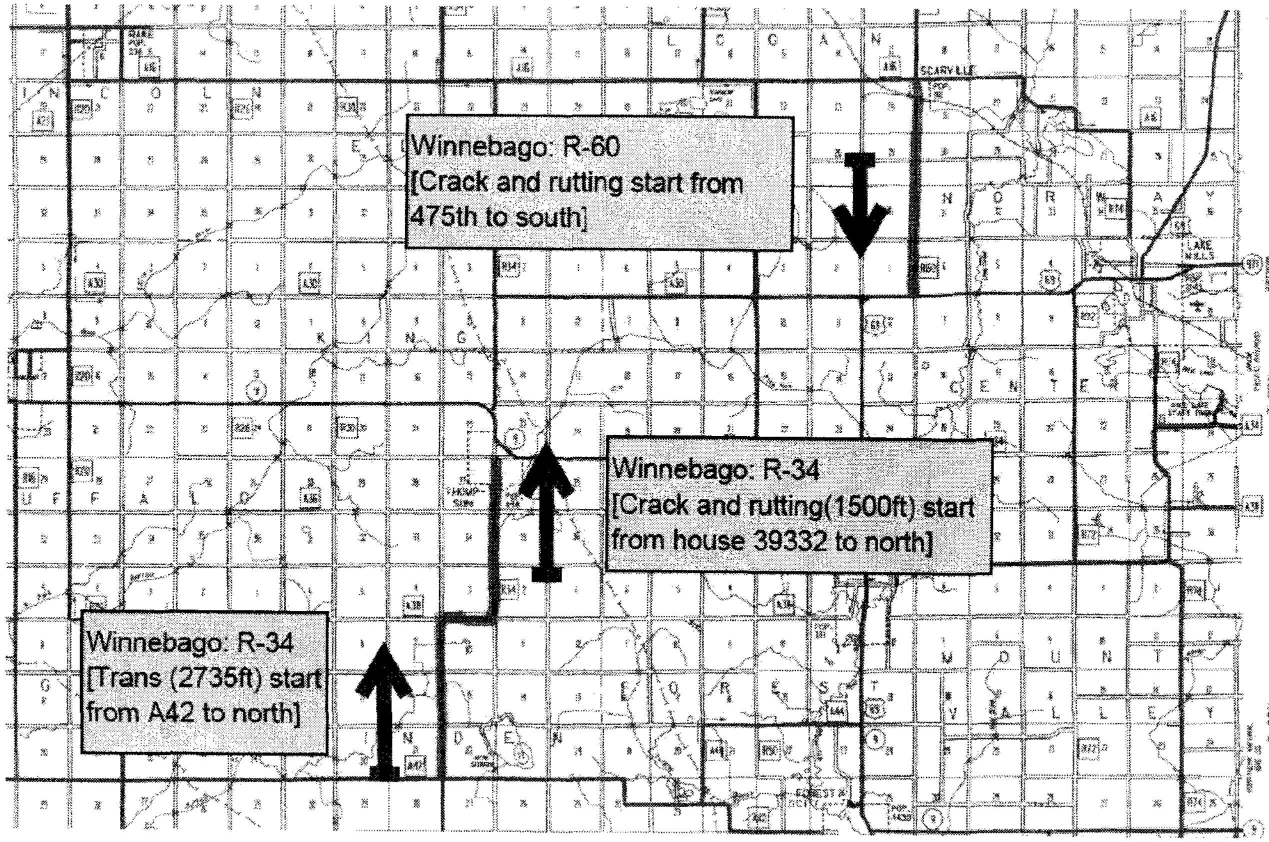
JANUARY 1, 1995

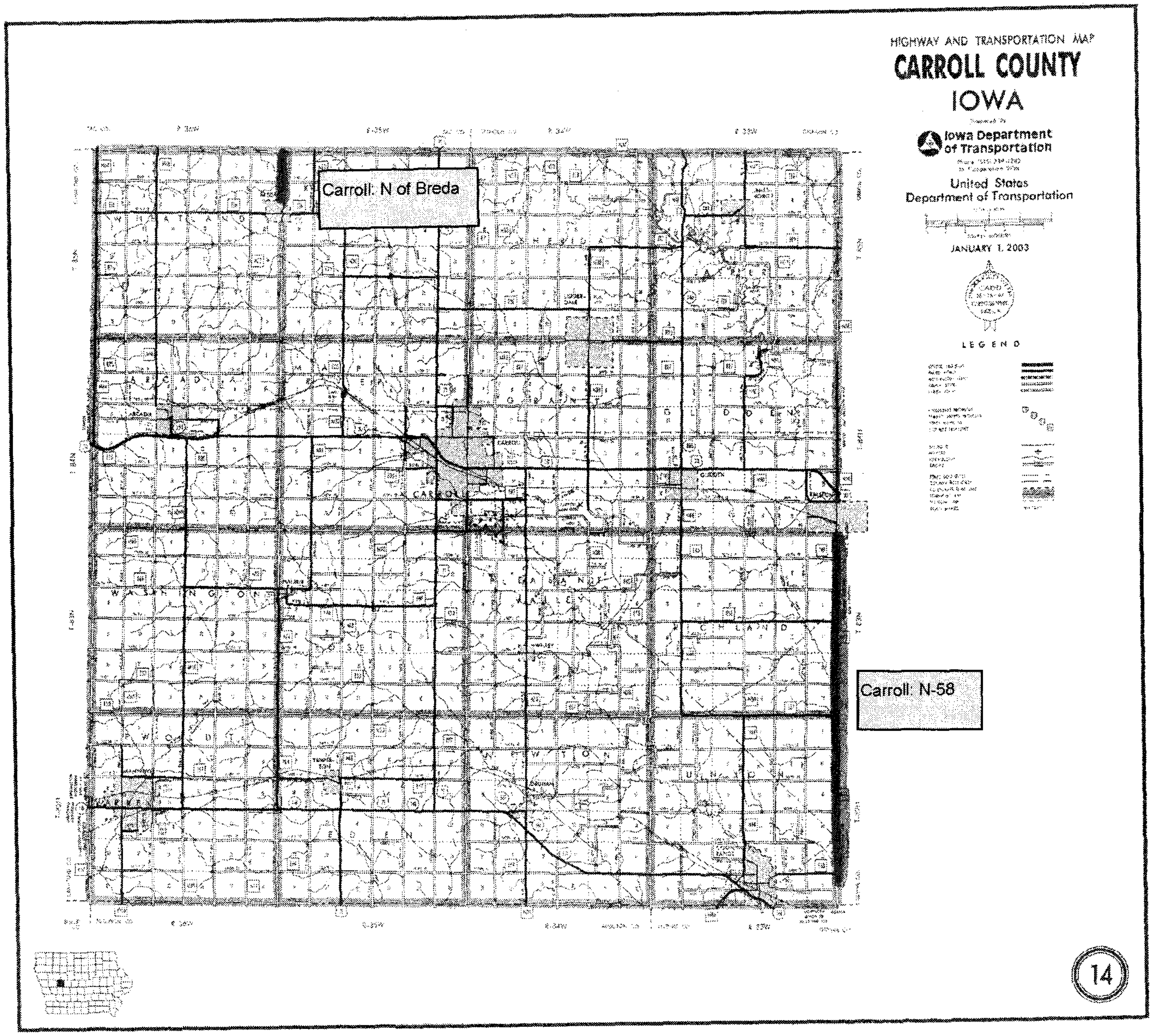
LEGEND

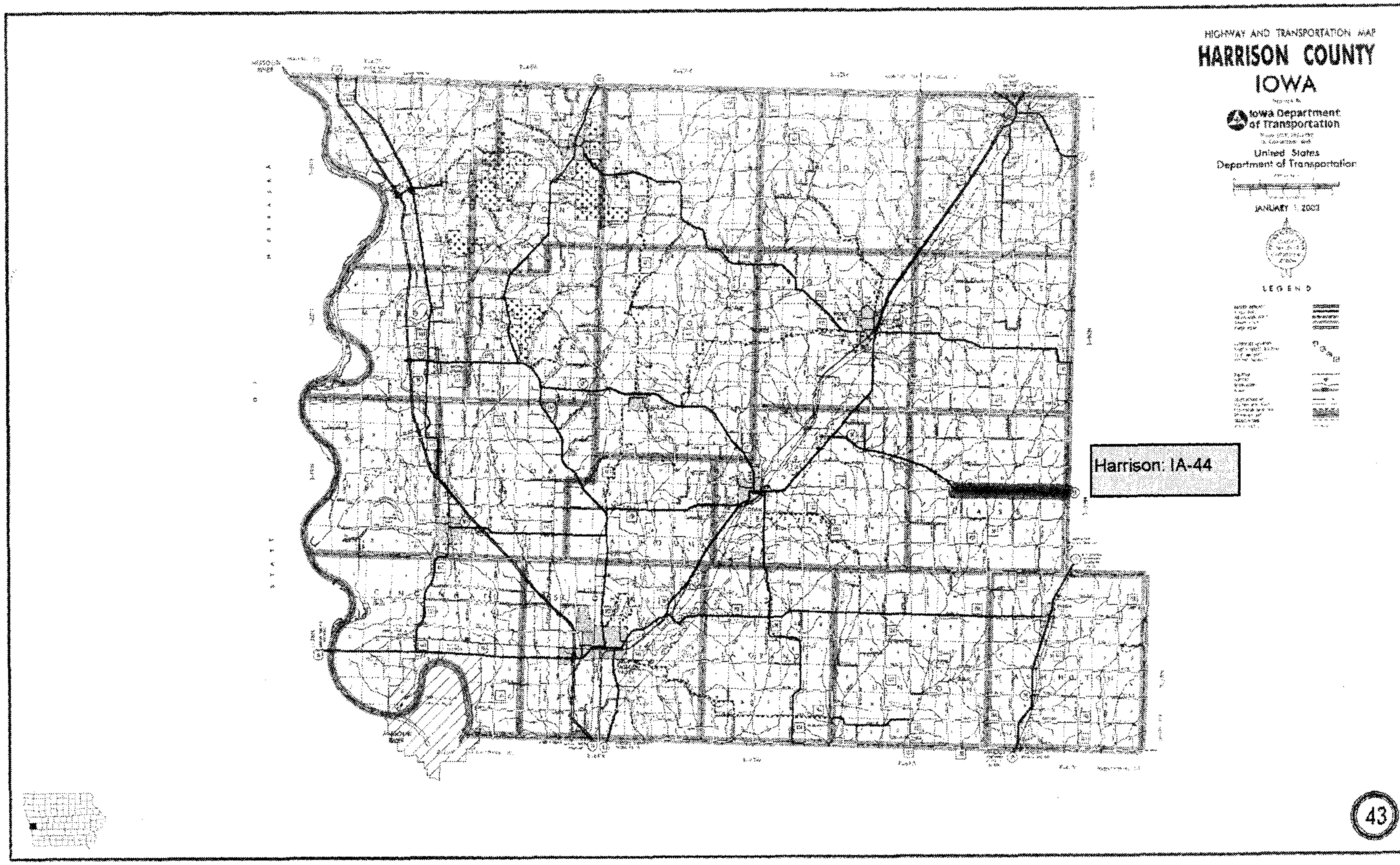


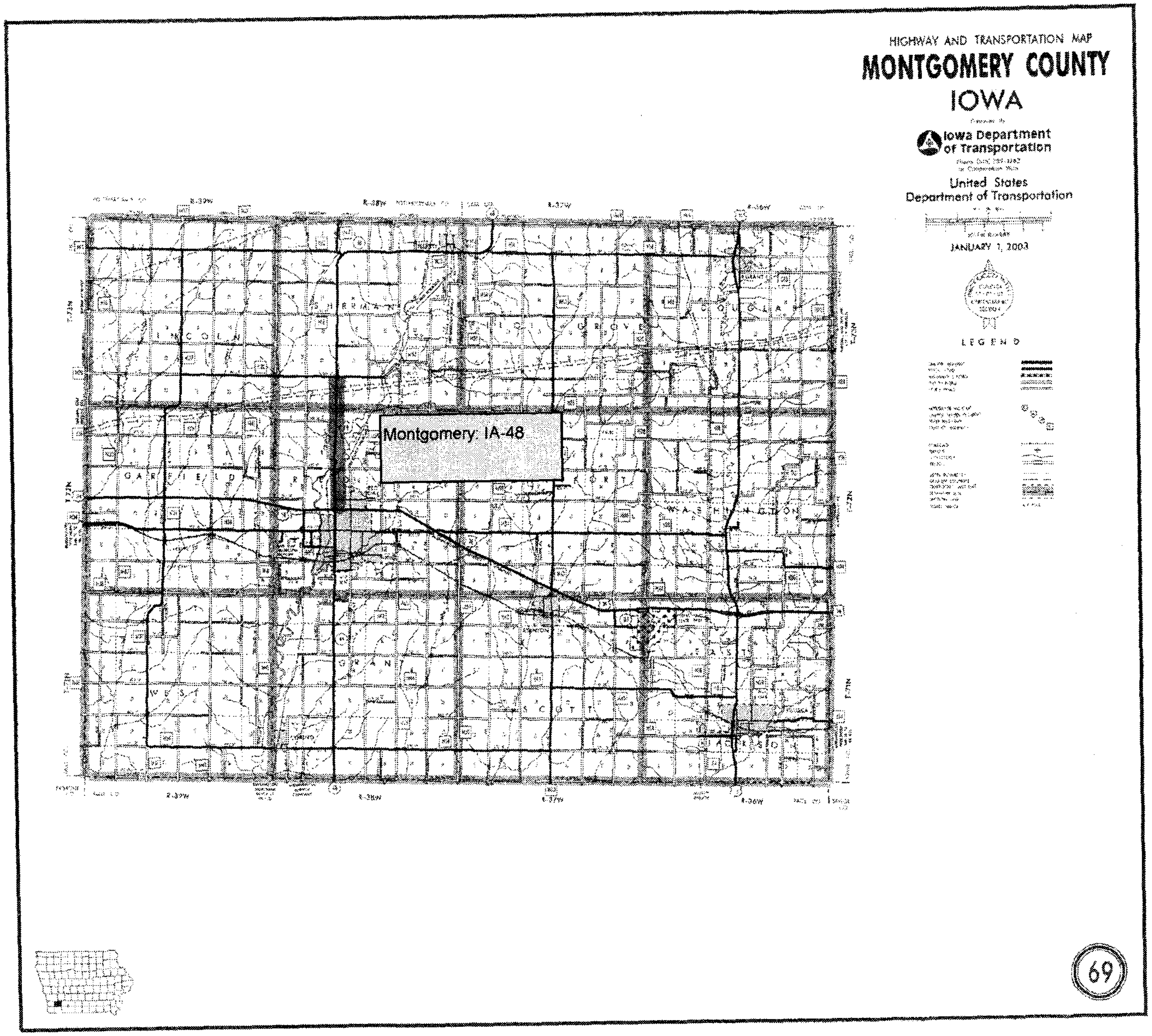


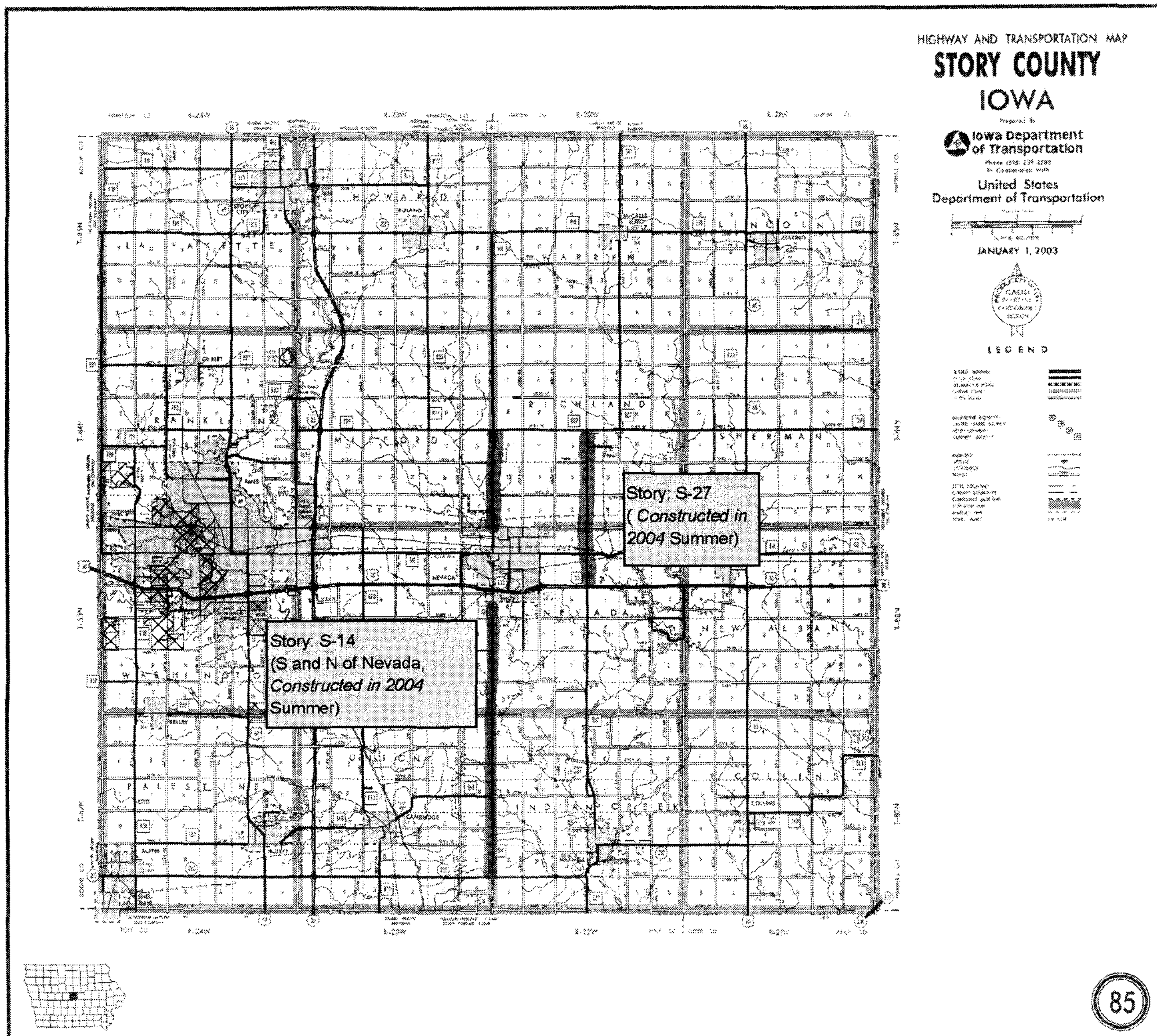
95

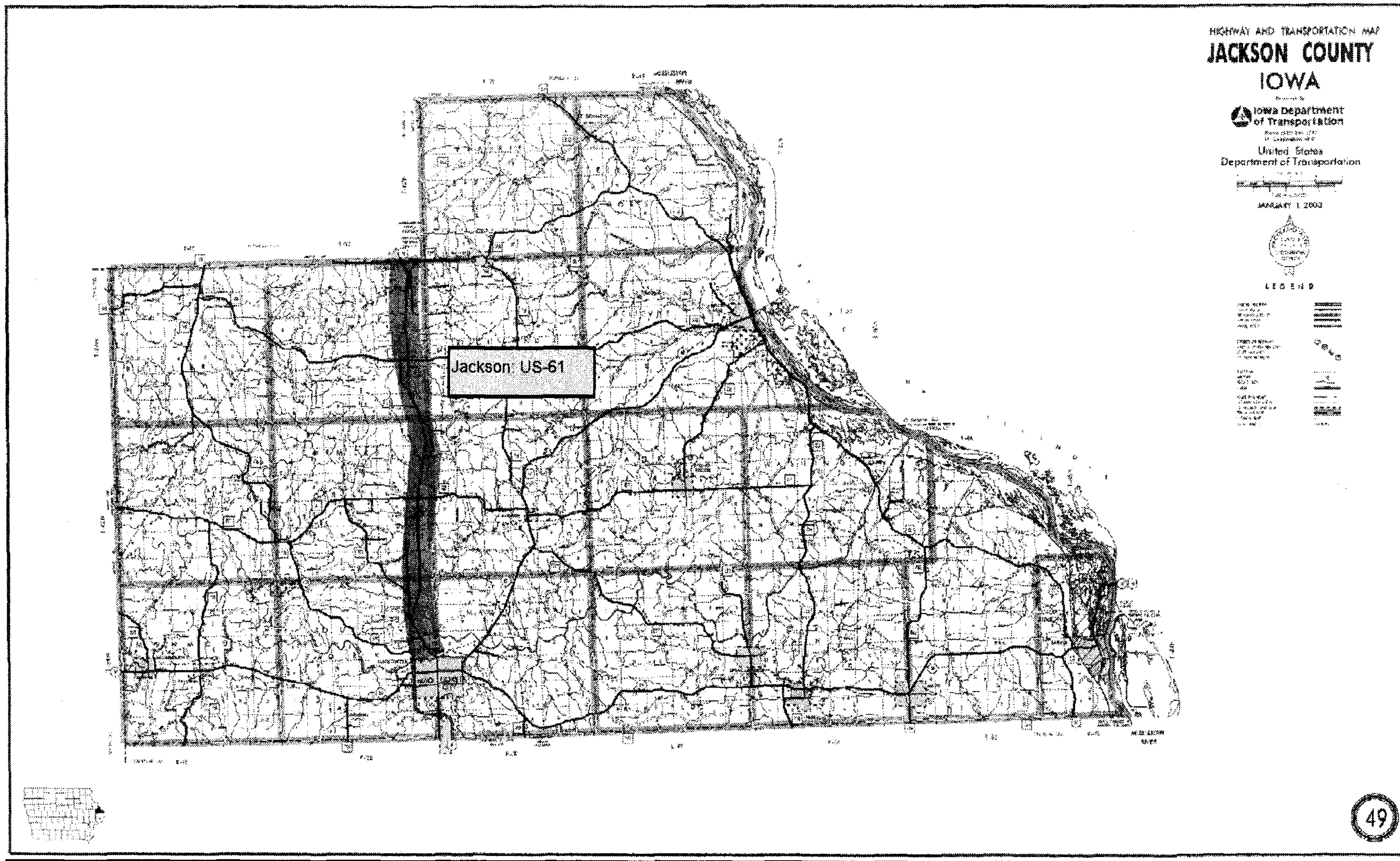

Winnebago: R-60
[Crack and rutting start from
475th to south]
Winnebago: R-34
[Crack and rutting(1500ft) start
from house 39332 to north]
Winnebago: R-34
[Trans (2735ft) start
from A42 to north]


HIGHWAY AND TRANSPORTATION MAP
CARROLL COUNTY
IOWA
Iowa Department of Transportation
United States
Department of Transportation
JANUARY 1, 2003
LEGEND
Carroll: N of Breda
Carroll: N-58
14

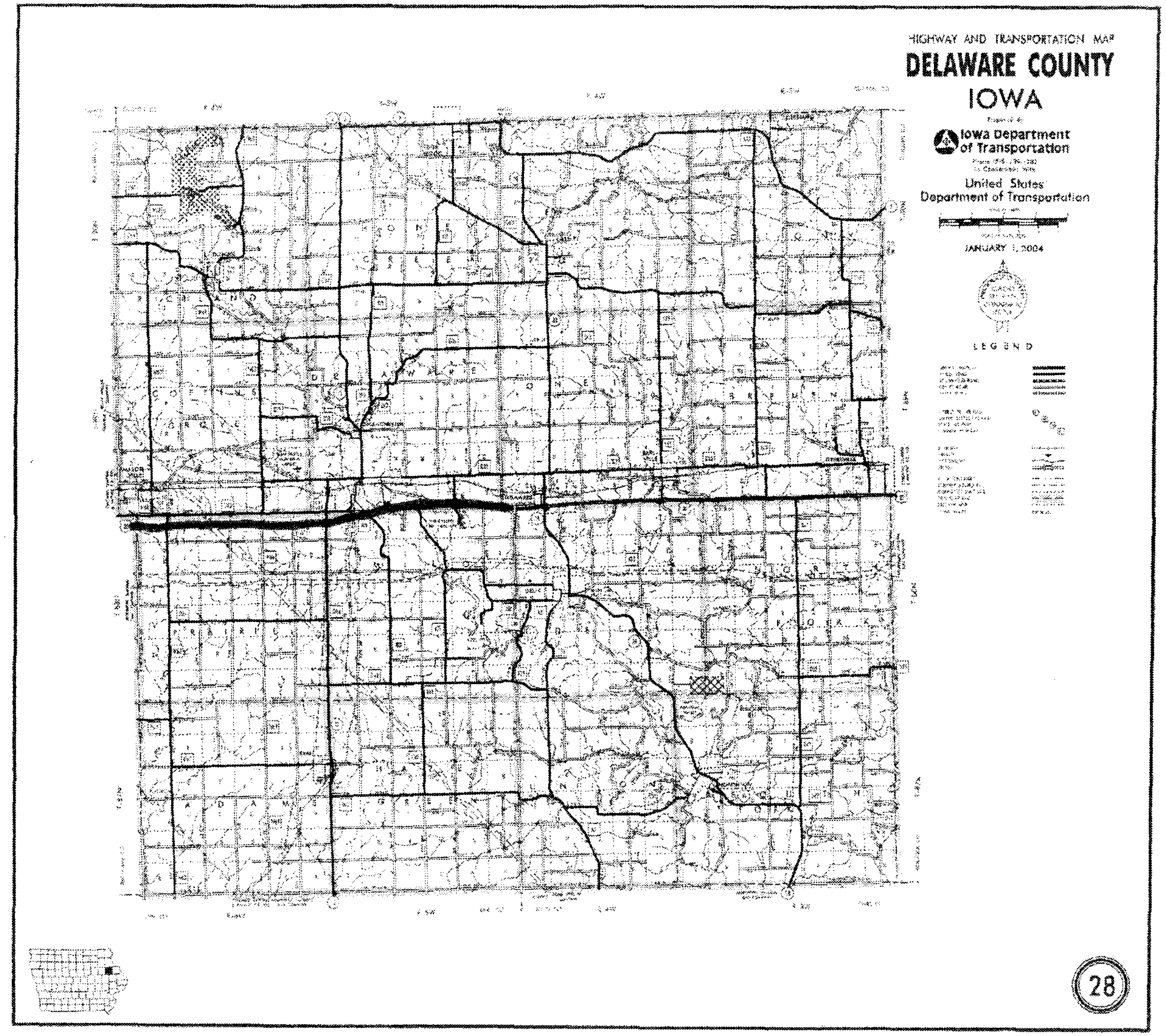

HIGHWAY AND TRANSPORTATION MAP
HARRISON COUNTY
IOWA
Iowa Department of Transportation
United States
Department of Transportation
LEGEND
Harrison: IA-44
43


HIGHWAY AND TRANSPORTATION MAP
MONTGOMERY COUNTY
IOWA
Iowa Department of Transportation
United States
Department of Transportation
JANUARY 1, 2003
LEGEND
Montgomery: IA-48
69


HIGHWAY AND TRANSPORTATION MAP
STORY COUNTY
IOWA
Iowa Department of Transportation
United States
Department of Transportation
JANUARY 1, 2003
LEGEND
Story: S-27
(Constructed in 2004 Summer)
Story: S-14
(S and N of Nevada, Constructed in 2004 Summer)
85



HIGHWAY AND TRANSPORTATION MAP
JACKSON COUNTY
IOWA
Iowa Department of Transportation
United States
Department of Transportation
JANUARY 1, 2003
LEGEND
Jackson US-61
49


HIGHWAY AND TRANSPORTATION MAP
DELAWARE COUNTY
IOWA
Iowa Department of Transportation
United States Department of Transportation
JANUARY 1, 2004
LEGEND
28

APPENDIX C. LAB DATA

Table C.1 Lab testing data -G_{mb}

Test Day	Sample I.D	A Mass of Dry Sample in Air (g)	B Mass of SSD Sample in Air (g)	C Mass of Sample in water (g)	Gmb Bulk Specific Gravity [A/(B-C)]	Absorption (B-A)/(B-C) X 100 (%)	Sample Thickness (in) 1	2	3	4	AVE.	Remark
6/15/2005	Tama/E66/1/1	848.7	852.8	465.8	2.193	1.059	2	2	2	2	2	
	Tama/E66/1/2	826.8	832.4	452.6	2.177	1.474	2	2	2	2	2	
	Tama/E66/1/3	755.1	757	427	2.288	0.576	2	1 13/16	1 10/16	1 8/16	1 12/16	
	Tama/E66/2/1	848.9	849.9	475.9	2.270	0.267	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
Average					**2.232**	**0.844**					**1.902**	
Standard Deviation					**0.055**	**0.532**					**0.127**	
6/27/2005	Montgomery/IA48/1a/1	823.1	824.2	464.2	2.286	0.306	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
	Montgomery/IA48/2/1	941.9	943.1	528.3	2.271	0.289	2	2	2	2	2	
	Montgomery/IA48/3/1	918.8	920.2	514.3	2.264	0.345	2	2	2	2	2	
	Montgomery/IA48/4b/1	810.5	813.1	447.9	2.219	0.712	1 13/16	1 14/16	1 14/16	1 14/16	1 14/16	
	Montgomery/IA48/4b/2	919.5	921.9	511.2	2.239	0.584	2	2	2	2	2	
	Montgomery/IA48/5a/1	887.4	888.5	496.4	2.263	0.281	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
	Montgomery/IA48/6a/1	853	854.1	476.6	2.260	0.291	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
Average					**2.257**	**0.401**					**1.926**	
Standard Deviation					**0.022**	**0.174**					**0.069**	
6/27/2005	Clinton/E50/1/1	835.4	843.2	453.6	2.144	2.002	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
	Clinton/E50/1/2	758.6	769.5	405.4	2.083	2.994	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
	Clinton/E50/2/1	789.6	799.2	428.8	2.132	2.592	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
	Clinton/E50/2/2	780.2	790.1	418	2.097	2.661	1 13/16	1 13/16	1 12/16	1 12/16	1 13/16	
	Clinton/E50/3/1	808.5	827.3	449.6	2.141	4.977	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
	Clinton/E50/5/1	822.7	826.4	449.5	2.183	0.982	1 14/16	1 14/16	1 14/16	1 14/16	1 14/16	
Average					**2.130**	**2.701**					**1.859**	
Standard Deviation					**0.036**	**1.321**					**0.038**	
6/27/2005	Jackson / US61/2a/1	925.9	928.1	510.6	2.218	0.527	2 1/16	2	2	2	2	
	Jackson / US61/3a/1	922.6	926.3	516	2.249	0.902	2	2 1/16	2 1/16	2	2 1/16	
	Jackson / US61/4/1	897.1	905.3	498.8	2.207	2.017	2 1/16	2 1/16	2 1/16	2	2 1/16	
	Jackson / US61/5/1	896.3	899.8	492.7	2.202	0.860	2	2	2	2	2	
Average					**2.219**	**1.076**					**2.023**	
Standard Deviation					**0.021**	**0.649**					**0.020**	

Table C.1 (continued)

Test Day	Sample I.D	A Mass of Dry Sample in Air (g)	B Mass of SSD Sample in Air (g)	C Mass of Sample in water (g)	Gmb Bulk Specific Gravity [A/(B-C)]	Absorption (B-A)/(B-C) X 100 (%)	Sample Thickness (in) 1	2	3	4	AVE.	Remark
6/27/2005	Muscatino/F70/2	370.4	373.1	200	2.140	1.560	12/16	12/16	12/16	12/16	12/16	Not for IDT
	Muscatino/F70/3	575.9	585.6	308.6	2.079	3.502	1 2/16	1 2/16	1 2/16	1 2/16	1 2/16	
	Muscatino/F70/4	642.7	652.1	344.5	2.089	3.056	1 4/16	1 4/16	1 4/16	1 4/16	1 4/16	
	Muscatino/F70/6	446.9	449.6	246.5	2.200	1.329	12/16	12/16	12/16	12/16	12/16	Not for IDT
Average					**2.127**	**2.362**					**0.969**	
Standard Deviation					**0.056**	**1.079**					**0.258**	
6/27/2005	Muscatine/Y14(S)/1/1	891.2	892.7	481.3	2.166	0.365	2	2	2	2	2	
	Muscatine/Y14(S)/2/1	888.9	896	489.6	2.187	1.747	2	2	2	2	2	
	Muscatine/Y14(S)/4/1	919.8	931.2	509	2.179	2.700	2	2	2 5/16	2 5/16	2 3/16	
	Muscatine/Y14(S)/6/1	904.6	911	500.8	2.205	1.560	2	2	2	2	2	
	Muscatine/Y14(S)/6/2	864.6	870.8	468.8	2.151	1.542	2	2	2	2 1/16	2	
Average					**2.178**	**1.583**					**2.034**	
Standard Deviation					**0.021**	**0.831**					**0.068**	
6/27/2005	Muscatine/Y14(N)/1/1	896.5	898.1	490.8	2.201	0.393	2	2	2 1/16	2	2	
	Muscatine/Y14(N)/2/1	888.8	898.2	484.4	2.148	2.272	2	2 1/16	2	2	2	
	Muscatine/Y14(N)/3/1	876.9	884.1	473	2.133	1.751	2	2	2	2	2	
	Muscatine/Y14(N)/4/1	898.7	908.9	489	2.140	2.429	2	2 1/16	2	2	2	
	Muscatine/Y14(N)/5/1	909.6	916	498.6	2.179	1.533	2	2	2	2	2	
	Muscatine/Y14(N)/6/1	871.5	887	469.5	2.087	3.713	2	2	2	2	2	
Average					**2.148**	**2.015**					**2.008**	
Standard Deviation					**0.039**	**1.100**					**0.009**	
6/27/2005	Muscatine/G28W/2/1	906.3	908.3	499.1	2.215	0.489	2	2	2	2	2	
	Muscatine/G28W/3/1	873.8	884.2	477	2.146	2.554	2	2	2	2	2	
	Muscatine/G28W/4/1	929.2	934.6	521.5	2.249	1.307	2	2	2	2	2	
	Muscatine/G28W/6/1	858	875.4	471.3	2.123	4.306	2	2	2	2	2	
Average					**2.183**	**2.164**					**2.000**	
Standard Deviation					**0.059**	**1.661**					**0.000**	
6/27/2005	Muscatine/G28E/2/1	830.9	838	439.2	2.084	1.780	2	2	1 15/16	1 15/16	2	
	Muscatine/G28E/3/1	813.1	826	430.5	2.056	3.262	1 15/16	1 15/16	1 15/16	1 15/16	1 15/16	
	Muscatine/G28E/5/1	836.3	854.5	446.1	2.048	4.456	2	2	1 14/16	1 14/16	1 15/16	
	Muscatine/G28E/6/1	825.7	837.5	438.3	2.068	2.956	2	2	2	2	2	
Average					**2.064**	**3.114**					**1.961**	
Standard Deviation					**0.016**	**1.100**					**0.030**	

Table C.1 (continued)

Test Day	Sample I.D	A Mass of Dry Sample in Air (g)	B Mass of SSD Sample in Air (g)	C Mass of Sample in water (g)	Gmb Bulk Specific Gravity [A/(B-C)]	Absorption (B-A)/(B-C) X 100 (%)	Sample Thickness (in) 1	2	3	4	AVE.	Remark
6/28/2005	Hardin/D35/1/1	924.5	925.8	517.5	2.264	0.318	2	2	2	2	2	
	Hardin/D35/2/1	878.7	881.2	485.9	2.223	0.632	1 14/16	2	2	2	2	
	Hardin/D35/3/1	862.7	865.1	470.3	2.185	0.608	1 14/16	2	2	2	2	
	Hardin/D35/4/1	886.5	888.7	484.7	2.194	0.545	2	2	2	2	2	
	Hardin/D35/5/1	984.2	988.5	537.1	2.180	0.953	2	2	2	2	2	
	Hardin/D35/6/1	881.4	884.1	488.4	2.227	0.682	2	2	2	1 15/16	2	
Average					**2.212**	**0.623**					**1.987**	
Standard Deviation					**0.032**	**0.206**					**0.015**	
6/28/2005	Clintone/Z30/1/1	843.2	846.5	464	2.204	0.863	1 14/16	1 14/'6	1 14/16	1 14/16	1 14/16	
	Clintone/Z30/2/1	897.7	903.8	493.4	2.187	1.486	2	2	2	2	2	
	Clintone/Z30/3/1	789.3	812.5	442	2.130	6.262	1 13/16	1 13/16	1 13/16	1 13/16	1 13/16	
	Clintone/Z30/4/1	884.4	897	486.6	2.155	3.070	2	2	2	2	2	
	Clintone/Z30/5/1	960.3	962.2	549	2.324	0.460	2	2	2	2	2	
	Clintone/Z30/6/1	890.5	907.1	498.6	2.180	4.064	2	2	2	2	2	
Average					**2.197**	**2.701**					**1.948**	
Standard Deviation					**0.068**	**2.216**					**0.083**	
6/28/2005	Cerro Codo/B43/2/1	849.8	855.1	473.8	2.229	1.390	2	2	2	1 10/16	1 15/16	
	Cerro Codo/B43/3/1	845.5	853.7	468.1	2.193	2.127	2	2	2	2	2	
	Cerro Codo/B43/4/1	829.5	833.4	456.8	2.203	1.036	2	2	1 13/16	1 13/16	1 15/16	
	Cerro Codo/B43/5/1	826.3	839.7	455	2.148	3.483	1 13/16	1 13/16	2	1 13/16	1 14/16	
	Cerro Codo/B43/6/1	838.6	844.6	459	2.175	1.556	1 13/16	1 10/16	1 10/16	1 13/16	1 12/16	
Average					**2.189**	**1.918**					**1.878**	
Standard Deviation					**0.030**	**0.959**					**0.103**	
6/28/2005	Cerro Codo/SS/5/1	852.3	854	468.3	2.210	0.441	1 15/16	1 15/16	1 15/16	1 15/16	1 15/16	
	Cerro Codo/SS/5/2	881.4	883	479.8	2.186	0.397	2	2	1 15/16	1 15/16	2	
	Cerro Codo/SS/5/3	880	881.3	476.6	2.174	0.321	1 14/16	2	2	1 14/16	1 15/16	
	Cerro Codo/SS/6/1	801.7	803.7	428.2	2.135	0.533	1 13/16	1 13/16	1 14/16	1 15/16	1 14/16	
Average					**2.176**	**0.423**					**1.926**	
Standard Deviation					**0.031**	**0.088**					**0.047**	

Table C.1 (continued)

Test Day	Sample I.D	A Mass of Dry Sample in Air (g)	B Mass of SSD Sample in Air (g)	C Mass of Sample in water (g)	Gmb Bulk Specific Gravity [A/(B-C)]	Absorption (B-A)/(B-C) X 100 (%)	Sample Thickness (in) 1	2	3	4	AVE.	Remark
6/28/2005	Tama/V18(B)/1/1	903.6	909.9	487.6	2.140	1.492	2	2	2 1/16	2 1/16	2 1/16	
	Tama/V18(B)/2/1	866.6	867.9	479	2.228	0.334	1 15/16	2	2	2	2	
	Tama/V18(B)/2/2	848.7	850.1	460.5	2.178	0.359	2	2	1 15/16	1 15/16	2	
	Tama/V18(B)/3/1	885.8	887.4	487.7	2.216	0.400	2	2	2	2	2	
	Tama/V18(B)/3/2	853.9	855.6	460.4	2.161	0.430	2	2	1 15/16	2	2	
	Tama/V18(B)/4/1	871.5	873.3	489.3	2.270	0.469	2	2	1 14/16	2	2	
	Tama/V18(B)/4/2	835.4	837	453.3	2.177	0.417	2	1 14/16	1 14/16	1 14/16	1 15/16	
	Tama/V18(B)/5/1	858.1	860	466.8	2.182	0.483	2	2	2	2	2	
	Average				**2.194**	**0.548**					**1.980**	
Standard Deviation					**0.042**	**0.385**					**0.036**	
6/28/2005	Boone/198th/1/1	899.7	900.8	512	2.314	0.283	1 15/16	1 15/16	2	2	2	
	Boone/198th/1/2	906.8	908.3	518.1	2.324	0.384	2	1 15/16	1 15/16	1 15/16	1 15/16	
	Boone/198th/2/1	863.5	865.5	487	2.281	0.528	2	1 15/16	1 13/16	1 15/16	1 15/16	
	Boone/198th/2/2	927.6	929.6	528.3	2.311	0.498	1 15/16	1 15/16	1 14/16	1 14/16	1 15/16	
	Boone/198th/3/1	913.5	915	519.5	2.310	0.379	1 14/16	2	1 14/16	1 13/16	1 14/16	
	Boone/198th/4/1	884.2	885.9	494.3	2.258	0.434	2	2	1 15/16	1 15/16	2	
	Boone/198th/4/2	899.7	901	506.5	2.281	0.330	2	1 13/16	2	1 14/16	1 15/16	
	Boone/198th/5/1	911.8	913.6	518.3	2.307	0.455	2	2	2	2	2	
	Boone/198th/6/1	883	884.7	498.6	2.287	0.440	1 15/16	1 15/16	1 15/16	1 15/16	1 15/16	
	Boone/198th/6/2	822.8	824.8	442	2.149	0.522	2	1 14/16	1 13/16	1 13/16	1 14/16	
	Boone/198th/7/1	930.7	932.8	530.1	2.311	0.521	2	1 14/16	1 13/16	1 13/16	1 14/16	
	Boone/198th/7/2	889.6	891.6	499.7	2.270	0.510	2	1 15/16	1 15/16	1 13/16	1 15/16	
	Average				**2.284**	**0.441**					**1.928**	
Standard Deviation					**0.047**	**0.082**					**0.039**	
6/28/2005	Boone/E52/1/1	928.3	930	521.9	2.275	0.417	2	2	2	2	2	
	Boone/E52/2/1	864.3	868.7	463.8	2.135	1.087	1 13/16	1 14/16	2	2	1 15/16	
	Boone/E52/3/1	896.1	899.5	492.7	2.203	0.836	2	2	1 15/16	2	2	
	Boone/E52/4/1	868.5	873.3	474.5	2.178	1.204	2	2	1 15/16	1 15/16	2	
	Boone/E52/5/1	851.6	860	456.9	2.113	2.084	2	2	1 13/16	2	1 15/16	
	Boone/E52/6/1	855.6	864.6	465.3	2.143	2.254	2	2	1 13/16	2	1 15/16	
	Boone/E52/7/1	851.9	855	458.6	2.149	0.782	1 13/16	2	2	2	1 15/16	
	Boone/E52/8/1	862.5	869.5	470.8	2.163	1.756	2	1 15/16	1 13/16	1 14/16	1 15/16	
	Average				**2.170**	**1.302**					**1.955**	
Standard Deviation					**0.051**	**0.660**					**0.031**	

Table C.1 (continued)

Test Day	Sample I.D	A Mass of Dry Sample in Air (g)	B Mass of SSD Sample in Air (g)	C Mass of Sample in water (g)	Gmb Bulk Specific Gravity [A/(B-C)]	Absorption (B-A)/(B-C) X 100 (%)	Sample Thickness (in) 1	2	3	4	AVE.	Remark
6/28/2005	Story/S14(SB)/4/1	897.5	899.4	503.1	2.265	0.479	1 14/16	1 14/16	2	2	1 15/16	
	Story/S14(SB)/4/2	589.2	594.4	321	2.155	1.902	1	1 4/16	1 5/16	1 4/16	1 3/16	
	Average				**2.210**	**1.191**					**1.570**	
	Standard Deviation				**0.078**	**1.006**					**0.519**	
6/28/2005	Story/S14(NB)/1/1	881.6	884	493.7	2.259	0.615	2	2	1 15/16	1 15/16	2	
	Story/S14(NB)/2/1	905.7	908.9	504.3	2.239	0.791	1 15/16	1 15/16	1 15/16	2	1 15/16	
	Story/S14(NB)/3/1	901.1	906.9	493.7	2.181	1.404	2	2	2	1 15/16	2	
	Story/S14(NB)/4/1	885.7	889.8	488	2.204	1.020	2	2	2	2	2	
	Story/S14(NB)/5/1	879.8	886	484.5	2.191	1.544	2	2	1 14/16	1 14/16	1 15/16	
	Story/S14(NB)/5/2	885.8	891.6	488.4	2.197	1.438	2	2	2	2	2	
	Average				**2.212**	**1.135**					**1.974**	
	Standard Deviation				**0.030**	**0.383**					**0.026**	
6/28/2005	Butler/T16/1/1	889.6	894.9	490.4	2.199	1.310	2 1/16	2 1/16	2	1 15/16	2	
	Butler/T16/2/1	880.6	889.2	481.3	2.159	2.108	2 1/16	2 1/16	2	2	2 1/16	
	Butler/T16/3/1	891.2	893	490.3	2.213	0.447	2	2	1 15/16	1 15/16	2	
	Butler/T16/4/1	875.2	879.9	478.8	2.182	1.172	2 1/16	2 1/16	2	2	2 1/16	
	Butler/T16/5/1	869.6	872.9	474	2.180	0.827	2	2	2	2	2	
	Butler/T16/6/1	879.4	882.9	482.4	2.196	0.874	2	2	2	2	2	
	Average				**2.188**	**1.123**					**2.008**	
	Standard Deviation				**0.019**	**0.568**					**0.024**	
6/28/2005	Calhoun/IA175/2/1	901.3	903.5	492.2	2.191	0.535	2	2	2	2	2	
	Calhoun/IA175/4/1	900.2	902.7	492.1	2.192	0.609	2	2	2	2	2	
	Calhoun/IA175/5/1	905.5	907.9	491.5	2.175	0.576	2	2	2	2	2	
	Average				**2.186**	**0.573**					**2.000**	
	Standard Deviation				**0.010**	**0.037**					**0.000**	
6/29/2005	Carroll/N58/1/1	906.8	908.4	508.3	2.266	0.400	2	2	2	2	2	
	Carroll/N58/2/1	918.4	920.2	516.9	2.277	0.446	2	2	2	2	2	
	Carroll/N58/3/1	852.4	867.1	466.8	2.129	3.672	2	2	2	2	2	
	Carroll/N58/4/1	830.3	848.4	459.5	2.135	4.654	1 15/16	1 15/16	1 15/16	1 15/16	1 15/16	
	Carroll/N58/6/1	872.5	888.8	476.3	2.115	3.952	2	2	2	2	2	
	Carroll/N58/6/2	841.1	864.4	465.6	2.109	5.843	1 15/16	1 15/16	1 15/16	1 15/16	1 15/16	
	Average				**2.172**	**3.161**					**1.979**	
	Standard Deviation				**0.078**	**2.249**					**0.032**	

Table C.1 (continued)

Test Day	Sample I.D	A Mass of Dry Sample in Air (g)	B Mass of SSD Sample in Air (g)	C Mass of Sample in water (g)	Gmb Bulk Specific Gravity [A/(B-C)]	Absorption (B-A)/(B-C) X 100 (%)	Sample Thickness (in) 1	2	3	4	AVE.	Remark
6/29/2005	Carroll/N of Breda /2/1	890.4	898.5	492.5	2.193	1.995	1 14/16	2	2	2	2	
	Carroll/N of Breda /3/1	700.8	715.4	382.7	2.106	4.388	1 9/16	1 9/16	1 9/16	1 9/16	1 9/16	
	Carroll/N of Breda /5/1	865.1	873	471.2	2.153	1.966	1 14/16	1 15/16	2	2	1 15/16	
	Carroll/N of Breda /6/1	1083.4	1094.5	593	2.160	2.213	2 6/16	2 6/16	2 6/16	2 7/16	2 6/16	
Average					**2.153**	**2.641**					**1.969**	
Standard Deviation					**0.036**	**1.170**					**0.338**	
6/29/2005	Winnebago/R34A /1/1	982.6	986.7	530.1	2.152	0.898	2 5/16	2 5/16	2 5/16	2 5/16	2 5/16	
	Winnebago/R34A /4/1	722.2	725.6	385.8	2.125	1.001	1 5/16	1 11/16	1 2/16	1 2/16	1 5/16	
Average					**2.139**	**0.949**					**1.813**	
Standard Deviation					**0.019**	**0.073**					**0.707**	
6/29/2005	Winnebago/R34B /3/1	777.8	781	384	1.959	0.806	1 14/16	1 15/16	2	1 15/16	1 15/16	
	Winnebago/R34B /6/1	809.4	816.7	426.7	2.075	1.872	2	2	2	2	2	
Average					**2.017**	**1.339**					**1.969**	
Standard Deviation					**0.082**	**0.754**					**0.044**	
6/29/2005	Winnebago/R60/1/1	838	841.5	440	2.087	0.872	1 14/16	2	2	2	2	
	Winebago/R60/2/1	827.2	832.2	434.9	2.082	1.258	1 14/16	2	2	2	2	
	Winebago/R60/4/1	828.3	835.6	432.3	2.054	1.810	1 15/16	2	2	2 1/16	2	
Average					**2.074**	**1.313**					**1.979**	
Standard Deviation					**0.018**	**0.472**					**0.018**	
6/29/2005	Delaware/US20/1/2	895.7	898.1	500.7	2.254	0.604	2	2	2	2	2	
	Delaware/US20/2/1	906.2	908	513.8	2.299	0.457	2	2	2	2	2	
	Delaware/US20/2/2	846.8	850.2	462.9	2.186	0.878	2	2	2	2	2	
	Delaware/US20/3/1	899.5	901.5	505.5	2.271	0.505	2	2	2	2	2	
	Delaware/US20/4/1	881.7	883.8	491.7	2.249	0.536	2	2	2	1 14/16	2	
	Delaware/US20/6/1	890.8	893.2	498.1	2.255	0.607	2	2	2	2	2	
Average					**2.252**	**0.598**					**1.995**	
Standard Deviation					**0.037**	**0.149**					**0.013**	
6/29/2005	Greene/IA144/1/1	963.7	965.2	547.5	2.307	0.359	2	2	2	2	2	
	Green/IA144/2/1	949.1	950.8	535.4	2.285	0.409	2	2	2	2	2	
	Green/IA144/2/2	954.2	960.2	524.7	2.191	1.378	2	2	2	2	2	
	Green/IA144/2/3	915.2	917.2	517.1	2.287	0.500	2	2 1/16	2 1/16	2	2 1/16	
	Green/IA144/6/1	904.8	907.4	499.5	2.218	0.637	2	2	2	2	2	
Average					**2.258**	**0.657**					**2.006**	
Standard Deviation					**0.050**	**0.417**					**0.014**	
6/29/2005	Guthrie/IA412/2/1	805.8	807.8	442.4	2.205	0.547	1 5/16	1 5/16	1 5/16	1 5/16	1 5/16	
	Guthrie/IA412/6/1	747.2	753	389.5	2.056	1.596	2	1 6/16	1 7/16	1 9/16	1 10/16	
Average					**2.130**	**1.071**					**1.453**	
Standard Deviation					**0.106**	**0.741**					**0.199**	

Table C.1 (continued)

Test Day	Sample I.D	A Mass of Dry Sample in Air (g)	B Mass of SSD Sample in Air (g)	C Mass of Sample in water (g)	Gmb Bulk Specific Gravity [A/(B-C)]	Absorption (B-A)/(B-C) X 100 (%)	Sample Thickness (in) 1	2	3	4	AVE.	Remark
6/29/2005	Tama/V18(A)/1/1	874	876.5	477.7	2.192	0.627	2 1/16	2	2	1 15/16	2	
	Tama/V18(A)/1/2	876	878.7	478.3	2.188	0.674	2 1/16	2	2	1 15/16	2	
	Tama/V18(A)/2/1	878.1	882.8	475.8	2.157	1.155	2	2	2	2	2	
	Tama/V18(A)/3/1	889.1	891	483.2	2.180	0.466	2	2	2	2 1/16	2	
	Tama/V18(A)/3/2	867.9	871.6	464.1	2.130	0.908	2	1 15/16	1 15/16	2	2	
	Tama/V18(A)/4/1	883.2	886.4	475.8	2.151	0.779	2	2	2	1 15/16	2	
Average					**2.166**	**0.768**					**1.995**	
Standard Deviation					**0.024**	**0.241**					**0.016**	
6/29/2005	Harrison/I44/1/1	936.3	938	524.2	2.263	0.411	2	2	2	2	2	
	Harrison/I44/2/1	903.5	905.2	506.3	2.265	0.426	1 14/16	1 15/16	2	1 15/16	1 15/16	
	Harrison/I44/3/1	926.9	928.7	516.3	2.248	0.436	2	2	2	2	2	
	Harrison/I44/4/1	911	912.7	507.4	2.248	0.419	2	2	2	2	2	
	Harrison/I44/5/1	911.9	913.7	507.2	2.243	0.443	2	2	2	2	2	
	Harrison/I44/6/1	898	899.4	500.5	2.251	0.351	1 15/16	2	1 15/16	1 15/16	1 15/16	
Average					**2.253**	**0.414**					**1.982**	
Standard Deviation					**0.009**	**0.033**					**0.029**	

Table C.2 Lab testing data – G_{mm}

Sample ID	Bag Weight (g)	Sample Weight in air (g)	Weight of Sample Opened in Water (g)	Density of Water (g/cm3) for temperature correction	Maximum Specific Gravity (g/cm3)
Tama/E66/1	76.500	2000.000	1167.000	0.99681	2.416
Tama/E66/2	76.400	2000.000	1166.800	0.99681	2.416
Montgomery/IA48/1	76.800	2000.100	1161.000	0.99733	2.400
Montgomery/IA48/2	76.000	2000.000	1158.200	0.99708	2.391
Clinton/E50/1	75.400	2000.100	1176.600	0.99708	2.445
Clinton/E50/2	76.000	2000.000	1173.500	0.99733	2.437
Jackson/US61/1	75.200	2000.100	1181.300	0.99681	2.458
Jackson/US61/2	75.400	2000.000	1181.600	0.99681	2.460
Muscatine/Y14(S)/1	75.900	2000.000	1167.400	0.99681	2.417
Muscatine/Y14(S)/2	76.400	2000.000	1167.500	0.99681	2.418
Muscatine/Y14(N)/1	76.100	2000.100	1177.800	0.99681	2.448
Muscatine/Y14(N)/2	75.800	2000.000	1177.200	0.99681	2.446
Muscatine/G28(W)/1	75.600	2000.000	1175.300	0.99681	2.441
Muscatine/G28(W)/2	76.500	2000.000	1176.900	0.99681	2.446
Muscatine/G28(E)/1	75.400	2000.000	1179.500	0.99681	2.453
Muscatine/G28(E)/2	75.500	2000.000	1177.000	0.99681	2.446
Hardin/D35/1	75.400	2000.000	1167.000	0.99681	2.416
Hardin/D35/2	75.300	2000.000	1163.800	0.99708	2.407
Clinton/Z30/1	75.800	2000.000	1186.600	0.99708	2.476
Clintone/Z30/2	75.800	2000.100	1183.500	0.99733	2.467
Cerro Godo/B43/1	75.600	2000.100	1188.100	0.99733	2.481
Cerro Godo/B43/2	75.200	2000.100	1184.000	0.99733	2.468
Cerro Godo/SS/1	75.2	2000.1	1177.1	0.997327	2.447
Cerro Godo/SS/2	75.3	2000.1	1172.4	0.997327	2.433

Table C.2 (continued)

Sample ID	Bag Weight (g)	Sample Weight in air (g)	Weight of Sample Opened in Water (g)	Density of Water (g/cm3) for temperature correction	Maximum Specific Gravity (g/cm3)
Tama/V18(b)/1	75.900	2000.000	1158.900	0.99733	2.394
Tama/V18(b)/2	75.900	2000.100	1161.100	0.99733	2.400
Story/S14(NB)/1	75	2000.1	1168.2	0.997075	2.42
Story/S14(NB)/2	75	2000.1	1161.7	0.997075	2.401
Calhoun/IA175/1	74.900	2000.100	1166.200	0.99733	2.415
Calhoun/IA175/2	74.700	2000.000	1167.300	0.99733	2.418
Bulter/T16/1	75.2	2000.1	1167.7	0.997327	2.419
Bulter/T16/2	75.6	2000	1163.4	0.997327	2.407
Boone/198th/1	75.300	2000.000	1172.200	0.99708	2.432
Boone/198th/2	75.500	2000.000	1179.800	0.99708	2.455
Boone/E52/1	75.3	2000	1162.9	0.997075	2.405
Boone/E52/2	74.8	2000.1	1162	0.997075	2.402
Green/IA144/1	76.100	2000.000	1166.900	0.99708	2.417
Green/IA144/2	75.400	2000.100	1166.900	0.99708	2.416
Tama/V18(A)/1	75.6	2000.1	1163	0.997327	2.406
Tama/V18(A)/2	75.4	2000	1161.7	0.997327	2.402
Harrison/IA44/1	75.400	2000.000	1146.500	0.99733	2.359
Harrison/IA44/2	75.300	2000.000	1147.000	0.99733	2.360
Carroll/N58/1	75.8	2000	1165.8	0.997327	2.414
Carroll/N58/2	75.1	2000	1156.8	0.997327	2.388
Winnebago/R60/1	75.200	2000.000	1162.900	0.99733	2.405
Winnebago/R60/2	75.200	2000.000	1156.400	0.99733	2.387
Delaware/US20/1	75.6	2000	1176.7	0.997327	2.446
Delaware/US20/2	75.5	2000	1171.3	0.997327	2.43
Carroll/Nof Brenda/1	75.200	2000.000	1170.900	0.99708	2.428
Carroll/Nof Brenda/2	75.600	2000.000	1170.700	0.99708	2.428

Table C.3 Lab testing data – IDT_{wet} and IDT_{dry}

I.D		P: Ultimate applieed load to fail specimen	P: Calibrated Load	F: Flow Value		St: Tensile strength		Sample Thickness	Remark (Sample State)
		lbf	lbf	1/20	IN	psi	KPa	IN	
Wet	Tama/E66/1/1	400	347	8.0	0.400	27.6	190.2	2	Uniform/No-Skew
	Tama/E66/1/2	200	162	8.0	0.400	12.9	88.8	2	Uniform/No-Skew
	Tama/E66/1/3	680	605	8.0	0.400	55.6	383.0	1 12/16	Uniform/Skew
	Tama/E66/2/1	300	254	8.0	0.400	21.6	148.8	1 14/16	Uniform/Skew
Average		395	342	8.0	0.400	29.4	202.7	1.902	
Standard Deviation		207	191	0.0	0.000	18.5	127.2	0.127	
Dry	Tama E66	250	208	12.8	0.640	16.6	114.1		
Wet	Montgomery/IA48/1a/1	230	190	12.8	0.640	16.1	110.9	1 14/16	Uniform/No-Skew
	Montgomery/IA48/4b/1	500	439	5.2	0.260	37.2656	256.9	1 14/16	Uniform/No-Skew
	Montgomery/IA48/4b/2	400	347	6.8	0.340	27.6	190.2	2	Uniform/No-Skew
	Montgomery/IA48/5a/1	300	254	11.6	0.580	21.6	148.8	1 14/16	Uniform/Skew
Average		358	307	9.1	0.455	25.6	176.7	1.906	
Standard Deviation		118	109	3.7	0.184	9.1	62.5	0.063	
Dry	Montgomery/IA48/2/1	310	263	8.4	0.420	21.0	144.5	2	Uniform/No-Skew
	Montgomery/IA48/3/1	310	263	10.0	0.500	21.0	144.5	2	Uniform/No-Skew
	Montgomery/IA48/6/1	290	245	10.4	0.520	20.8	143.4	1 14/16	Uniform/No-Skew
Average		303	257	9.6	0.480	20.9	144.1	1.569	
Standard Deviation		12	11	1.1	0.053	0.1	0.7	0.844	
Wet	Clinton/E50/1/1	510	448	8.0	0.400	38.0	262.3	1 14/16	Uniform/No-Skew
	Clinton/E50/2/2	230	190	4.0	0.200	16.6415	114.7	1 13/16	Skew
	Clinton/E50/5/1	430	374	8.0	0.400	31.8	219.1	1 14/16	Uniform/No-Skew
Average		390	337	6.7	0.333	28.8	198.7	1.854	
Standard Deviation		144	133	2.3	0.115	11.0	75.9	0.036	
Dry	Clinton/E50/1/2	550	485	4.0	0.200	41.2	284.0	1 14/16	Uniform/No-Skew
	Clinton/E50/2/1	650	578	6.0	0.300	49.0	338.1	1 14/16	Uniform/No-Skew
	Clinton/E50/3/1	500	439	6.0	0.300	37.3	256.9	1 14/16	Uniform/No-Skew
Average		567	501	5.3	0.267	42.5	293.0	1.503	
Standard Deviation		76	71	1.2	0.058	6.0	41.3	0.820	

Table C.3 (continued)

I.D		P: Ultimate applieed load to fail	P: Calibrated Load	F: Flow Value		St: Tensile strength		Sample Thickness	Remark (Sample State)
		lbf	lbf	1/20	IN	psi	KPa	IN	
Wet	Jackson / US61/2a/1	180	143	10.0	0.500	11.4	78.6	2	Uniform/Skew
	Jackson / US61/3a/1	180	143	8.4	0.420	11.1	76.2	2 1/16	Uniform/Skew
	Jackson / US61/4/1	110	79	10.0	0.500	6.3	43.1	2	Uniform/No-Skew
	Jackson / US61/5/1	160	125	8.0	0.400	9.6	66.4	2 1/16	Uniform/No-Skew
Average		158	123	9.1	0.455	9.6	66.1	2.031	
Standard Deviation		33	31	1.1	0.053	2.3	16.2	0.036	
Dry	Muscatine/F70/3/1	100	100	4.8	0.240	12.7	87.4	1 4/16	Non-Uni (H)
	Muscatine/F70/4/1	150	150	4.0	0.200	18.1	125.1	1 5/16	Non-Uni (H)
Average		125	125	4.4	0.220	15.4	106.2	1.157	
Standard Deviation		35	35	0.6	0.028	3.9	26.7	0.827	
Wet	Muscatine/Y14(S)/1/1	550	485	N/A	N/A	38.6	266.2	2	Uniform/No-Skew
	Muscatine/Y14(S)/4/1	200	162	8.0	0.400	11.8	81.2	2 3/16	Uniform/Skew
	Muscatine/Y14(S)/6/2	250	208	4.8	0.240	16.6	114.1	2	Uniform/Skew
Average		333	285	6.4	0.320	22.3	153.8	2.063	
Standard Deviation		189	175	2.3	0.113	14.3	98.7	0.108	
Dry	Muscatine/Y14(S)/2/1	860	772	6.0	0.300	61.4	423.4	2	Uniform/No-Skew
	Muscatine/Y14(S)/6/1	560	494	6.0	0.300	39.3	271.3	2	Uniform/No-Skew
Average		710	633	6.0	0.300	50.4	347.4	1.543	
Standard Deviation		212	196	0.0	0.000	15.6	107.6	0.957	
Wet	Muscatine/Y14(N)/1/1	420	365	8.4	0.420	29.1	200.3	2	Uniform/Skew
	Muscatine/Y14(N)/2/1	470	411	8.0	0.400	32.7	225.7	2	Uniform/Skew
	Muscatine/Y14(N)/3/1	430	374	8.0	0.400	29.8	205.4	2	Uniform/No-Skew
Average		440	384	8.1	0.407	30.5	210.5	2.000	
Standard Deviation		26	24	0.2	0.012	1.9	13.4	0.000	
Dry	Muscatine/Y14(N)/4/1	580	513	8.0	0.400	40.8	281.4	2	Uniform/Skew
	Muscatine/Y14(N)/5/1	670	596	9.2	0.460	47.4	327.1	2	Uniform/No-Skew
	Muscatine/Y14(N)/6/1	400	347	6.8	0.340	27.6	190.2	2	Uniform/No-Skew
Average		550	485	8.0	0.400	38.6	266.2	1.600	
Standard Deviation		137	127	1.2	0.060	10.1	69.7	0.894	

Table C.3 (continued)

I.D		P		F		St		Sample Thickness	Remark (Sample State)
		Ultimate applieed load to fail	Calibrated Load	Flow Value		Tensile strength			
		lbf	lbf	1/20	IN	psi	KPa	IN	
Wet	Muscatine/G28W/1/1	280	236	6.0	0.300	18.8	129.3	2	Uniform/No-Skew
	Muscatine/G28W/2/1	250	208	8.0	0.400	16.6	114.1	2	Uniform/No-Skew
	Muscatine/G28W/3/1	100	69	7.2	0.360	5.5	38.1	2	Uni/Skew
	Muscatine/G28W/4/1	310	263	9.6	0.480	21.0	144.5	2	Uniform/No-Skew
Average		235	194	7.7	0.385	15.4	106.5	2.000	
Standard Deviation		93	86	1.5	0.075	6.9	47.3	0.000	
Wet	Muscatine/G28(E)/2/1	210	210	4.0	0.200	16.7	115.1	2	Uniform/Skew
	Muscatine/G28(E)/3/1	185	185	8.0	0.400	15.2	104.6	1 15/16	Uniform/Skew
	Muscatine/G28(E)/5/1	200	200	8.0	0.400	16.4	113.1	1 15/16	Uniform/Skew
	Muscatine/G28(E)/6/1	278	278	6.0	0.300	22.1	152.4	2	Uniform/Skew
Average		218	218	6.5	0.325	17.6	121.3	1.969	
Standard Deviation		41	41	1.9	0.096	3.1	21.3	0.036	
Wet	Hardin/D35/4/1	650	650	10.0	0.500	51.8	356.9	2	Uniform/No-Skew
	Hardin/D35/5/1	248	248	8.0	0.400	19.7	136.0	2	Non-Uni (L)
	Hardin/D35/6/1	740	741	8.0	0.400	58.9	406.4	2	Uniform/Skew
Average		546	546	8.7	0.433	43.5	299.7	2.000	
Standard Deviation		262	262	1.2	0.058	20.9	144.0	0.000	
Dry	Hardin/D35/2/1	460	460	12.4	0.620	36.6	252.5	2	Uniform/Skew
	Hardin/D35/3/1	652	652	11.2	0.560	51.9	358.0	2	Uniform/Skew
Average		556	556	11.8	0.590	44.3	305.2	1.500	
Standard Deviation		136	136	0.8	0.042	10.8	74.6	1.000	
Wet	Clintone/Z35/3/1	650	650	10.0	0.500	51.8	356.9	2	Uniform/No-Skew
	Clintone/Z35/5/1	248	248	8.0	0.400	19.7	136.0	2	Non-Uni (L)
	Clintone/Z35/6/1	740	741	8.0	0.400	58.9	406.4	2	Uniform/Skew
Average		546	546	8.7	0.433	43.5	299.7	2.000	
Standard Deviation		262	262	1.2	0.058	20.9	144.0	0.000	
Dry	Clintone/Z35/4/1	460	460	12.4	0.620	36.6	252.5	2	Uniform/Skew
	Clintone/Z35/4/1	248	248	8.0	0.400	19.7	136.0	2	Non-Uni (L)
	Clintone/Z35/4/1	652	652	11.2	0.560	51.9	358.0	2	Uniform/Skew
Average		453	453	10.5	0.527	36.1	248.8	1.600	
Standard Deviation		202	202	2.3	0.114	16.1	111.1	0.894	

Table C.3 (continued)

I.D		P		F		St		Sample Thickness	Remark (Sample State)
		Ultimate applieed load to fail	Calibrated Load	Flow Value		Tensile strength			
		lbf	lbf	1/20	IN	psi	KPa	IN	
Wet	Cerro Gordo/B43/2/1	191	191	9.2	0.460	15.7	108.0	1 15/16	Uniform/Skew
	Cerro Gordo/B43/4/1	238	238	12.4	0.620	19.5	134.7	1 15/16	Uniform/Skew
	Cerro Gordo/B43/6/1	195	195	8.8	0.440	17.7	122.1	1 12/16	Uniform/Skew
Average		208	208	10.1	0.507	17.6	121.6	1.875	
Standard Deviation		26	26	2.0	0.099	1.9	13.3	0.108	
Dry	Cerro Gordo/B43/3/1	785	786	5.2	0.260	62.5	431.1	2	Uniform/No-Skew
	Cerro Gordo/B43/5/1	1024	1025	4.8	0.240	87.0	599.9	1 14/16	Uniform/No-Skew
Average		905	905	5.0	0.250	74.8	515.5	1.465	
Standard Deviation		169	169	0.3	0.014	17.3	119.4	0.906	
Wet	Cerro Gordo/SS/5/1	350	350	8.0	0.400	28.7	198.2	1 15/16	Uniform/No-Skew
	Cerro Gordo/SS/5/2	330	330	6.0	0.300	26.3	181.0	2	Uniform/Skew
	Cerro Gordo/SS/5/3	325	325	12.0	0.600	26.7	184.0	1 15/16	Uniform/No-Skew
	Cerro Gordo/SS/6/1	358	358	10.0	0.500	30.4	209.5	1 14/16	Uniform/Skew
Average		341	341	9.0	0.450	28.0	193.2	1.938	
Standard Deviation		16	16	2.6	0.129	1.9	13.2	0.051	
Wet	Tama/V18(B)/2/1	275	275	16.0	0.800	21.9	150.8	2	Uniform/Skew
	Tama/V18(B)/2/2	335	335	8.0	0.400	26.7	183.8	2	Uniform/Skew
	Tama/V18(B)/4/2	300	300	10.0	0.500	24.6	169.8	1 15/16	Uniform/Skew
	Tama/V18(B)/5/1	370	370	12.0	0.600	29.4	203.0	2	Uniform/No-Skew
Average		320	320	11.5	0.575	25.7	176.8	1.984	
Standard Deviation		41	42	3.4	0.171	3.2	22.1	0.031	
Dry	Tama/V18(B)/1/1	550	550	12.0	0.600	42.5	292.8	2 1/16	Uniform/Skew
	Tama/V18(B)/3/1	405	405	6.0	0.300	32.2	222.2	2	Uniform/No-Skew
	Tama/V18(B)/3/2	422	422	8.0	0.400	33.6	231.6	2	Uniform/Skew
	Tama/V18(B)/4/1	535	535	8.0	0.400	42.6	293.7	2	Uniform/Skew
Average		478	478	8.5	0.425	37.7	260.1	1.680	
Standard Deviation		75	75	2.5	0.126	5.6	38.5	0.808	
Wet	Boone/198th/2/1	290	290	6.4	0.320	23.8	164.2	1 15/16	Uniform/Skew
	Boone/198th/2/2	140	140	8.0	0.400	11.5	79.1	1 15/16	Uniform/Skew
	Boone/198th/4/2	212	212	10.0	0.500	17.4	119.9	1 15/16	Uniform/Skew
	Boone/198th/5/1	320	320	6.0	0.300	25.5	175.5	2	Uniform/No-Skew
	Boone/198th/6/2	198	198	8.8	0.440	16.8	115.7	1 14/16	Uniform/Skew
	Boone/198th/7/2	260	260	8.0	0.400	21.3	147.1	1 15/16	Uniform/Skew
Average		237	236	7.9	0.393	19.4	133.6	1.938	
Standard Deviation		66	66	1.5	0.074	5.2	35.7	0.040	

Table C.3 (continued)

I.D		P		F		St			
		Ultimate applieed load to fail	Calibrated Load	Flow Value		Tensile strength		Sample Thickness	Remark (Sample State)
		lbf	lbf	1/20	IN	psi	KPa	IN	
Dry	Boone/198th/1/1	235	235	7.2	0.360	18.7	128.8	2	Uniform/Skew
	Boone/198th/1/2	200	200	6.0	0.300	16.4	113.1	1 15/16	Uniform/No-Skew
	Boone/198th/3/1	355	355	4.0	0.200	30.1	207.7	1 14/16	Uniform/Skew
	Boone/198th/4/1	320	320	6.0	0.300	25.5	175.5	2	Uniform/Skew
	Boone/198th/6/1	735	736	4.0	0.200	60.4	416.6	1 15/16	Uniform/No-Skew
	Boone/198th/7/1	288	288	4.8	0.240	24.4	168.5	1 14/16	Uniform/Skew
Average		356	355	5.3	0.267	29.3	201.7	1.700	
Standard Deviation		194	195	1.3	0.064	16.0	110.6	0.673	
Wet	Boone/E52/1/1	299	299	10.4	0.520	23.8	164.0	2	Uniform/No-Skew
	Boone/E52/3/1	405	405	16.0	0.800	32.2	222.2	2	Uniform/Skew
	Boone/E52/4/1	318	318	8.0	0.400	25.3	174.4	2	Uniform/Skew
	Boone/E52/5/1	270	270	11.2	0.560	22.2	152.8	1 15/16	Uniform/Skew
Average		323	323	11.4	0.570	25.9	178.4	1.984	
Standard Deviation		58	58	3.4	0.168	4.4	30.6	0.031	
Dry	Boone/E52/6/1	690	691	8.4	0.420	56.7	391.1	1 15/16	Uniform/Skew
	Boone/E52/7/1	510	510	10.0	0.500	41.9	289.0	1 15/16	Uniform/Skew
	Boone/E52/8/1	650	650	10.0	0.500	53.4	368.4	1 15/16	Uniform/Skew
Average		617	617	9.5	0.473	50.7	349.5	1.566	
Standard Deviation		95	95	0.9	0.046	7.8	53.6	0.858	
Wet	Story/S14(SB)/4/1	330	330	16.0	0.800	27.1	186.9	1 15/16	Uniform/Skew
	Story/S14(SB)/4/2	73	72	10.0	0.500	8.8	60.6	1 5/16	Non-Uni (H)
Average		202	201	13.0	0.650	17.9	123.7	1.625	
Standard Deviation		182	182	4.2	0.212	12.9	89.3	0.442	
Wet	Story/S14(NB)/1/1	180	180	14.4	0.720	14.3	98.6	2	Uniform/Skew
	Story/S14(NB)/2/1	152	152	12.0	0.600	12.5	85.9	1 15/16	Uniform/No-Skew
	Story/S14(NB)/5/2	148	148	16.4	0.820	11.7	81.0	2	Uniform/Skew
Average		160	160	14.3	0.713	12.8	88.5	1.979	
Standard Deviation		17	17	2.2	0.110	1.3	9.1	0.036	
Dry	Story/S14(NB)/3/1	125	125	16.0	0.800	9.9	68.4	2	Uniform/Skew
	Story/S14(NB)/4/1	157	157	12.0	0.600	12.5	85.9	2	Uniform/No-Skew
	Story/S14(NB)/5/1	150	150	8.0	0.400	11.9	82.1	2	Uniform/Skew
Average		144	144	12.0	0.600	11.4	78.8	1.603	
Standard Deviation		17	17	4.0	0.200	1.3	9.2	0.876	

Table C.3 (continued)

I.D		P		F		St		Sample Thickness	Remark (Sample State)
		Ultimate applieed load to fail	Calibrated Load	Flow Value		Tensile strength			
		lbf	lbf	1/20	IN	psi	KPa	IN	
Wet	Butler/T16/1/1	180	180	12.8	0.640	14.3	98.6	2	Uniform/Skew
	Butler/T16/3/1	350	350	12.4	0.620	27.8	192.0	2	Uniform/Skew
	Butler/T16/5/1	220	220	16.0	0.800	17.5	120.6	2	Uniform/No-Skew
Average		250	250	13.7	0.687	19.9	137.1	2.000	
Standard Deviation		89	89	2.0	0.099	7.1	48.8	0.000	
Dry	Butler/T16/2/1	380	380	12.8	0.640	29.3	202.2	2 1/16	Uniform/Skew
	Butler/T16/4/1	367	367	16.0	0.800	28.3	195.3	2 1/16	Uniform/Skew
	Butler/T16/6/1	522	522	10.4	0.520	41.6	286.5	2	Uniform/No-Skew
Average		423	423	13.1	0.653	33.1	228.0	1.625	
Standard Deviation		86	86	2.8	0.140	7.4	50.8	0.909	
Wet	Calhoun/IA175/2/1	259	259	8.0	0.400	20.6	142.0	2	Uniform/No-Skew
	Calhoun/IA175/4/1	210	210	12.0	0.600	16.7	115.1	2	Uniform/No-Skew
	Calhoun/IA175/5/1	175	175	7.6	0.380	13.9	95.8	2	Uniform/No-Skew
Average		215	214	9.2	0.460	17.1	117.6	2.000	
Standard Deviation		42	42	2.4	0.122	3.4	23.2	0.000	
Wet	Carroll/N58/1/1	408	408	14.8	0.740	32.5	223.9	2	Uniform/No-Skew
	Carroll/N58/4/1	110	110	13.2	0.660	9.0	62.0	1 15/16	Uniform/No-Skew
	Carroll/N58/6/1	104	104	16.0	0.800	14.0	96.5	2	Uniform/No-Skew
Average		207	207	14.7	0.733	18.5	127.5	1.979	
Standard Deviation		174	174	1.4	0.070	12.4	85.2	0.036	
Dry	Carroll/N58/2/1	214	214	14.0	0.700	17.0	117.3	2	Uniform/No-Skew
	Carroll/N58/3/1	150	150	14.0	0.700	11.9	82.1	2	Uniform/No-Skew
	Carroll/N58/6/2	160	160	16.0	0.800	13.1	90.4	1 15/16	Uniform/No-Skew
Average		175	174	14.7	0.733	14.0	96.6	1.591	
Standard Deviation		34	34	1.2	0.058	2.7	18.4	0.869	
Wet	Carroll/N of Breda /2/1	230	230	4.8	0.240	18.3	126.1	2	Uniform/Skew
	Carroll/N of Breda /3/1	145	145	7.2	0.360	14.7	101.6	1 9/16	Non-Uni (H)
	Carroll/N of Breda /5/1	170	170	16.0	0.800	8.0	55.2	1 15/16	Uniform/Skew
	Carroll/N of Breda /6/1	310	310	12.4	0.620	8.0	55.2	2 7/16	Non-Uni (H)
Average		214	213	10.1	0.505	12.3	84.5	1.984	
Standard Deviation		73	74	5.1	0.253	5	35	0.359	

Table C.3 (continued)

I.D		P		F		St		Sample Thickness	Remark (Sample State)
		Ultimate applieed load to fail	Calibrated Load	Flow Value		Tensile strength			
		lbf	lbf	1/20	IN	psi	KPa	IN	
Wet	Winnebago/R34A /1/1	360	360	14.4	0.720	28.6	197.5	2	Non-Uni (H)
	Winnebago/R34A /4/1	250	250	14.8	0.740	24.5	168.7	1 10/16	Non-Uni (H)
Average		305	305	14.6	0.730	26.6	183.1	1.813	
Standard Deviation		78	78	0	0.014	3	20	0.265	
Wet	Winnebago/R34B /3/1	285	285	10.4	0.520	23.4	161.3	1 15/16	Uniform/Skew
	Winnebago/R34B /6/1	231	231	8.0	0.400	18.4	126.6	2	Uniform/No-Skew
Average		258	258	9.2	0.460	20.9	144.0	1.969	
Standard Deviation		38	38	2	0.085	4	25	0.044	
Wet	Winebagol/R60/1/1	170	170	10.4	0.520	13.5	93.1	2	Uniform/Skew
	Winebagol/R60/2/1	315	315	6.0	0.300	25.1	172.8	2	Uniform/Skew
	Winebagol/R60/4/1	260	260	12.0	0.600	20.7	142.5	2	Uniform/Skew
Average		248	248	9.5	0.473	19.7	136.1	2.000	
Standard Deviation		73	73	3.1	0.155	5.8	40.2	0.000	
Wet	Delaware/US20/2/1	230	230	16.0	0.800	18.3	126.1	2	Uniform/No-Skew
	Delaware/US20/4/1	175	175	10.0	0.500	13.9	95.8	2	Uniform/Skew
	Delaware/US20/6/1	210	210	14.8	0.740	16.7	115.1	2	Uniform/No-Skew
Average		205	205	13.6	0.680	16.3	112.3	2.000	
Standard Deviation		28	28	3.2	0.159	2.2	15.3	0.000	
Dry	Delaware/US20/1/2	250	250	9.6	0.480	19.9	137.1	2	Uniform/No-Skew
	Delaware/US20/2/2	240	240	14.0	0.700	19.1	131.6	2	Uniform/No-Skew
	Delaware/US20/3/1	270	270	12.0	0.600	21.5	148.0	2	Uniform/No-Skew
Average		253	253	11.9	0.593	20.1	138.9	1.600	
Standard Deviation		15	15	2.2	0.110	1.2	8.4	0.894	
Wet	Green/IA144/2/2	154	154	14.4	0.720	12.2	84.3	2	Uniform/No-Skew
	Green/IA144/2/3	250	250	12.0	0.600	19.3	132.9	2 1/16	Uniform/Skew
	Green/IA144/6/1	270	270	13.6	0.680	21.5	148.0	2	Uniform/No-Skew
Average		225	224	13.3	0.667	17.7	121.7	2.021	
Standard Deviation		62	62	1.2	0.061	4.8	33.3	0.036	

Table C.3 (continued)

I.D		P		F		St			
		Ultimate applieed load to fail	Calibrated Load	Flow Value		Tensile strength		Sample Thickness	Remark (Sample State)
		lbf	lbf	1/20	IN	psi	KPa	IN	
Dry	Green/IA144/1/1	400	400	7.2	0.360	31.8	219.5	2	Uniform/No-Skew
	Green/IA144/2/1	325	325	10.0	0.500	25.9	178.3	2	Uniform/No-Skew
Average		363	362	8.6	0.430	20.8	198.9	1.514	
Standard Deviation		53	53	2.0	0.099	4.2	29.1	0.985	
Wet	Guthrie/IA4/2/1	310	310	7.6	0.380	26.3	181.4	1 14/16	Non-Uni (H)
	Guthrie/IA4/6/1	225	225	8.4	0.420	22.0	151.8	1 10/16	Non-Uni (H)
Average		268	267	8.0	0.400	24.2	166.6	1.750	
Standard Deviation		60	60	0.6	0.028	3.0	20.9	0.177	
Wet	Tama/V18(A)/1/1	410	410	9.6	0.480	32.6	225.0	2	Uniform/Skew
	Tama/V18(A)/2/1	190	190	8.0	0.400	15.1	104.1	2	Uniform/No-Skew
	Tama/V18(A)/3/1	245	245	9.2	0.460	19.5	134.3	2	Uniform/Skew
Average		282	282	8.9	0.447	22.4	154.5	2.000	
Standard Deviation		114	115	0.8	0.042	9.1	62.9	0.000	
Dry	Tama/V18(A)/1/2	550	550	6.8	0.340	43.8	301.9	2	Uniform/Skew
	Tama/V18(A)/3/1	437	437	10.8	0.540	34.8	239.8	2	Uniform/Skew
	Tama/V18(A)/4/1	470	470	8.0	0.400	37.4	258.0	2	Uniform/Skew
Average		486	486	8.5	0.427	38.7	266.6	1.600	
Standard Deviation		58	58	2.1	0.103	4.6	31.9	0.894	
Wet	Harrison/I44/3/1	315	315	12.8	0.640	25.1	172.8	2	Uniform/No-Skew
	Harrison/I44/4/1	375	375	12.8	0.640	29.8	205.8	2	Uniform/No-Skew
	Harrison/I44/6/1	380	380	14.0	0.700	31.2	215.2	1 15/16	Uniform/Skew
Average		357	357	13.2	0.660	28.7	197.9	1.979	
Standard Deviation		36	36	0.7	0.035	3.2	22.3	0.036	
Dry	Harrison/I44/1/1	328	328	16.0	0.800	26.1	179.9	2	Uniform/No-Skew
	Harrison/I44/2/1	440	440	14.0	0.700	36.2	249.3	1 15/16	Uniform/Skew
	Harrison/I44/1/1	350	350	14.0	0.700	27.8	192.0	2	Uniform/No-Skew
Average		373	373	14.7	0.733	30.0	207.1	1.591	
Standard Deviation		59	59	1.2	0.058	5.4	37.0	0.869	

Table C.4 Lab testing data – Penetration

County	Road	Test 1	Test 2	Test 3	Average
Boone	E-52	6	10	6	7.3
Boone	198th	30	32	26	29.3
Butler	T-16	10	6	13	9.7
Calhoun	IA-175	4	5	5	4.7
Carroll	N-58	20	22	26	22.7
Carroll	N of Breda	0	0	0	0.0
Cerro Gordo	S.S.	12	18	20	16.7
Cerro Gordo	B-43	4	9	5	6.0
Clinton	Z-30	5	5	4	4.7
Clinton	E-50	4	7	3	4.7
Delaware	US-20	16	20	12	16.0
Greene	IA-144	18	14	15	15.7
Guthrie	IA-4	4	5	0	3.0
Hardin	D-35	14	15	15	14.7
Harrison	IA-44	30	31	30	30.3
Jackson	US-61	15	10	20	15.0
Montgomery	IA-48	25	28	25	26.0
Muscatine	F-70	13	12	12	12.3
Muscatine	G-28W	5	3	4	4.0
Muscatine	G-28E	10	6	5	7.0
Muscatine	Y-14N	9	10	13	10.7
Muscatine	Y-14S	8	5	5	6.0
Story	S-14 SB	20	25	26	23.7
Story	S-14 NB	20	20	21	20.3
Tama	V-18a	5	5	4	4.7
Tama	V-18b	25	15	20	20.0
Tama	E-66	24	20	26	23.3
Winnebago	R-34a	3	6	1	3.3
Winnebago	R-34b	0	0	0	0.0
Winnebago	R-60	5	2	0	2.3

Table C.5 Lab testing data – S(t) and m-value

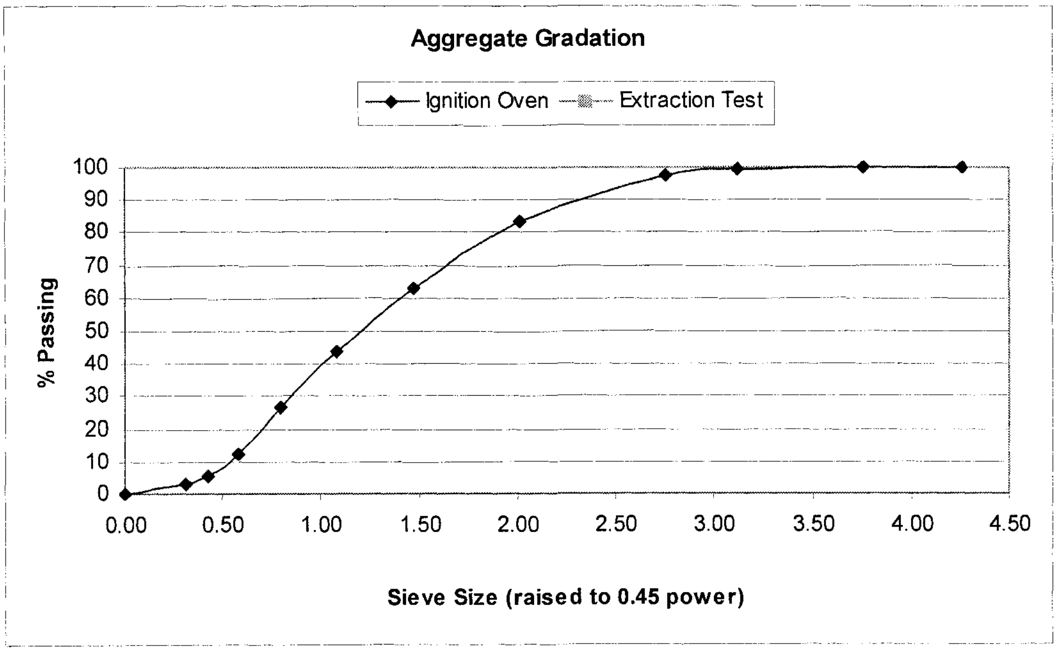
	-12 C		-18 C		-24 C	
	S (Mpa)	m-value	S (Mpa)	m-value	S (Mpa)	m-value
Boone 198th	87	0.365	204	0.285	405	0.240
Boone E52	226	0.245	410	0.199	659	0.151
Butler T16	253	0.285	442	0.217	772	0.175
Calhoun IA 175	224	0.260	429	0.209	720	0.172
Carroll N58	89	0.404	229	0.319	480	0.244
Carroll N of Breda	391	0.229	681	0.178	1040	0.163
CC B43	269	0.258	603	0.199	1010	0.150
CC SS	198	0.308	391	0.231	733	0.199
Clinton E50	370	0.238	678	0.179	1000	0.160
Clinton Z30	349	0.245	655	0.211	990	0.175
Delaware US20	138	0.320	318	0.266	595	0.218
Green IA144	205	0.318	436	0.237	773	0.191
Guthrie IA4	404	0.212	651	0.184	1010	0.161
Hardin D35	285	0.234	494	0.205	827	0.172
Harrison IA144	506	0.196	285	0.270	136	0.323
Jackson US61	331	0.231	583	0.197	619	0.157
Montgomery IA48	155	0.300	319	0.252	586	0.206
Muscatine F70	178	0.325	404	0.241	707	0.200
Muscatine G28E	255	0.266	509	0.214	872	0.170
Muscatine G28W	275	0.254	555	0.204	939	0.156
Muscatine Y14N	256	0.248	464	0.211	770	0.183
Muscatine Y14S	262	0.209	602	0.205	908	0.167
Story S14 NB	206	0.313	434	0.237	750	0.183
Story S14 SB	261	0.266	473	0.209	802	0.151
Tama V18A	150	0.350	358	0.274	711	0.205
Tama V18b	163	0.323	338	0.261	655	0.256
Winnebago R34A	384	0.223	677	0.184	1010	0.166
Winnebago R34B	511	0.186	813	0.174	1080	0.139
WinnebagoR60	586	0.184	962	0.163	1290	0.123

APPENDIX D. AGGREGATE GRADATIONS

Boone 198th

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	99.1	
3/8"	9.5	2.754	97.4	
#4	4.75	2.016	83.5	
#8	2.36	1.472	62.9	
#16	1.18	1.077	44.1	
#30	0.6	0.795	26.3	
#50	0.3	0.582	12.1	
#100	0.15	0.426	5.8	
#200	0.075	0.312	3.0	
Pan	0	0.000	0.0	

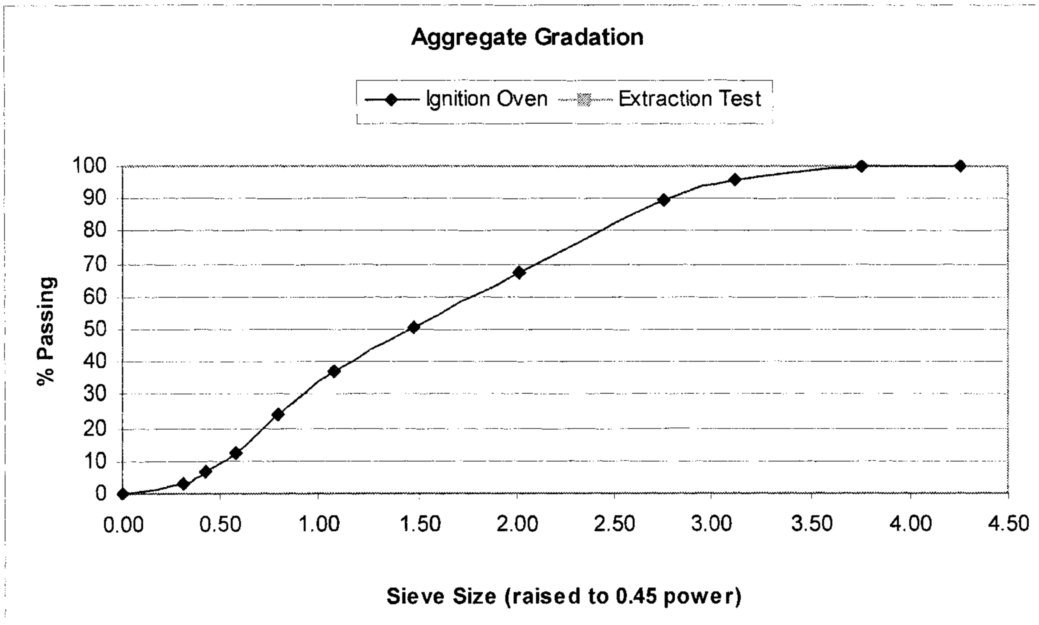
Aggregate Type: Gravel



Boone E52

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	95.4	
3/8"	9.5	2.754	89.6	
#4	4.75	2.016	67.0	
#8	2.36	1.472	50.4	
#16	1.18	1.077	37.3	
#30	0.6	0.795	23.9	
#50	0.3	0.582	12.6	
#100	0.15	0.426	6.8	
#200	0.075	0.312	2.8	
Pan	0	0.000	0.0	

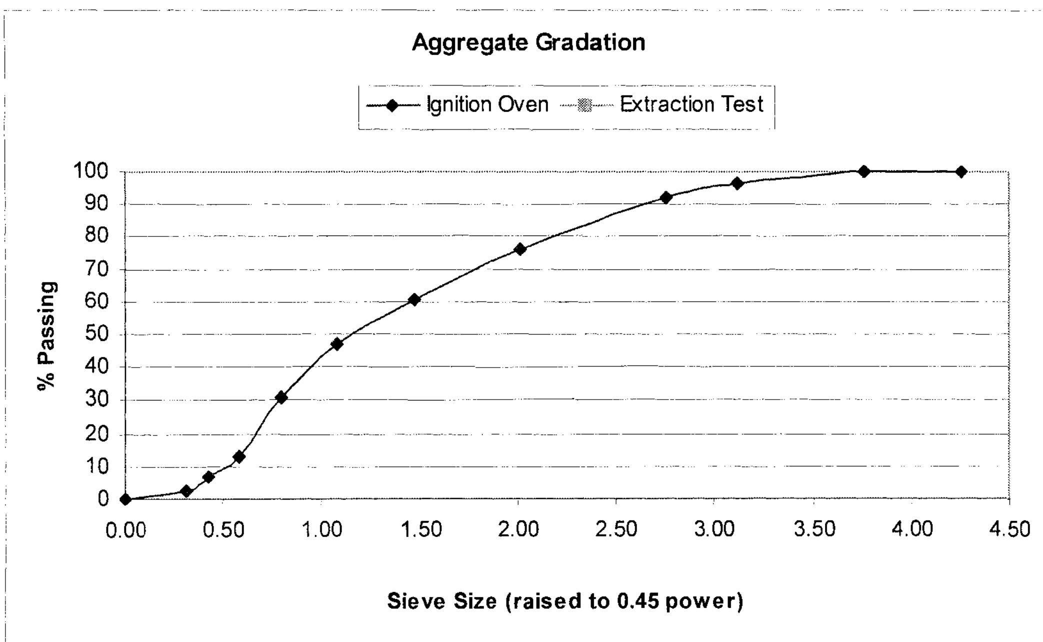
Aggregate Type: Gravel



Butler T16

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	96.6	
3/8"	9.5	2.754	92.2	
#4	4.75	2.016	76.2	
#8	2.36	1.472	60.7	
#16	1.18	1.077	46.9	
#30	0.6	0.795	30.7	
#50	0.3	0.582	13.0	
#100	0.15	0.426	6.5	
#200	0.075	0.312	2.5	
Pan	0	0.000	0.0	

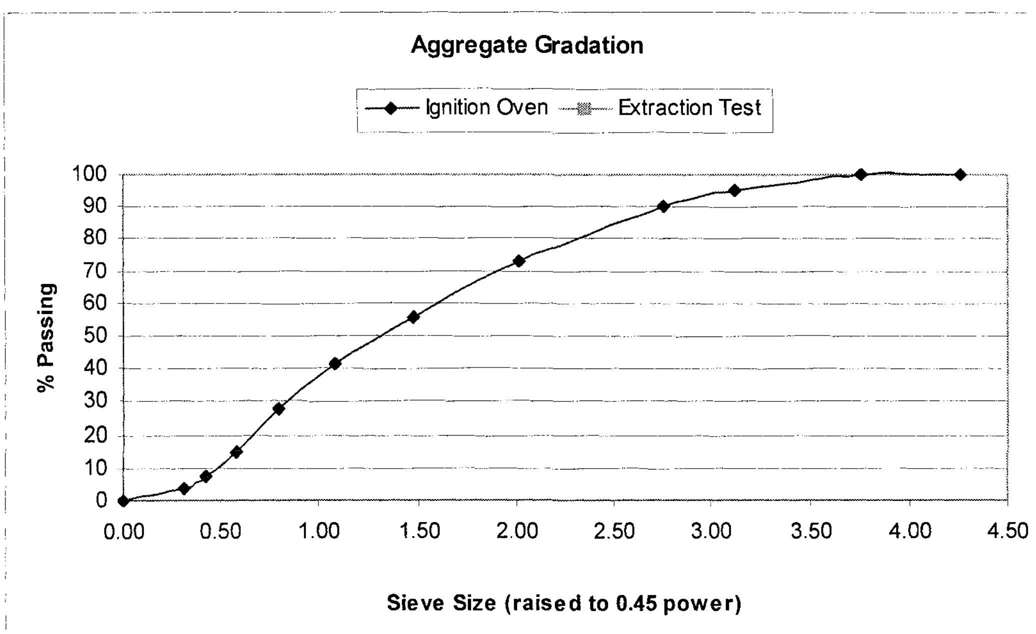
Aggregate Type: Crushed Gravel



Calhoun IA175

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	99.7	
1/2"	12.5	3.116	95.0	
3/8"	9.5	2.754	90.4	
#4	4.75	2.016	73.1	
#8	2.36	1.472	55.5	
#16	1.18	1.077	41.3	
#30	0.6	0.795	27.6	
#50	0.3	0.582	14.7	
#100	0.15	0.426	7.6	
#200	0.075	0.312	3.4	
Pan	0	0.000	0.0	

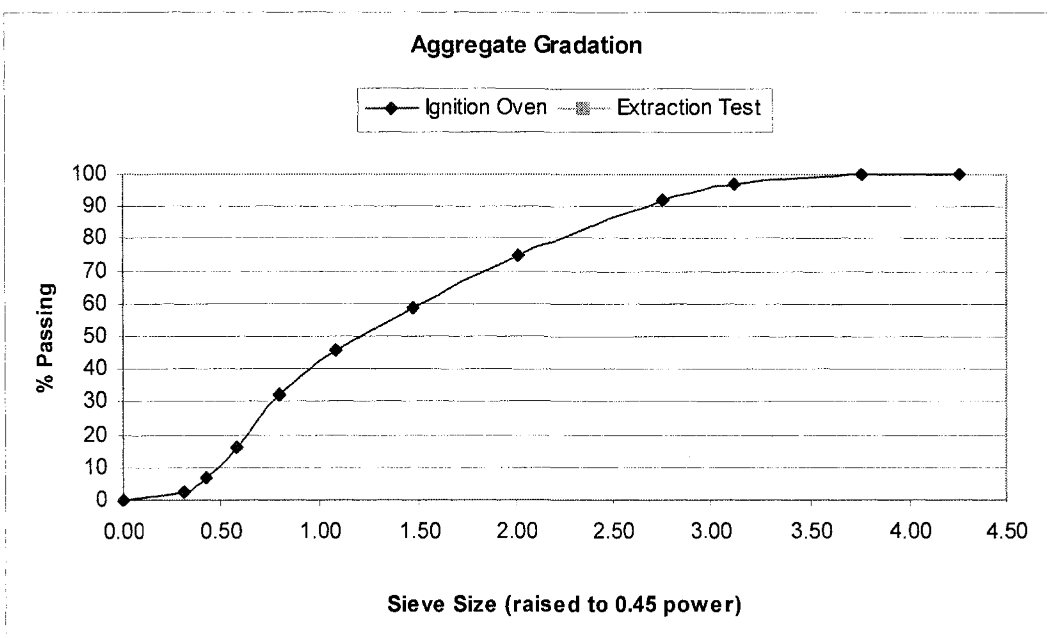
Aggregate Type: Crushed Gravel



Carroll N58

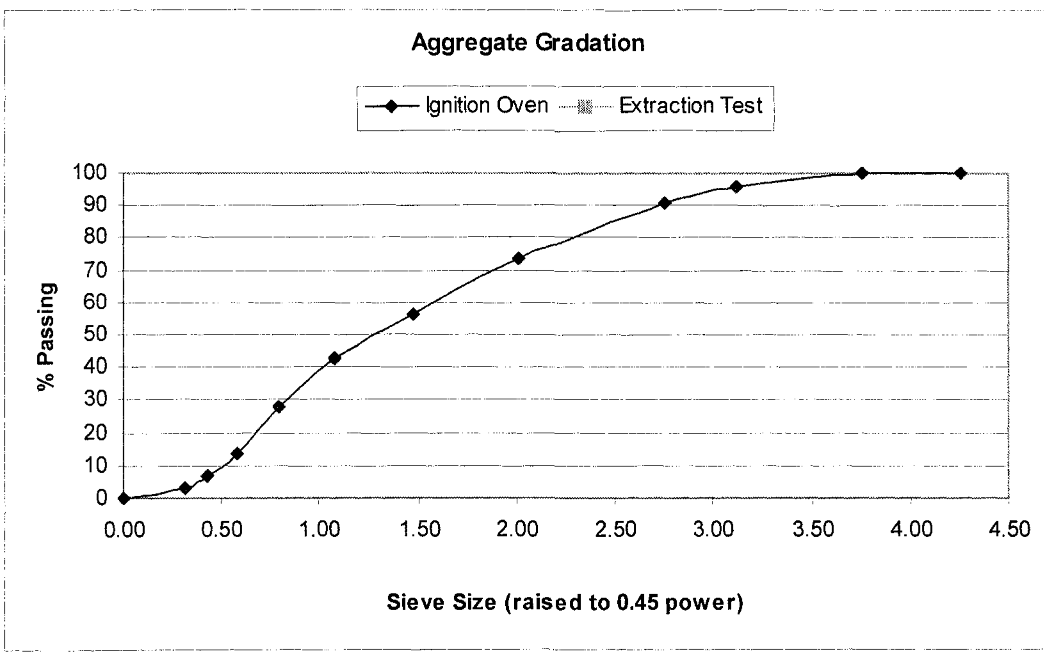
Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	96.9	
3/8"	9.5	2.754	91.9	
#4	4.75	2.016	74.4	
#8	2.36	1.472	58.4	
#16	1.18	1.077	45.6	
#30	0.6	0.795	32.2	
#50	0.3	0.582	16.0	
#100	0.15	0.426	6.7	
#200	0.075	0.312	2.6	
Pan	0	0.000	0.0	

Aggregate Type: Crushed Gravel



Carroll N. of Brenda

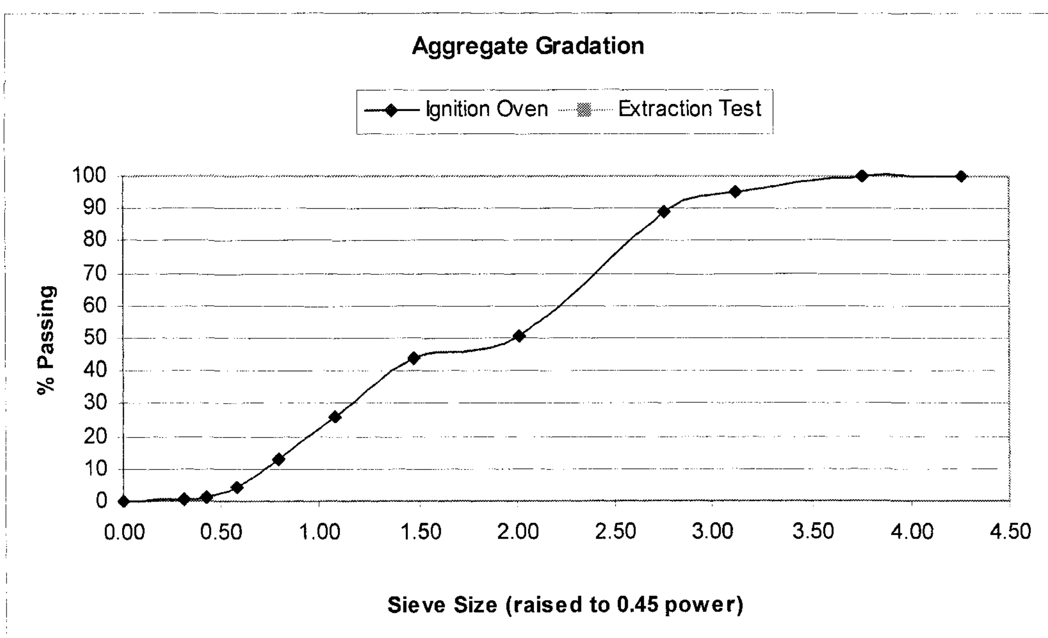
Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	95.9	
3/8"	9.5	2.754	90.7	
#4	4.75	2.016	73.4	
#8	2.36	1.472	56.0	
#16	1.18	1.077	42.3	
#30	0.6	0.795	27.9	
#50	0.3	0.582	13.8	
#100	0.15	0.426	6.7	
#200	0.075	0.312	2.9	
Pan	0	0.000	0.0	
Aggregate Type:	Gravel			



Cerro Gordo B43

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	99.7	
1/2"	12.5	3.116	95.0	
3/8"	9.5	2.754	88.9	
#4	4.75	2.016	50.8	
#8	2.36	1.472	43.6	
#16	1.18	1.077	26.2	
#30	0.6	0.795	12.8	
#50	0.3	0.582	4.3	
#100	0.15	0.426	1.4	
#200	0.075	0.312	0.6	
Pan	0	0.000	0.0	

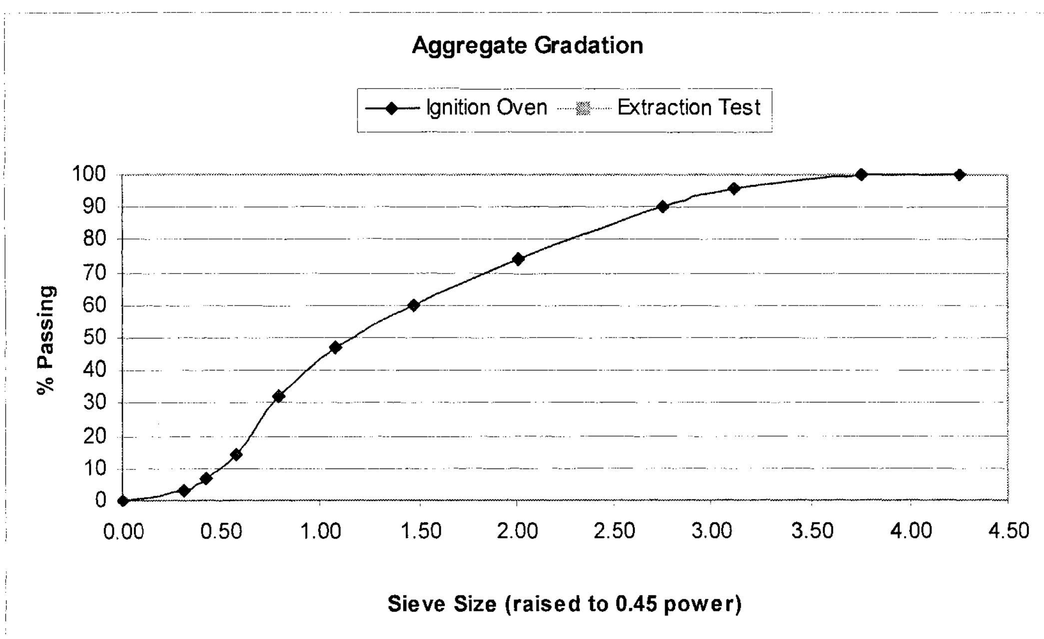
Aggregate Type: Limestone



Cerro Gordo SS

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	95.8	
3/8"	9.5	2.754	90.4	
#4	4.75	2.016	74.1	
#8	2.36	1.472	59.9	
#16	1.18	1.077	46.9	
#30	0.6	0.795	31.9	
#50	0.3	0.582	14.4	
#100	0.15	0.426	6.7	
#200	0.075	0.312	2.9	
Pan	0	0.000	0.0	

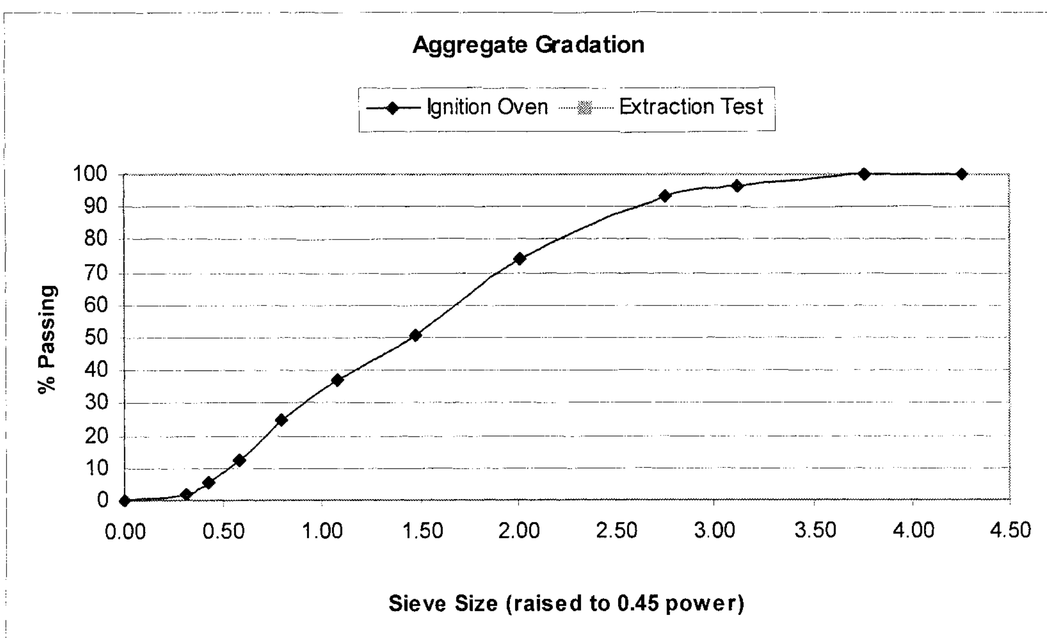
Aggregate Type: Limestone



Clinton E50

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	96.4	
3/8"	9.5	2.754	93.2	
#4	4.75	2.016	74.1	
#8	2.36	1.472	50.7	
#16	1.18	1.077	37.3	
#30	0.6	0.795	24.6	
#50	0.3	0.582	12.1	
#100	0.15	0.426	5.7	
#200	0.075	0.312	1.8	
Pan	0	0.000	0.0	

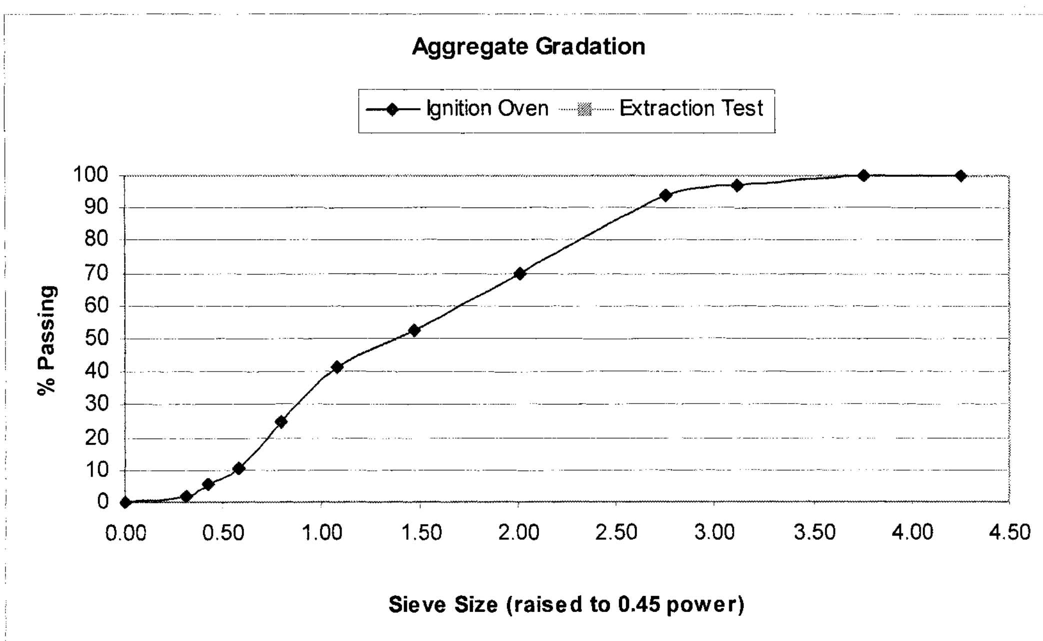
Aggregate Type: Limestone



Clinton Z30

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	96.9	
3/8"	9.5	2.754	93.6	
#4	4.75	2.016	69.9	
#8	2.36	1.472	52.5	
#16	1.18	1.077	41.1	
#30	0.6	0.795	24.5	
#50	0.3	0.582	10.8	
#100	0.15	0.426	5.6	
#200	0.075	0.312	2.0	
Pan	0	0.000	0.0	

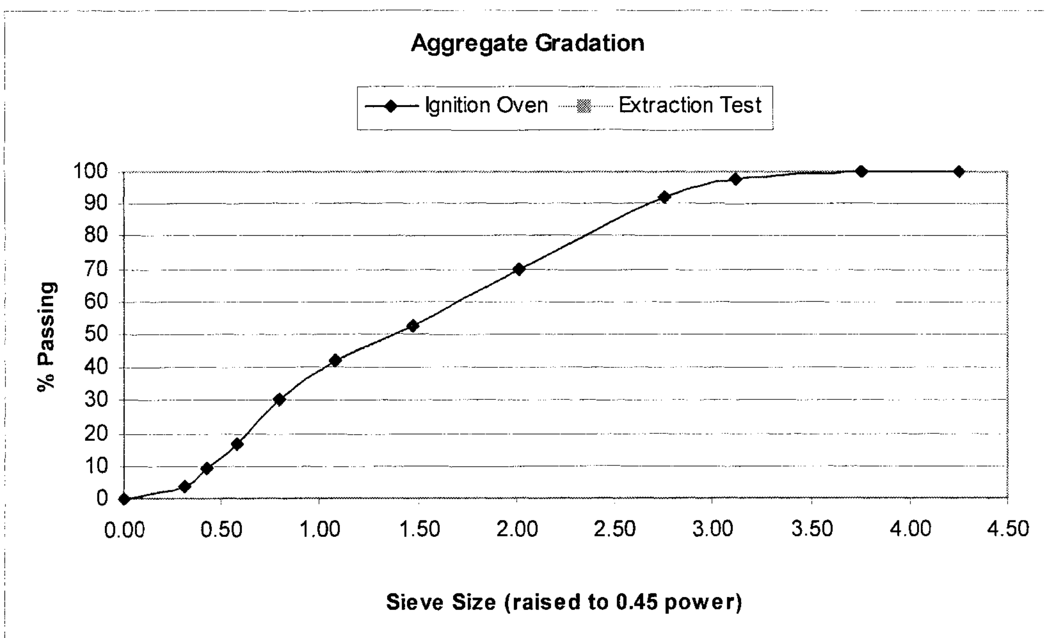
Aggregate Type: Limestone



Delaware US20

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	97.4	
3/8"	9.5	2.754	91.7	
#4	4.75	2.016	69.9	
#8	2.36	1.472	52.4	
#16	1.18	1.077	41.7	
#30	0.6	0.795	30.1	
#50	0.3	0.582	16.8	
#100	0.15	0.426	9.5	
#200	0.075	0.312	4.0	
Pan	0	0.000	0.0	

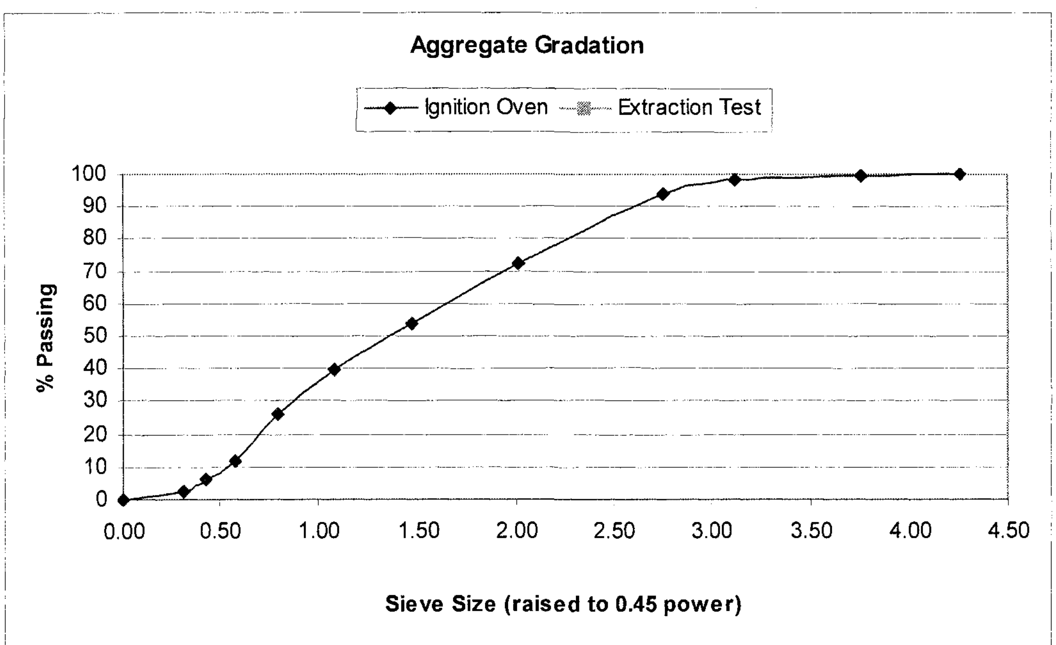
Aggregate Type: Curshed Gravel



Greene IA144

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	99.6	
1/2"	12.5	3.116	98.1	
3/8"	9.5	2.754	93.9	
#4	4.75	2.016	72.1	
#8	2.36	1.472	53.8	
#16	1.18	1.077	39.3	
#30	0.6	0.795	25.8	
#50	0.3	0.582	12.0	
#100	0.15	0.426	5.9	
#200	0.075	0.312	2.3	
Pan	0	0.000	0.0	

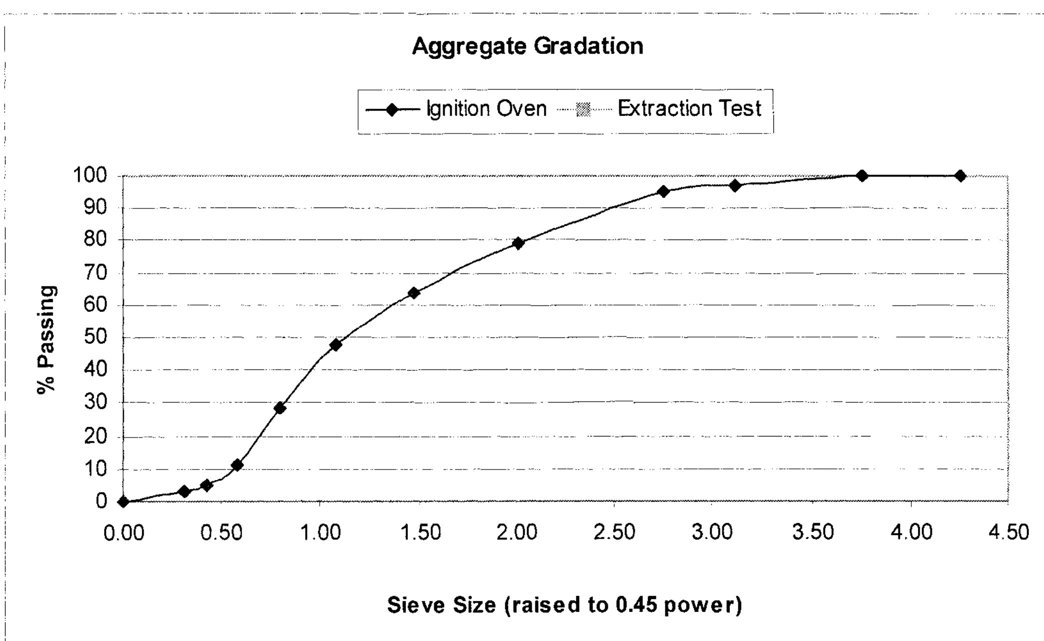
Aggregate Type: Crushed Gravel



Guthrie IA4

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	96.8	
3/8"	9.5	2.754	95.0	
#4	4.75	2.016	79.3	
#8	2.36	1.472	63.5	
#16	1.18	1.077	47.8	
#30	0.6	0.795	28.5	
#50	0.3	0.582	11.3	
#100	0.15	0.426	4.7	
#200	0.075	0.312	2.8	
Pan	0	0.000	0.0	

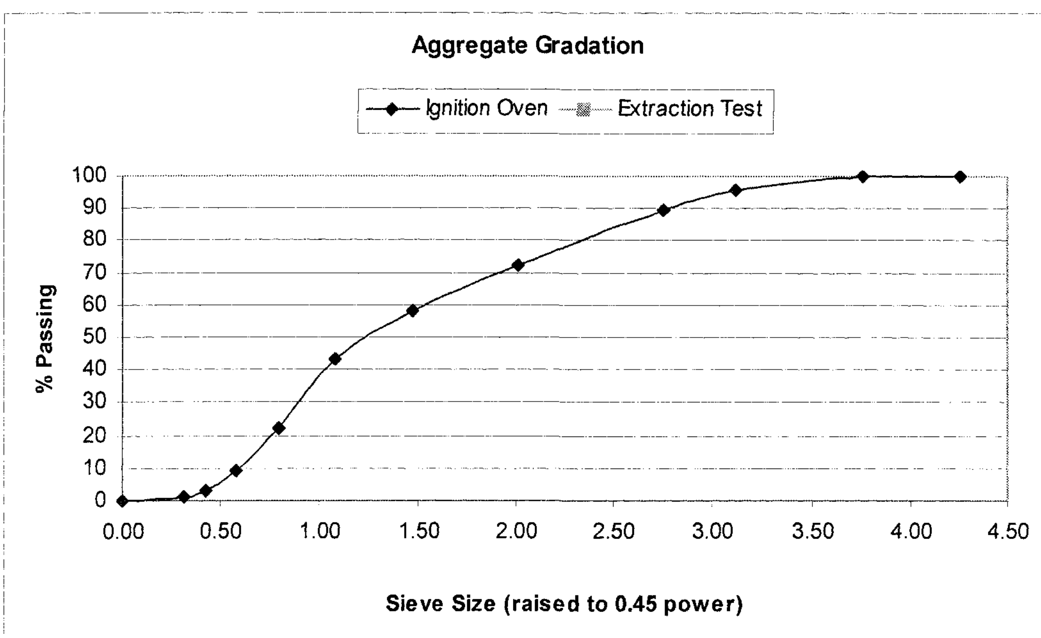
Aggregate Type: Gravel



Hardin D35

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	95.5	
3/8"	9.5	2.754	89.4	
#4	4.75	2.016	72.3	
#8	2.36	1.472	58.3	
#16	1.18	1.077	43.5	
#30	0.6	0.795	22.0	
#50	0.3	0.582	9.1	
#100	0.15	0.426	3.2	
#200	0.075	0.312	1.1	
Pan	0	0.000	0.0	

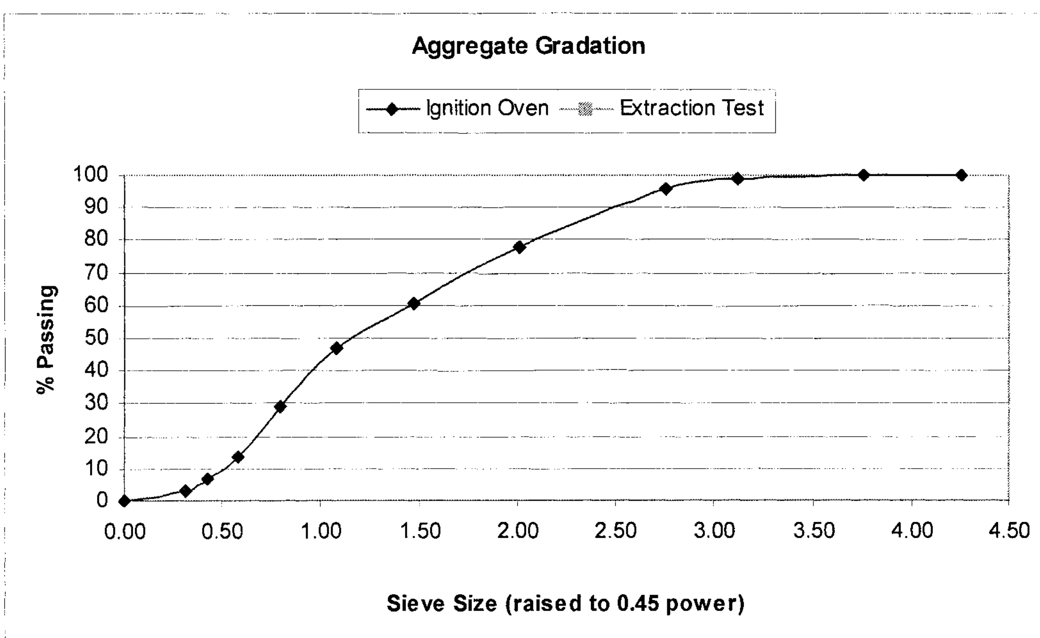
Aggregate Type: Gravel



Harrison IA144

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	98.5	
3/8"	9.5	2.754	95.6	
#4	4.75	2.016	77.6	
#8	2.36	1.472	60.5	
#16	1.18	1.077	47.2	
#30	0.6	0.795	29.3	
#50	0.3	0.582	13.4	
#100	0.15	0.426	6.9	
#200	0.075	0.312	3.0	
Pan	0	0.000	0.0	

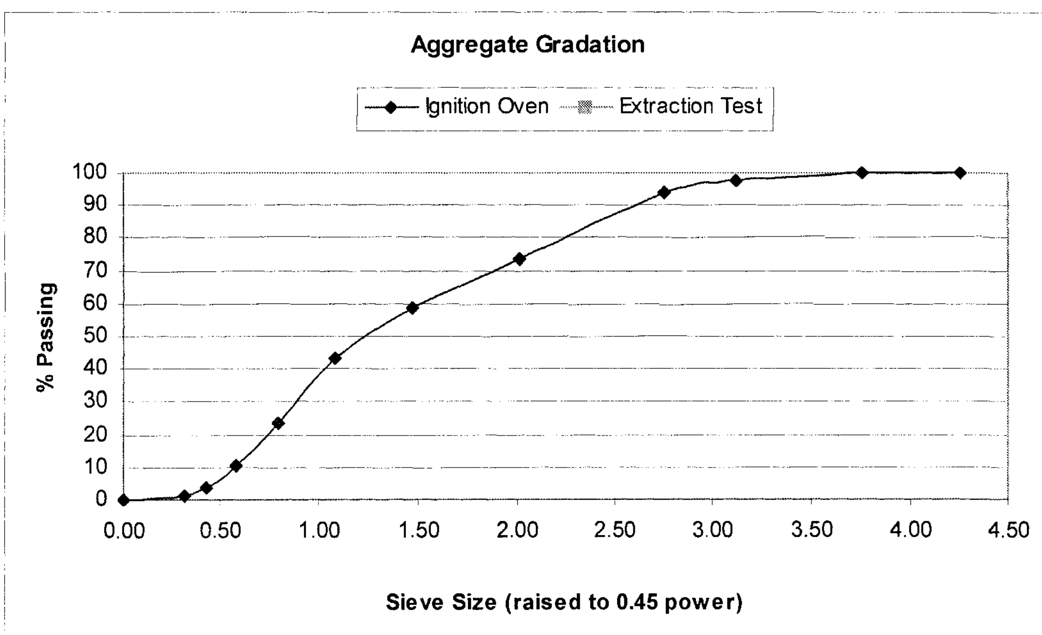
Aggregate Type: Crushed Gravel



Jackson US61

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	99.7	
1/2"	12.5	3.116	97.6	
3/8"	9.5	2.754	93.6	
#4	4.75	2.016	73.2	
#8	2.36	1.472	58.6	
#16	1.18	1.077	43.0	
#30	0.6	0.795	23.4	
#50	0.3	0.582	10.7	
#100	0.15	0.426	3.6	
#200	0.075	0.312	1.0	
Pan	0	0.000	0.0	

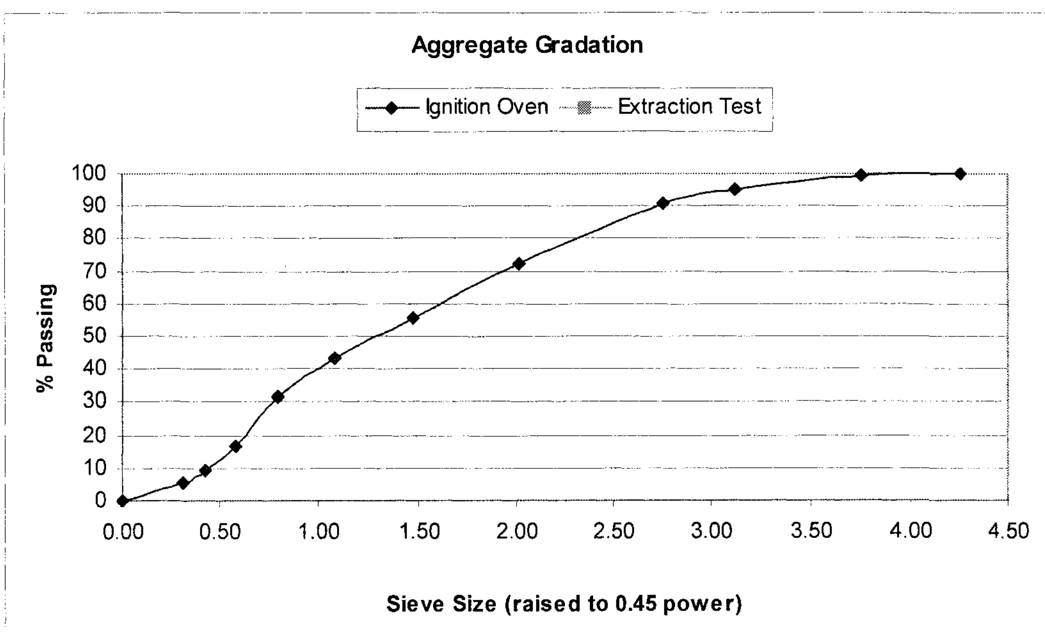
Aggregate Type: Limestone



Montgomery IA48

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	99.4	
1/2"	12.5	3.116	94.8	
3/8"	9.5	2.754	90.5	
#4	4.75	2.016	72.1	
#8	2.36	1.472	55.8	
#16	1.18	1.077	43.4	
#30	0.6	0.795	31.7	
#50	0.3	0.582	16.8	
#100	0.15	0.426	9.1	
#200	0.075	0.312	5.6	
Pan	0	0.000	0.0	

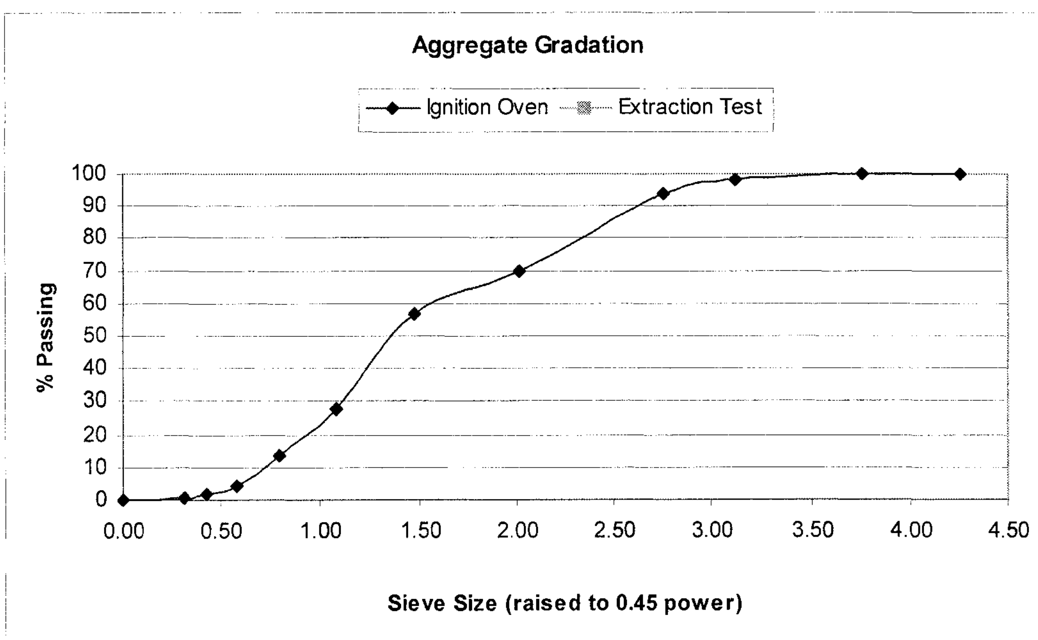
Aggregate Type: Limestone



Muscatine G28E

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	98.4	
3/8"	9.5	2.754	93.8	
#4	4.75	2.016	70.0	
#8	2.36	1.472	56.5	
#16	1.18	1.077	27.7	
#30	0.6	0.795	13.3	
#50	0.3	0.582	4.4	
#100	0.15	0.426	1.6	
#200	0.075	0.312	0.6	
Pan	0	0.000	0.0	

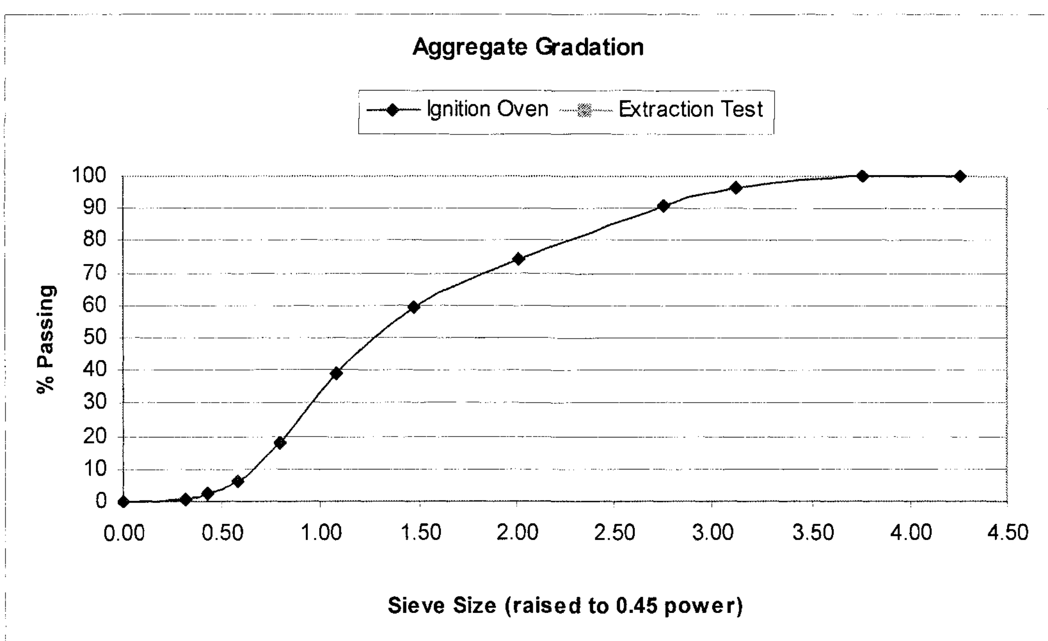
Aggregate Type: Limestone



Muscatine G28W

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	99.8	
1/2"	12.5	3.116	96.2	
3/8"	9.5	2.754	90.9	
#4	4.75	2.016	73.8	
#8	2.36	1.472	59.0	
#16	1.18	1.077	38.6	
#30	0.6	0.795	18.1	
#50	0.3	0.582	6.3	
#100	0.15	0.426	2.3	
#200	0.075	0.312	0.8	
Pan	0	0.000	0.0	

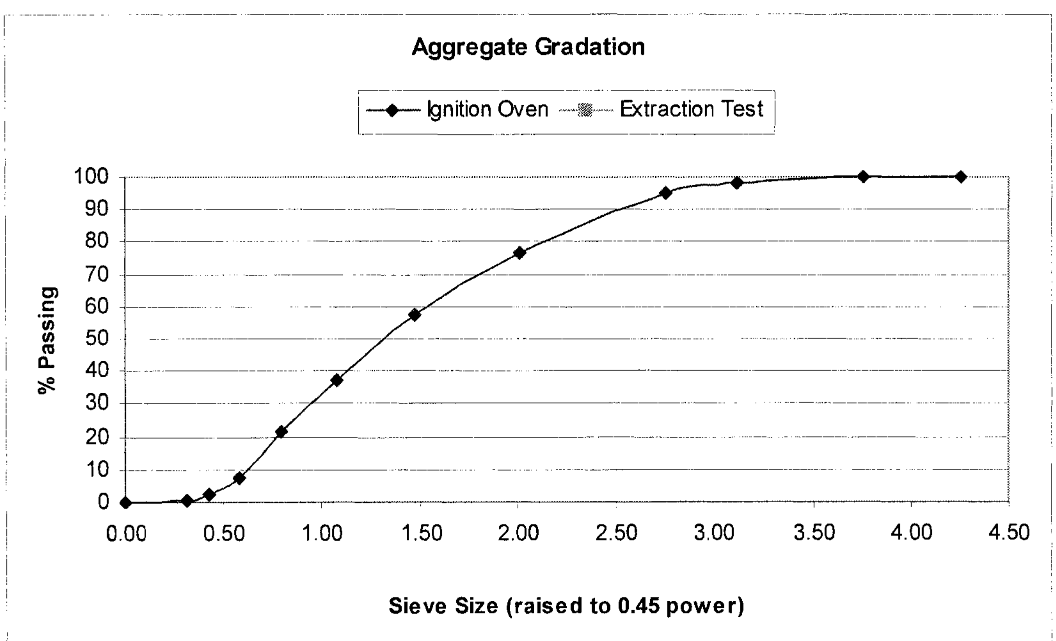
Aggregate Type: Limestone



Muscatine Y14N

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	98.3	
3/8"	9.5	2.754	95.0	
#4	4.75	2.016	76.5	
#8	2.36	1.472	57.2	
#16	1.18	1.077	36.9	
#30	0.6	0.795	21.4	
#50	0.3	0.582	7.2	
#100	0.15	0.426	2.6	
#200	0.075	0.312	0.9	
Pan	0	0.000	0.0	

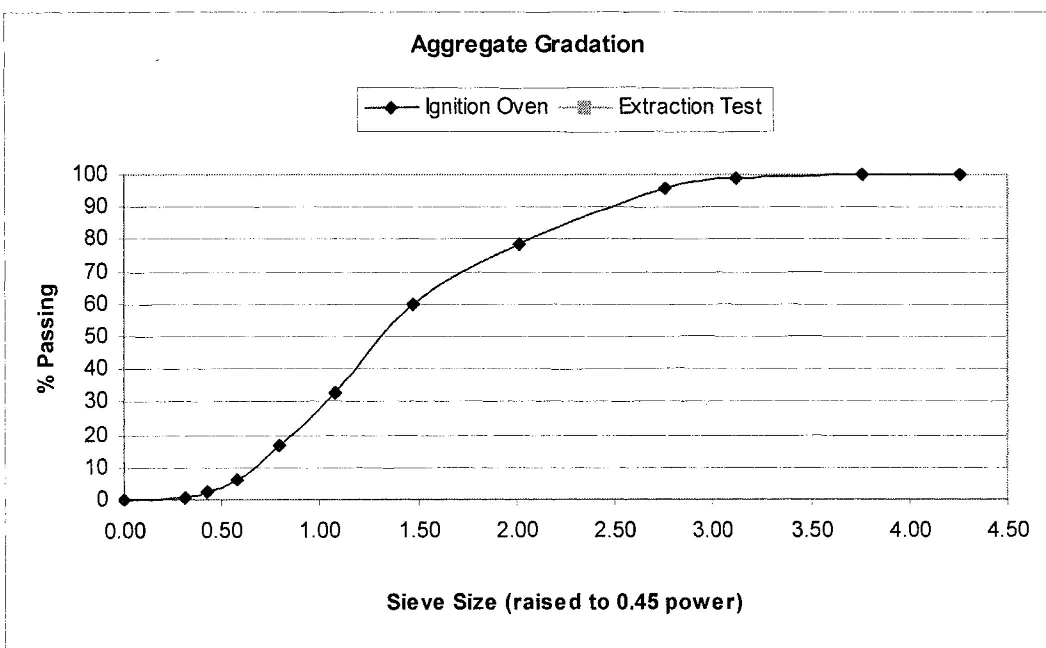
Aggregate Type: Limestone



Muscatine Y14S

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	99.8	
1/2"	12.5	3.116	98.5	
3/8"	9.5	2.754	95.7	
#4	4.75	2.016	78.3	
#8	2.36	1.472	59.6	
#16	1.18	1.077	32.9	
#30	0.6	0.795	16.9	
#50	0.3	0.582	6.4	
#100	0.15	0.426	2.2	
#200	0.075	0.312	0.7	
Pan	0	0.000	0.0	

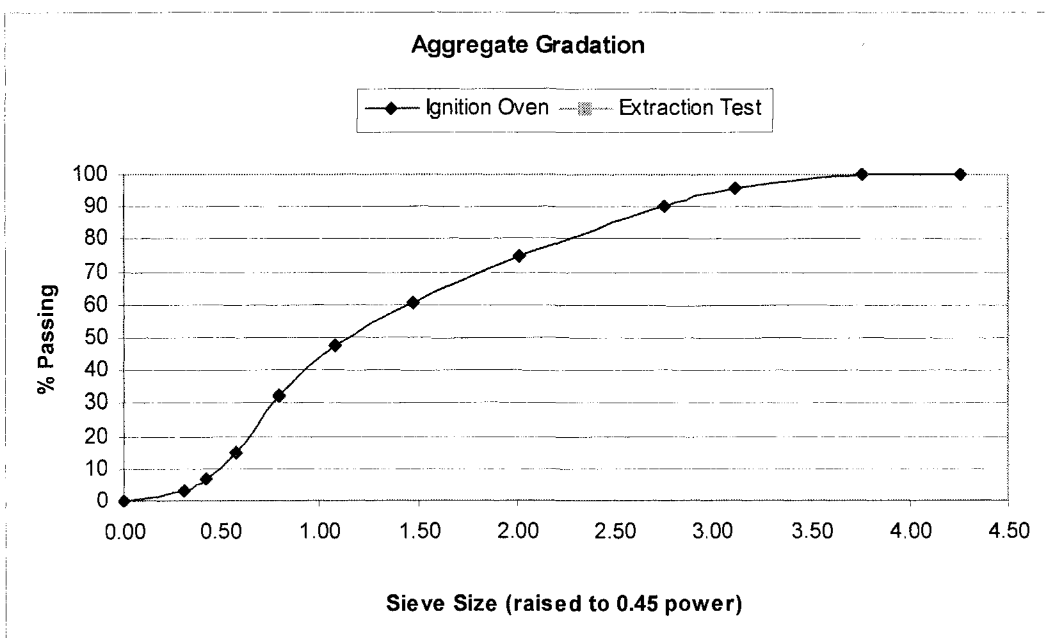
Aggregate Type: Limestone



Story S14 NB

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	95.7	
3/8"	9.5	2.754	90.3	
#4	4.75	2.016	74.7	
#8	2.36	1.472	60.5	
#16	1.18	1.077	47.4	
#30	0.6	0.795	32.3	
#50	0.3	0.582	14.7	
#100	0.15	0.426	7.0	
#200	0.075	0.312	3.0	
Pan	0	0.000	0.0	

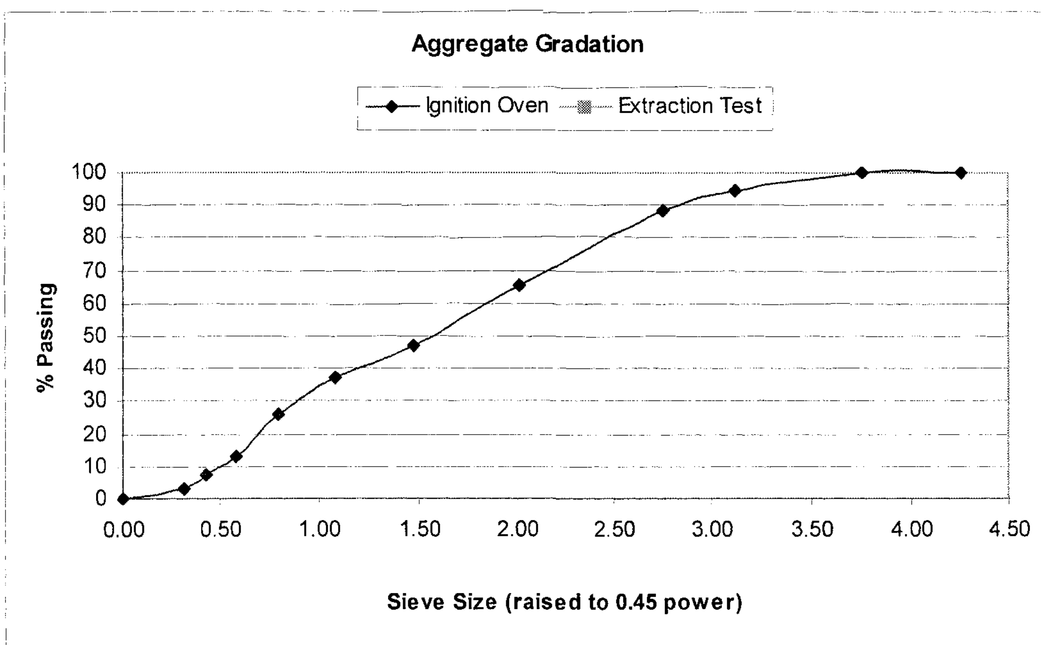
Aggregate Type: Crushed Gravel



Tama E66

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	94.4	
3/8"	9.5	2.754	88.2	
#4	4.75	2.016	65.4	
#8	2.36	1.472	47.2	
#16	1.18	1.077	37.0	
#30	0.6	0.795	25.7	
#50	0.3	0.582	12.9	
#100	0.15	0.426	7.3	
#200	0.075	0.312	3.0	
Pan	0	0.000	0.0	

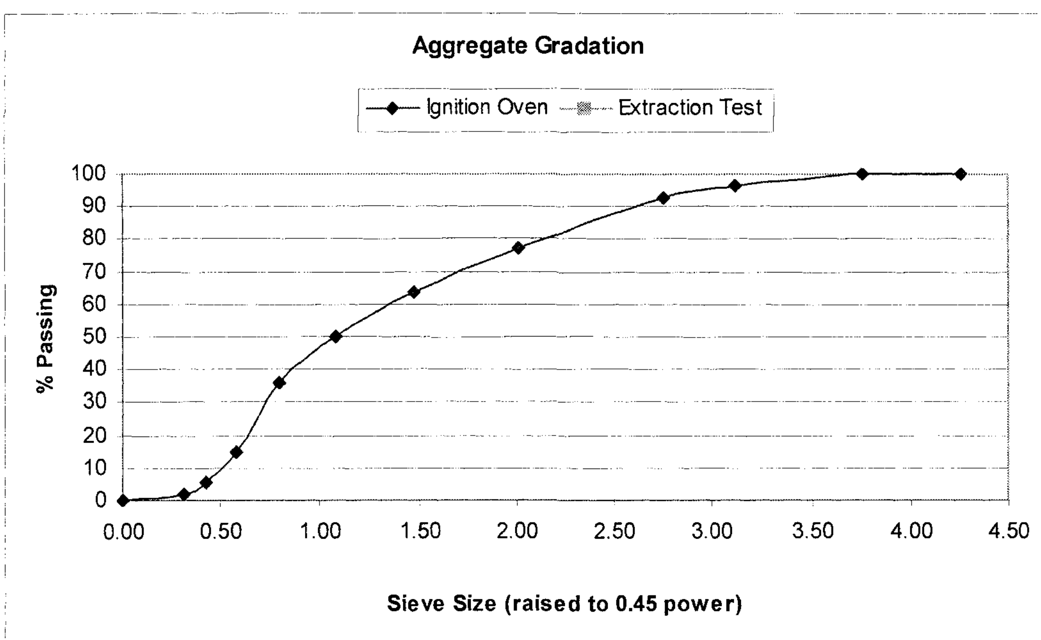
Aggregate Type: Limestone



Tama V18A

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	96.6	
3/8"	9.5	2.754	92.6	
#4	4.75	2.016	77.2	
#8	2.36	1.472	63.5	
#16	1.18	1.077	50.0	
#30	0.6	0.795	35.5	
#50	0.3	0.582	14.7	
#100	0.15	0.426	5.5	
#200	0.075	0.312	1.8	
Pan	0	0.000	0.0	

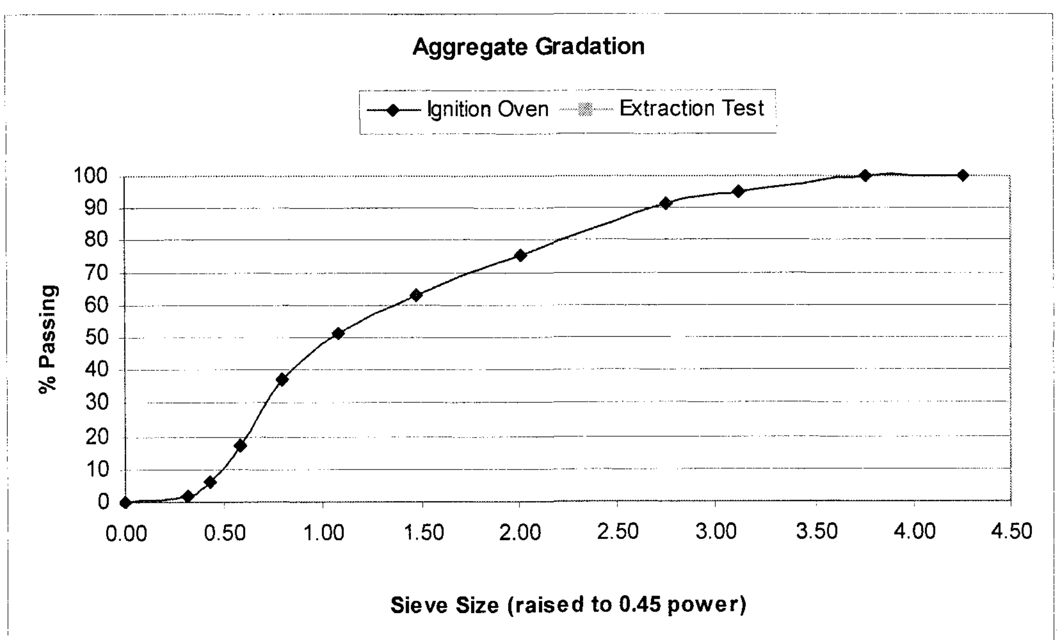
Aggregate Type: Crushed Gravel



Tama V18b

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	94.9	
3/8"	9.5	2.754	91.1	
#4	4.75	2.016	75.6	
#8	2.36	1.472	62.7	
#16	1.18	1.077	51.2	
#30	0.6	0.795	36.9	
#50	0.3	0.582	17.1	
#100	0.15	0.426	6.3	
#200	0.075	0.312	1.8	
Pan	0	0.000	0.0	

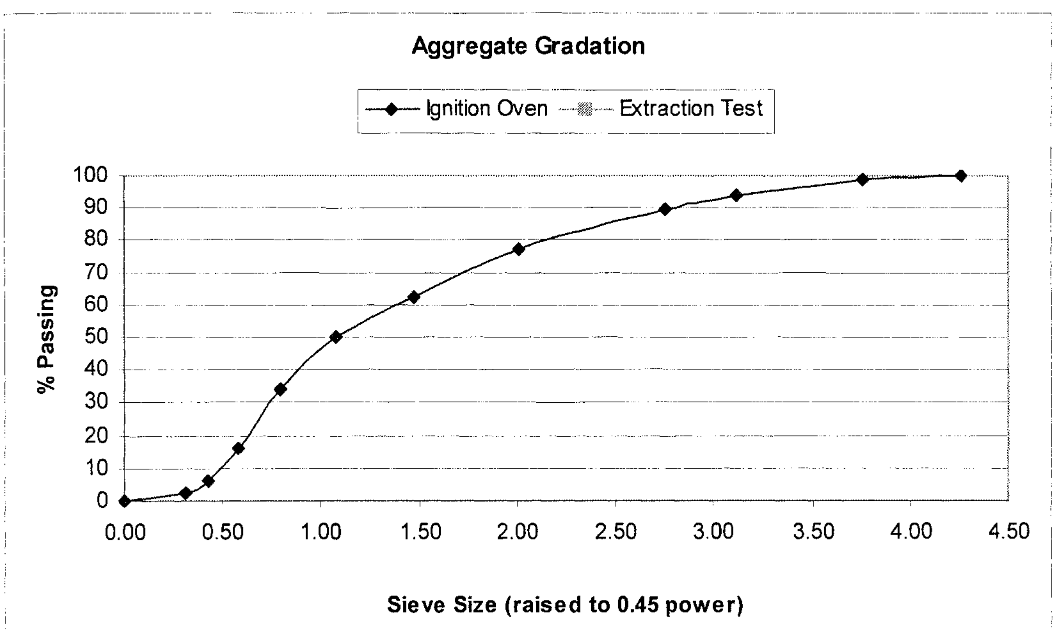
Aggregate Type: Crushed Gravel



Winnebago R34A

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	98.7	
1/2"	12.5	3.116	94.0	
3/8"	9.5	2.754	89.7	
#4	4.75	2.016	77.0	
#8	2.36	1.472	62.6	
#16	1.18	1.077	50.3	
#30	0.6	0.795	34.0	
#50	0.3	0.582	15.8	
#100	0.15	0.426	6.4	
#200	0.075	0.312	2.5	
Pan	0	0.000	0.0	

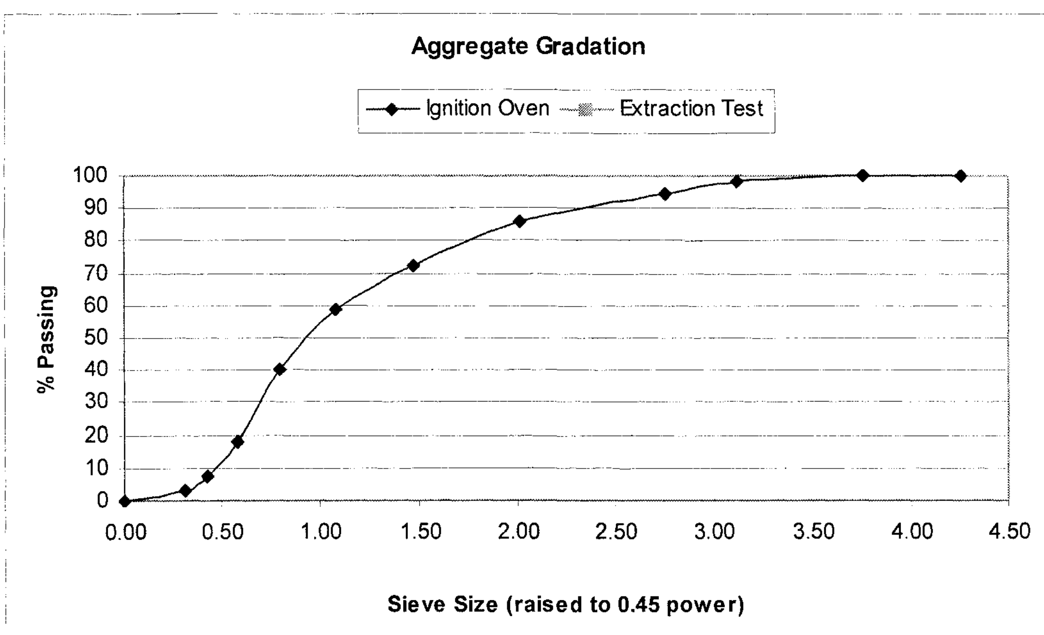
Aggregate Type: Crushed Gravel



Winnebago R34B

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	98.4	
3/8"	9.5	2.754	94.2	
#4	4.75	2.016	85.5	
#8	2.36	1.472	72.5	
#16	1.18	1.077	58.7	
#30	0.6	0.795	40.4	
#50	0.3	0.582	18.0	
#100	0.15	0.426	7.4	
#200	0.075	0.312	3.3	
Pan	0	0.000	0.0	

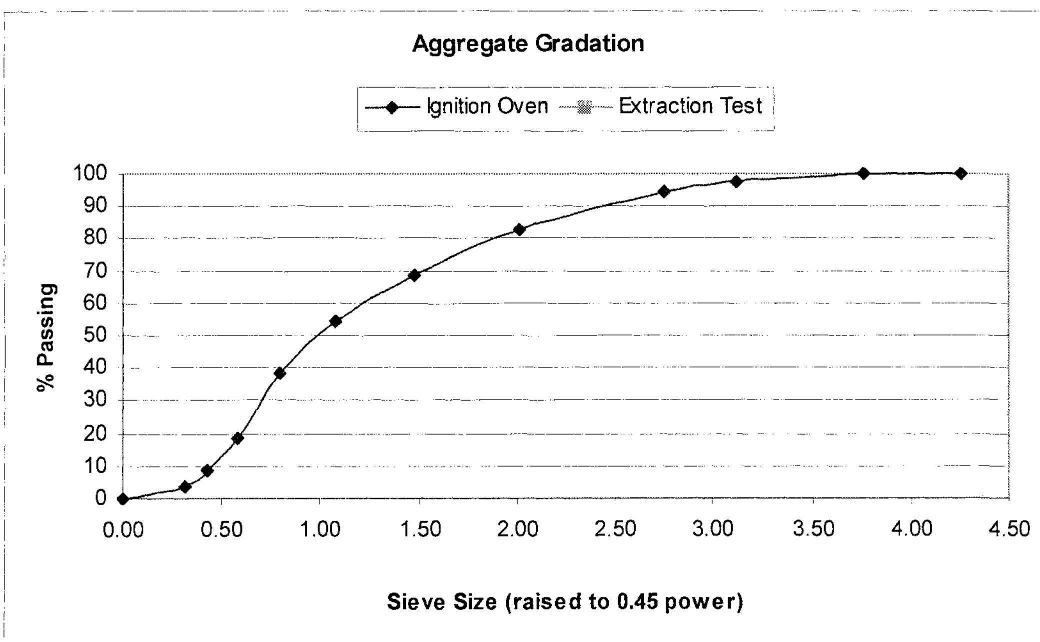
Aggregate Type: Crushed Gravel



Winnebago R60

Aggregate Gradation				
Sieve Size (Customary)	Sieve Size (mm)	Sieve Size to 0.45 power	Percent Passing	
			Ignition Oven	Extraction
1"	25	4.257	100.0	
3/4"	19	3.762	100.0	
1/2"	12.5	3.116	97.3	
3/8"	9.5	2.754	94.2	
#4	4.75	2.016	82.6	
#8	2.36	1.472	68.6	
#16	1.18	1.077	54.6	
#30	0.6	0.795	38.3	
#50	0.3	0.582	18.7	
#100	0.15	0.426	8.4	
#200	0.075	0.312	3.8	
Pan	0	0.000	0.0	

Aggregate Type: Crushed Gravel



APPENDIX E. FALLING WEIGHT DEFLECTOMETER (FWD) RAW DATA

M3

Date-Time: 12-13-2004 8:36: 9
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Boone 198th
Temp: 10
Operator: bad
Comments:
1 1 0.000 1 9.14 14.12 12.74 11.24 9.39 7.79 5.34 3.51 2.57 10.93 21.2
GPS Position: Latitude = Longitude =
Note:
2 1 105.000 1 8.81 13.35 12.39 11.15 9.48 7.96 5.44 3.57 2.43 10.84 20.9
GPS Position: Latitude = Longitude =
Note:
3 1 211.000 1 9.35 15.91 14.26 12.30 9.94 7.90 5.04 3.16 2.37 11.82 20.9
GPS Position: Latitude = Longitude =
Note:
4 1 304.000 1 9.42 12.68 11.75 10.26 8.39 6.75 4.38 2.81 2.15 9.45 21.2
GPS Position: Latitude = Longitude =
Note:
5 1 402.000 1 9.27 15.28 14.84 12.82 10.26 8.03 5.00 3.09 2.44 11.74 21.2
GPS Position: Latitude = Longitude =
Note:
6 1 503.000 1 9.20 13.40 13.30 11.83 9.93 8.18 5.50 3.53 2.64 11.41 21.2
GPS Position: Latitude = Longitude =
Note:
7 1 603.000 1 9.45 14.62 13.19 11.56 9.42 7.50 4.68 2.81 2.22 11.14 22.3
GPS Position: Latitude = Longitude =
Note:
8 1 752.000 1 8.59 18.47 16.23 14.07 11.41 9.18 5.92 3.73 2.86 14.05 22.0
GPS Position: Latitude = Longitude =
Note:
9 1 813.000 1 9.63 16.59 15.14 13.35 10.93 8.84 5.88 3.82 2.62 13.18 23.4
GPS Position: Latitude = Longitude =
Note:
10 1 917.000 1 9.82 15.26 13.52 11.51 9.07 7.06 4.43 2.84 1.96 12.88 21.6
GPS Position: Latitude = Longitude =
Note:
11 1 1004.000 1 9.71 14.67 13.53 11.77 9.51 7.55 4.85 3.14 2.20 10.71 22.0
GPS Position: Latitude = Longitude =
Note:
12 1 1108.000 1 9.48 26.65 24.21 19.85 14.85 10.91 6.14 3.67 2.56 17.62 23.4
GPS Position: Latitude = Longitude =
Note:
13 1 1205.000 1 9.66 13.68 12.59 11.03 9.06 7.35 4.83 3.15 2.27 10.32 23.1
GPS Position: Latitude = Longitude =
Note:
14 1 1307.000 1 9.16 14.22 12.86 11.02 8.79 6.92 4.41 2.85 2.52 10.23 22.0
GPS Position: Latitude = Longitude =
Note:
15 1 1404.000 1 9.51 12.43 11.55 10.16 8.34 6.77 4.60 3.06 2.28 9.37 23.4
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 9.56 17.07 15.70 13.55 10.80 8.38 4.99 2.94 2.09 12.36 24.5
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 9:35:14
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Boone E52
Temp: 10
Operator: bad
Comments:
1 1 0.000 1 10.12 14.08 12.87 11.54 9.87 8.30 5.84 4.02 2.80 11.74 730.6
GPS Position: Latitude = Longitude =
Note:
2 1 104.000 1 9.80 22.37 21.78 19.24 15.94 13.01 8.40 3.16 2.63 15.95 729.1
GPS Position: Latitude = Longitude =
Note:
3 1 201.000 1 10.11 18.57 18.08 16.15 13.74 11.51 8.28 4.70 2.36 14.35 731.7
GPS Position: Latitude = Longitude =
Note:
4 1 305.000 1 10.15 17.74 16.82 14.86 12.26 9.90 6.44 4.11 2.83 13.26 733.9
GPS Position: Latitude = Longitude =
Note:
5 1 402.000 1 10.15 17.02 16.08 14.13 11.74 9.60 6.47 4.28 3.00 12.91 735.4
GPS Position: Latitude = Longitude =
Note:
6 1 507.000 1 10.18 14.37 13.54 12.09 10.19 8.48 5.83 3.89 2.68 11.09 735.4
GPS Position: Latitude = Longitude =
Note:
7 1 616.000 1 10.21 16.64 15.69 13.94 11.66 9.60 6.47 4.28 3.13 12.98 735.0
GPS Position: Latitude = Longitude =
Note:
8 1 705.000 1 10.24 17.36 15.65 13.75 11.33 9.18 6.03 3.89 2.75 13.51 737.5
GPS Position: Latitude = Longitude =
Note:
9 1 806.000 1 10.16 16.57 15.58 13.76 11.53 9.51 6.40 4.22 2.95 12.99 738.6
GPS Position: Latitude = Longitude =
Note:
10 1 913.000 1 10.29 16.31 15.09 13.47 11.40 9.44 6.45 4.38 3.13 13.19 739.7
GPS Position: Latitude = Longitude =
Note:
11 1 1001.000 1 10.33 13.75 12.90 11.72 10.13 8.61 6.15 4.33 3.06 11.35 740.5
GPS Position: Latitude = Longitude =
Note:
12 1 1112.000 1 10.33 12.49 11.77 10.72 9.29 7.96 5.84 4.20 3.03 10.48 740.1
GPS Position: Latitude = Longitude =
Note:
13 1 1207.000 1 10.27 13.95 13.42 12.13 10.41 8.77 6.22 4.33 3.12 11.09 739.7
GPS Position: Latitude = Longitude =
Note:
14 1 1430.000 1 10.36 15.75 14.77 13.41 11.56 9.76 6.94 4.75 3.32 12.88 741.2
GPS Position: Latitude = Longitude =
Note:
15 1 1434.000 1 10.23 16.30 14.57 13.05 11.15 9.37 6.57 4.46 3.06 14.87 739.7
GPS Position: Latitude = Longitude =
Note:
16 1 1505.000 1 10.41 14.74 13.58 12.04 10.16 8.39 5.67 3.80 2.56 11.92 739.7
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 3-30-2005 13:13:15
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Butler T16
Temp: 56
Operator: Colton/Denekas
Comments:
1 1 0.000 1 9.20 16.67 13.55 11.37 8.93 6.99 4.56 3.07 2.36 11.33 64.8
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 8.69 17.85 15.86 13.55 10.73 8.42 5.32 3.38 2.46 12.41 64.1
GPS Position: Latitude = Longitude =
Note:
3 1 201.000 1 8.90 23.78 20.69 17.32 13.52 10.42 6.26 3.76 2.60 16.43 63.7
GPS Position: Latitude = Longitude =
Note:
4 1 300.000 1 8.77 25.02 21.11 17.71 13.82 10.80 6.65 4.10 2.78 17.44 63.7
GPS Position: Latitude = Longitude =
Note:
5 1 401.000 1 8.62 25.11 21.80 18.24 14.33 11.27 7.08 4.36 2.90 16.92 62.3
GPS Position: Latitude = Longitude =
Note:
6 1 502.000 1 8.75 21.10 18.36 15.73 12.67 10.15 6.56 4.12 2.82 15.38 62.6
GPS Position: Latitude = Longitude =
Note:
7 1 600.000 1 8.71 21.17 20.11 18.20 15.82 13.72 9.08 4.37 3.33 15.88 61.9
GPS Position: Latitude = Longitude =
Note:
8 1 703.000 1 9.15 14.70 13.70 12.33 10.47 8.79 6.30 4.41 3.21 11.64 63.0
GPS Position: Latitude = Longitude =
Note:
9 1 800.000 1 9.10 15.36 13.69 12.17 10.40 8.83 6.33 4.36 3.12 11.85 62.6
GPS Position: Latitude = Longitude =
Note:
10 1 902.000 1 8.74 27.80 23.97 20.63 16.48 13.07 8.00 4.87 3.24 19.54 62.6
GPS Position: Latitude = Longitude =
Note:
11 1 1002.000 1 8.95 24.88 20.74 17.51 13.79 10.80 6.72 4.13 2.84 17.39 63.0
GPS Position: Latitude = Longitude =
Note:
12 1 1100.000 1 9.05 23.04 19.45 16.37 12.76 9.79 5.91 3.55 2.38 15.83 62.3
GPS Position: Latitude = Longitude =
Note:
13 1 1200.000 1 8.67 21.12 18.13 15.35 11.95 9.16 5.59 3.38 2.42 14.56 61.5
GPS Position: Latitude = Longitude =
Note:
14 1 1302.000 1 8.79 26.37 22.79 18.88 14.54 11.07 6.45 3.72 2.46 18.25 62.3
GPS Position: Latitude = Longitude =
Note:
15 1 1404.000 1 8.75 25.34 22.07 18.57 14.73 11.58 7.16 4.25 2.87 17.72 63.0
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 8.50 27.92 23.62 20.28 15.74 12.20 7.46 4.48 3.05 18.66 63.0
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-15-2004 10:46:46
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Calhoun IA175
Temp: 33
Operator: COLTON / DENEKAS
Comments: IA4/IA175 EASTBOUND
1 1 0.000 1 9.16 4.01 3.87 3.65 3.38 3.13 2.64 2.14 1.74 3.61 43.6
GPS Position: Latitude = Longitude =
Note:
2 1 122.000 1 9.32 4.13 3.97 3.72 3.45 3.20 2.70 2.19 1.74 3.63 44.7
GPS Position: Latitude = Longitude =
Note:
3 1 206.000 1 9.21 4.16 4.05 3.82 3.58 3.33 2.89 2.41 1.96 3.73 45.0
GPS Position: Latitude = Longitude =
Note:
4 1 307.000 1 9.34 4.02 3.90 3.72 3.50 3.29 2.87 2.38 1.97 3.67 46.5
GPS Position: Latitude = Longitude =
Note:
5 1 399.000 1 9.41 4.52 4.37 4.13 3.87 3.62 3.10 2.57 2.10 4.13 47.2
GPS Position: Latitude = Longitude =
Note:
6 1 501.000 1 9.26 4.19 4.02 3.78 3.52 3.26 2.76 2.25 1.81 3.71 47.6
GPS Position: Latitude = Longitude =
Note:
7 1 602.000 1 9.04 4.33 4.16 3.93 3.65 3.40 2.88 2.34 1.89 3.86 46.9
GPS Position: Latitude = Longitude =
Note:
8 1 700.000 1 9.22 4.16 4.06 3.85 3.62 3.38 2.93 2.42 2.01 3.77 48.7
GPS Position: Latitude = Longitude =
Note:
9 1 801.000 1 9.07 4.33 4.22 4.03 3.80 3.60 3.20 2.75 2.36 3.97 49.8
GPS Position: Latitude = Longitude =
Note:
10 1 900.000 1 9.11 4.16 4.11 3.95 3.75 3.59 3.25 2.85 2.51 3.87 49.8
GPS Position: Latitude = Longitude =
Note:
11 1 999.000 1 9.16 4.09 4.02 3.84 3.63 3.47 3.12 2.71 2.44 3.78 49.8
GPS Position: Latitude = Longitude =
Note:
12 1 1100.000 1 9.21 4.57 4.47 4.26 4.01 3.82 3.39 2.94 2.52 4.15 49.8
GPS Position: Latitude = Longitude =
Note:
13 1 1201.000 1 9.05 4.40 4.26 4.07 3.87 3.71 3.37 2.96 2.65 4.05 50.5
GPS Position: Latitude = Longitude =
Note:
14 1 1314.000 1 9.12 4.02 3.90 3.71 3.47 3.25 2.83 2.38 1.98 3.68 49.4
GPS Position: Latitude = Longitude =
Note:
15 1 1399.000 1 9.05 4.70 4.52 4.26 3.98 3.70 3.11 2.52 1.98 4.09 49.4
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 9.26 4.37 4.22 3.99 3.72 3.46 2.96 2.42 1.99 3.94 50.5
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 3-31-2005 8:17:17
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04
096017F04 096018F04 096019F04
Weight/spring: 3
Location: Carroll N58
Temp: 41
Operator: Colto/Stephes
Comments:
1 1 0.000 1 9.07 4.83 4.66 4.29 3.84 3.39 2.64 2.00 1.50 4.06 48.7
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 9.09 7.28 7.13 6.66 6.09 5.47 4.40 3.39 2.56 6.31 50.5
GPS Position: Latitude = 42°2.868940 North Longitude = 0°0.000000 East
Note:
3 1 201.000 1 8.92 9.43 9.17 8.57 7.77 6.91 5.45 4.11 3.03 8.21 52.4
GPS Position: Latitude = 42°2.868940 North Longitude = 0°0.900000 East
Note:
4 1 300.000 1 9.02 10.46 10.13 9.39 8.42 7.43 5.71 4.23 3.07 8.94 52.7
GPS Position: Latitude = 42°2.868940 North Longitude = 0°9.000000 East
Note:
5 1 402.000 1 8.97 9.18 8.80 8.13 7.28 6.43 4.98 3.73 2.76 7.70 52.7
GPS Position: Latitude = 42°2.868940 North Longitude = 0°0.000000 East
Note:
6 1 500.000 1 9.05 7.74 7.30 6.67 5.87 5.11 3.83 2.78 1.69 6.57 52.7
GPS Position: Latitude = 42°2.868940 North Longitude = 0°0.000000 East
Note:
7 1 606.000 1 8.84 7.91 7.26 6.51 5.66 4.92 3.74 2.78 2.33 6.51 53.5
GPS Position: Latitude = 42°2.868940 North Longitude = 0°0.000000 East
Note:
8 1 704.000 1 8.75 8.24 7.57 6.78 5.87 5.09 3.87 2.87 2.19 6.81 53.1
GPS Position: Latitude = 42°2.868940 North Longitude = 0°0.000000 East
Note:
9 1 802.000 1 9.06 8.49 8.01 7.21 6.29 5.45 4.11 3.03 2.33 6.81 53.1
GPS Position: Latitude = 42°2.868940 North Longitude = 0°0.000000 East
Note:
10 1 899.000 1 9.10 9.25 8.67 7.84 6.80 5.77 4.12 2.86 2.20 7.31 54.6
GPS Position: Latitude = 42°2.868940 North Longitude = 0°1.000000 East
Note:
11 1 1002.000 1 8.66 7.75 7.27 6.50 5.62 4.86 3.68 2.72 2.17 6.22 54.9
GPS Position: Latitude = 42°2.868940 North Longitude = 0°1.000000 East
Note:
12 1 1101.000 1 9.01 7.84 7.59 6.90 6.05 5.22 3.83 2.74 2.08 6.13 54.2
GPS Position: Latitude = 0°0.000000 South Longitude = 0°0.000000 East
Note:
13 1 1205.000 1 9.17 10.55 9.79 8.80 7.60 6.55 4.89 3.61 2.78 8.66 54.9
GPS Position: Latitude = 41°56.822820 North Longitude = 94°37.771021 West
Note:
14 1 1302.000 1 9.06 9.68 9.31 8.45 7.42 6.50 4.95 3.65 2.87 7.94 54.6
GPS Position: Latitude = 41°56.802744 North Longitude = 94°37.768930 West
Note:
15 1 1400.000 1 8.94 10.55 10.35 9.49 8.31 7.15 5.21 3.70 2.88 8.50 54.6
GPS Position: Latitude = 41°56.786651 North Longitude = 94°37.768529 West
Note:
16 1 1502.000 1 8.90 11.20 10.67 9.53 8.07 6.81 4.82 3.45 2.78 8.80 55.3
GPS Position: Latitude = 41°56.769120 North Longitude = 94°37.768131 West
Note:

M3
Date-Time: 12-15-2004 11:49:50
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Carroll N. of Breda
Temp: 35
Operator: COLTON / DENEKAS
Comments: NORTH OF BREDA, CARROLL CO., NORTHBOUND
1 1 0.000 1 8.76 8.98 8.56 8.02 7.30 6.64 5.42 4.20 3.23 8.04 43.6
GPS Position: Latitude = Longitude =
Note:
2 1 102.000 1 9.05 6.92 6.63 6.21 5.68 5.25 4.46 3.63 2.97 6.08 43.2
GPS Position: Latitude = Longitude =
Note:
3 1 201.000 1 8.89 9.06 8.58 7.94 7.17 6.51 5.35 4.30 3.46 7.77 44.3
GPS Position: Latitude = Longitude =
Note:
4 1 300.000 1 8.74 11.30 10.87 10.09 9.02 8.09 6.42 4.95 3.87 9.60 45.0
GPS Position: Latitude = Longitude =
Note:
5 1 400.000 1 8.96 11.68 10.98 10.17 9.13 8.21 6.50 4.98 3.87 9.94 45.4
GPS Position: Latitude = Longitude =
Note:
6 1 500.000 1 8.76 9.45 9.21 8.65 7.78 7.02 5.60 4.33 3.31 8.18 46.1
GPS Position: Latitude = Longitude =
Note:
7 1 612.000 1 8.77 10.46 9.98 9.31 8.41 7.62 6.17 4.76 3.63 8.92 45.8
GPS Position: Latitude = Longitude =
Note:
8 1 736.000 1 8.80 10.11 9.48 8.68 7.73 6.86 5.41 4.13 3.20 8.34 45.4
GPS Position: Latitude = Longitude =
Note:
9 1 814.000 1 8.71 10.04 9.49 8.79 7.95 7.18 5.77 4.46 3.45 8.56 45.0
GPS Position: Latitude = Longitude =
Note:
10 1 899.000 1 8.66 12.18 11.61 10.75 9.65 8.68 6.86 5.24 3.97 10.44 46.1
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 8.79 11.99 11.27 10.35 9.12 8.08 6.20 4.65 3.47 10.01 46.9
GPS Position: Latitude = Longitude =
Note:
12 1 1100.000 1 8.76 11.63 11.14 10.18 8.97 7.94 6.10 4.55 3.38 9.74 46.9
GPS Position: Latitude = Longitude =
Note:
13 1 1199.000 1 8.82 11.33 10.73 9.85 8.74 7.75 5.99 4.43 3.28 9.34 47.6
GPS Position: Latitude = Longitude =
Note:
14 1 1302.000 1 8.66 12.45 11.79 10.54 9.02 7.73 5.73 4.12 2.91 9.91 47.2
GPS Position: Latitude = Longitude =
Note:
15 1 1401.000 1 8.59 11.02 10.37 9.57 8.59 7.67 5.94 4.41 3.21 9.49 47.2
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 8.71 12.16 11.36 10.44 9.26 8.20 6.35 4.76 3.54 10.11 47.6
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-14-2004 14:54:50
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04
096017F04 096018F04 096019F04
Weight/spring: 3
Location: Cerro Gordo B43
Temp: 23
Operator: bad
Comments:
1 1 0.000 1 9.29 6.18 5.59 5.14 4.72 4.32 3.57 2.84 2.29 5.11 35.5
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 9.45 5.50 5.17 4.77 4.41 4.11 3.49 2.84 2.29 4.54 35.2
GPS Position: Latitude = Longitude =
Note:
3 1 200.000 1 9.53 5.68 5.36 5.03 4.69 4.38 3.73 3.04 2.48 4.91 35.2
GPS Position: Latitude = Longitude =
Note:
4 1 301.000 1 9.50 4.95 4.81 4.47 4.16 3.86 3.32 2.73 2.25 4.27 35.5
GPS Position: Latitude = Longitude =
Note:
5 1 401.000 1 9.41 5.92 5.55 5.11 4.70 4.30 3.56 2.86 2.32 4.89 35.5
GPS Position: Latitude = Longitude =
Note:
6 1 500.000 1 9.47 4.75 4.36 4.02 3.69 3.38 2.82 2.26 1.82 3.91 35.2
GPS Position: Latitude = Longitude =
Note:
7 1 602.000 1 9.15 5.21 5.00 4.59 4.22 3.87 3.17 2.51 1.95 4.21 35.5
GPS Position: Latitude = Longitude =
Note:
8 1 702.000 1 9.19 4.99 4.86 4.44 4.05 3.71 3.11 2.51 2.08 4.14 35.5
GPS Position: Latitude = Longitude =
Note:
9 1 811.000 1 9.37 4.67 4.41 4.04 3.69 3.35 2.72 2.13 1.70 3.84 35.5
GPS Position: Latitude = Longitude =
Note:
10 1 963.000 1 9.42 4.19 3.99 3.65 3.32 2.99 2.37 1.84 1.43 3.45 34.1
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 9.42 4.03 3.89 3.51 3.16 2.84 2.25 1.75 1.38 3.26 35.2
GPS Position: Latitude = Longitude =
Note:
12 1 1100.000 1 9.31 4.46 4.39 4.04 3.74 3.39 2.76 2.20 1.75 3.79 35.9
GPS Position: Latitude = Longitude =
Note:
13 1 1200.000 1 9.27 4.96 4.90 4.58 4.17 3.76 3.05 2.37 1.87 4.06 35.9
GPS Position: Latitude = Longitude =
Note:
14 1 1303.000 1 9.40 4.88 4.48 4.12 3.75 3.41 2.81 2.24 1.78 4.07 36.3
GPS Position: Latitude = Longitude =
Note:
15 1 1400.000 1 9.27 4.65 4.17 3.86 3.54 3.20 2.61 2.02 1.61 3.89 33.3
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 9.34 3.74 3.54 3.31 3.05 2.80 2.33 1.88 1.55 3.25 33.3
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-15-2004 6:46:17
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Cerro Gordo S. Shore
Temp: 14
Operator: COLTON / DENEKAS
Comments: RTE B35 EASTBOUND

```
1 1   0.000 1  9.68  4.24  4.09  3.82  3.50  3.19  2.62  2.08  1.68  3.85  23.8
GPS Position: Latitude =    Longitude =
Note:
2 1 103.000 1 10.02  2.56  2.46  2.28  2.11  1.94  1.66  1.37  1.18  2.25  24.2
GPS Position: Latitude =    Longitude =
Note:
3 1 199.000 1  9.80  2.49  2.32  2.13  1.96  1.82  1.56  1.30  1.10  2.08  24.2
GPS Position: Latitude =    Longitude =
Note:
4 1 300.000 1  9.60  4.11  4.06  3.81  3.51  3.24  2.71  2.18  1.71  3.55  24.2
GPS Position: Latitude =    Longitude =
Note:
5 1 401.000 1  9.78  3.71  3.65  3.41  3.11  2.86  2.36  1.92  1.59  3.29  24.9
GPS Position: Latitude =    Longitude =
Note:
6 1 502.000 1  9.76  4.08  3.96  3.70  3.40  3.13  2.63  2.17  1.81  3.61  24.9
GPS Position: Latitude =    Longitude =
Note:
7 1 600.000 1  9.53  5.41  5.27  4.81  4.29  3.83  3.02  2.38  1.94  4.39  25.3
GPS Position: Latitude =    Longitude =
Note:
8 1 706.000 1  9.58  4.42  4.26  3.96  3.60  3.29  2.72  2.20  1.78  3.88  24.2
GPS Position: Latitude =    Longitude =
Note:
9 1 796.000 1  9.61  4.92  4.80  4.45  4.06  3.67  2.94  2.28  1.77  4.23  24.9
GPS Position: Latitude =    Longitude =
Note:
10 1 900.000 1  9.31  5.20  5.17  4.79  4.35  3.93  3.15  2.44  1.91  4.37  24.5
GPS Position: Latitude =    Longitude =
Note:
11 1 1000.000 1  9.58  8.52  6.72  6.05  5.24  4.53  3.39  2.50  1.79  6.77  25.3
GPS Position: Latitude =    Longitude =
Note:
12 1 1102.000 1  9.67  5.09  4.90  4.53  4.10  3.68  2.92  2.23  1.70  4.33  24.5
GPS Position: Latitude =    Longitude =
Note:
13 1 1199.000 1  9.67  6.23  6.04  5.59  5.05  4.51  3.54  2.67  2.01  5.30  25.6
GPS Position: Latitude =    Longitude =
Note:
14 1 1305.000 1  9.60  5.97  5.74  5.30  4.77  4.28  3.35  2.55  1.94  5.06  25.3
GPS Position: Latitude =    Longitude =
Note:
15 1 1425.000 1  9.06  5.35  5.23  4.83  4.41  3.97  3.16  2.45  1.84  4.57  23.4
GPS Position: Latitude =    Longitude =
Note:
16 1 1501.000 1  8.99  6.00  5.61  5.20  4.75  4.29  3.44  2.64  2.08  5.28  25.3
GPS Position: Latitude =    Longitude =
Note:
```

M3
Date-Time: 12-14-2004 9:17:41
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04
096017F04 096018F04 096019F04
Weight/spring: 3
Location: Clinton E50
Temp: 11
Operator: bad
Comments:
1 1   0.000 1 9.50 11.93 10.91 9.89 8.68 7.53 5.68 4.24 3.28 9.66 23.8
GPS Position: Latitude =   Longitude =
Note:
2 1 121.000 1 9.30 12.11 11.38 10.34 9.00 7.81 5.79 4.19 3.02 9.64 24.2
GPS Position: Latitude =   Longitude =
Note:
3 1 201.000 1 9.36 9.03 8.65 7.92 6.99 6.12 4.66 3.44 2.60 7.35 23.4
GPS Position: Latitude =   Longitude =
Note:
4 1 301.000 1 8.60 8.62 8.34 7.63 6.75 5.92 4.47 3.28 2.44 7.26 24.5
GPS Position: Latitude =   Longitude =
Note:
5 1 405.000 1 9.02 11.03 10.40 9.42 8.25 7.17 5.35 3.88 2.82 9.11 24.5
GPS Position: Latitude =   Longitude =
Note:
6 1 500.000 1 8.95 11.64 10.92 9.95 8.67 7.48 5.57 4.09 3.11 9.56 24.5
GPS Position: Latitude =   Longitude =
Note:
7 1 600.000 1 9.15 9.64 9.57 8.87 7.98 7.12 5.56 4.14 2.57 7.99 25.3
GPS Position: Latitude =   Longitude =
Note:
8 1 706.000 1 9.16 9.92 9.71 8.97 8.07 7.18 5.60 4.10 2.89 8.30 26.0
GPS Position: Latitude =   Longitude =
Note:
9 1 802.000 1 9.34 9.20 8.83 8.08 7.17 6.26 4.72 3.44 2.55 7.69 26.0
GPS Position: Latitude =   Longitude =
Note:
10 1 902.000 1 9.24 11.03 10.36 9.43 8.27 7.22 5.51 4.09 3.04 9.16 26.0
GPS Position: Latitude =   Longitude =
Note:
11 1 1000.000 1 9.29 10.49 10.00 9.17 8.14 7.13 5.48 4.06 3.07 8.84 26.0
GPS Position: Latitude =   Longitude =
Note:
12 1 1104.000 1 9.01 8.98 8.62 7.91 7.03 6.18 4.71 3.49 2.68 7.52 26.0
GPS Position: Latitude =   Longitude =
Note:
13 1 1201.000 1 8.89 7.52 7.33 6.74 6.04 5.36 4.12 3.06 2.63 6.81 26.0
GPS Position: Latitude =   Longitude =
Note:
14 1 1302.000 1 9.11 12.24 9.71 8.38 6.84 5.78 4.28 3.11 2.39 9.49 26.0
GPS Position: Latitude =   Longitude =
Note:
15 1 1402.000 1 9.11 7.42 7.20 6.76 6.21 5.62 4.56 3.52 3.06 6.61 26.0
GPS Position: Latitude =   Longitude =
Note:
16 1 1501.000 1 8.89 7.99 7.66 7.06 6.32 5.59 4.31 3.19 2.37 6.81 25.6
GPS Position: Latitude =   Longitude =
Note:

M3
Date-Time: 12-14-2004 8:33: 9
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Clinton Z30
Temp: 8
Operator: bad
Comments:
1 1 0.000 1 10.03 6.55 5.89 5.33 4.65 4.08 3.12 2.30 1.74 5.27 44.7
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 9.88 6.99 6.64 6.09 5.41 4.75 3.54 2.55 1.82 5.91 38.5
GPS Position: Latitude = Longitude =
Note:
3 1 206.000 1 9.83 6.26 6.01 5.53 4.96 4.38 3.32 2.43 1.77 5.28 41.7
GPS Position: Latitude = Longitude =
Note:
4 1 301.000 1 9.46 6.07 5.76 5.23 4.57 3.98 2.95 2.11 1.56 4.98 42.8
GPS Position: Latitude = Longitude =
Note:
5 1 409.000 1 9.58 5.74 5.61 5.13 4.59 4.00 3.03 2.22 1.65 4.75 39.6
GPS Position: Latitude = Longitude =
Note:
6 1 500.000 1 9.38 8.54 8.36 7.79 7.00 6.24 4.85 3.62 2.63 7.27 38.5
GPS Position: Latitude = Longitude =
Note:
7 1 609.000 1 9.40 6.45 6.22 5.72 5.09 4.50 3.42 2.52 1.89 5.35 40.6
GPS Position: Latitude = Longitude =
Note:
8 1 701.000 1 9.55 6.71 6.58 6.10 5.55 5.01 4.01 3.08 2.37 5.71 39.6
GPS Position: Latitude = Longitude =
Note:
9 1 801.000 1 9.09 6.63 6.54 6.09 5.53 4.97 3.95 3.01 2.28 5.73 39.2
GPS Position: Latitude = Longitude =
Note:
10 1 900.000 1 9.25 6.39 6.17 5.66 5.04 4.44 3.38 2.51 1.96 5.38 42.1
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 9.53 5.71 5.33 4.83 4.26 3.75 2.87 2.18 1.68 5.02 41.7
GPS Position: Latitude = Longitude =
Note:
12 1 1101.000 1 9.71 4.83 4.73 4.45 4.14 3.84 3.13 2.37 1.86 4.15 33.0
GPS Position: Latitude = Longitude =
Note:
13 1 1202.000 1 9.50 4.71 4.57 4.24 3.86 3.48 2.80 2.16 1.68 3.98 33.0
GPS Position: Latitude = Longitude =
Note:
14 1 1397.000 1 9.46 10.29 9.97 8.94 7.68 6.50 4.57 3.11 2.16 8.34 33.0
GPS Position: Latitude = Longitude =
Note:
15 1 1401.000 1 9.50 6.32 6.08 5.62 5.08 4.56 3.55 2.66 1.96 5.41 33.3
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 9.70 5.79 5.41 5.02 4.57 4.13 3.30 2.52 1.91 5.08 33.3
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-14-2004 11:55:55
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Delaware US20
Temp: 17
Operator: bad
Comments:
1 1 48.000 1 9.78 1.76 1.57 1.45 1.35 1.26 1.08 0.00 0.63 1.41 30.0
GPS Position: Latitude = Longitude =
Note:
2 1 111.000 1 9.92 1.68 1.46 1.34 1.21 1.10 0.90 0.69 0.00 1.33 30.0
GPS Position: Latitude = Longitude =
Note:
3 1 201.000 1 9.75 2.12 1.99 1.82 1.66 1.49 1.23 0.97 0.77 1.76 29.3
GPS Position: Latitude = Longitude =
Note:
4 1 301.000 1 9.70 2.03 1.83 1.68 1.56 1.43 1.21 0.96 0.00 1.67 30.4
GPS Position: Latitude = Longitude =
Note:
5 1 401.000 1 9.60 2.23 2.04 1.88 1.73 1.56 1.24 0.98 0.48 1.78 30.0
GPS Position: Latitude = Longitude =
Note:
6 1 500.000 1 9.71 1.95 1.80 1.65 1.50 1.36 1.12 0.88 0.37 1.58 30.0
GPS Position: Latitude = Longitude =
Note:
7 1 689.000 1 9.58 2.48 2.29 2.07 1.88 1.70 1.40 1.10 0.88 2.04 30.8
GPS Position: Latitude = Longitude =
Note:
8 1 701.000 1 9.57 3.09 2.84 2.59 2.34 2.09 1.67 1.27 0.97 2.65 30.4
GPS Position: Latitude = Longitude =
Note:
9 1 813.000 1 9.42 2.78 2.63 2.45 2.28 2.13 1.82 1.50 1.27 2.41 30.4
GPS Position: Latitude = Longitude =
Note:
10 1 901.000 1 9.61 2.85 2.71 2.50 2.30 2.11 1.76 1.42 1.18 2.42 30.4
GPS Position: Latitude = Longitude =
Note:
11 1 1012.000 1 9.57 2.62 2.40 2.20 2.00 1.82 1.52 1.23 1.06 2.15 31.1
GPS Position: Latitude = Longitude =
Note:
12 1 1101.000 1 9.52 2.32 2.20 2.03 1.88 1.74 1.48 1.21 1.02 1.96 30.8
GPS Position: Latitude = Longitude =
Note:
13 1 1256.000 1 9.56 3.07 2.89 2.66 2.43 2.21 1.82 1.42 1.10 2.53 32.2
GPS Position: Latitude = Longitude =
Note:
14 1 1343.000 1 9.51 3.79 3.56 3.24 2.90 2.58 2.03 1.54 1.18 3.17 31.5
GPS Position: Latitude = Longitude =
Note:
15 1 1421.000 1 9.38 2.00 1.84 1.67 1.53 1.43 1.23 1.07 0.72 1.58 32.6
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 9.43 2.71 2.50 2.32 2.14 1.95 1.60 1.27 1.11 2.22 32.2
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 3-31-2005 9:52:33
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Greene IA144
Temp: 45
Operator: Colton/Stephens
Comments:
1 1 0.000 1 8.41 19.58 17.20 14.38 11.91 9.68 6.28 3.98 2.76 14.00 57.9
GPS Position: Latitude = 41°53.899240 North Longitude = 94°9.886849 West
Note:
2 1 101.000 1 8.56 14.78 12.99 11.34 9.53 7.87 5.34 3.60 2.64 10.83 58.6
GPS Position: Latitude = 41°53.912917 North Longitude = 94°9.900007 West
Note:
3 1 201.000 1 8.50 12.21 11.01 9.94 8.62 7.43 5.37 3.73 2.79 9.22 59.0
GPS Position: Latitude = 41°53.926647 North Longitude = 94°9.912918 West
Note:
4 1 300.000 1 8.50 13.18 11.96 10.61 9.02 7.65 5.44 3.71 2.68 10.21 58.6
GPS Position: Latitude = 41°53.940205 North Longitude = 94°9.925837 West
Note:
5 1 400.000 1 8.55 15.19 13.50 11.96 10.08 8.44 5.91 4.11 3.15 11.17 57.9
GPS Position: Latitude = 41°53.954002 North Longitude = 94°9.938764 West
Note:
6 1 502.000 1 8.48 13.86 12.41 11.00 9.35 7.94 5.35 3.81 2.99 10.19 58.2
GPS Position: Latitude = 41°53.967669 North Longitude = 94°9.951789 West
Note:
7 1 600.000 1 8.56 18.22 14.64 11.34 9.18 7.44 5.03 3.44 2.62 12.21 58.6
GPS Position: Latitude = 41°53.980653 North Longitude = 94°9.964273 West
Note:
8 1 701.000 1 8.38 14.97 13.24 11.78 9.96 8.16 5.04 3.38 2.59 11.12 59.7
GPS Position: Latitude = 41°53.994070 North Longitude = 94°9.977096 West
Note:
9 1 802.000 1 8.40 14.68 12.89 10.94 8.75 6.93 4.39 2.92 2.23 10.54 59.7
GPS Position: Latitude = 41°54.007426 North Longitude = 94°9.989810 West
Note:
10 1 902.000 1 8.67 15.60 13.02 11.24 9.14 7.42 5.09 3.56 2.76 11.16 60.1
GPS Position: Latitude = 41°54.020772 North Longitude = 94°10.002568 West
Note:
11 1 1002.000 1 8.43 12.98 11.64 10.48 9.05 7.65 5.31 3.59 2.68 10.00 59.7
GPS Position: Latitude = 41°54.034297 North Longitude = 94°10.015406 West
Note:
12 1 1101.000 1 8.38 18.22 16.05 13.84 11.15 8.81 5.53 3.58 2.79 12.46 59.7
GPS Position: Latitude = 41°54.047381 North Longitude = 94°10.028029 West
Note:
13 1 1202.000 1 8.33 16.49 14.72 12.59 10.27 8.26 5.35 3.59 2.78 11.50 59.3
GPS Position: Latitude = 41°54.062034 North Longitude = 94°10.041914 West
Note:
14 1 1306.000 1 8.48 14.39 12.70 11.13 9.37 7.84 5.36 3.60 2.60 10.41 59.7
GPS Position: Latitude = 41°54.076512 North Longitude = 94°10.055745 West
Note:
15 1 1409.000 1 8.31 16.61 14.95 13.08 10.70 8.65 5.65 3.65 2.58 11.87 59.7
GPS Position: Latitude = 41°54.090087 North Longitude = 94°10.068853 West
Note:
16 1 1493.000 1 8.39 17.01 14.33 12.31 10.15 8.37 5.74 3.89 2.81 11.92 59.7
GPS Position: Latitude = 41°54.099005 North Longitude = 94°10.077235 West
Note:

M3
Date-Time: 3-31-2005 9: 4:46
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Guthrie IA4
Temp: 40
Operator: Colton/Stephens
Comments:
1 1 0.000 1 8.75 8.55 7.30 6.09 4.83 3.89 2.67 1.86 1.57 5.79 53.8
GPS Position: Latitude = 41°46.633703 North Longitude = 94°22.049217 West
Note:
2 1 116.000 1 8.75 9.50 8.32 7.25 5.99 4.97 3.47 2.40 1.93 6.97 54.6
GPS Position: Latitude = 41°46.652822 North Longitude = 94°22.048793 West
Note:
3 1 200.000 1 8.72 11.01 10.25 8.86 7.18 5.45 3.17 2.18 1.92 7.25 54.6
GPS Position: Latitude = 41°46.666376 North Longitude = 94°22.048572 West
Note:
4 1 308.000 1 8.76 8.66 7.97 6.99 5.82 4.79 3.25 2.20 1.87 6.49 54.9
GPS Position: Latitude = 41°46.686248 North Longitude = 94°22.048163 West
Note:
5 1 401.000 1 8.71 9.40 8.57 7.35 5.98 4.85 3.27 2.25 1.89 6.84 54.6
GPS Position: Latitude = 41°46.700869 North Longitude = 94°22.047011 West
Note:
6 1 500.000 1 8.70 11.05 10.12 8.68 7.03 5.66 3.72 2.43 1.97 7.91 53.8
GPS Position: Latitude = 41°46.718068 North Longitude = 94°22.046983 West
Note:
7 1 603.000 1 8.61 10.41 9.50 8.17 6.62 5.35 3.54 2.39 1.60 7.54 53.8
GPS Position: Latitude = 41°46.734327 North Longitude = 94°22.046821 West
Note:
8 1 701.000 1 8.69 12.97 12.05 10.38 8.29 6.57 4.21 2.83 2.34 9.19 53.8
GPS Position: Latitude = 41°46.750536 North Longitude = 94°22.046494 West
Note:
9 1 801.000 1 8.62 10.48 9.46 8.18 6.72 5.56 3.97 2.92 2.53 7.77 53.8
GPS Position: Latitude = 41°46.766797 North Longitude = 94°22.045948 West
Note:
10 1 902.000 1 8.97 7.73 7.15 6.33 5.26 4.33 3.08 2.25 1.98 5.86 54.2
GPS Position: Latitude = 41°46.782143 North Longitude = 94°22.045162 West
Note:
11 1 1003.000 1 8.89 10.78 9.51 8.13 6.47 5.18 3.47 2.40 2.01 7.83 53.5
GPS Position: Latitude = 41°46.801401 North Longitude = 94°22.044783 West
Note:
12 1 1102.000 1 8.96 8.19 7.45 6.48 5.33 4.35 2.95 2.03 1.78 6.07 53.5
GPS Position: Latitude = 41°46.816692 North Longitude = 94°22.044366 West
Note:
13 1 1205.000 1 8.86 9.33 8.73 7.65 6.33 5.19 3.58 2.47 2.07 6.96 54.9
GPS Position: Latitude = 41°46.833718 North Longitude = 94°22.044071 West
Note:
14 1 1304.000 1 8.84 9.17 8.54 7.62 6.50 5.50 3.97 2.83 2.34 7.14 54.6
GPS Position: Latitude = 41°46.850051 North Longitude = 94°22.043721 West
Note:
15 1 1400.000 1 8.77 10.82 10.01 8.79 7.31 5.97 4.00 2.67 2.10 8.10 54.6
GPS Position: Latitude = 41°46.864991 North Longitude = 94°22.043355 West
Note:
16 1 1501.000 1 8.85 11.90 10.64 9.11 7.39 5.98 4.02 2.70 1.67 8.49 54.6
GPS Position: Latitude = 41°46.878652 North Longitude = 94°22.043062 West
Note:

```
M3
Date-Time:  3-30-2005 12:18:19
Sensors: 096011F04  096012F04  096013F04  096014F04  096015F04  096016F04
096017F04  096018F04  096019F04
Weight/spring: 3
```

Location: Hardin D35

```
Temp: 70
Operator: Colton/Denekas
Comments:
1 1   0.000 1  9.06 12.21  9.86  8.40  6.85  5.62  3.92  2.78  2.15  8.55  79.1
GPS Position: Latitude =    Longitude =
Note:
2 1  99.000 1  8.82 17.58 15.49 13.25 10.71  8.56  5.54  3.63  2.97 13.04  79.5
GPS Position: Latitude =    Longitude =
Note:
3 1 214.000 1  8.64 18.98 15.95 13.47 10.51  8.09  4.81  2.90  2.71 13.45  79.8
GPS Position: Latitude =    Longitude =
Note:
4 1 299.000 1  8.38 25.44 21.09 17.61 13.51 10.24  5.86  3.43  2.66 16.11  80.9
GPS Position: Latitude =    Longitude =
Note:
5 1 402.000 1  8.65 20.54 17.58 15.16 12.32  9.83  6.24  4.02  2.92 16.22  79.1
GPS Position: Latitude =    Longitude =
Note:
6 1 500.000 1  8.46 31.78 23.98 19.77 15.06 11.40  6.72  4.21  3.48 21.63  79.1
GPS Position: Latitude =    Longitude =
Note:
7 1 602.000 1  7.91 39.80 34.04 27.76 19.83 14.34  6.84  4.33  3.92 27.86  79.8
GPS Position: Latitude =    Longitude =
Note:
8 1 700.000 1  8.28 24.57 20.80 17.57 13.78 10.82  6.79  4.42  3.76 18.77  79.8
GPS Position: Latitude =    Longitude =
Note:
9 1 801.000 1  8.26 22.93 20.47 17.65 14.33 11.53  7.56  4.91  3.70 17.77  79.1
GPS Position: Latitude =    Longitude =
Note:
10 1 902.000 1  8.03 41.49 37.60 29.79 21.26 14.32  6.80  4.28  3.70 31.80  79.5
GPS Position: Latitude =    Longitude =
Note:
11 1 1001.000 1  9.17 48.58 43.74 35.41 25.92 16.98  8.01  4.74  3.93 32.91  78.0
GPS Position: Latitude =    Longitude =
Note:
12 1 1100.000 1  9.20 30.12 26.57 22.80 17.89 13.87  8.39  5.07  3.46 24.05  77.6
GPS Position: Latitude =    Longitude =
Note:
13 1 1199.000 1  9.55 10.39  9.87  9.03  8.08  7.20  5.68  4.22  3.35  8.39  77.6
GPS Position: Latitude =    Longitude =
Note:
14 1 1300.000 1  9.40 23.40 21.41 18.69 15.33 12.43  8.18  5.28  3.72 17.49  78.4
GPS Position: Latitude =    Longitude =
Note:
15 1 1400.000 1  9.53 26.43 24.17 21.01 17.20 13.74  8.67  5.25  3.59 19.78  78.4
GPS Position: Latitude =    Longitude =
Note:
16 1 1498.000 1  9.24 27.35 23.71 19.22 14.36 10.53  5.64  3.15  2.80 16.93  80.2
GPS Position: Latitude =    Longitude =
Note:
```

M3
Date-Time: 12-15-2004 13:30:48
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Harrison IA44
Temp: 37
Operator: COLTON / DENEKAS
Comments: IA 44 WESTBOUND
1 1 0.000 1 8.91 5.76 4.91 4.66 4.34 4.04 3.46 2.86 2.47 4.53 46.9
GPS Position: Latitude = Longitude =
Note:
2 1 113.000 1 9.02 4.90 4.69 4.44 4.12 3.83 3.26 2.69 2.23 4.29 46.5
GPS Position: Latitude = Longitude =
Note:
3 1 207.000 1 8.90 5.67 4.96 4.67 4.32 4.00 3.38 2.76 2.26 4.48 46.5
GPS Position: Latitude = Longitude =
Note:
4 1 309.000 1 9.06 4.83 4.97 4.70 4.37 4.06 3.49 2.89 2.40 4.54 46.9
GPS Position: Latitude = Longitude =
Note:
4 1 311.000 1 8.95 8.35 4.95 4.68 4.35 4.07 3.48 2.87 2.36 4.54 46.5
GPS Position: Latitude = Longitude =
Note:
5 1 399.000 1 8.85 7.86 5.28 4.97 4.61 4.26 3.65 3.01 2.45 4.79 46.9
GPS Position: Latitude = Longitude =
Note:
6 1 497.000 1 8.75 6.09 5.84 5.49 5.06 4.65 3.91 3.17 2.54 5.41 46.9
GPS Position: Latitude = Longitude =
Note:
7 1 604.000 1 8.89 5.26 5.23 4.93 4.58 4.23 3.59 2.92 2.40 4.91 47.2
GPS Position: Latitude = Longitude =
Note:
8 1 734.000 1 8.80 6.91 6.55 6.11 5.57 5.06 4.16 3.28 2.61 6.10 47.6
GPS Position: Latitude = Longitude =
Note:
9 1 825.000 1 8.89 4.68 4.69 4.39 4.03 3.73 3.21 2.67 2.21 4.24 49.1
GPS Position: Latitude = Longitude =
Note:
9 1 825.000 1 8.87 4.86 4.68 4.37 4.02 3.72 3.20 2.64 2.21 4.23 48.3
GPS Position: Latitude = Longitude =
Note:
10 1 898.000 1 8.91 3.96 4.13 3.93 3.73 3.55 3.18 2.72 2.32 3.97 49.8
GPS Position: Latitude = Longitude =
Note:
10 1 944.000 1 8.74 4.16 4.14 3.94 3.75 3.56 3.20 2.74 2.37 4.00 46.5
GPS Position: Latitude = Longitude =
Note:
11 1 1004.000 1 8.86 4.22 3.95 3.76 3.58 3.43 3.09 2.66 2.34 3.75 48.3
GPS Position: Latitude = Longitude =
Note:
12 1 1158.000 1 8.46 4.01 4.01 3.78 3.54 3.30 2.86 2.42 2.02 3.73 49.8
GPS Position: Latitude = Longitude =
Note:
13 1 1224.000 1 9.76 5.33 5.04 4.75 4.42 4.09 3.49 2.86 2.37 4.84 46.5
GPS Position: Latitude = Longitude =
Note:
14 1 1300.000 1 9.77 5.92 5.85 5.52 5.13 4.75 4.03 3.28 2.70 5.64 48.7
GPS Position: Latitude = Longitude =
Note:
15 1 1401.000 1 9.56 5.88 5.63 5.35 5.05 4.71 4.08 3.38 2.85 5.46 48.7

```
GPS Position: Latitude =     Longitude =
Note:
16 1 1502.000 1  9.63  4.18  3.93  3.76  3.59  3.43  3.08  2.66  2.32  3.86  47.6
GPS Position: Latitude =     Longitude =
Note:
```

M3
Date-Time: 12-14-2004 10:33:59
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Jackson US61
Temp: 14
Operator: bad
Comments:
1 1 0.000 1 9.36 3.61 3.29 3.05 2.80 2.57 2.13 1.71 1.35 3.54 30.4
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 9.46 3.41 3.37 3.09 2.81 2.56 2.14 1.74 1.40 2.85 30.0
GPS Position: Latitude = Longitude =
Note:
3 1 260.000 1 9.52 2.93 2.77 2.55 2.32 2.13 1.80 1.48 1.23 2.39 30.8
GPS Position: Latitude = Longitude =
Note:
4 1 300.000 1 9.47 3.83 3.72 3.44 3.14 2.87 2.35 1.82 1.40 3.20 30.4
GPS Position: Latitude = Longitude =
Note:
5 1 403.000 1 9.40 3.49 3.34 3.09 2.84 2.63 2.22 1.80 1.39 2.92 31.1
GPS Position: Latitude = Longitude =
Note:
6 1 500.000 1 9.43 3.51 3.40 3.16 2.91 2.70 2.30 1.90 1.51 3.06 30.8
GPS Position: Latitude = Longitude =
Note:
7 1 604.000 1 9.34 5.42 5.22 4.82 4.40 3.97 3.21 2.46 1.84 4.64 30.0
GPS Position: Latitude = Longitude =
Note:
8 1 701.000 1 9.25 2.81 2.67 2.45 2.26 2.10 1.85 1.65 1.46 2.32 31.1
GPS Position: Latitude = Longitude =
Note:
9 1 803.000 1 9.35 2.79 2.64 2.44 2.28 2.13 1.88 1.62 1.51 2.36 30.4
GPS Position: Latitude = Longitude =
Note:
10 1 901.000 1 9.37 2.80 2.66 2.46 2.30 2.16 1.92 1.66 1.57 2.37 31.1
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 9.19 3.02 2.90 2.70 2.53 2.38 2.11 1.86 0.00 2.57 31.1
GPS Position: Latitude = Longitude =
Note:
12 1 1109.000 1 9.17 2.94 2.82 2.62 2.46 2.33 2.07 1.79 1.64 2.50 31.1
GPS Position: Latitude = Longitude =
Note:
13 1 1202.000 1 9.12 2.98 2.85 2.62 2.42 2.27 1.97 1.65 1.52 2.53 31.1
GPS Position: Latitude = Longitude =
Note:
14 1 1401.000 1 9.19 2.76 2.61 2.43 2.30 2.16 1.95 1.74 1.62 2.40 31.1
GPS Position: Latitude = Longitude =
Note:
15 1 1401.000 1 9.14 2.61 2.50 2.34 2.20 2.08 1.86 1.62 1.47 2.25 31.1
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 9.41 2.62 2.41 2.25 2.10 1.97 1.75 1.50 0.00 2.25 31.1
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-15-2004 15:18: 5
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Montgomery IA48
Temp: 40
Operator: COLTON / DENEKAS
Comments: IA 48 SOUTHBOUND
1 1 0.000 1 10.15 5.10 4.71 4.39 4.04 3.72 3.13 2.50 2.00 4.33 49.4
GPS Position: Latitude = Longitude =
Note:
2 1 102.000 1 10.01 5.47 5.05 4.70 4.29 3.88 3.17 2.46 1.87 4.64 49.4
GPS Position: Latitude = Longitude =
Note:
3 1 301.000 1 9.76 6.14 5.61 5.20 4.77 4.36 3.56 2.75 2.08 5.11 49.4
GPS Position: Latitude = Longitude =
Note:
4 1 301.000 1 9.92 7.48 7.30 6.68 5.85 5.14 3.92 2.90 2.10 6.06 49.8
GPS Position: Latitude = Longitude =
Note:
5 1 404.000 1 9.78 6.48 6.03 5.58 5.04 4.59 3.74 2.87 2.15 5.41 49.4
GPS Position: Latitude = Longitude =
Note:
6 1 503.000 1 9.86 6.01 5.55 5.14 4.68 4.24 3.48 2.71 2.11 5.09 49.8
GPS Position: Latitude = Longitude =
Note:
7 1 601.000 1 9.98 6.15 5.58 5.09 4.60 4.13 3.33 2.58 1.97 5.16 49.4
GPS Position: Latitude = Longitude =
Note:
8 1 705.000 1 9.70 6.77 6.27 5.79 5.22 4.69 3.61 2.65 2.25 5.51 49.1
GPS Position: Latitude = Longitude =
Note:
9 1 802.000 1 9.93 6.12 5.55 5.08 4.58 4.12 3.34 2.61 2.03 5.00 48.7
GPS Position: Latitude = Longitude =
Note:
10 1 903.000 1 9.95 5.16 4.93 4.57 4.17 3.80 3.15 2.49 1.95 4.46 46.5
GPS Position: Latitude = Longitude =
Note:
11 1 1005.000 1 9.72 4.53 4.14 3.84 3.54 3.26 2.78 2.26 1.87 3.67 49.8
GPS Position: Latitude = Longitude =
Note:
12 1 1103.000 1 9.80 4.87 4.35 4.00 3.64 3.33 2.77 2.22 1.84 4.29 49.8
GPS Position: Latitude = Longitude =
Note:
13 1 1200.000 1 9.81 4.24 3.91 3.63 3.34 3.10 2.64 2.14 1.74 3.50 49.1
GPS Position: Latitude = Longitude =
Note:
14 1 1303.000 1 9.75 5.23 4.67 4.31 3.95 3.61 3.02 2.39 1.89 4.44 49.8
GPS Position: Latitude = Longitude =
Note:
15 1 1401.000 1 9.78 4.87 4.54 4.23 3.87 3.57 3.01 2.41 1.91 4.14 49.8
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 10.06 6.40 5.92 5.55 5.16 4.70 3.59 2.55 1.91 5.34 49.4
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 16: 9:21
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Muscatine F70
Temp: 17
Operator: bad
Comments:
1 1 0.000 1 9.07 8.58 7.22 6.28 5.31 4.47 3.22 2.31 1.69 6.30 27.5
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 8.86 12.33 10.93 9.19 7.24 5.60 3.43 2.03 1.57 8.47 28.2
GPS Position: Latitude = Longitude =
Note:
3 1 205.000 1 8.71 10.88 9.89 8.36 6.52 5.11 3.20 2.17 1.71 7.74 27.8
GPS Position: Latitude = Longitude =
Note:
4 1 299.000 1 8.84 12.46 11.27 9.53 7.44 5.73 3.43 2.16 1.63 8.60 27.1
GPS Position: Latitude = Longitude =
Note:
5 1 399.000 1 8.79 16.35 13.32 10.34 7.12 4.83 2.28 1.53 1.31 9.05 28.2
GPS Position: Latitude = Longitude =
Note:
6 1 498.000 1 9.01 9.81 8.60 7.07 5.53 4.34 2.76 1.82 1.53 6.28 28.2
GPS Position: Latitude = Longitude =
Note:
7 1 624.000 1 8.96 6.79 6.22 5.40 4.54 3.82 2.77 2.01 1.56 4.93 28.9
GPS Position: Latitude = Longitude =
Note:
8 1 707.000 1 8.89 7.57 7.01 6.17 5.15 4.31 3.05 2.20 1.75 5.71 28.2
GPS Position: Latitude = Longitude =
Note:
9 1 815.000 1 8.90 6.32 5.72 5.02 4.25 3.64 2.70 2.01 1.61 4.70 29.3
GPS Position: Latitude = Longitude =
Note:
10 1 902.000 1 8.81 8.20 7.73 6.71 5.47 4.48 3.07 2.14 1.68 5.94 28.2
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 8.92 7.00 6.33 5.54 4.62 3.86 2.76 1.97 1.51 5.21 27.8
GPS Position: Latitude = Longitude =
Note:
12 1 1158.000 1 8.84 7.51 6.76 5.78 4.73 3.90 2.69 1.88 1.56 5.29 27.5
GPS Position: Latitude = Longitude =
Note:
13 1 1201.000 1 8.84 6.65 6.13 5.35 4.44 3.69 2.63 1.89 1.48 4.75 28.2
GPS Position: Latitude = Longitude =
Note:
14 1 1301.000 1 8.84 6.20 5.90 5.06 4.16 3.46 2.48 1.82 1.54 4.32 28.2
GPS Position: Latitude = Longitude =
Note:
15 1 1400.000 1 8.76 8.21 7.48 6.49 5.42 4.51 3.16 2.25 1.77 5.89 28.6
GPS Position: Latitude = Longitude =
Note:
16 1 1499.000 1 8.87 7.47 6.36 5.55 4.68 3.95 2.88 2.11 1.63 5.72 28.2
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 16:36:31
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04
096017F04 096018F04 096019F04
Weight/spring: 3
Location: Muscatine G28
Temp: 17
Operator: bad
Comments:
1 1 2.000 1 8.89 12.19 10.83 9.40 7.66 6.02 3.71 2.29 1.65 9.60 26.0
GPS Position: Latitude = Longitude =
Note:
2 1 132.000 1 9.02 9.93 9.58 8.41 7.05 5.83 3.92 2.52 1.72 7.99 26.4
GPS Position: Latitude = Longitude =
Note:
3 1 207.000 1 8.87 11.82 10.20 8.87 7.26 5.87 3.76 2.35 1.57 8.14 26.0
GPS Position: Latitude = Longitude =
Note:
4 1 312.000 1 8.90 11.17 10.21 8.87 7.27 5.82 3.65 2.23 1.49 8.23 26.4
GPS Position: Latitude = Longitude =
Note:
5 1 404.000 1 9.00 11.80 10.43 9.01 7.36 5.94 3.75 2.28 1.58 8.61 26.0
GPS Position: Latitude = Longitude =
Note:
6 1 503.000 1 8.89 8.70 8.15 7.34 6.37 5.51 4.03 2.79 1.97 7.06 26.4
GPS Position: Latitude = Longitude =
Note:
7 1 708.000 1 8.91 8.20 7.74 6.84 5.94 5.18 3.81 2.67 1.85 6.23 27.1
GPS Position: Latitude = Longitude =
Note:
8 1 710.000 1 9.05 6.69 6.24 5.74 5.19 4.66 3.65 2.71 1.95 5.55 26.7
GPS Position: Latitude = Longitude =
Note:
9 1 838.000 1 9.06 7.47 6.89 6.15 5.36 4.65 3.48 2.56 1.98 5.88 26.0
GPS Position: Latitude = Longitude =
Note:
10 1 893.000 1 8.84 8.25 7.83 6.90 6.00 5.17 3.74 2.57 1.79 6.29 26.0
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 8.91 12.82 11.54 10.00 8.17 6.62 4.32 2.74 1.84 9.31 26.4
GPS Position: Latitude = Longitude =
Note:
12 1 1113.000 1 8.61 16.19 14.38 12.15 9.26 6.56 3.18 1.91 1.35 10.89 27.1
GPS Position: Latitude = Longitude =
Note:
13 1 1202.000 1 8.94 8.06 7.58 6.70 5.73 4.84 3.44 2.42 1.76 6.21 27.5
GPS Position: Latitude = Longitude =
Note:
14 1 1303.000 1 8.67 9.89 8.82 7.61 6.36 5.33 3.78 2.63 1.94 6.93 27.1
GPS Position: Latitude = Longitude =
Note:
15 1 1402.000 1 8.74 12.51 11.31 9.69 7.94 6.43 4.21 2.76 1.95 9.02 26.4
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 8.95 9.31 7.82 6.78 5.55 4.51 3.05 2.10 1.53 7.10 25.6
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 16:47:12
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Muscatine G28E
Temp: 16
Operator: bad
Comments:
1 1 0.000 1 9.12 8.17 7.81 6.69 5.35 4.26 2.87 2.05 1.64 6.23 26.4
GPS Position: Latitude = Longitude =
Note:
2 1 99.000 1 8.92 8.59 8.05 7.13 5.91 4.83 3.25 2.20 1.74 6.50 27.8
GPS Position: Latitude = Longitude =
Note:
3 1 200.000 1 9.01 8.27 7.50 6.58 5.52 4.60 3.26 2.35 1.82 6.32 28.2
GPS Position: Latitude = Longitude =
Note:
4 1 301.000 1 8.92 9.15 8.47 7.44 6.24 5.18 3.63 2.58 1.99 6.86 27.8
GPS Position: Latitude = Longitude =
Note:
5 1 401.000 1 8.94 8.32 7.63 6.68 5.58 4.65 3.28 2.38 1.87 6.18 28.2
GPS Position: Latitude = Longitude =
Note:
6 1 535.000 1 8.90 8.82 8.04 6.97 5.76 4.74 3.26 2.30 1.88 6.55 28.2
GPS Position: Latitude = Longitude =
Note:
7 1 693.000 1 8.70 10.30 9.44 8.03 6.42 5.17 3.45 2.36 1.80 7.33 28.2
GPS Position: Latitude = Longitude =
Note:
8 1 702.000 1 8.80 8.38 7.72 6.68 5.50 4.49 3.06 2.10 1.63 6.09 28.2
GPS Position: Latitude = Longitude =
Note:
9 1 804.000 1 8.81 9.00 8.28 7.15 5.80 4.63 3.00 1.98 1.48 6.32 29.3
GPS Position: Latitude = Longitude =
Note:
10 1 908.000 1 8.97 7.55 6.77 5.88 4.84 3.97 2.70 1.89 1.45 5.60 28.6
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 8.85 7.68 7.12 6.22 5.19 4.33 3.20 2.49 0.00 5.44 28.2
GPS Position: Latitude = Longitude =
Note:
12 1 1101.000 1 8.90 7.45 7.11 6.21 5.17 4.26 2.99 2.13 1.68 5.57 28.6
GPS Position: Latitude = Longitude =
Note:
13 1 1202.000 1 8.77 8.59 7.71 6.65 5.43 4.42 3.02 2.10 1.61 6.31 28.6
GPS Position: Latitude = Longitude =
Note:
14 1 1307.000 1 8.64 9.83 8.94 7.68 6.24 5.07 3.51 2.52 2.01 7.10 29.7
GPS Position: Latitude = Longitude =
Note:
15 1 1402.000 1 8.75 9.21 8.30 7.11 5.77 4.69 3.21 2.27 1.78 6.75 28.9
GPS Position: Latitude = Longitude =
Note:
16 1 1511.000 1 8.95 9.84 8.44 7.24 5.74 4.58 3.08 2.19 1.71 7.36 29.3
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 15:34:29
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Muscatine Y14N
Temp: 18
Operator: bad
Comments:
1 1 0.000 1 9.22 9.08 8.33 7.56 6.61 5.67 4.13 2.93 2.10 7.43 31.9
GPS Position: Latitude = Longitude =
Note:
2 1 107.000 1 9.20 10.46 9.74 8.74 7.47 6.33 4.50 3.17 2.34 8.63 31.5
GPS Position: Latitude = Longitude =
Note:
3 1 203.000 1 9.10 9.29 8.76 7.98 6.97 5.96 4.33 3.11 2.33 7.71 31.5
GPS Position: Latitude = Longitude =
Note:
4 1 387.000 1 9.07 11.69 11.09 9.95 8.44 7.08 4.93 3.41 2.47 9.31 28.9
GPS Position: Latitude = Longitude =
Note:
5 1 402.000 1 8.85 13.38 12.62 11.20 9.39 7.77 5.30 3.65 2.71 10.27 30.4
GPS Position: Latitude = Longitude =
Note:
6 1 507.000 1 8.85 15.02 14.38 12.90 11.02 9.31 6.58 4.57 3.29 12.05 28.9
GPS Position: Latitude = Longitude =
Note:
7 1 603.000 1 8.82 13.45 12.94 11.58 9.72 8.02 5.40 3.54 2.45 10.29 29.3
GPS Position: Latitude = Longitude =
Note:
8 1 707.000 1 8.57 19.44 18.10 16.02 13.28 10.81 7.05 4.50 3.34 14.53 28.6
GPS Position: Latitude = Longitude =
Note:
9 1 802.000 1 8.55 17.87 16.70 14.72 12.21 9.95 6.49 4.16 3.00 13.56 28.2
GPS Position: Latitude = Longitude =
Note:
10 1 911.000 1 8.62 14.96 14.28 12.57 10.30 8.34 5.41 3.52 2.62 11.14 28.2
GPS Position: Latitude = Longitude =
Note:
11 1 1004.000 1 8.56 19.36 18.05 15.26 12.05 9.32 5.81 3.30 2.54 13.21 28.9
GPS Position: Latitude = Longitude =
Note:
12 1 1106.000 1 8.95 10.81 10.46 9.38 7.83 6.33 4.28 2.95 2.25 8.34 29.7
GPS Position: Latitude = Longitude =
Note:
13 1 1199.000 1 8.87 11.01 10.62 9.62 8.38 7.18 5.21 3.74 2.90 8.91 31.5
GPS Position: Latitude = Longitude =
Note:
14 1 1324.000 1 8.82 13.53 13.24 11.95 10.28 8.90 5.26 2.44 2.13 9.88 27.8
GPS Position: Latitude = Longitude =
Note:
15 1 1394.000 1 8.95 10.43 10.07 8.99 7.70 6.53 4.69 3.33 2.48 8.40 27.5
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 8.96 11.61 11.32 10.05 8.46 7.04 4.85 3.27 2.30 10.06 27.1
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 15:13:32
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Muscatine Y14S
Temp: 16
Operator: bad
Comments:
1 1 0.000 1 9.46 10.40 9.56 8.49 7.11 5.82 3.90 2.66 2.00 8.26 33.0
GPS Position: Latitude = Longitude =
Note:
2 1 94.000 1 8.48 17.90 16.28 14.02 11.02 8.54 5.03 3.02 2.23 12.81 33.3
GPS Position: Latitude = Longitude =
Note:
3 1 200.000 1 8.77 16.68 15.61 13.64 11.18 9.00 5.66 3.47 2.42 12.22 29.3
GPS Position: Latitude = Longitude =
Note:
4 1 305.000 1 8.46 16.58 14.97 12.92 10.38 8.14 4.93 2.96 2.13 12.13 33.3
GPS Position: Latitude = Longitude =
Note:
5 1 403.000 1 7.86 23.49 21.58 18.27 13.62 9.90 4.53 2.89 2.44 18.27 35.2
GPS Position: Latitude = Longitude =
Note:
6 1 506.000 1 9.38 9.58 9.29 8.66 7.83 6.93 5.19 3.64 2.61 8.45 36.3
GPS Position: Latitude = Longitude =
Note: patch
7 1 610.000 1 9.11 10.07 9.81 9.11 8.18 7.20 5.39 3.84 2.76 8.72 36.3
GPS Position: Latitude = Longitude =
Note: patch
8 1 722.000 1 8.90 14.78 14.17 12.47 10.42 8.54 5.64 3.65 2.59 11.72 34.8
GPS Position: Latitude = Longitude =
Note:
9 1 801.000 1 8.80 11.21 10.97 9.83 8.55 7.32 5.26 3.64 2.52 9.93 35.9
GPS Position: Latitude = Longitude =
Note:
10 1 905.000 1 8.69 16.41 15.39 13.67 11.46 9.47 6.34 3.81 2.60 12.47 35.9
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 8.44 22.38 20.52 17.78 14.29 11.21 6.79 3.93 2.83 16.98 36.3
GPS Position: Latitude = Longitude =
Note:
12 1 1102.000 1 8.66 15.40 13.94 12.13 10.09 8.30 5.43 2.84 2.25 11.28 37.4
GPS Position: Latitude = Longitude =
Note:
13 1 1198.000 1 9.00 17.95 16.43 14.68 12.42 10.37 7.05 4.62 3.26 14.01 36.3
GPS Position: Latitude = Longitude =
Note:
14 1 1298.000 1 8.05 15.29 14.82 13.47 11.37 9.76 7.05 4.55 2.48 12.48 37.4
GPS Position: Latitude = Longitude =
Note:
15 1 1413.000 1 8.54 8.66 8.32 7.63 6.78 5.93 4.47 3.29 2.70 7.28 35.2
GPS Position: Latitude = Longitude =
Note:
16 1 1498.000 1 9.01 14.10 13.71 12.61 11.30 10.05 3.96 3.09 2.36 11.00 35.9
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 3-30-2005 10:49:41
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04
096017F04 096018F04 096019F04
Weight/spring: 3
Location: Story S14NB
Temp: 71
Operator: Colton/Denekas
Comments:
1 1 0.000 1 8.77 5.95 5.20 4.72 4.24 3.83 3.08 2.50 2.09 4.67 82.0
GPS Position: Latitude = Longitude =
Note:
2 1 103.000 1 8.89 9.78 8.37 7.37 6.32 5.48 4.17 3.10 2.45 7.24 85.3
GPS Position: Latitude = Longitude =
Note:
3 1 200.000 1 8.86 10.09 8.88 7.86 6.78 5.89 4.48 3.33 2.62 7.69 86.1
GPS Position: Latitude = Longitude =
Note:
4 1 299.000 1 8.76 9.48 8.37 7.52 6.61 5.83 4.62 3.56 2.98 7.33 87.5
GPS Position: Latitude = Longitude =
Note:
5 1 402.000 1 8.72 11.17 9.81 8.63 7.37 6.36 4.87 3.70 3.06 8.40 88.3
GPS Position: Latitude = Longitude =
Note:
6 1 501.000 1 8.86 10.54 9.29 8.28 7.09 6.15 4.73 3.56 2.85 8.14 87.5
GPS Position: Latitude = Longitude =
Note:
7 1 599.000 1 8.86 11.51 9.95 8.78 7.51 6.44 4.75 3.46 2.59 8.70 88.3
GPS Position: Latitude = Longitude =
Note:
8 1 700.000 1 8.59 10.61 9.11 7.92 6.68 5.70 4.19 3.06 2.35 7.56 89.4
GPS Position: Latitude = Longitude =
Note:
9 1 805.000 1 8.72 13.37 11.77 10.29 8.54 7.09 4.96 3.39 2.46 9.86 88.6
GPS Position: Latitude = Longitude =
Note:
10 1 899.000 1 8.52 13.34 11.47 9.99 8.36 7.00 4.96 3.45 2.49 9.74 89.0
GPS Position: Latitude = Longitude =
Note:
11 1 1000.000 1 8.45 12.56 10.93 9.53 7.97 6.73 4.87 3.44 2.52 9.14 88.6
GPS Position: Latitude = Longitude =
Note:
12 1 1101.000 1 8.44 15.01 13.29 11.54 9.62 8.04 5.66 3.89 2.79 11.44 88.3
GPS Position: Latitude = Longitude =
Note:
13 1 1200.000 1 8.40 12.87 11.18 9.71 8.12 6.81 4.88 3.45 2.50 9.36 87.2
GPS Position: Latitude = Longitude =
Note:
14 1 1299.000 1 8.41 11.43 10.33 9.11 7.79 6.67 4.94 3.54 2.71 8.55 87.9
GPS Position: Latitude = Longitude =
Note:
15 1 1401.000 1 8.46 12.84 10.63 8.96 7.32 6.02 4.20 2.94 2.39 8.44 88.3
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 8.50 16.33 14.26 12.46 10.36 8.63 6.07 4.18 3.31 12.13 87.9
GPS Position: Latitude = Longitude =
Note:

```
M3
Date-Time:  3-30-2005 10:24:40
Sensors: 096011F04  096012F04  096013F04  096014F04  096015F04  096016F04
096017F04  096018F04  096019F04
Weight/spring: 3
```
Location: Story S14SB
```
Temp: 68
Operator: Colton/Denekas
Comments:
1 1   0.000 1  9.63 15.26 13.29 11.63  9.75  8.19  5.82  4.07  2.91 11.18  82.4
GPS Position: Latitude =    Longitude =
Note:
2 1 101.000 1  9.83 13.05 11.21  9.81  8.20  6.83  4.78  3.32  2.51  9.56  83.1
GPS Position: Latitude =    Longitude =
Note:
3 1 200.000 1  9.05 13.21 11.29  9.63  7.76  6.26  4.20  2.78  2.02  9.42  81.3
GPS Position: Latitude =    Longitude =
Note:
4 1 298.000 1  8.96 14.88 12.88 11.23  9.25  7.61  5.36  3.88  3.16 11.01  82.4
GPS Position: Latitude =    Longitude =
Note:
5 1 404.000 1  8.66 15.54 13.29 11.47  9.49  7.88  5.54  3.83  3.06 11.10  81.3
GPS Position: Latitude =    Longitude =
Note:
6 1 501.000 1  8.86 15.81 13.33 11.45  9.37  7.72  5.41  3.74  3.13 11.27  80.6
GPS Position: Latitude =    Longitude =
Note:
7 1 599.000 1  8.74 15.17 13.03 11.37  9.41  7.77  5.49  3.94  3.36 11.00  80.9
GPS Position: Latitude =    Longitude =
Note:
8 1 702.000 1  8.66 15.41 12.91 10.97  8.91  7.32  5.05  3.44  2.79 10.64  82.4
GPS Position: Latitude =    Longitude =
Note:
9 1 800.000 1  8.67 15.12 13.21 11.57  9.67  8.07  5.60  3.82  3.06 10.92  82.8
GPS Position: Latitude =    Longitude =
Note:
10 1 900.000 1  8.67 11.81  9.80  8.24  6.72  5.55  3.85  2.65  2.22  7.73  83.5
GPS Position: Latitude =    Longitude =
Note:
11 1 1001.000 1  8.76 14.41 12.35 10.67  8.82  7.33  5.07  3.47  2.55 10.26  83.5
GPS Position: Latitude =    Longitude =
Note:
12 1 1101.000 1  8.64 16.90 14.83 12.95 10.83  9.04  6.38  4.37  3.41 12.53  83.9
GPS Position: Latitude =    Longitude =
Note:
13 1 1200.000 1  8.55 15.92 13.75 11.85  9.80  8.15  5.85  4.14  3.41 11.61  83.5
GPS Position: Latitude =    Longitude =
Note:
14 1 1301.000 1  8.50 14.78 13.24 11.53  9.60  7.97  5.58  3.89  3.22 10.75  84.2
GPS Position: Latitude =    Longitude =
Note:
15 1 1400.000 1  8.65 15.22 13.58 11.78  9.75  8.11  5.70  3.94  3.14 10.80  84.2
GPS Position: Latitude =    Longitude =
Note:
16 1 1501.000 1  8.61 13.08 11.22  9.51  7.72  6.30  4.28  2.87  2.36  9.05  84.6
GPS Position: Latitude =    Longitude =
Note:
```

M3
Date-Time: 3-30-2005 11:11:32
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Story S27
Temp: 69
Operator: Colton/Denekas
Comments:
1 1 0.000 1 8.49 10.57 9.30 8.20 7.06 6.13 4.63 3.45 2.76 7.85 82.8
GPS Position: Latitude = Longitude =
Note:
2 1 100.000 1 8.69 15.01 12.92 11.19 9.24 7.66 5.31 3.59 2.70 10.98 82.8
GPS Position: Latitude = Longitude =
Note:
3 1 200.000 1 8.43 15.56 13.86 12.03 9.93 8.21 5.72 3.92 3.09 11.71 83.9
GPS Position: Latitude = Longitude =
Note:
4 1 306.000 1 8.52 14.88 13.50 11.84 9.88 8.25 5.77 3.96 3.21 10.87 85.3
GPS Position: Latitude = Longitude =
Note:
5 1 405.000 1 8.56 18.13 16.06 13.99 11.58 9.52 6.46 4.27 3.19 13.71 86.4
GPS Position: Latitude = Longitude =
Note:
6 1 501.000 1 8.51 14.28 12.46 10.77 8.88 7.28 4.90 3.24 2.18 10.25 86.1
GPS Position: Latitude = Longitude =
Note:
7 1 600.000 1 8.51 16.78 14.81 12.93 10.75 8.91 6.13 4.12 3.11 12.50 85.7
GPS Position: Latitude = Longitude =
Note:
8 1 700.000 1 8.72 15.63 13.84 12.14 10.14 8.47 5.90 4.01 2.87 12.05 86.1
GPS Position: Latitude = Longitude =
Note:
9 1 800.000 1 8.49 17.02 15.14 13.19 10.92 8.97 6.10 4.03 3.07 12.77 86.1
GPS Position: Latitude = Longitude =
Note:
10 1 901.000 1 8.39 18.05 15.68 13.52 11.05 9.02 6.06 4.00 2.96 13.15 87.5
GPS Position: Latitude = Longitude =
Note:
11 1 1001.000 1 8.48 15.09 13.17 11.33 9.33 7.68 5.25 3.55 2.49 10.91 87.2
GPS Position: Latitude = Longitude =
Note:
12 1 1101.000 1 8.55 16.72 14.89 13.02 10.78 8.90 6.06 4.02 3.03 12.55 86.1
GPS Position: Latitude = Longitude =
Note:
13 1 1199.000 1 8.25 16.14 14.50 12.78 10.82 9.12 6.56 4.55 3.51 12.33 85.3
GPS Position: Latitude = Longitude =
Note:
14 1 1300.000 1 8.51 15.11 13.15 11.56 9.71 8.19 5.89 4.11 3.28 11.70 86.1
GPS Position: Latitude = Longitude =
Note:
15 1 1400.000 1 8.40 13.50 11.99 10.70 9.14 7.80 5.62 3.89 2.76 10.36 86.4
GPS Position: Latitude = Longitude =
Note:
16 1 1503.000 1 8.31 17.54 15.61 13.81 11.67 9.93 7.15 4.96 3.82 13.47 86.4
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 12:29:48
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Tama E66
Temp: 31
Operator: bad
Comments:
1 1 0.000 1 9.19 7.10 6.73 6.35 5.98 5.63 4.95 4.16 3.49 6.37 31.5
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 8.92 11.06 10.54 9.76 8.83 7.94 6.35 4.88 3.75 9.47 34.1
GPS Position: Latitude = Longitude =
Note:
3 1 260.000 1 8.89 10.02 9.56 8.86 8.06 7.27 5.81 4.45 3.42 8.66 34.8
GPS Position: Latitude = Longitude =
Note:
4 1 378.000 1 8.87 10.12 9.64 8.91 8.08 7.26 5.83 4.49 3.47 8.68 36.3
GPS Position: Latitude = Longitude =
Note:
5 1 409.000 1 8.90 11.08 10.71 9.91 8.96 8.08 6.50 5.03 3.91 9.42 37.4
GPS Position: Latitude = Longitude =
Note:
6 1 603.000 1 8.76 11.25 11.03 10.24 9.29 8.31 6.47 4.66 3.14 9.38 37.0
GPS Position: Latitude = Longitude =
Note:
7 1 617.000 1 8.90 9.23 8.79 8.14 7.40 6.73 5.53 4.37 3.45 7.89 37.4
GPS Position: Latitude = Longitude =
Note:
8 1 700.000 1 8.90 10.20 9.83 9.06 8.15 7.31 5.87 4.57 3.58 8.69 37.4
GPS Position: Latitude = Longitude =
Note:
9 1 801.000 1 8.65 11.11 10.92 10.14 9.13 8.15 6.37 4.75 3.54 9.42 36.6
GPS Position: Latitude = Longitude =
Note:
10 1 902.000 1 8.82 10.25 9.92 9.19 8.32 7.50 6.07 4.77 3.77 8.91 37.4
GPS Position: Latitude = Longitude =
Note:
11 1 1028.000 1 8.80 9.67 9.24 8.60 7.84 7.06 5.69 4.41 3.46 8.31 36.3
GPS Position: Latitude = Longitude =
Note:
12 1 1101.000 1 8.85 9.36 9.04 8.43 7.68 6.96 5.65 4.37 3.38 8.19 37.0
GPS Position: Latitude = Longitude =
Note:
13 1 1203.000 1 8.91 6.87 6.73 6.21 5.59 5.00 3.99 3.10 2.45 5.81 37.4
GPS Position: Latitude = Longitude =
Note:
14 1 1300.000 1 8.89 8.52 8.24 7.69 7.03 6.36 5.11 3.91 3.00 7.39 39.2
GPS Position: Latitude = Longitude =
Note:
15 1 1400.000 1 8.66 9.21 9.01 8.40 7.65 6.91 5.57 4.33 3.34 7.90 39.6
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 8.79 8.84 8.47 7.95 7.36 6.77 5.66 4.52 3.58 7.95 38.1
GPS Position: Latitude = Longitude =
Note:

M3
Date-Time: 12-13-2004 11:58:30
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Tama V18A
Temp: 14
Operator: bad
Comments:
1 1 0.000 1 9.21 5.70 5.36 4.93 4.44 3.97 3.14 2.38 1.83 4.72 28.9
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 9.17 8.46 7.76 6.96 6.05 5.24 3.91 2.86 2.16 6.58 30.0
GPS Position: Latitude = Longitude =
Note:
3 1 202.000 1 9.20 8.87 8.18 7.28 6.23 5.34 3.87 2.82 2.11 6.91 30.0
GPS Position: Latitude = Longitude =
Note:
4 1 388.000 1 9.11 8.85 8.11 7.24 6.21 5.32 3.91 2.84 2.16 6.97 30.4
GPS Position: Latitude = Longitude =
Note:
5 1 398.000 1 9.21 9.43 8.62 7.66 6.56 5.58 4.04 2.89 2.16 7.19 31.1
GPS Position: Latitude = Longitude =
Note:
6 1 500.000 1 9.17 10.64 9.71 8.54 7.23 6.06 4.21 2.95 2.17 8.04 30.8
GPS Position: Latitude = Longitude =
Note:
7 1 634.000 1 8.87 12.51 11.52 10.10 8.25 6.75 4.57 3.18 2.41 9.16 31.1
GPS Position: Latitude = Longitude =
Note:
8 1 784.000 1 9.06 10.63 9.80 8.71 7.40 6.26 4.51 3.27 2.47 8.15 31.9
GPS Position: Latitude = Longitude =
Note:
9 1 824.000 1 9.10 12.11 11.29 9.94 8.34 6.97 4.96 3.56 2.63 9.43 32.2
GPS Position: Latitude = Longitude =
Note:
10 1 902.000 1 9.14 11.79 10.75 9.48 7.91 6.54 4.52 3.08 2.13 8.84 31.9
GPS Position: Latitude = Longitude =
Note:
11 1 1001.000 1 9.09 11.31 10.45 9.23 7.72 6.41 4.37 2.91 2.03 8.58 32.2
GPS Position: Latitude = Longitude =
Note:
12 1 1204.000 1 9.02 13.88 12.99 11.51 9.58 7.86 5.27 3.48 2.38 10.60 33.7
GPS Position: Latitude = Longitude =
Note:
13 1 1204.000 1 9.09 9.88 9.30 8.38 7.30 6.28 4.59 3.23 2.28 8.00 33.3
GPS Position: Latitude = Longitude =
Note:
14 1 1302.000 1 9.21 10.67 9.66 8.56 7.27 6.11 4.34 3.06 2.19 8.17 33.0
GPS Position: Latitude = Longitude =
Note:
15 1 1401.000 1 9.07 10.15 9.31 8.24 7.00 5.90 4.18 2.90 2.03 7.90 33.0
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 9.22 8.77 7.55 6.62 5.50 4.55 3.10 2.11 1.51 6.77 34.4
GPS Position: Latitude = Longitude =
Note:

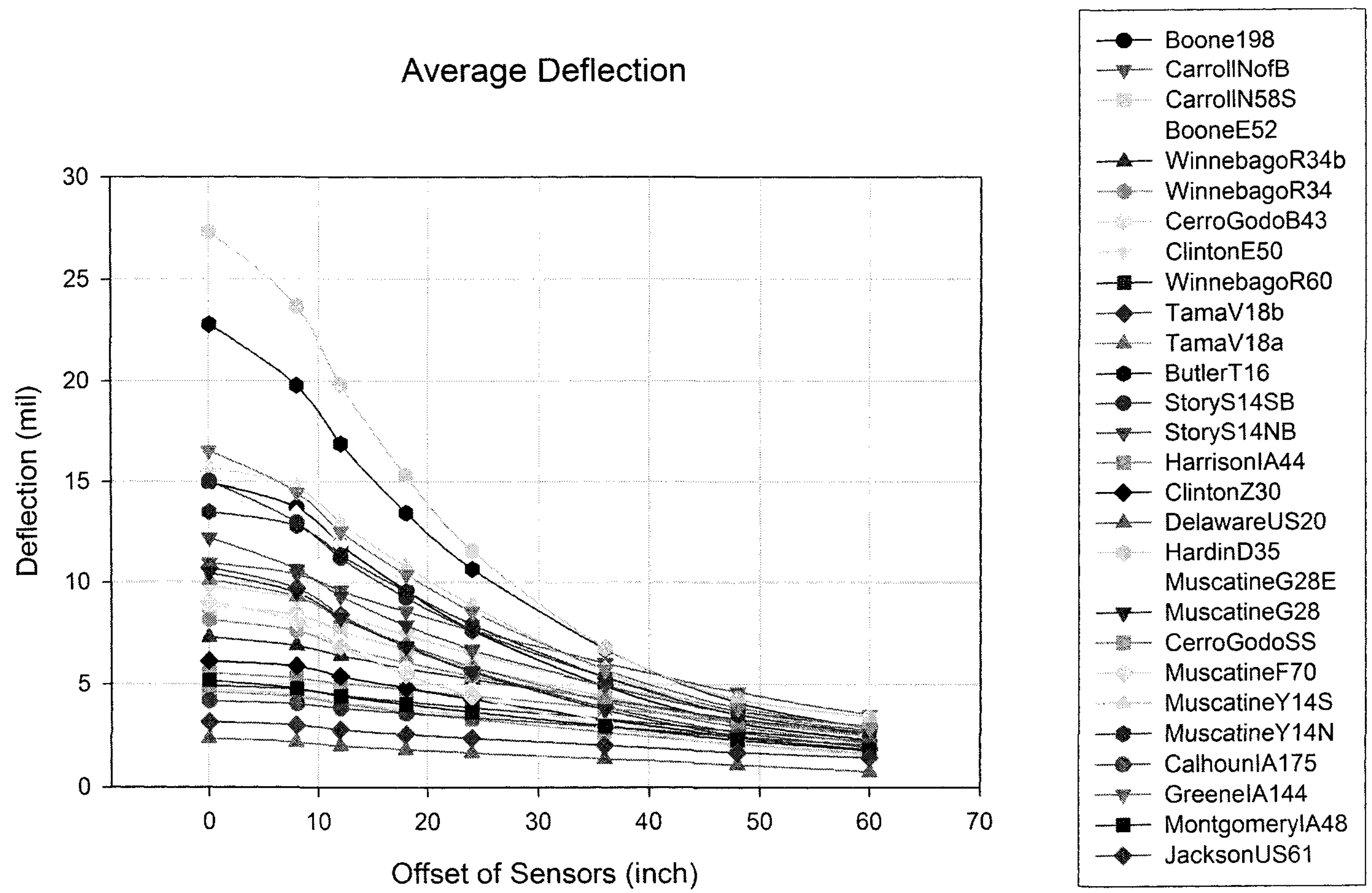
M3
Date-Time: 12-13-2004 12:15:16
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Tama V18B
Temp: 29
Operator: bad
Comments:
1 1 0.000 1 9.09 10.02 9.38 8.35 7.02 5.86 4.03 2.73 1.89 7.92 31.1
GPS Position: Latitude = Longitude =
Note:
2 1 188.000 1 9.05 12.09 11.21 9.91 8.39 7.05 4.94 3.39 2.29 9.28 33.3
GPS Position: Latitude = Longitude =
Note:
3 1 302.000 1 8.86 12.19 10.89 9.54 8.01 6.70 4.71 3.23 2.23 9.00 33.0
GPS Position: Latitude = Longitude =
Note:
4 1 302.000 1 8.91 15.12 13.41 11.47 9.27 7.44 4.86 3.19 2.15 10.54 33.3
GPS Position: Latitude = Longitude =
Note:
5 1 401.000 1 9.11 11.47 10.06 8.52 6.85 5.53 3.72 2.55 1.89 7.67 34.4
GPS Position: Latitude = Longitude =
Note:
6 1 516.000 1 8.94 12.17 10.53 8.85 7.00 5.52 3.57 2.43 1.86 8.30 33.7
GPS Position: Latitude = Longitude =
Note:
7 1 601.000 1 9.00 10.24 8.96 7.63 6.19 5.04 3.43 2.38 1.83 6.85 35.2
GPS Position: Latitude = Longitude =
Note:
8 1 707.000 1 9.01 11.83 9.89 8.14 6.33 4.97 3.21 2.25 1.64 7.81 34.4
GPS Position: Latitude = Longitude =
Note:
9 1 802.000 1 8.92 12.56 11.36 9.45 7.38 5.83 3.77 2.48 1.76 8.26 34.4
GPS Position: Latitude = Longitude =
Note:
10 1 901.000 1 8.90 9.67 9.18 7.97 6.59 5.43 3.77 2.62 1.91 7.04 31.9
GPS Position: Latitude = Longitude =
Note:
11 1 1008.000 1 9.02 9.45 8.68 7.71 6.57 5.59 4.06 2.92 2.19 7.28 32.2
GPS Position: Latitude = Longitude =
Note:
12 1 1116.000 1 9.14 9.03 8.30 7.17 5.97 4.97 3.52 2.54 1.94 6.55 32.6
GPS Position: Latitude = Longitude =
Note:
13 1 1200.000 1 9.05 9.42 8.70 7.64 6.41 5.33 3.67 2.51 1.83 7.07 33.3
GPS Position: Latitude = Longitude =
Note:
14 1 1300.000 1 8.97 9.85 8.95 7.82 6.47 5.32 3.63 2.48 1.85 7.22 33.0
GPS Position: Latitude = Longitude =
Note:
15 1 1400.000 1 8.90 7.78 7.29 6.50 5.54 4.68 3.34 2.34 1.75 6.01 34.4
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 8.80 8.22 8.17 7.27 6.23 5.31 3.85 2.70 1.97 6.39 33.3
GPS Position: Latitude = Longitude =
Note:

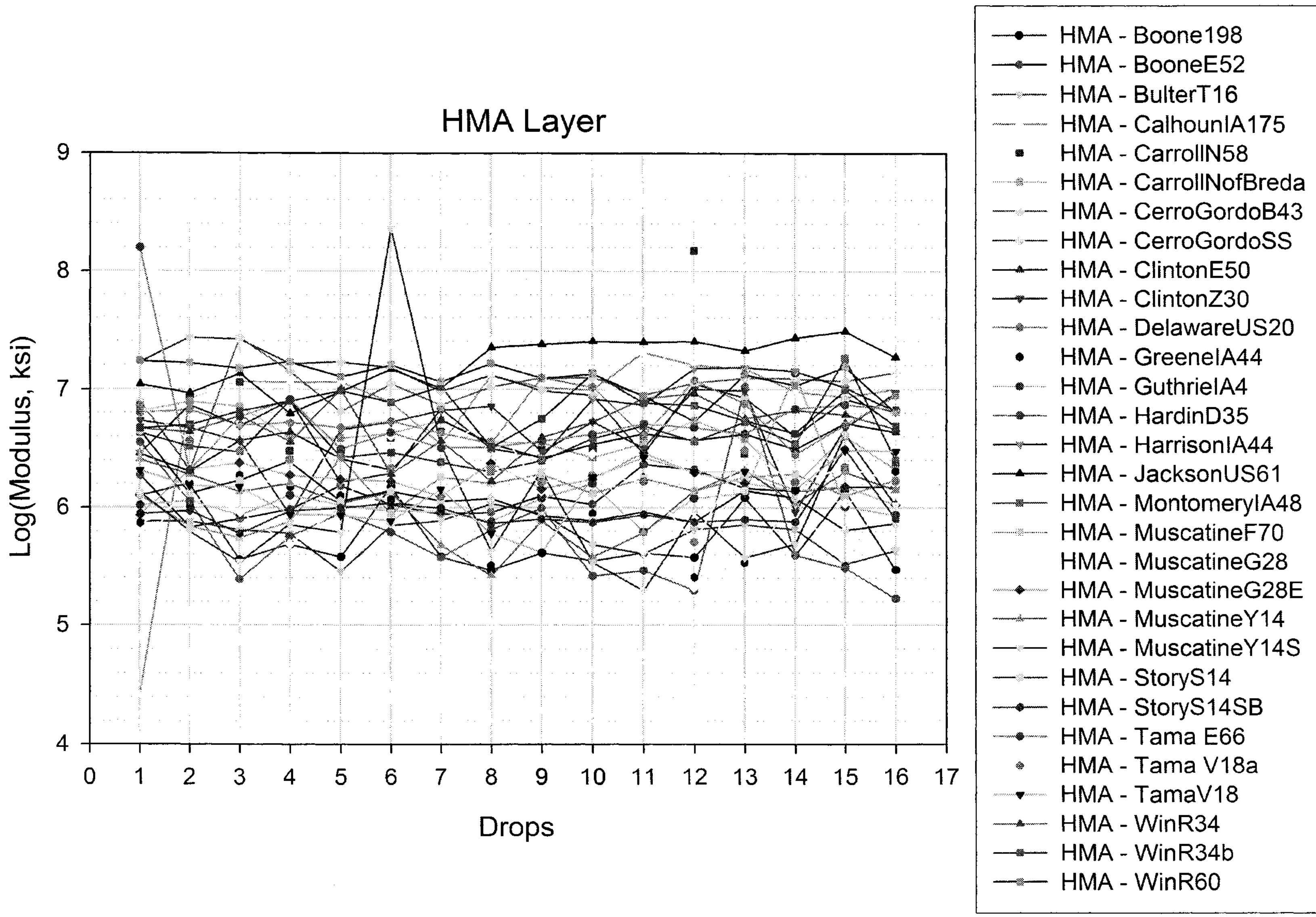
M3
Date-Time: 12-15-2004 7:47:29
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Winnebago R60
Temp: 17
Operator: COLTON / DENEKAS
Comments: RTE R60 SOUTHBOUND
1 1 0.000 1 9.41 3.86 3.62 3.39 3.17 2.94 2.51 2.05 1.69 3.37 25.3
GPS Position: Latitude = Longitude =
Note:
2 1 101.000 1 9.40 4.60 4.44 4.15 3.86 3.59 3.05 2.48 1.93 4.05 25.3
GPS Position: Latitude = Longitude =
Note:
3 1 202.000 1 9.40 4.47 4.34 4.08 3.79 3.50 2.97 2.42 1.95 3.94 24.9
GPS Position: Latitude = Longitude =
Note:
4 1 287.000 1 9.32 4.36 4.20 3.94 3.65 3.35 2.82 2.29 1.81 3.76 24.9
GPS Position: Latitude = Longitude =
Note:
5 1 400.000 1 9.29 4.34 4.17 3.90 3.58 3.28 2.72 2.17 1.70 3.75 25.3
GPS Position: Latitude = Longitude =
Note:
6 1 504.000 1 9.21 4.34 4.17 3.91 3.60 3.29 2.73 2.17 1.74 3.83 25.3
GPS Position: Latitude = Longitude =
Note:
7 1 607.000 1 9.14 4.98 4.90 4.58 4.22 3.88 3.22 2.57 2.07 4.42 26.4
GPS Position: Latitude = Longitude =
Note:
8 1 715.000 1 9.30 4.54 4.38 4.15 3.86 3.58 3.08 2.55 2.10 4.10 26.0
GPS Position: Latitude = Longitude =
Note:
9 1 802.000 1 9.07 4.64 4.44 4.17 3.83 3.51 2.96 2.37 1.93 4.15 26.4
GPS Position: Latitude = Longitude =
Note:
10 1 916.000 1 9.17 5.42 5.14 4.81 4.41 4.05 3.42 2.76 2.21 5.16 26.0
GPS Position: Latitude = Longitude =
Note:
11 1 1001.000 1 9.36 6.83 6.48 6.03 5.54 5.15 4.41 3.64 2.95 6.25 25.3
GPS Position: Latitude = Longitude =
Note:
12 1 1092.000 1 9.32 5.23 5.08 4.80 4.51 4.23 3.69 3.11 2.62 4.71 25.6
GPS Position: Latitude = Longitude =
Note:
13 1 1202.000 1 9.11 5.57 5.47 5.18 4.87 4.58 4.01 3.40 2.86 5.12 26.0
GPS Position: Latitude = Longitude =
Note:
14 1 1303.000 1 9.19 5.16 5.02 4.76 4.48 4.21 3.74 3.11 2.50 4.63 26.0
GPS Position: Latitude = Longitude =
Note:
15 1 1415.000 1 9.04 6.07 6.00 5.74 5.45 5.17 4.59 3.88 3.30 5.56 26.4
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 9.14 6.25 6.13 5.84 5.44 5.12 4.43 3.72 3.11 5.63 26.4
GPS Position: Latitude = Longitude =
Note:

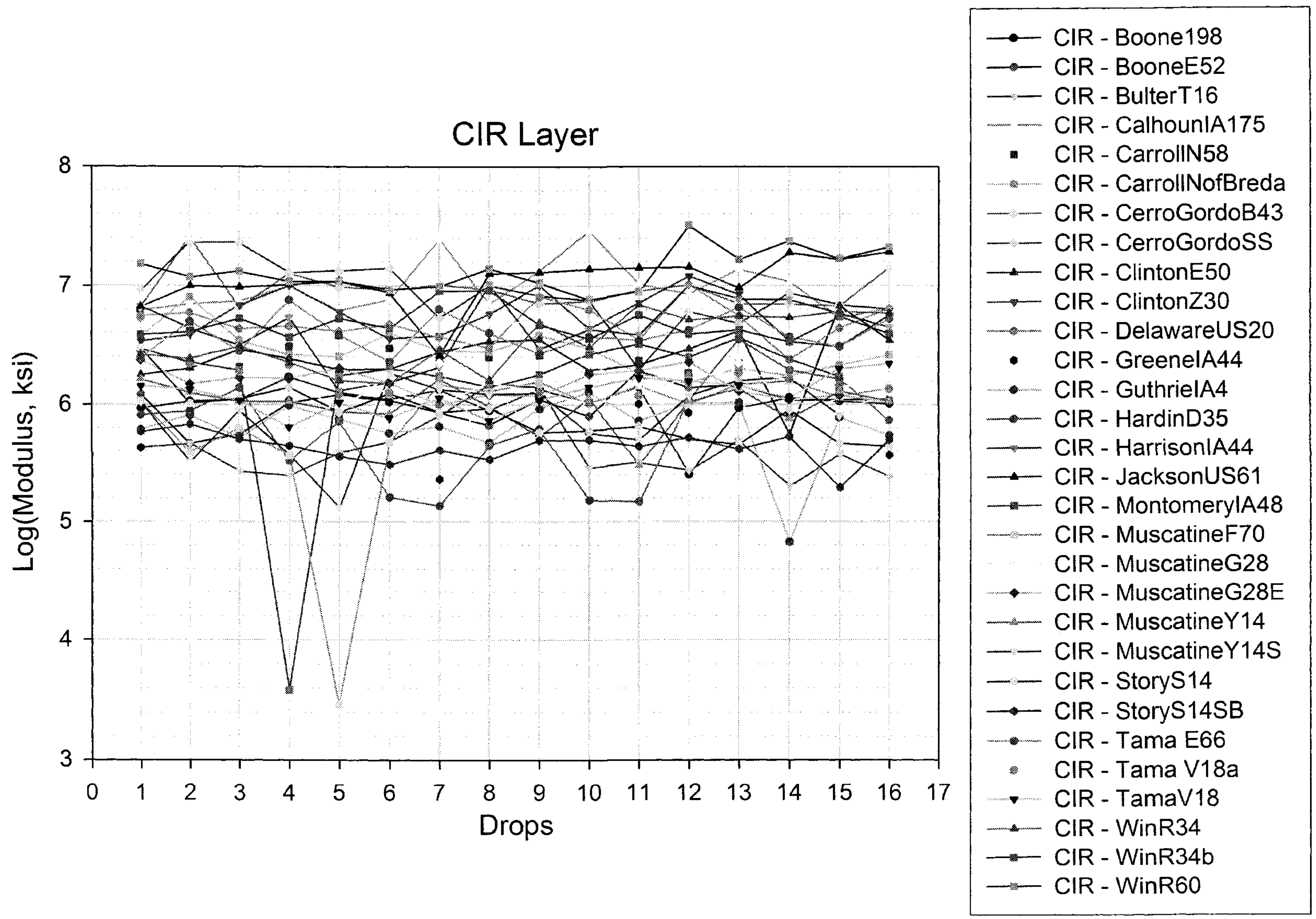
M3
Date-Time: 12-14-2004 16: 6:33
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Winnebago R34
Temp: 23
Operator: bad
Comments:
1 1 0.000 1 9.17 8.94 8.30 7.60 6.78 6.02 4.63 3.44 2.38 7.33 32.2
GPS Position: Latitude = Longitude =
Note:
2 1 103.000 1 9.14 8.87 8.46 7.49 6.57 5.78 4.48 3.42 2.66 7.07 32.6
GPS Position: Latitude = Longitude =
Note:
3 1 204.000 1 9.06 8.50 7.92 7.18 6.43 5.79 4.63 3.62 2.85 6.95 32.6
GPS Position: Latitude = Longitude =
Note:
4 1 306.000 1 8.99 8.51 7.73 6.79 5.89 5.21 3.99 3.02 2.30 6.49 33.3
GPS Position: Latitude = Longitude =
Note:
5 1 401.000 1 8.74 8.16 7.31 6.54 5.73 5.09 3.93 2.99 2.28 6.37 33.0
GPS Position: Latitude = Longitude =
Note:
6 1 501.000 1 8.84 10.90 10.42 9.02 7.59 6.49 4.72 3.47 2.64 8.27 33.0
GPS Position: Latitude = Longitude =
Note:
7 1 613.000 1 9.38 9.26 8.85 8.01 7.06 6.21 4.79 3.61 2.78 7.43 32.2
GPS Position: Latitude = Longitude =
Note:
8 1 792.000 1 8.94 12.12 11.29 9.91 8.51 7.31 5.37 3.90 3.01 9.44 31.9
GPS Position: Latitude = Longitude =
Note:
9 1 802.000 1 9.38 7.84 7.36 6.77 6.06 5.43 4.28 3.25 2.48 6.59 32.2
GPS Position: Latitude = Longitude =
Note:
10 1 902.000 1 9.34 7.77 7.19 6.45 5.70 5.06 3.98 3.05 2.36 6.21 32.6
GPS Position: Latitude = Longitude =
Note:
11 1 1007.000 1 9.40 5.70 5.20 4.78 4.33 3.95 3.26 2.63 2.15 4.63 30.8
GPS Position: Latitude = Longitude =
Note:
12 1 1100.000 1 9.07 6.51 6.07 5.57 5.06 4.61 3.81 3.06 2.51 5.39 31.5
GPS Position: Latitude = Longitude =
Note:
13 1 1210.000 1 9.30 7.45 6.99 6.48 5.91 5.35 4.33 3.38 2.61 6.26 31.1
GPS Position: Latitude = Longitude =
Note:
14 1 1303.000 1 9.02 6.99 6.64 6.12 5.65 5.22 4.13 3.15 2.45 5.74 33.0
GPS Position: Latitude = Longitude =
Note:
15 1 1397.000 1 8.99 6.63 6.31 5.76 5.21 4.73 3.86 3.07 2.43 5.50 31.9
GPS Position: Latitude = Longitude =
Note:
16 1 1500.000 1 9.07 7.48 7.04 6.50 5.91 5.40 4.32 3.33 2.57 6.39 32.2
GPS Position: Latitude = Longitude =
Note:

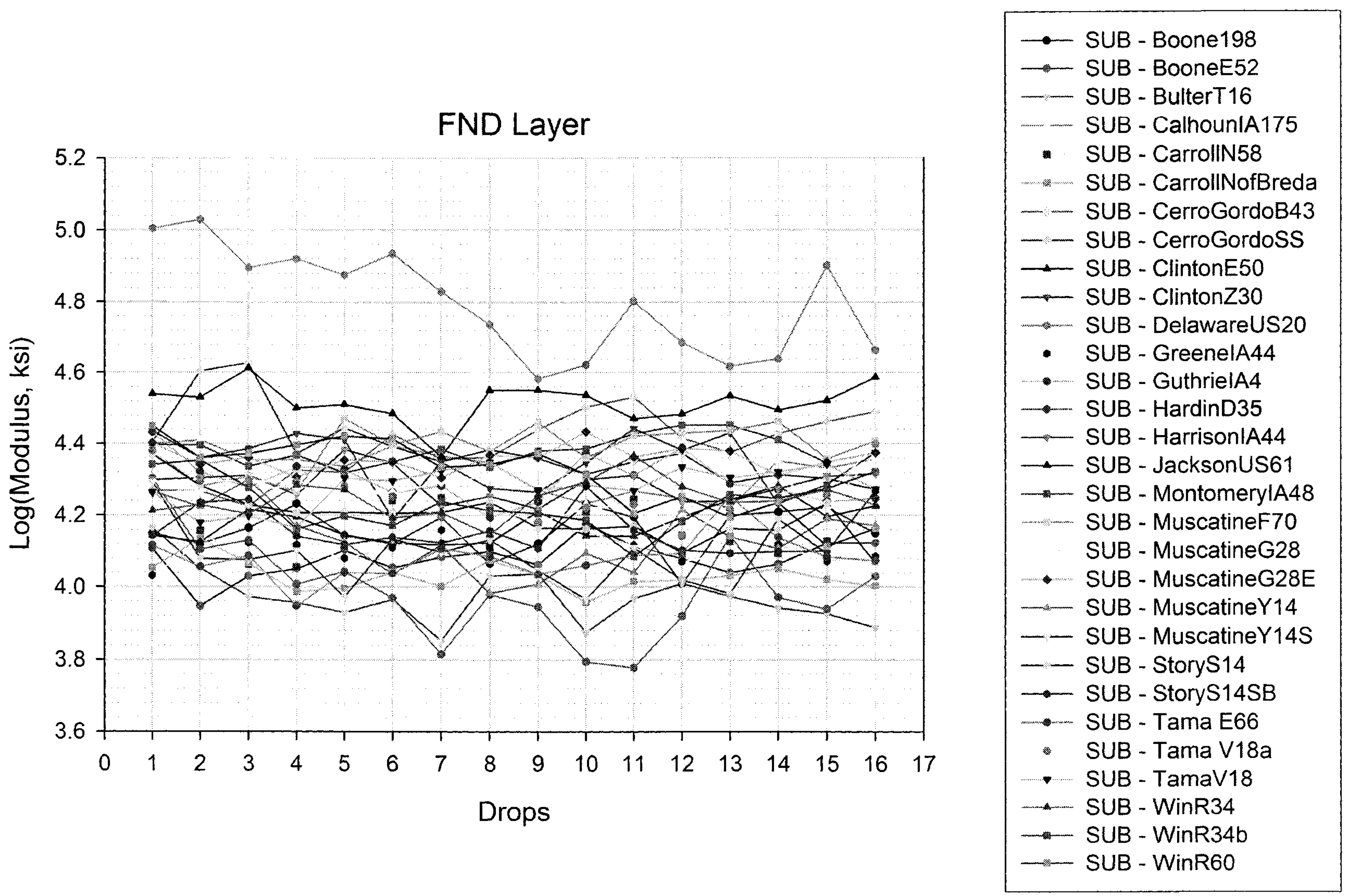
M3
Date-Time: 12-14-2004 16:28:16
Sensors: 096011F04 096012F04 096013F04 096014F04 096015F04 096016F04 096017F04 096018F04 096019F04
Weight/spring: 3
Location: Winnebago R34B
Temp: 25
Operator: bad
Comments:
1 1 0.000 1 9.14 7.34 6.00 5.48 4.94 4.43 3.61 2.85 2.28 5.50 30.8
GPS Position: Latitude = Longitude =
Note:
2 1 104.000 1 9.00 6.56 5.96 5.35 4.78 4.26 3.36 2.54 1.90 5.48 32.2
GPS Position: Latitude = Longitude =
Note:
3 1 209.000 1 8.90 6.63 6.22 5.71 5.17 4.67 3.79 2.99 2.34 6.04 31.5
GPS Position: Latitude = Longitude =
Note:
4 1 301.000 1 8.92 8.28 7.79 7.19 6.54 5.96 4.88 3.86 3.00 7.02 31.1
GPS Position: Latitude = Longitude =
Note:
5 1 434.000 1 8.94 7.06 6.48 6.41 5.88 5.34 4.38 3.39 2.60 6.32 31.5
GPS Position: Latitude = Longitude =
Note:
6 1 502.000 1 8.89 7.83 7.43 6.87 6.29 5.73 4.72 3.71 2.90 6.74 31.5
GPS Position: Latitude = Longitude =
Note:
7 1 611.000 1 8.91 5.88 5.72 5.32 4.92 4.60 3.88 3.12 2.51 5.00 31.1
GPS Position: Latitude = Longitude =
Note:
8 1 701.000 1 8.91 7.29 6.95 6.43 5.86 5.33 4.36 3.42 2.69 6.25 30.4
GPS Position: Latitude = Longitude =
Note:
9 1 807.000 1 8.87 7.66 7.23 6.69 6.07 5.51 4.45 3.44 2.65 6.62 31.5
GPS Position: Latitude = Longitude =
Note:
10 1 900.000 1 8.84 7.42 7.05 6.53 5.96 5.46 4.48 3.57 2.86 6.33 31.1
GPS Position: Latitude = Longitude =
Note:
11 1 997.000 1 8.61 8.01 7.91 7.47 7.02 6.59 5.31 4.09 3.61 6.78 32.2
GPS Position: Latitude = Longitude =
Note:
12 1 1113.000 1 8.90 7.82 7.56 7.00 6.34 5.76 4.64 3.58 2.68 6.71 31.1
GPS Position: Latitude = Longitude =
Note:
13 1 1202.000 1 8.74 7.17 6.69 6.13 5.54 4.96 3.95 3.03 2.27 5.91 30.8
GPS Position: Latitude = Longitude =
Note:
14 1 1300.000 1 8.86 7.94 7.39 6.74 6.01 5.36 4.16 3.10 2.27 6.44 31.1
GPS Position: Latitude = Longitude =
Note:
15 1 1405.000 1 8.80 6.15 5.89 5.45 4.97 4.53 3.72 2.91 2.30 5.14 31.5
GPS Position: Latitude = Longitude =
Note:
16 1 1501.000 1 8.85 6.80 6.19 5.68 5.06 4.51 3.53 2.65 1.95 5.76 31.1
GPS Position: Latitude = Longitude =
Note:

APPENDIX F. FWD DEFLECTIONS AND MODULI

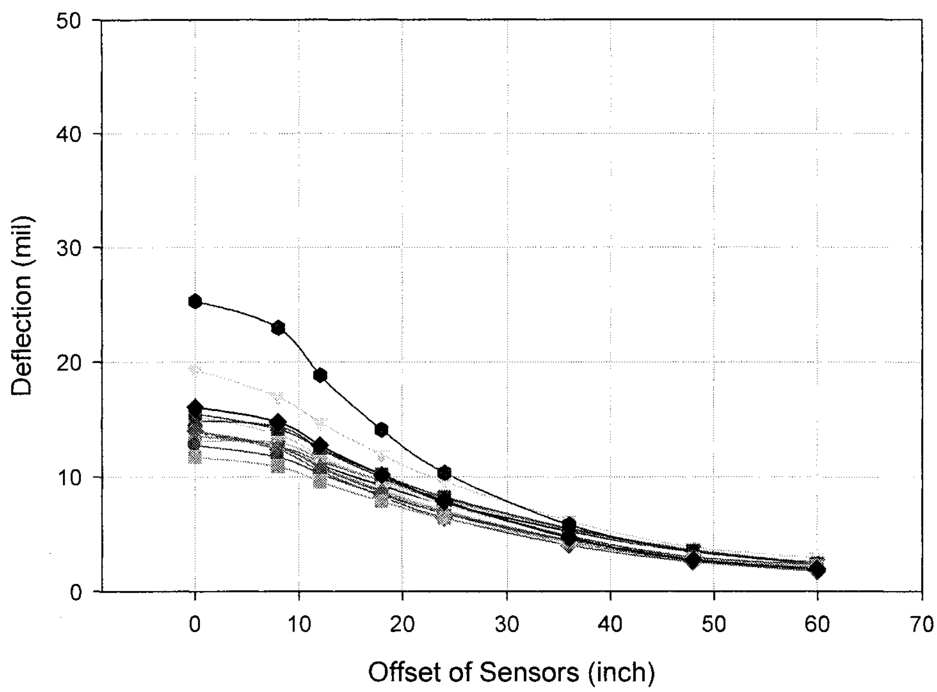

Average Deflection
Deflection (mil)
Offset of Sensors (inch)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
Boone198
CarrollNofB
CarrollN58S
BooneE52
WinnebagoR34b
WinnebagoR34
CerroGodoB43
ClintonE50
WinnebagoR60
TamaV18b
TamaV18a
ButlerT16
StoryS14SB
StoryS14NB
HarrisonIA44
ClintonZ30
DelawareUS20
HardinD35
MuscatineG28E
MuscatineG28
CerroGodoSS
MuscatineF70
MuscatineY14S
MuscatineY14N
CalhounIA175
GreeneIA144
MontgomeryIA48
JacksonUS61

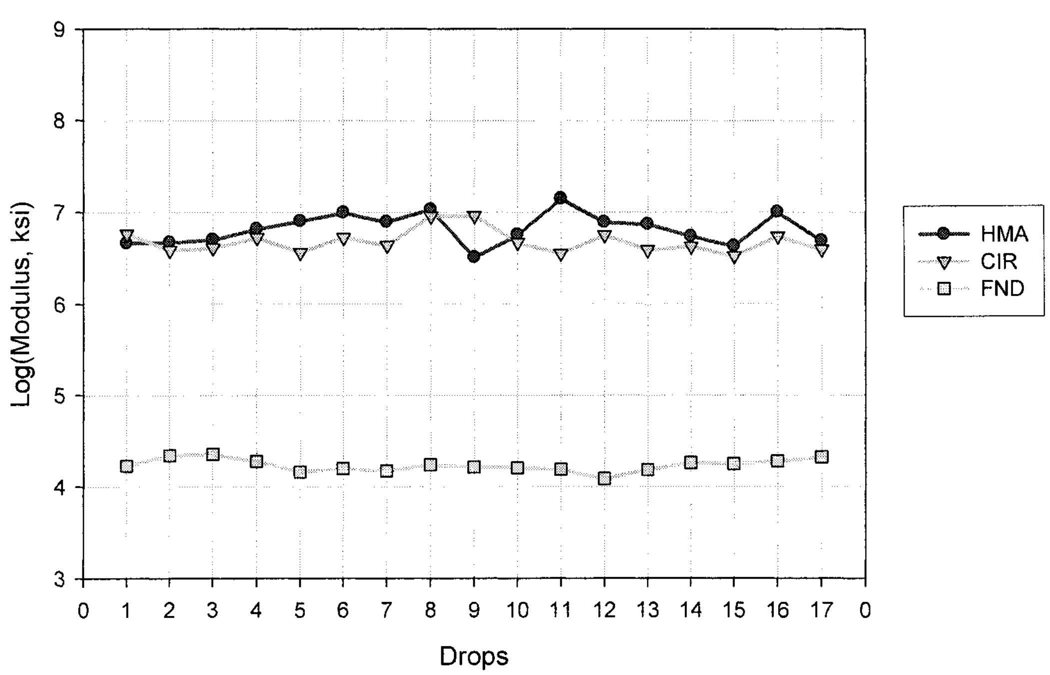

HMA Layer
Log(Modulus, ksi)
Drops
9
8
7
6
5
4
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
HMA - Boone198
HMA - BooneE52
HMA - BulterT16
HMA - CalhounIA175
HMA - CarrollN58
HMA - CarrollNofBreda
HMA - CerroGordoB43
HMA - CerroGordoSS
HMA - ClintonE50
HMA - ClintonZ30
HMA - DelawareUS20
HMA - GreeneIA44
HMA - GuthrieIA4
HMA - HardinD35
HMA - HarrisonIA44
HMA - JacksonUS61
HMA - MontomeryIA48
HMA - MuscatineF70
HMA - MuscatineG28
HMA - MuscatineG28E
HMA - MuscatineY14
HMA - MuscatineY14S
HMA - StoryS14
HMA - StoryS14SB
HMA - Tama E66
HMA - Tama V18a
HMA - TamaV18
HMA - WinR34
HMA - WinR34b
HMA - WinR60


CIR Layer
8
7
6
5
4
3
Log(Modulus, ksi)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Drops
CIR - Boone198
CIR - BooneE52
CIR - BulterT16
CIR - CalhounIA175
CIR - CarrollN58
CIR - CarrollNofBreda
CIR - CerroGordoB43
CIR - CerroGordoSS
CIR - ClintonE50
CIR - ClintonZ30
CIR - DelawareUS20
CIR - GreeneIA44
CIR - GuthrieIA4
CIR - HardinD35
CIR - HarrisonIA44
CIR - JacksonUS61
CIR - MontomeryIA48
CIR - MuscatineF70
CIR - MuscatineG28
CIR - MuscatineG28E
CIR - MuscatineY14
CIR - MuscatineY14S
CIR - StoryS14
CIR - StoryS14SB
CIR - Tama E66
CIR - Tama V18a
CIR - TamaV18
CIR - WinR34
CIR - WinR34b
CIR - WinR60

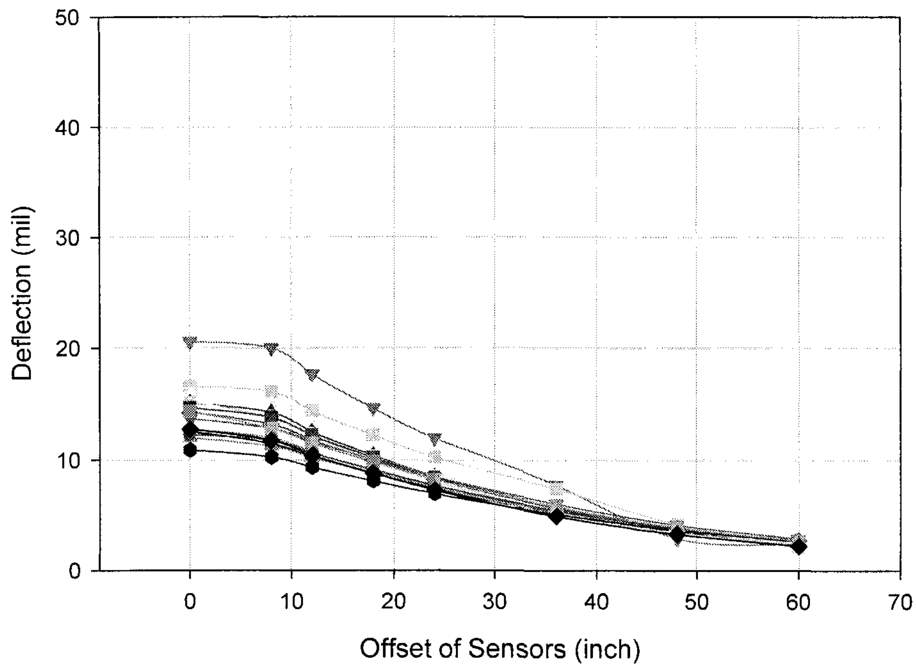

FND Layer
Log(Modulus, ksi)
Drops
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
SUB - Boone198
SUB - BooneE52
SUB - BulterT16
SUB - CalhounIA175
SUB - CarrollN58
SUB - CarrollNofBreda
SUB - CerroGordoB43
SUB - CerroGordoSS
SUB - ClintonE50
SUB - ClintonZ30
SUB - DelawareUS20
SUB - GreeneIA44
SUB - GuthrieIA4
SUB - HardinD35
SUB - HarrisonIA44
SUB - JacksonUS61
SUB - MontomeryIA48
SUB - MuscatineF70
SUB - MuscatineG28
SUB - MuscatineG28E
SUB - MuscatineY14
SUB - MuscatineY14S
SUB - StoryS14
SUB - StoryS14SB
SUB - Tama E66
SUB - Tama V18a
SUB - TamaV18
SUB - WinR34
SUB - WinR34b
SUB - WinR60

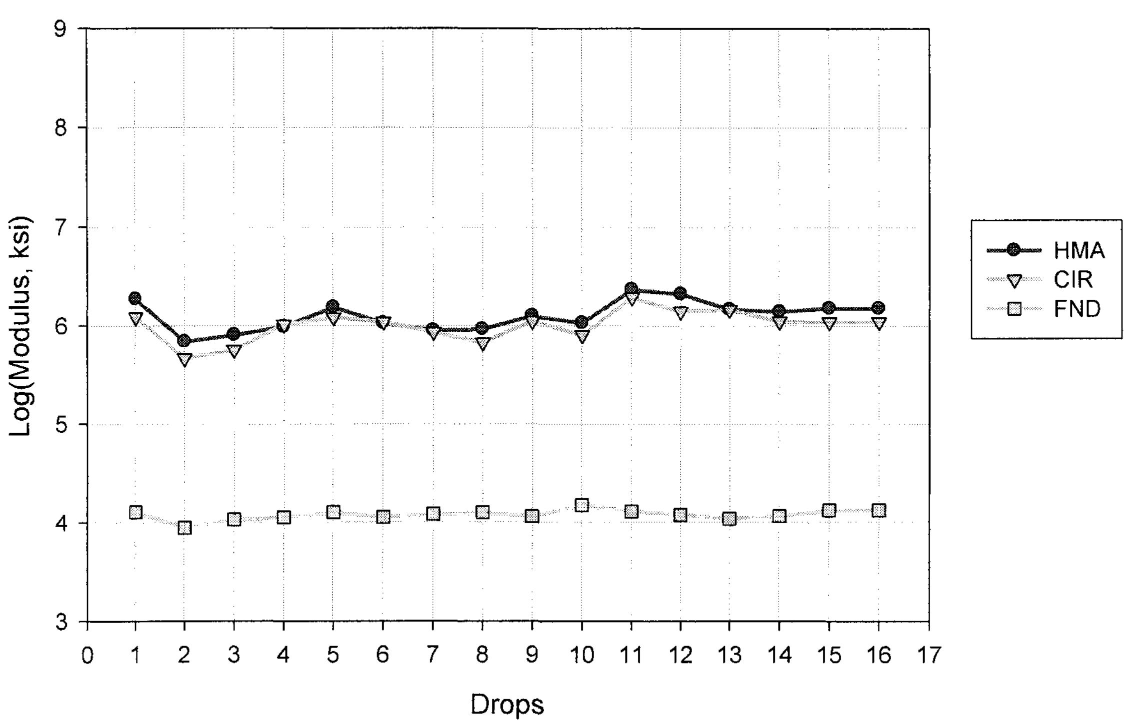
Boone198


50
40
30
20
10
0
Deflection (mil)
0
10
20
30
40
50
60
70
Offset of Sensors (inch)

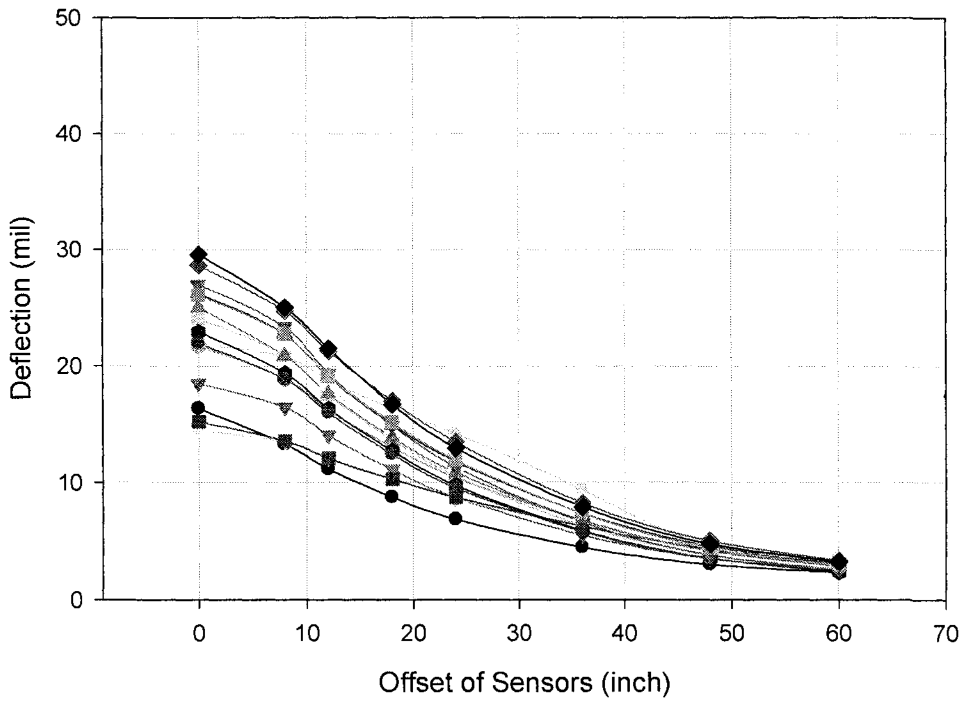

9
8
7
6
5
4
3
Log(Modulus, ksi)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 0
Drops
HMA
CIR
FND

BooneE52

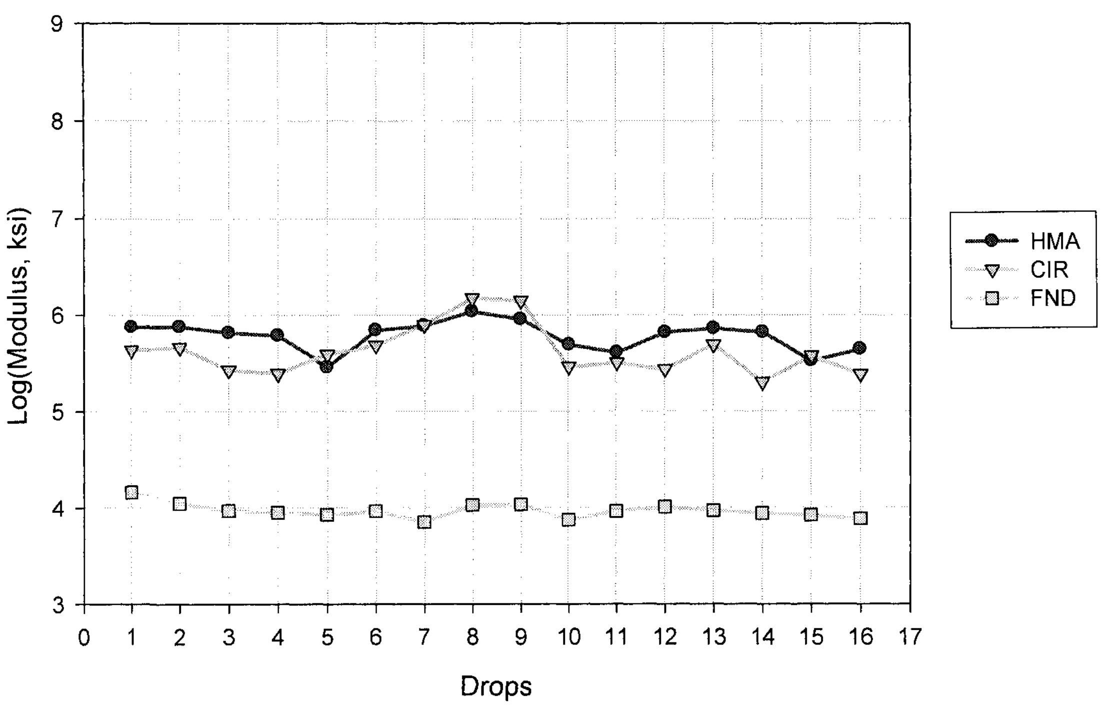

Deflection (mil)
Offset of Sensors (inch)
0
10
20
30
40
50
60
70


Log(Modulus, ksi)
Drops
HMA
CIR
FND

ButlerT16

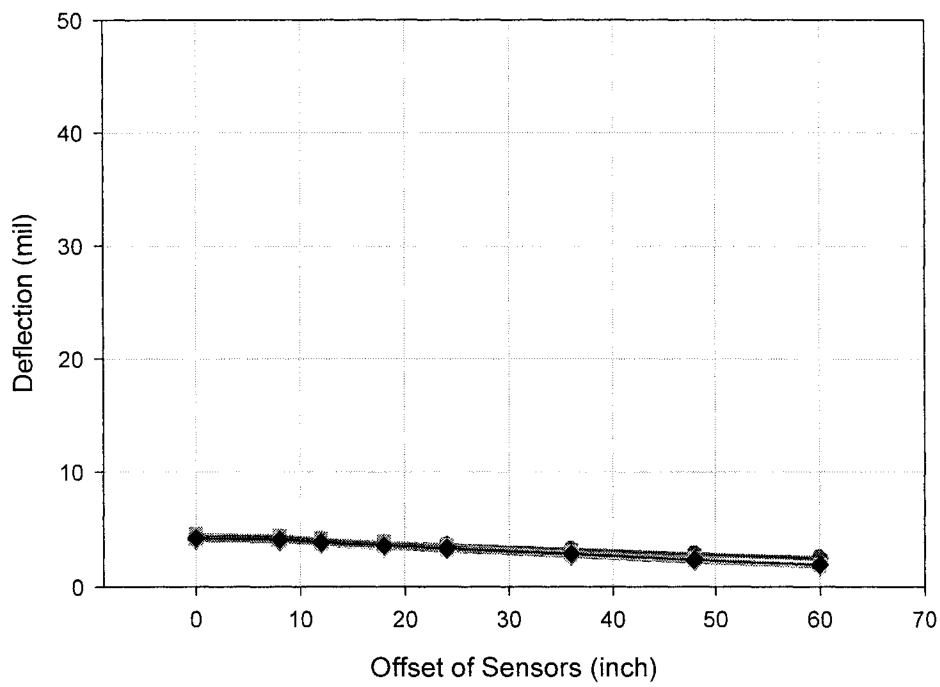


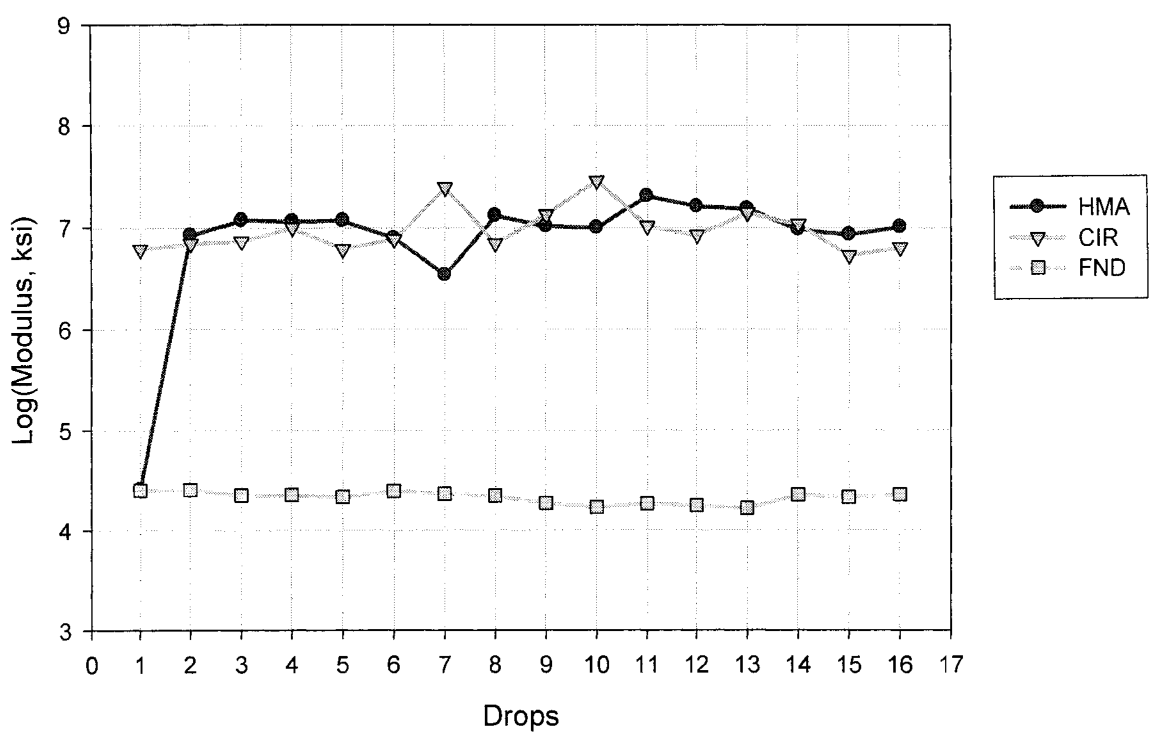
Deflection (mil)
Offset of Sensors (inch)

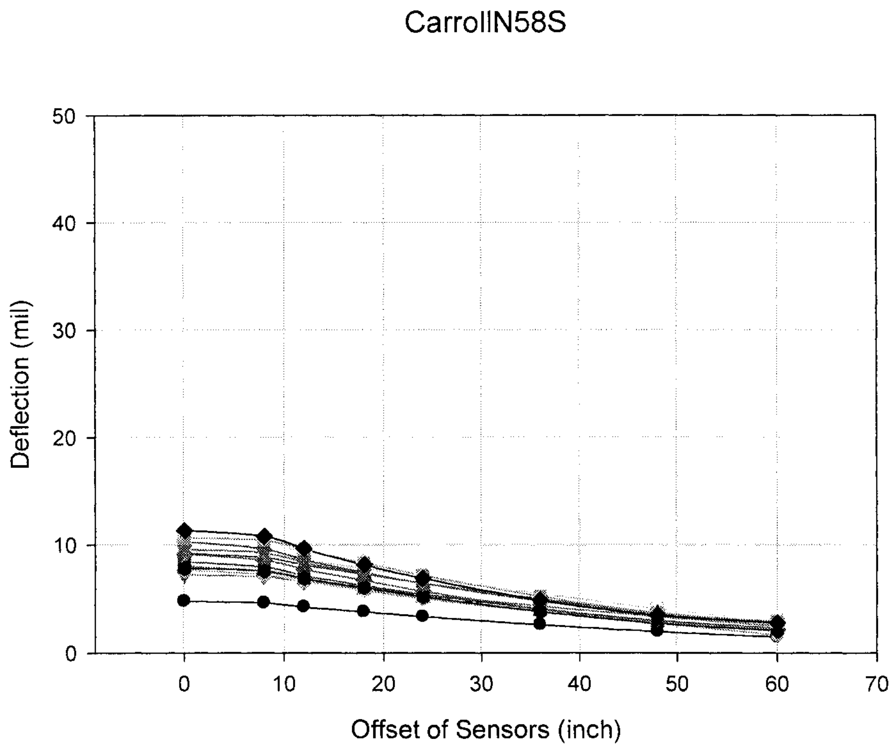


Log(Modulus, ksi)
Drops
HMA
CIR
FND

CalhounIA175






CarrollN58S
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40
30
20
10
0
Deflection (mil)
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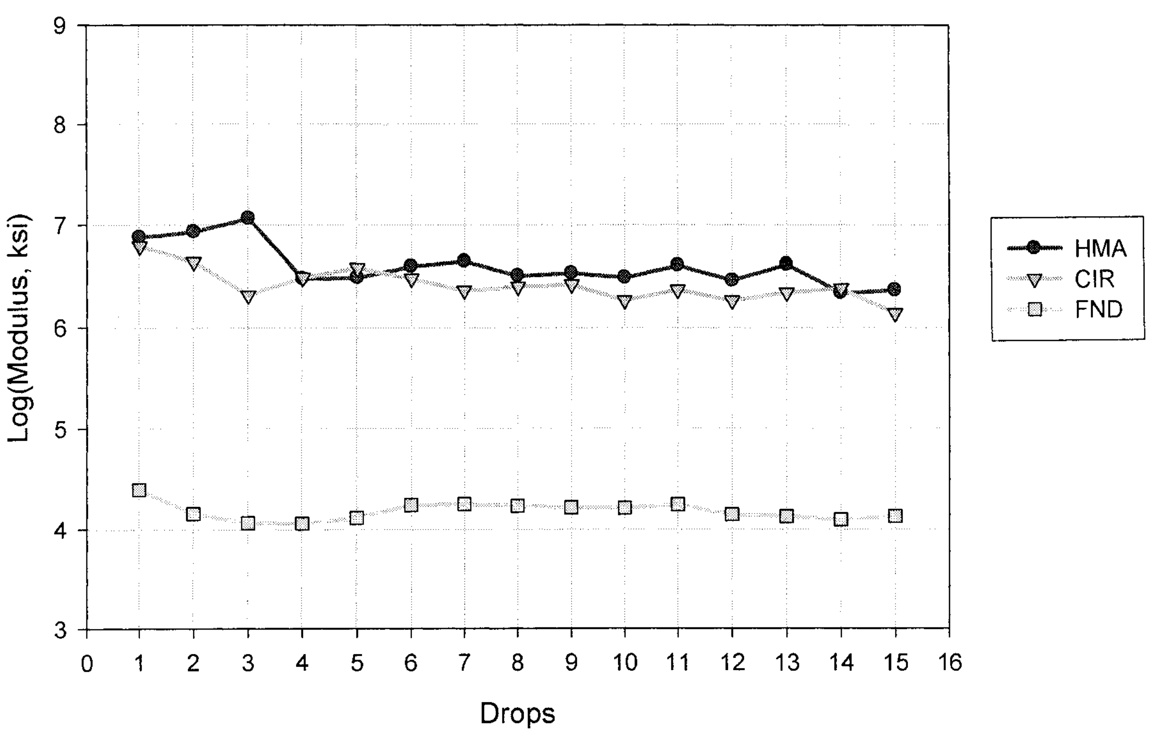
10
20
30
40
50
60
70
Offset of Sensors (inch)


9
8
7
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5
4
3
Log(Modulus, ksi)
0
1
2
3
4
5
6
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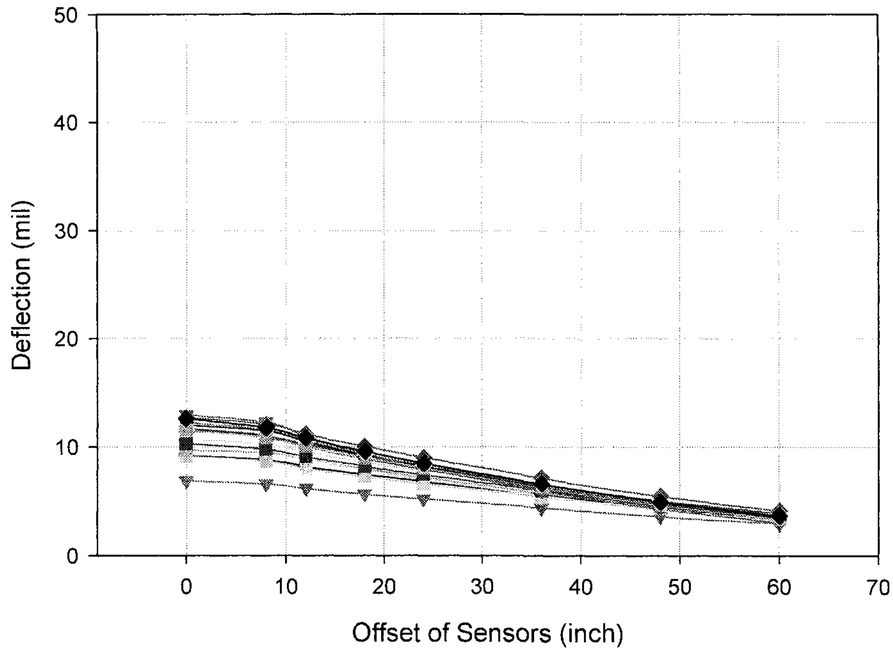
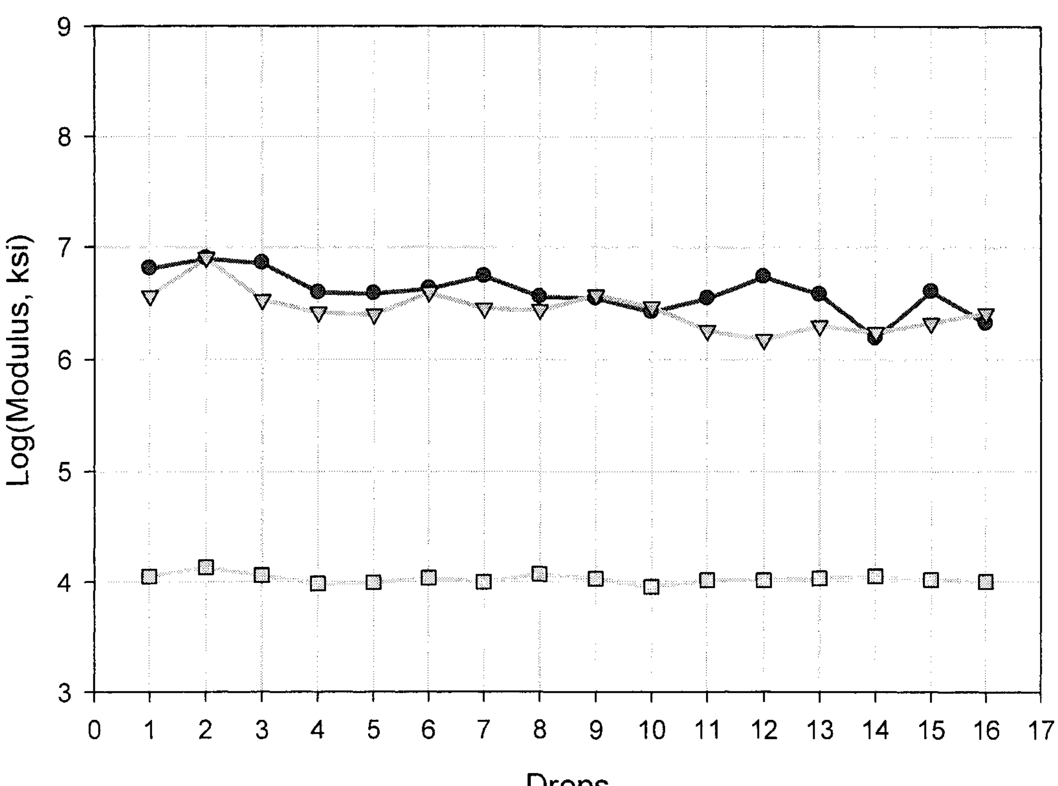
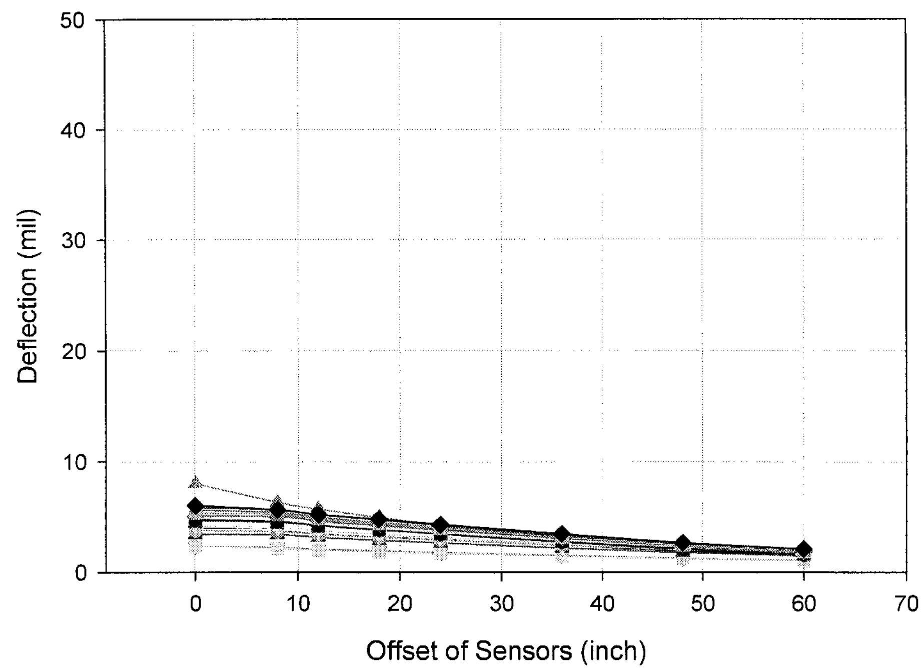
8
9
10
11
12
13
14
15
16
Drops
HMA
CIR
FND

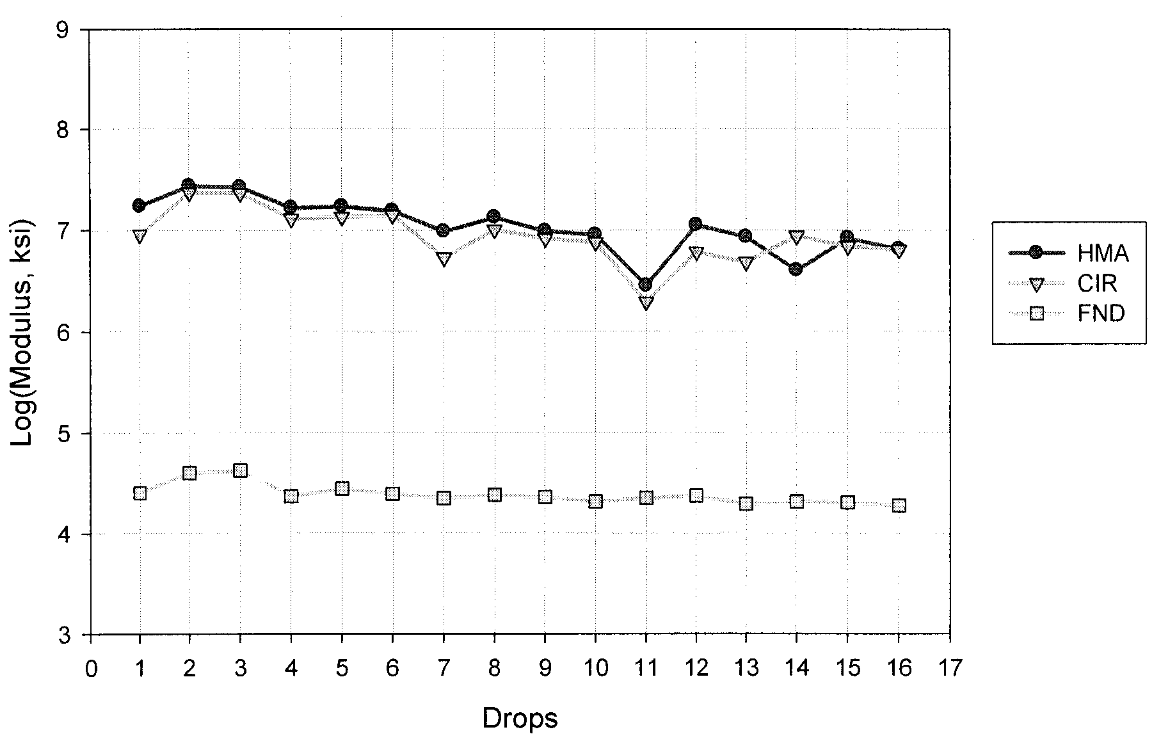
CarrollNofB



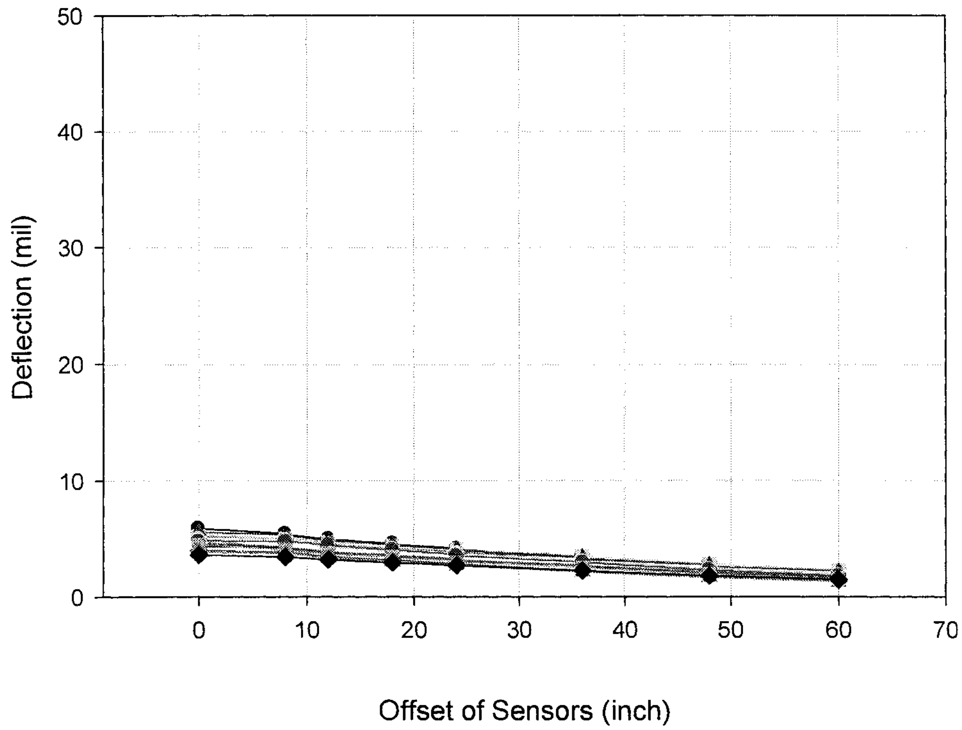


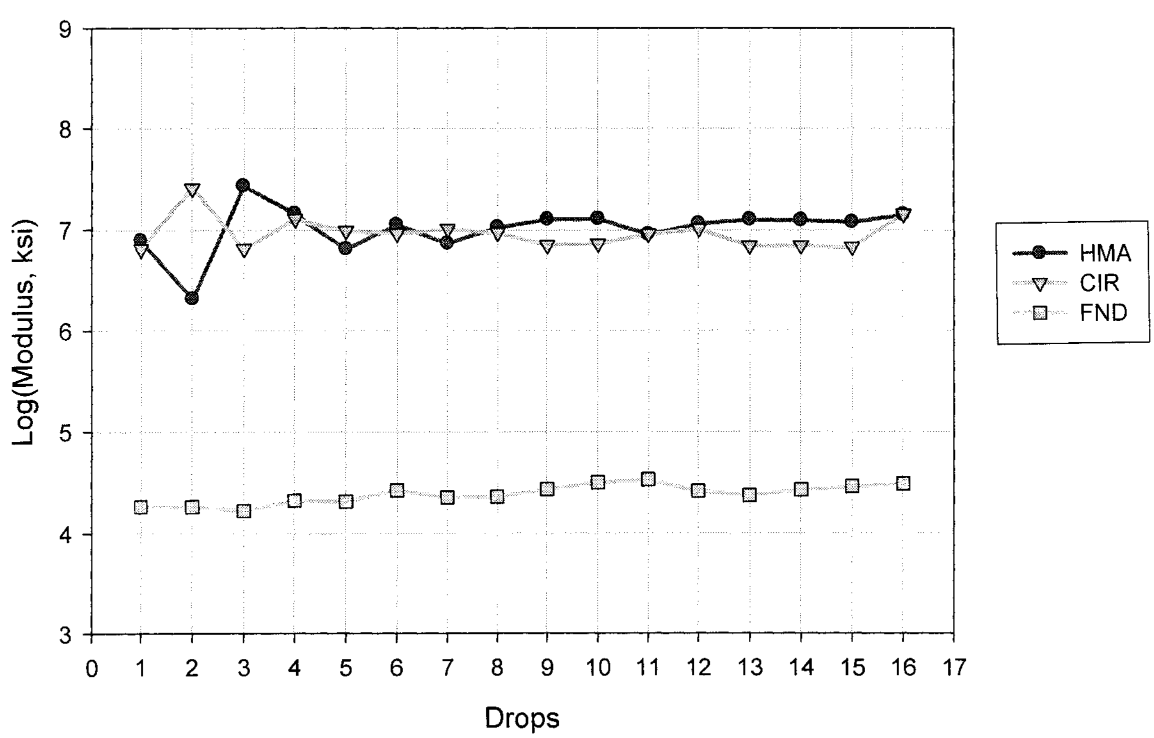
CerroGodoSS



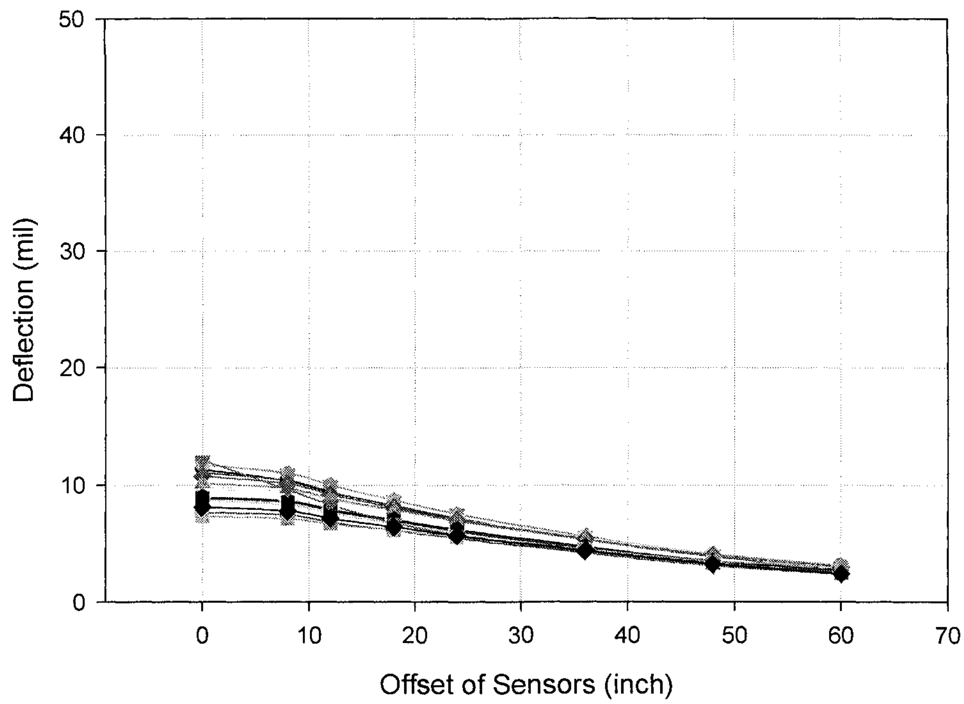


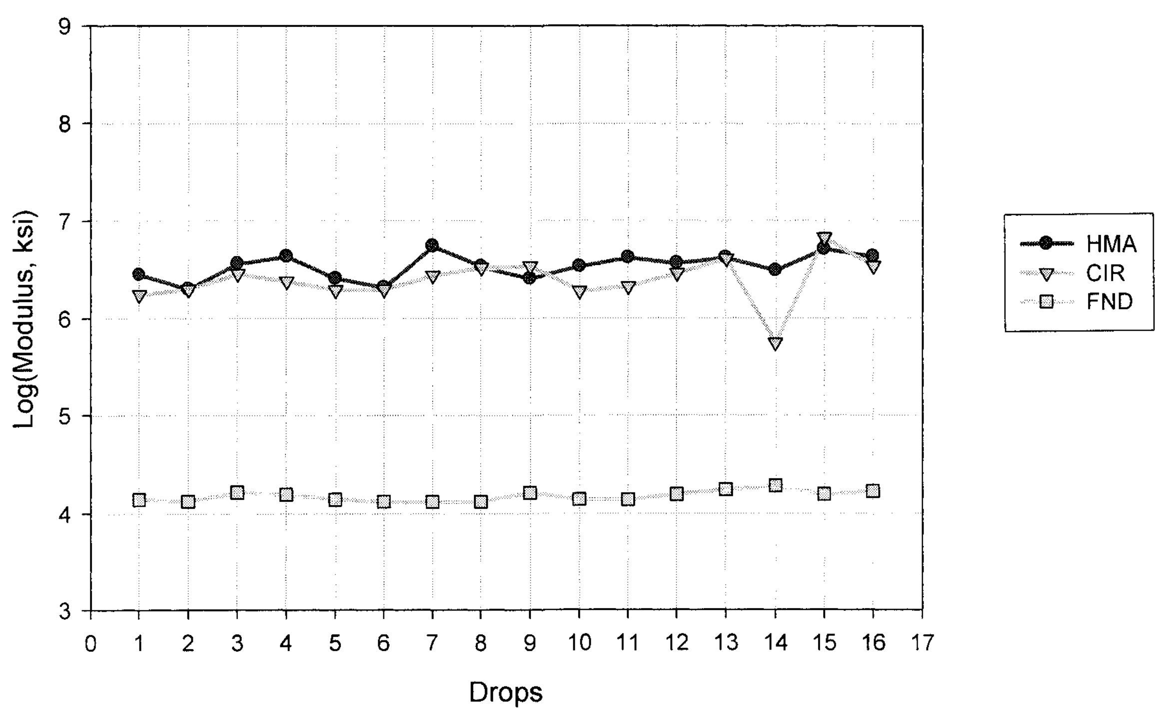
CerroGodoB43



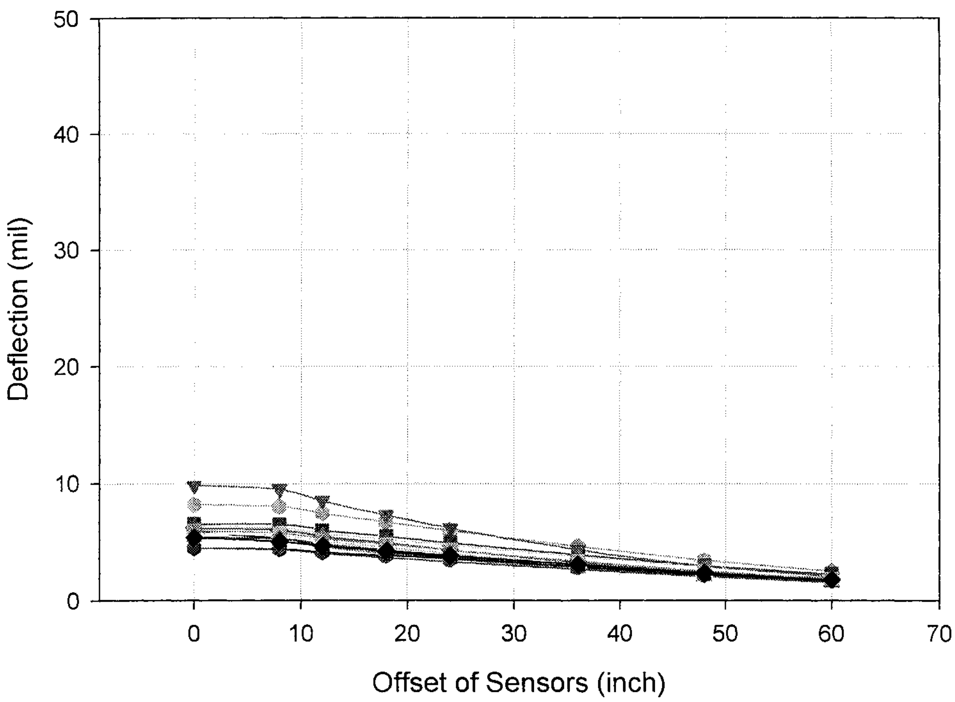


ClintonE50


Deflection (mil)
50
40
30
20
10
0
0
10
20
30
40
50
60
70
Offset of Sensors (inch)


Log(Modulus, ksi)
9
8
7
6
5
4
3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Drops
HMA
CIR
FND

ClintonZ30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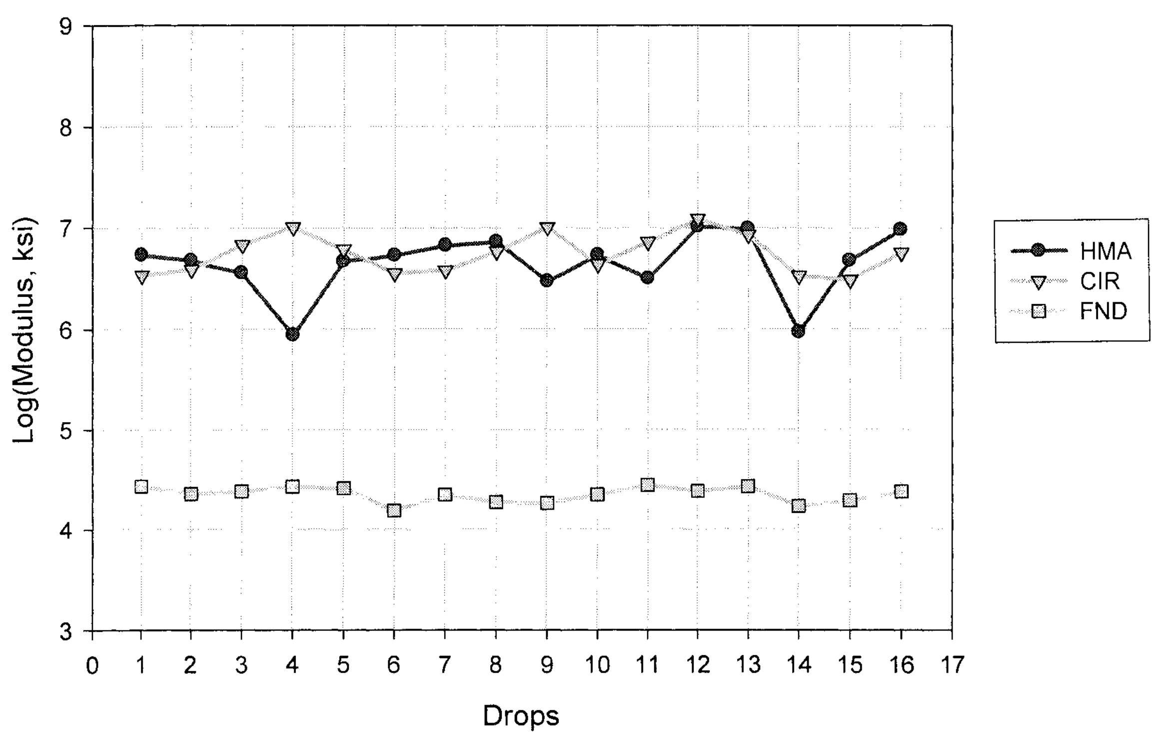
40
30
20
10
0
Deflection (mil)
0
10
20
30
40
50
60
70
Offset of Sensors (inch)


9
8
7
6
5
4
3
Log(Modulus, ksi)
0
1
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4
5
6
7
8
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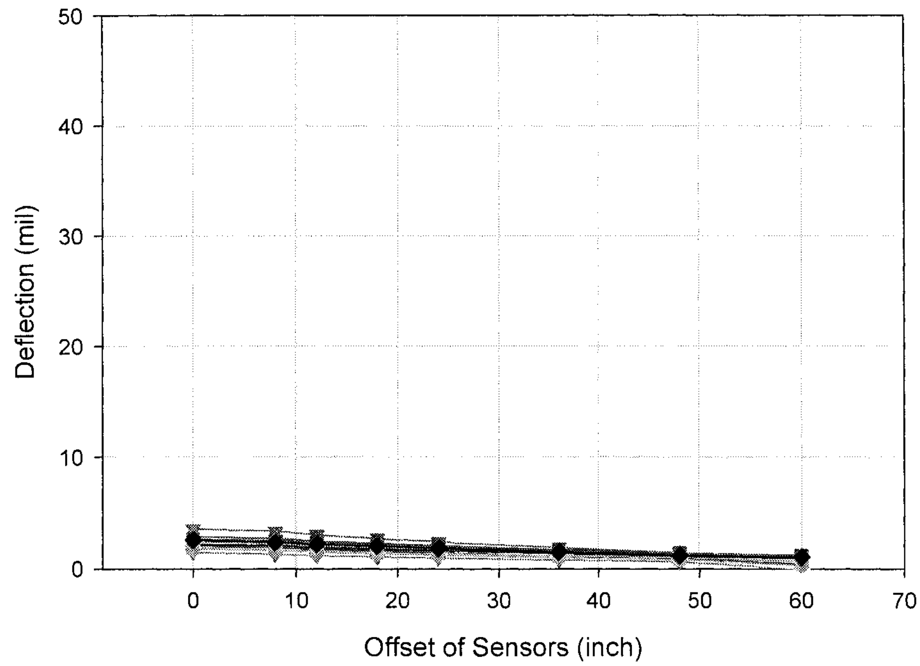
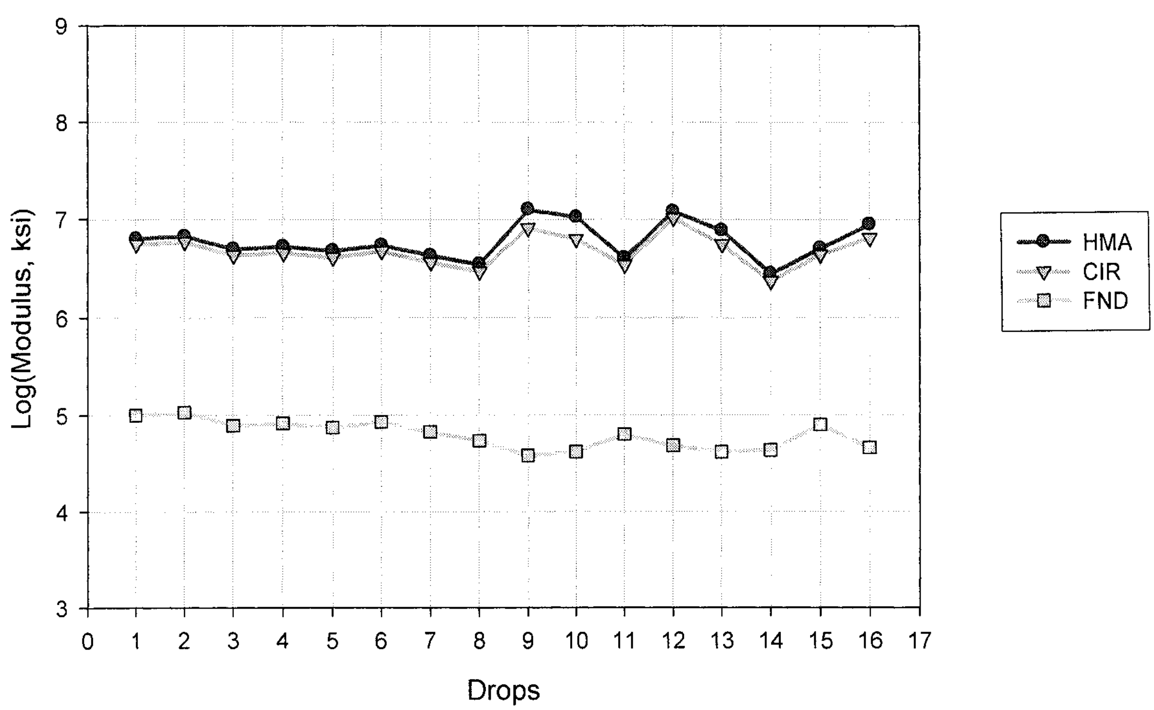
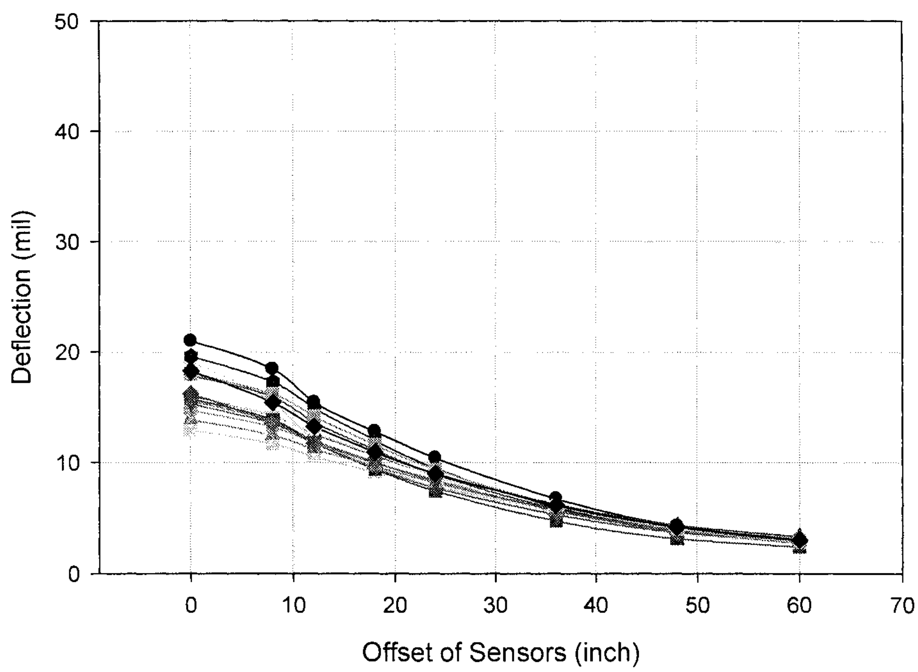
10
11
12
13
14
15
16
17
Drops
HMA
CIR
FND

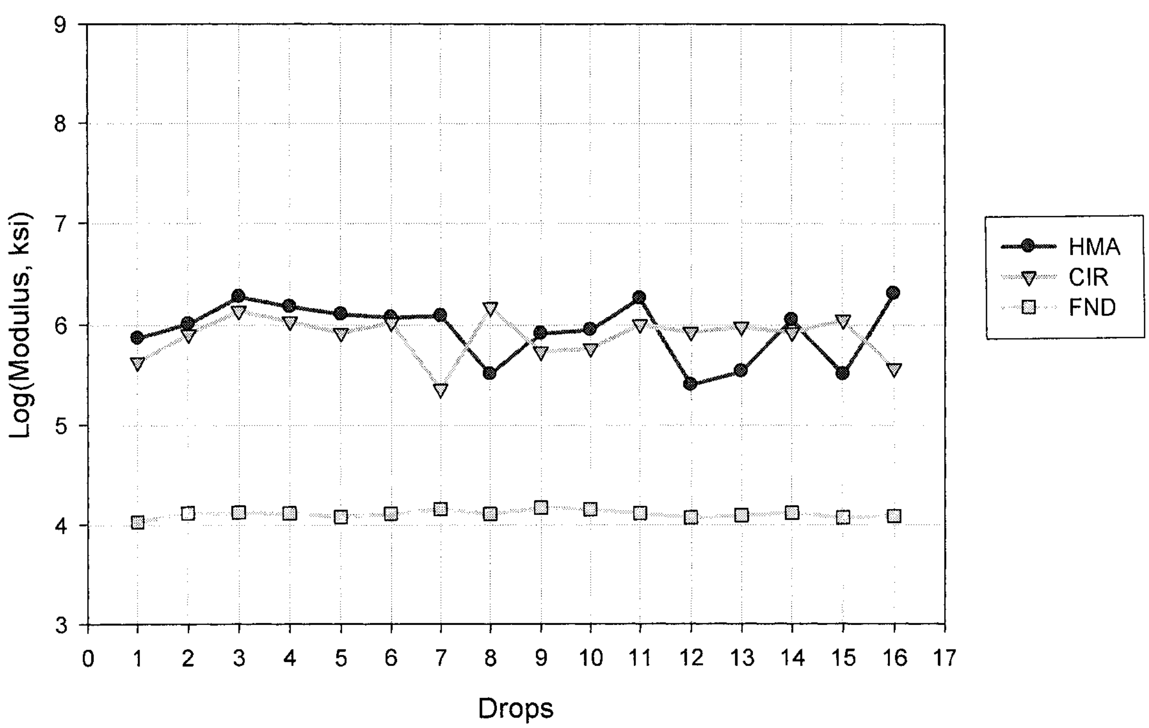
DelawareUS20



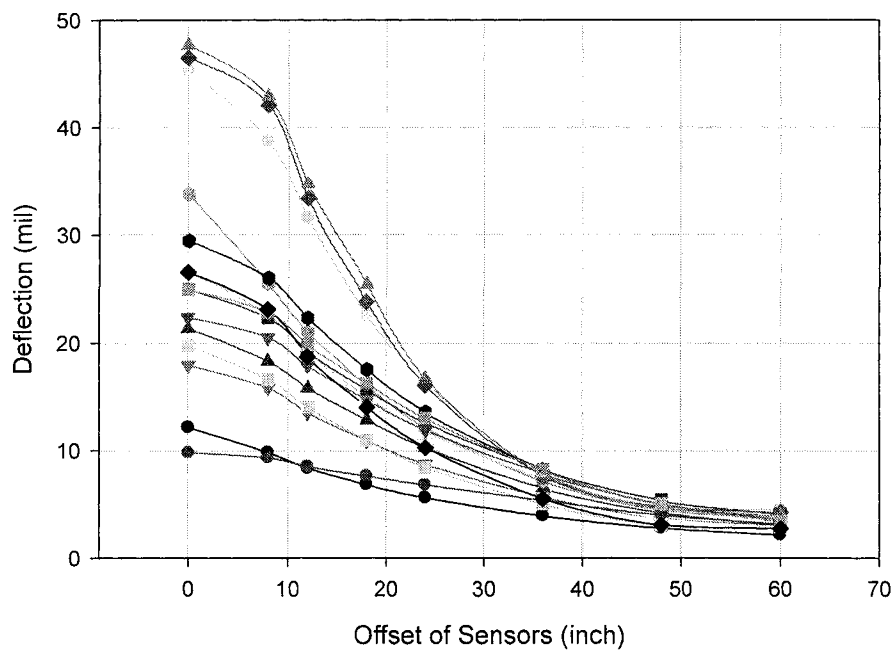


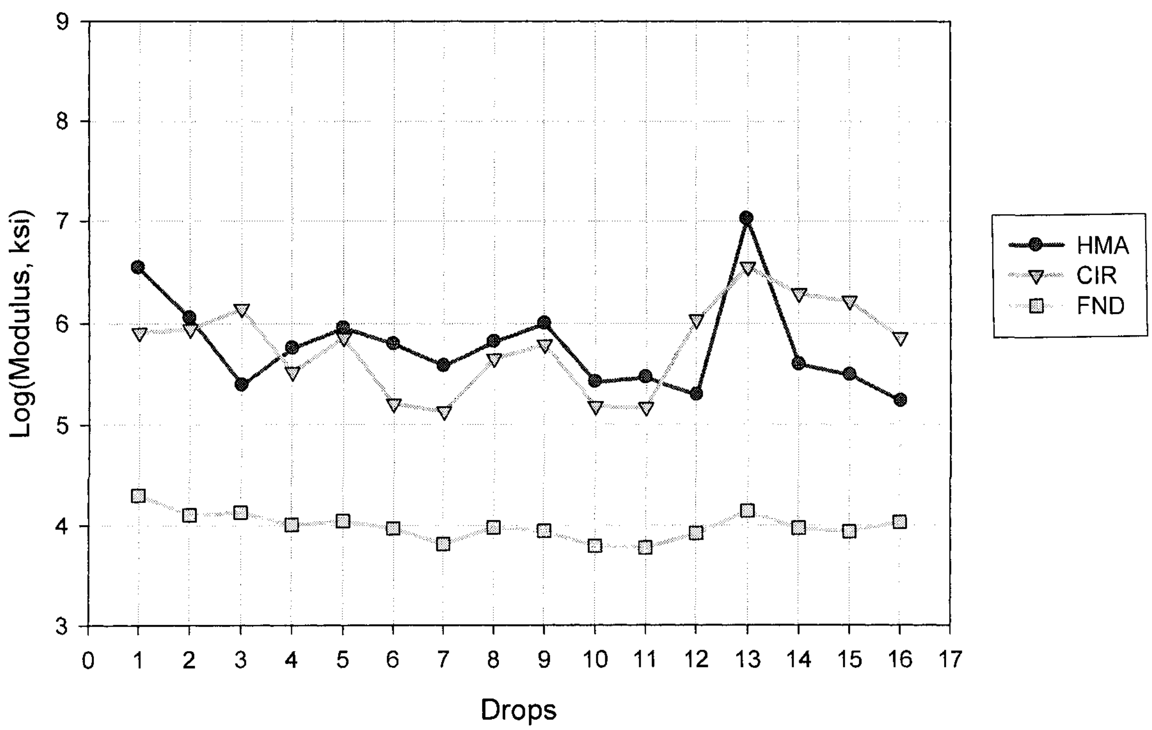
GreeneIA144



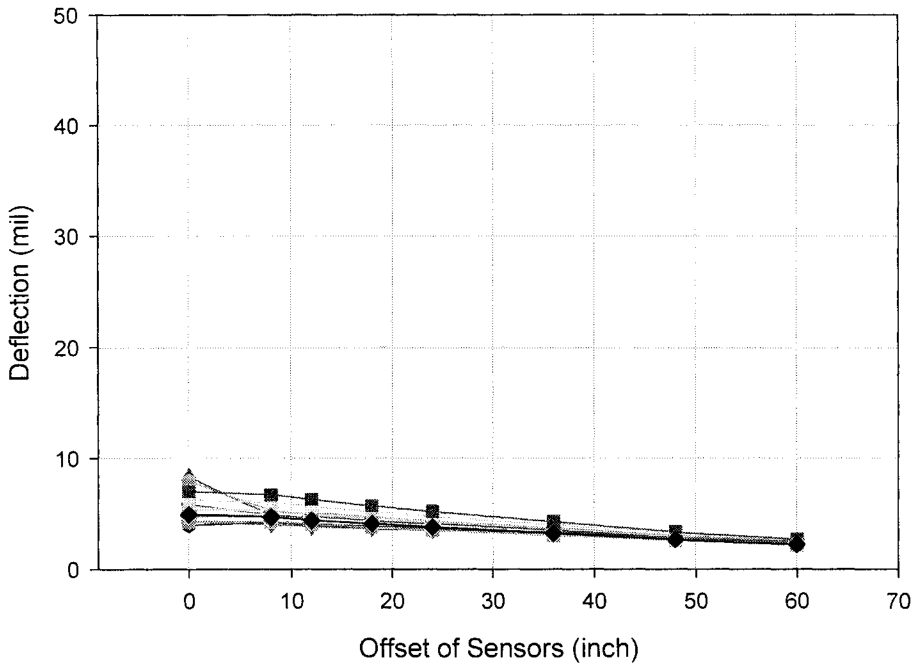


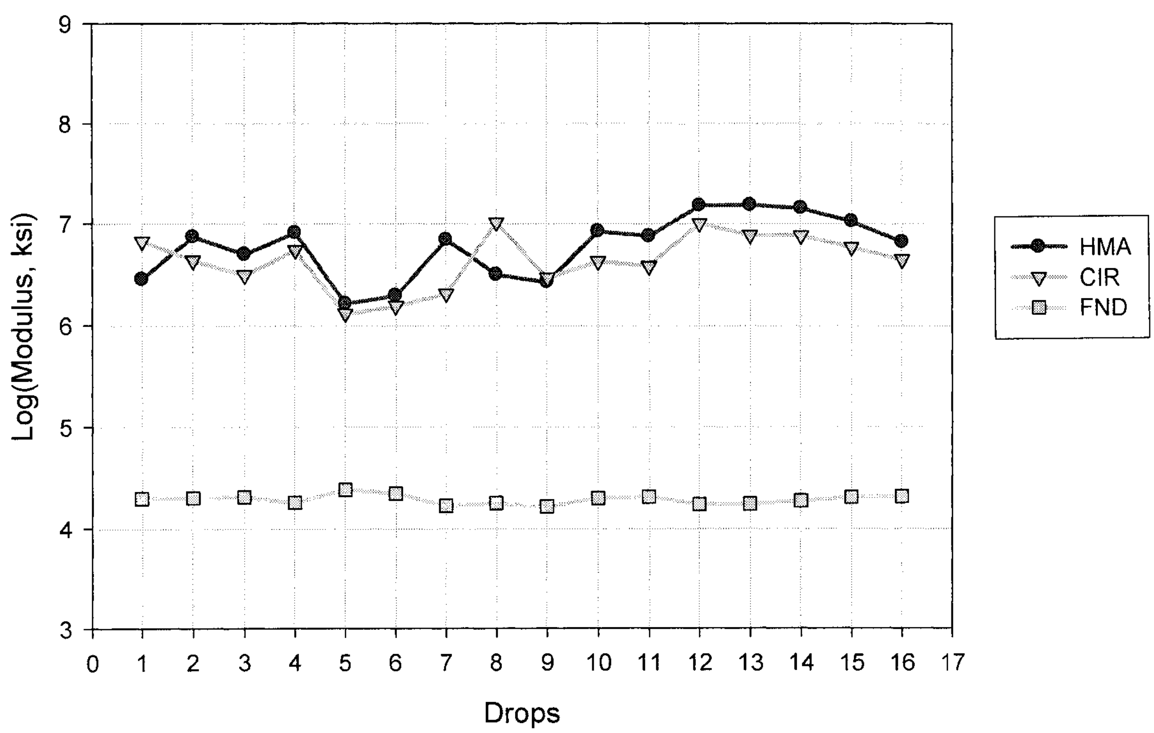
HardinD35


50
40
30
20
10
0
Deflection (mil)
0
10
20
30
40
50
60
70
Offset of Sensors (inch)

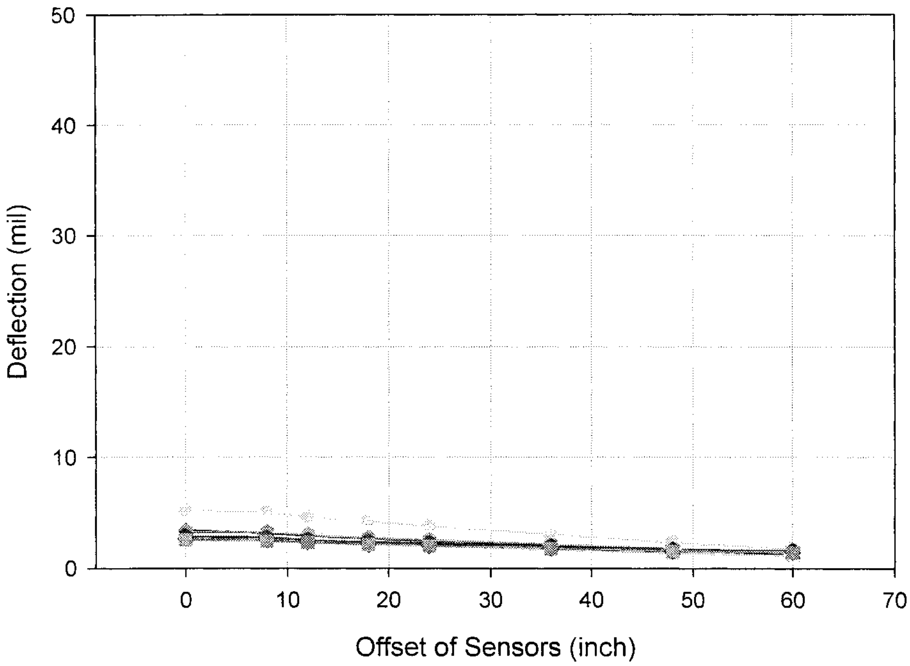

9
8
7
6
5
4
3
Log(Modulus, ksi)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Drops
HMA
CIR
FND

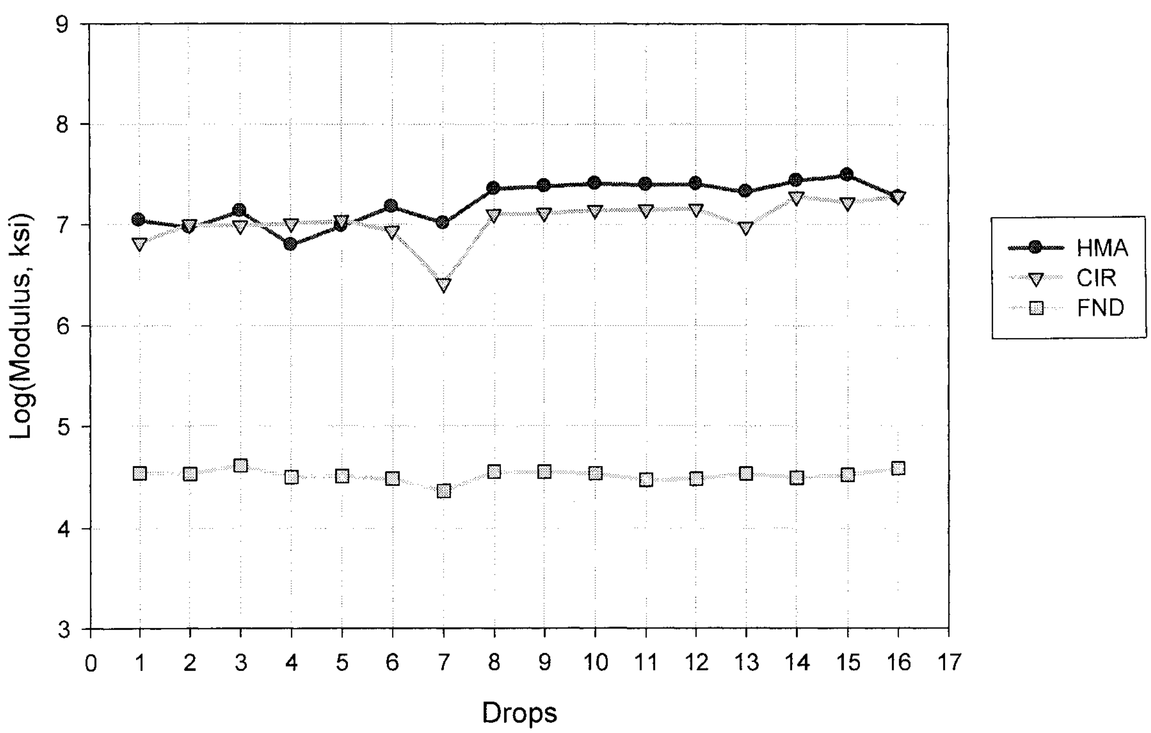
HarrisonIA44



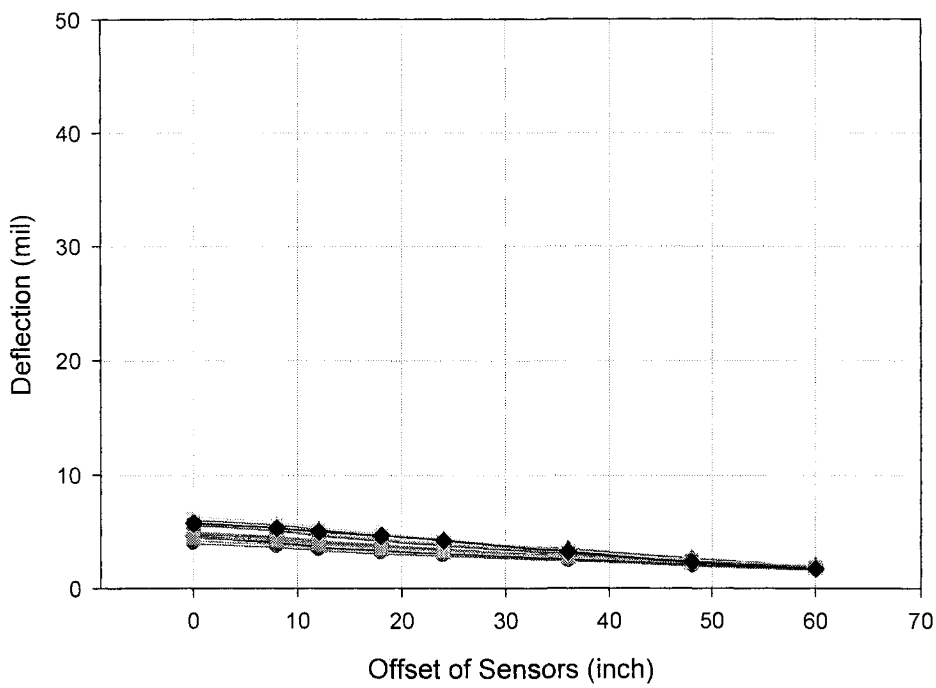


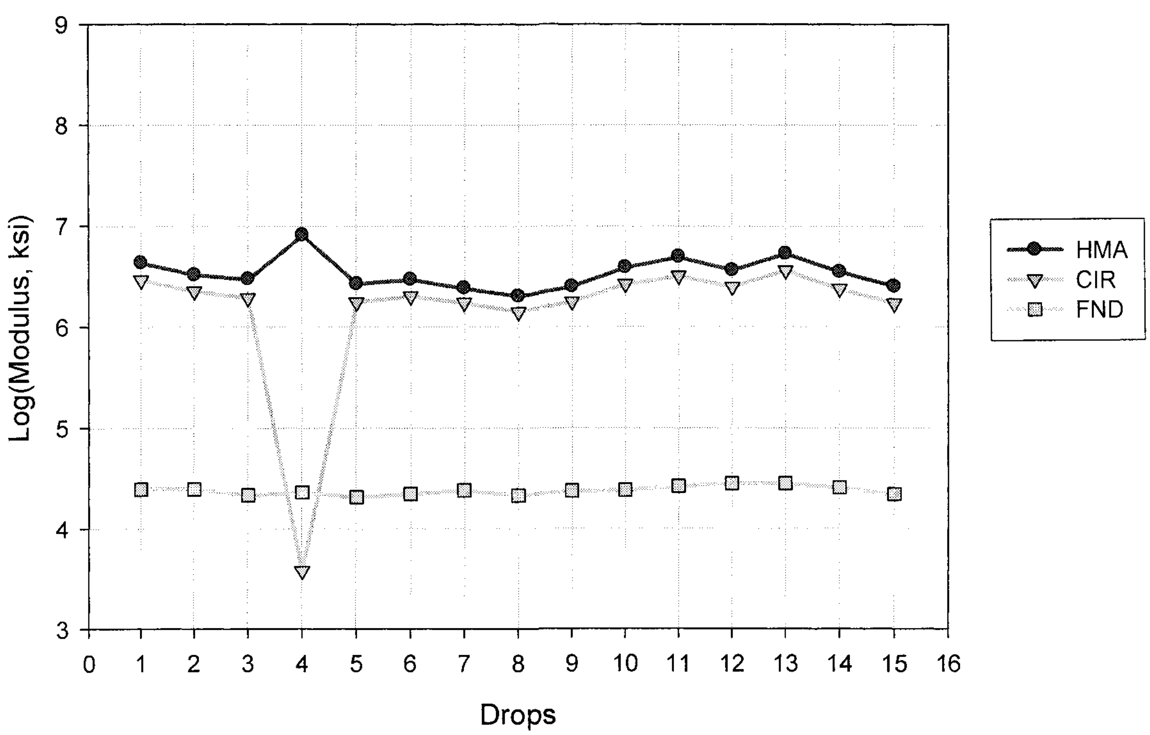
JacksonUS61



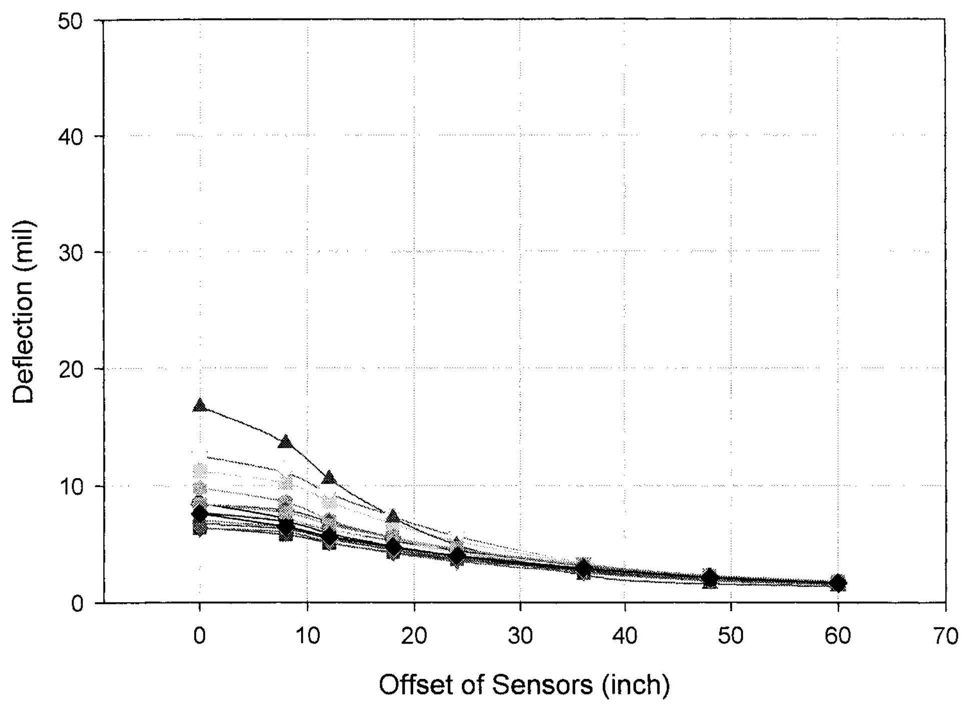


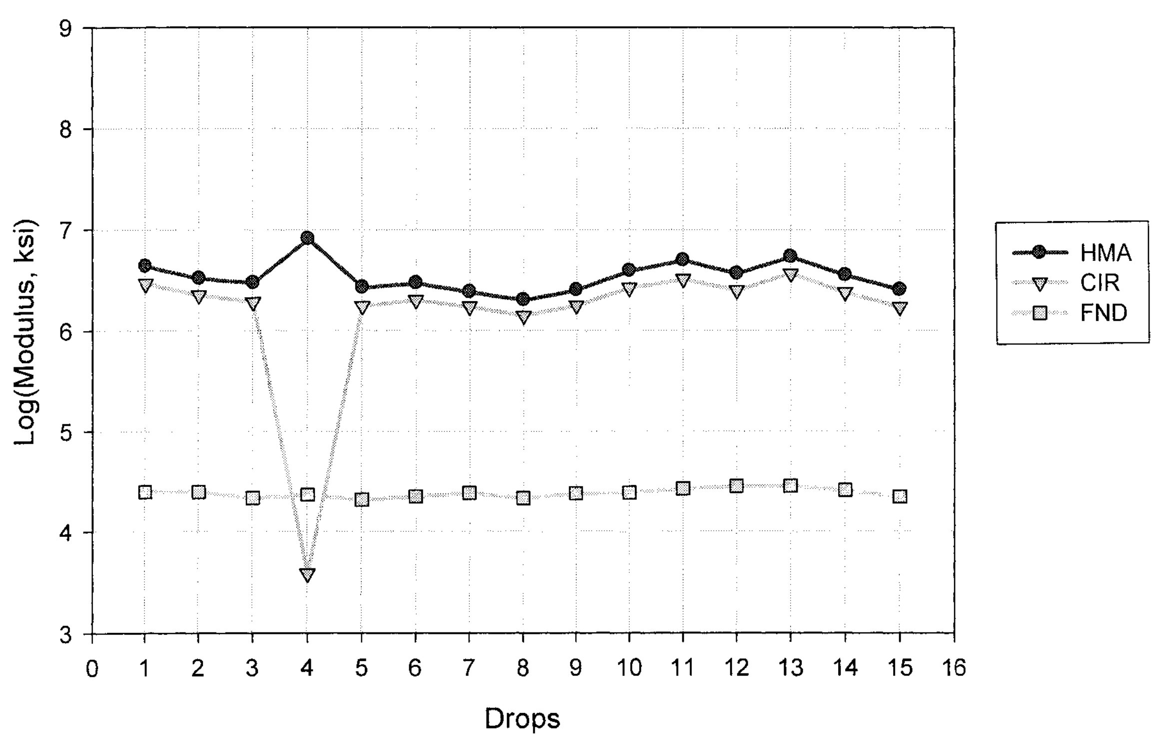
MontgomeryIA48



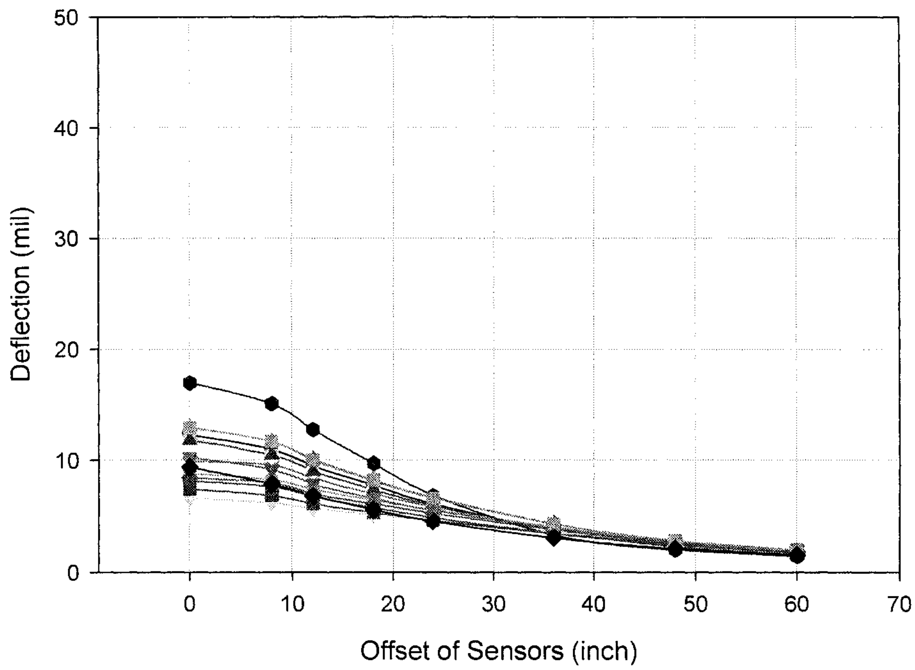


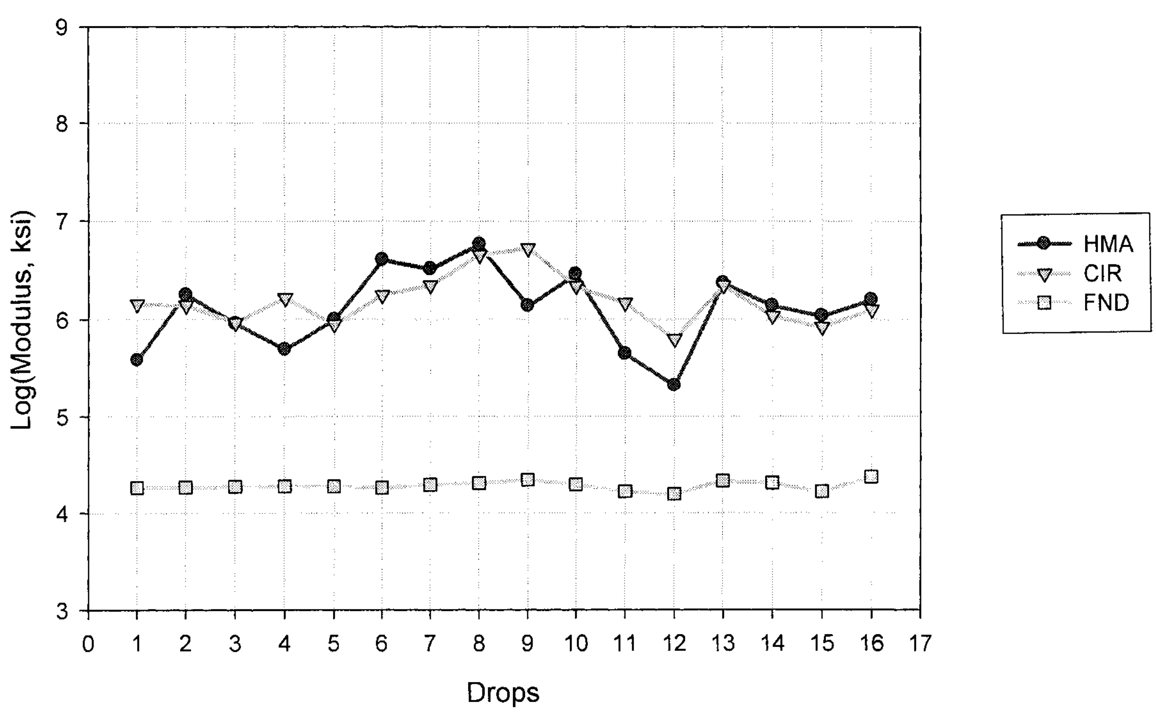
MuscatineF70



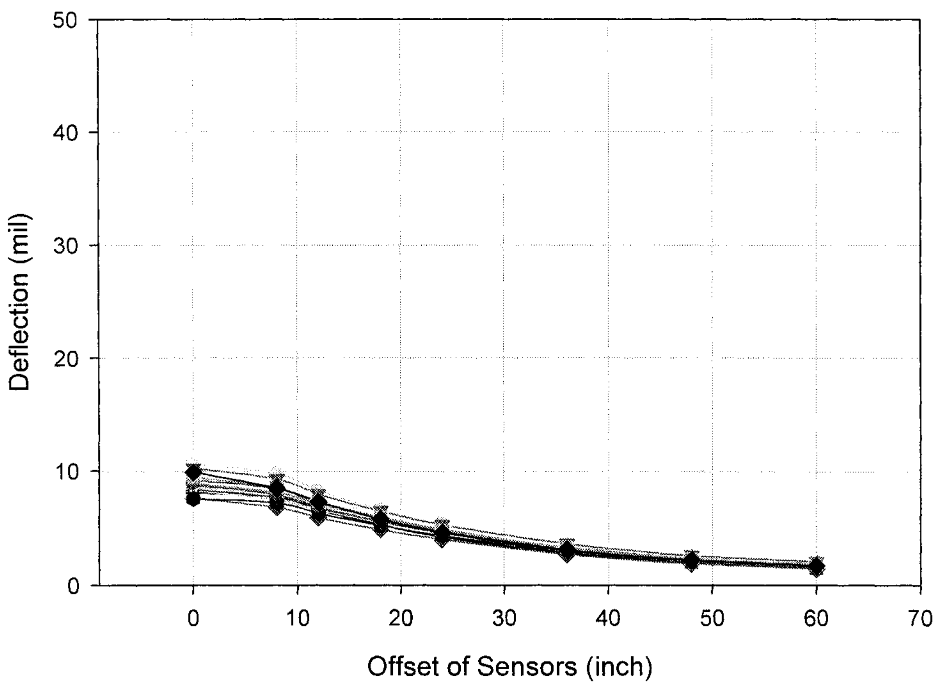


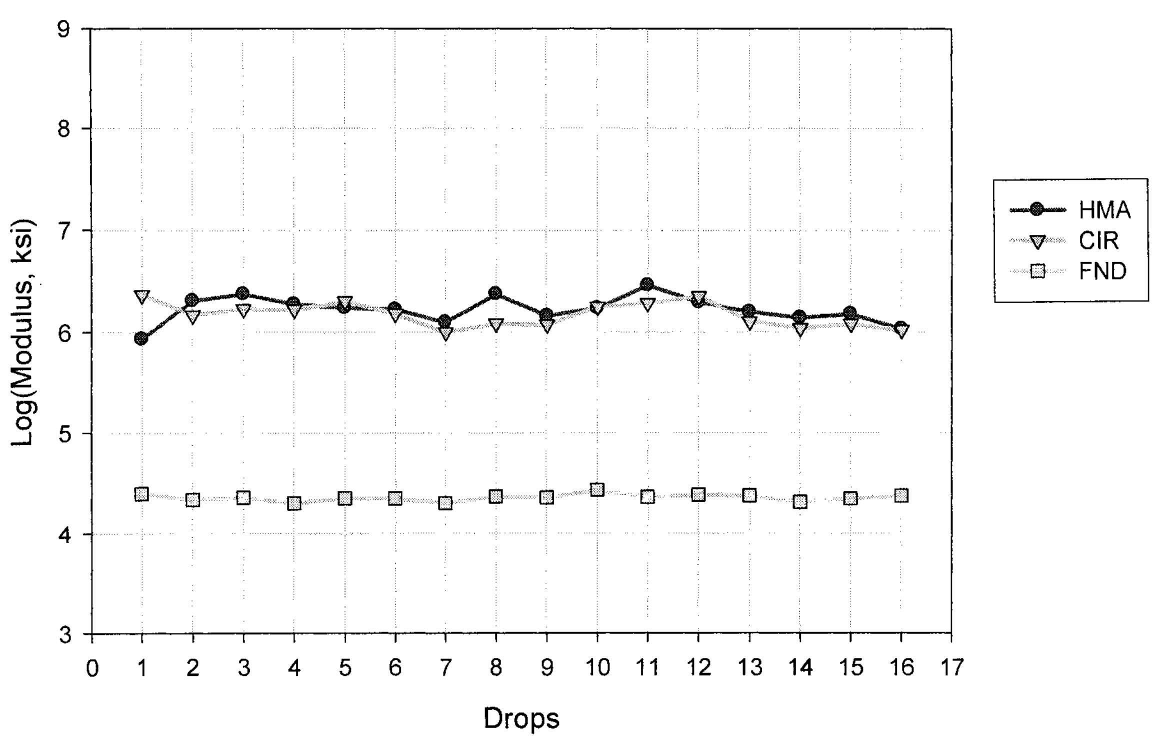
MuscatineG28





MuscatineG28E





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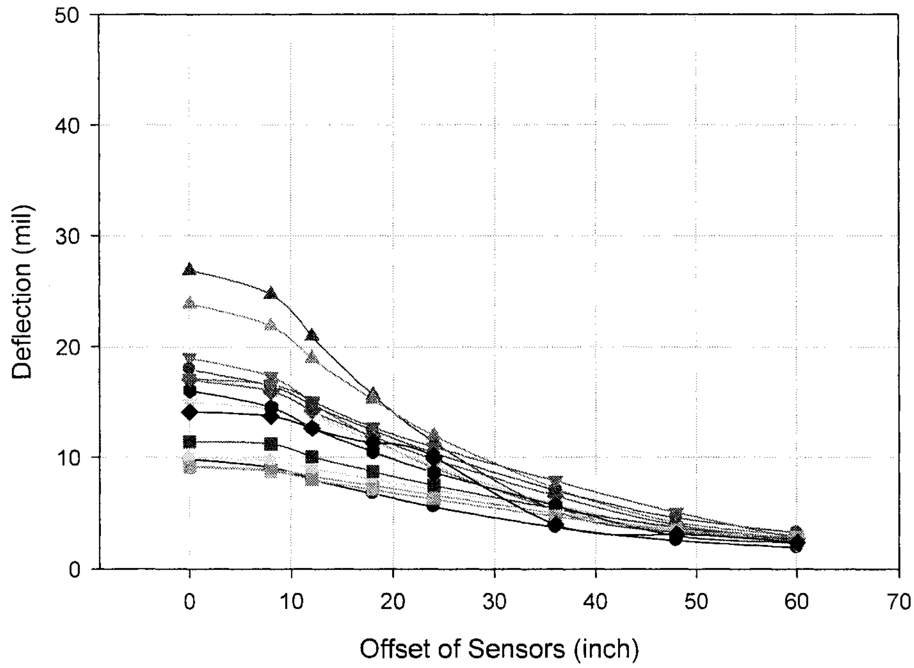
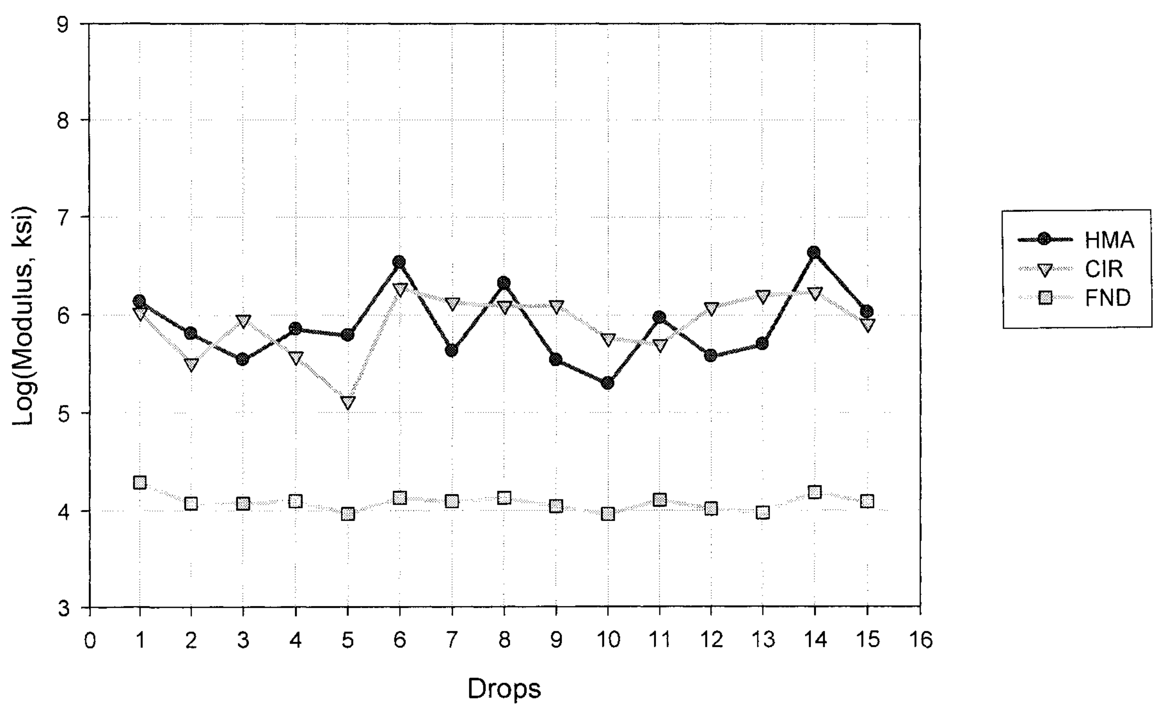
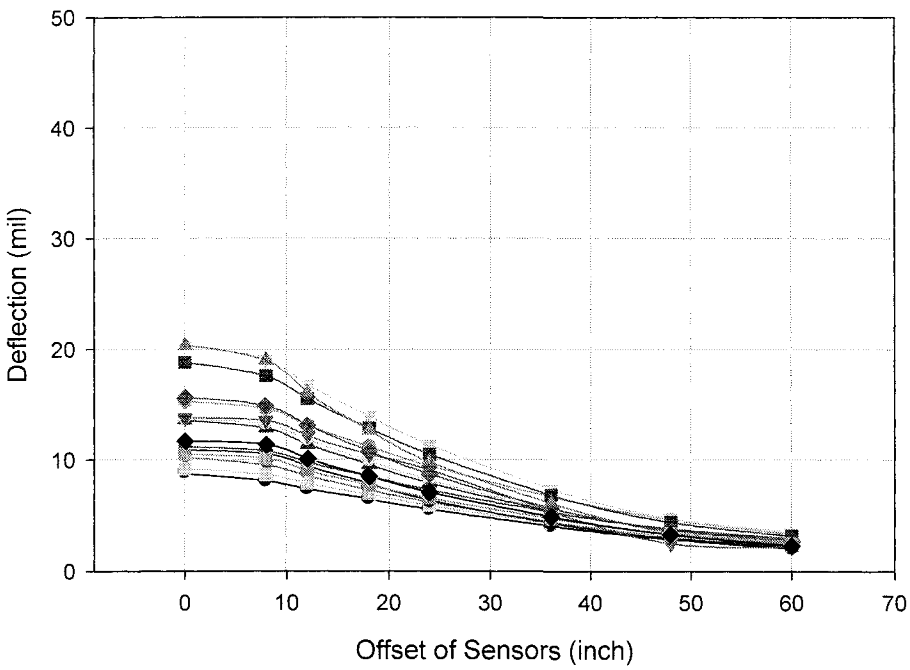
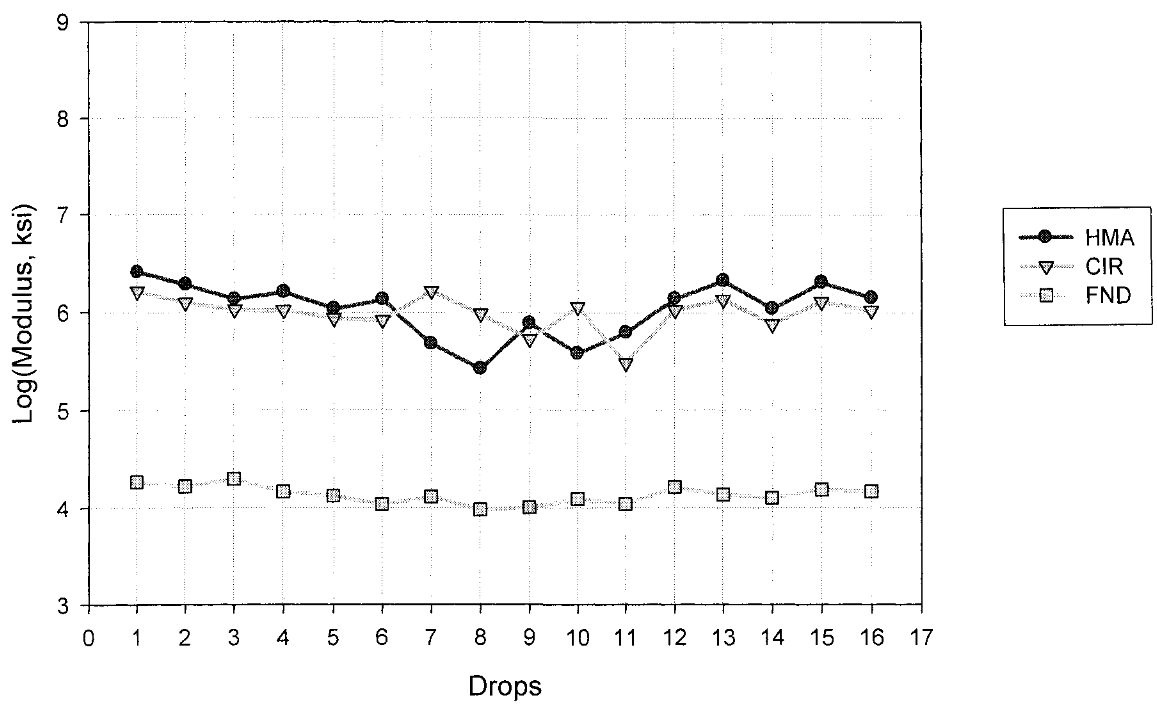


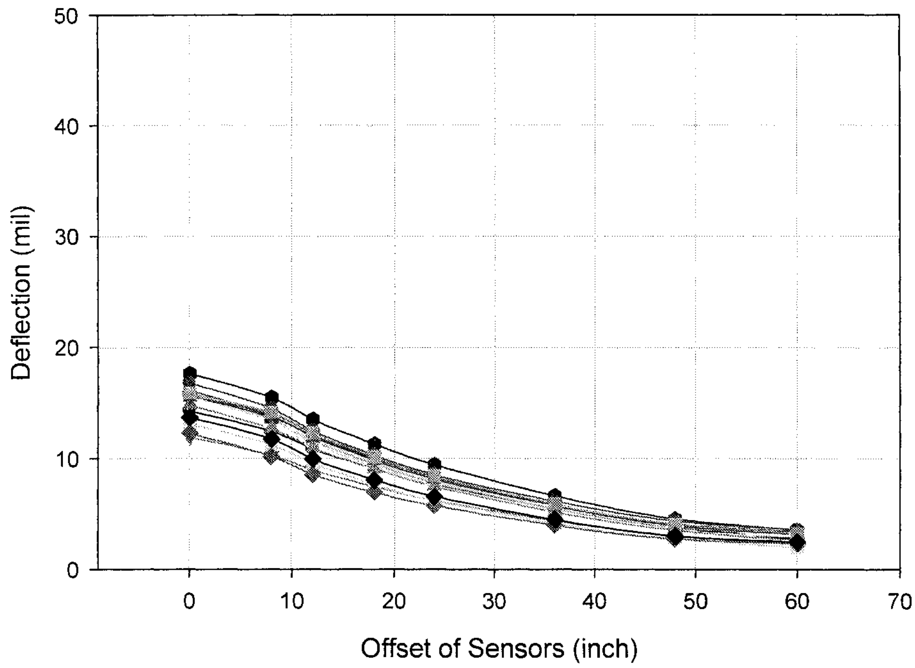


MuscatineY14N

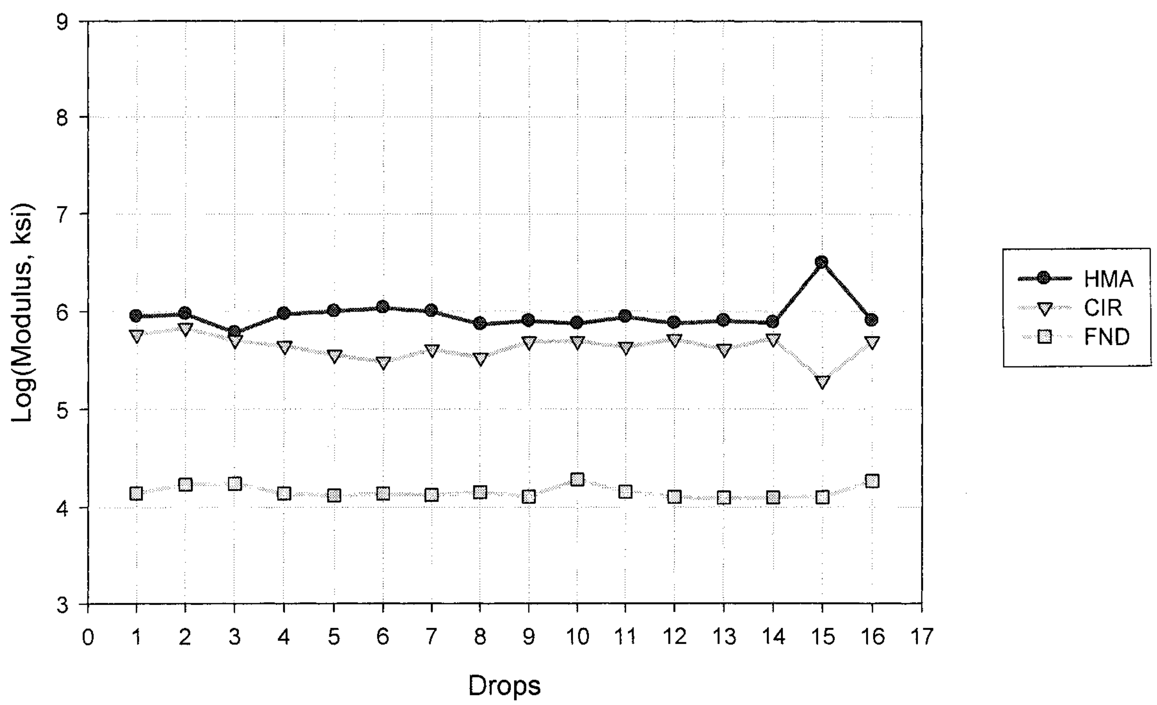




StoryS14SB

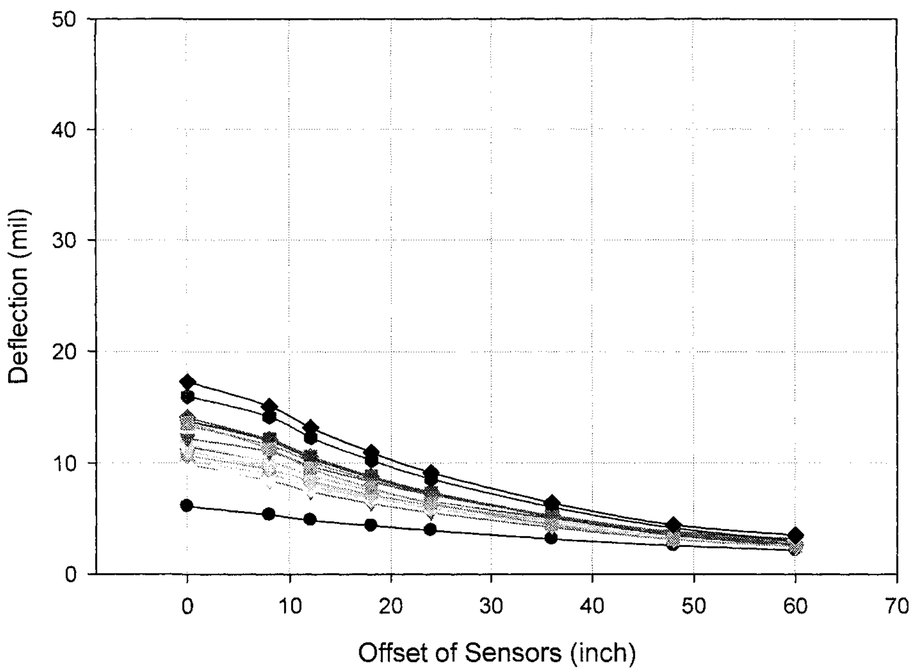


Deflection (mil)
Offset of Sensors (inch)
0
10
20
30
40
50
60
70

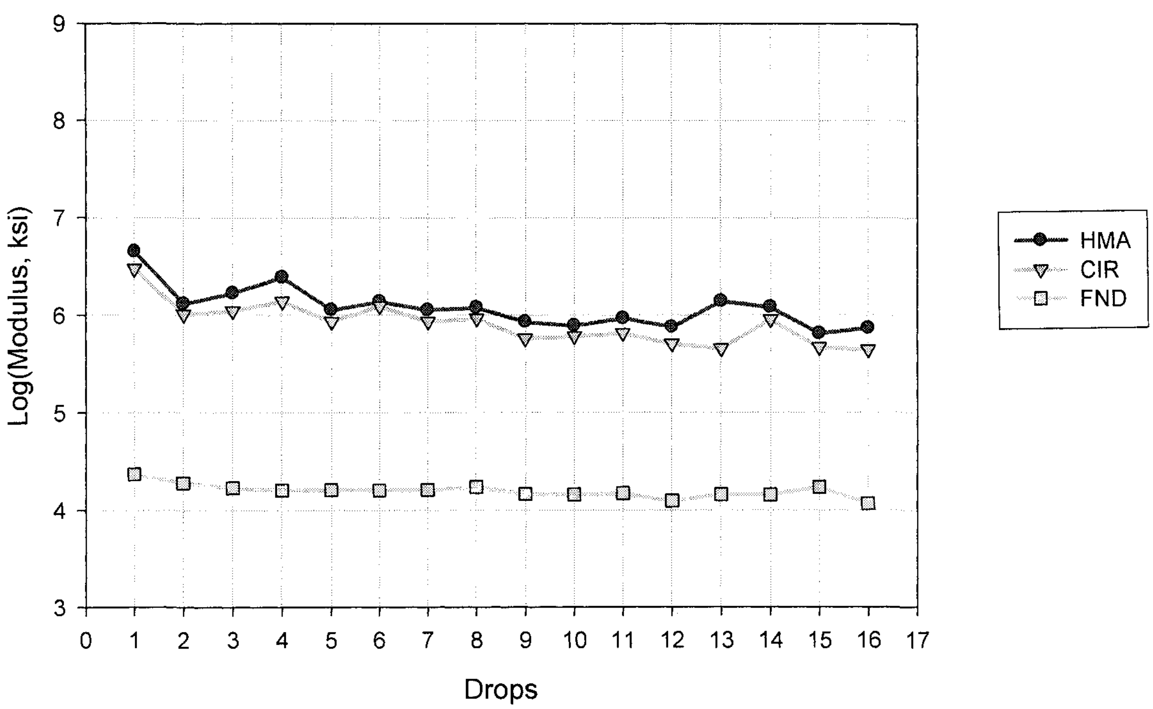


Log(Modulus, ksi)
Drops
HMA
CIR
FND

StoryS14NB

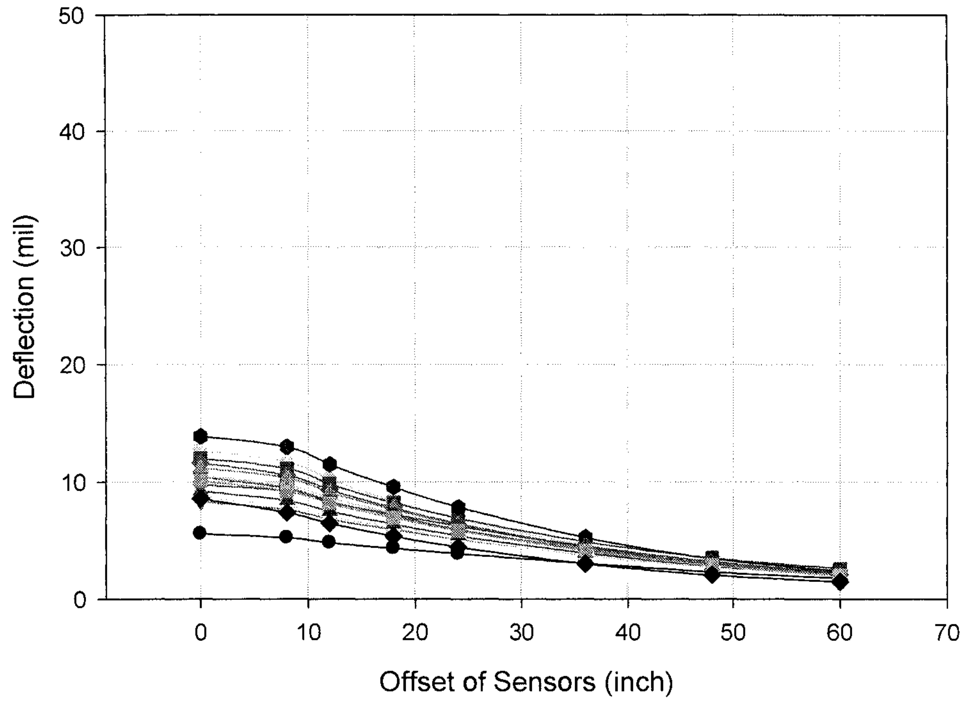


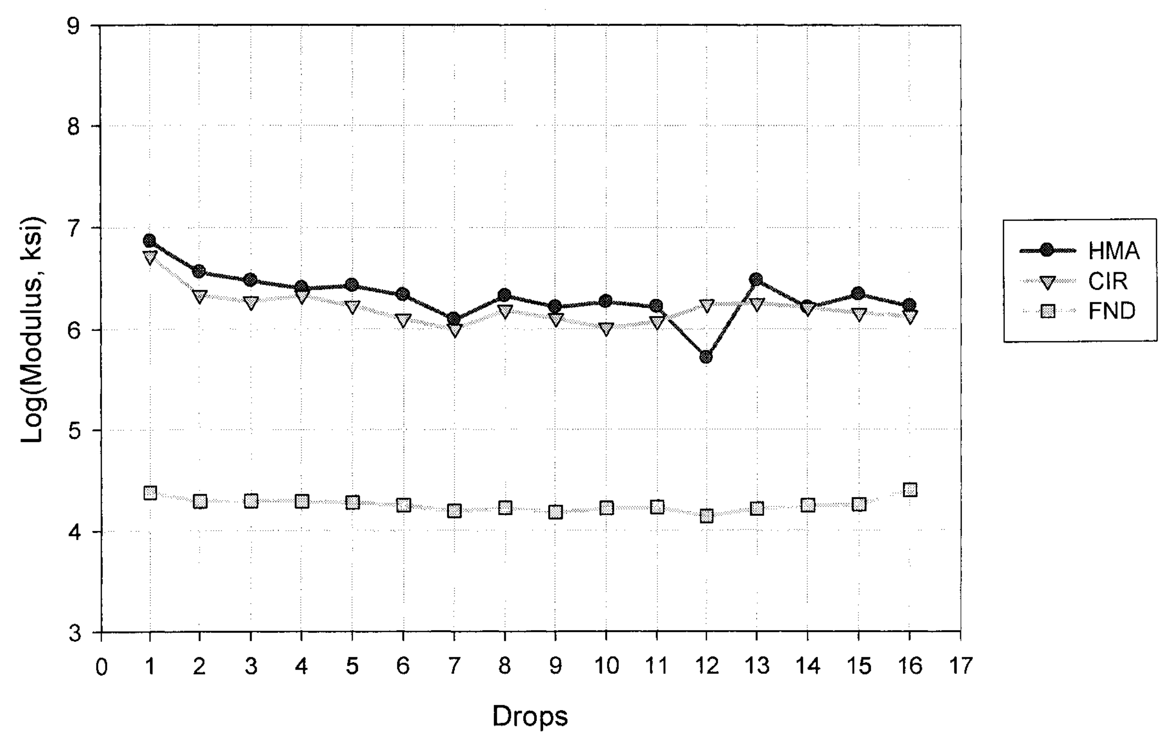
50
40
30
20
10
0
Deflection (mil)
0
10
20
30
40
50
60
70
Offset of Sensors (inch)



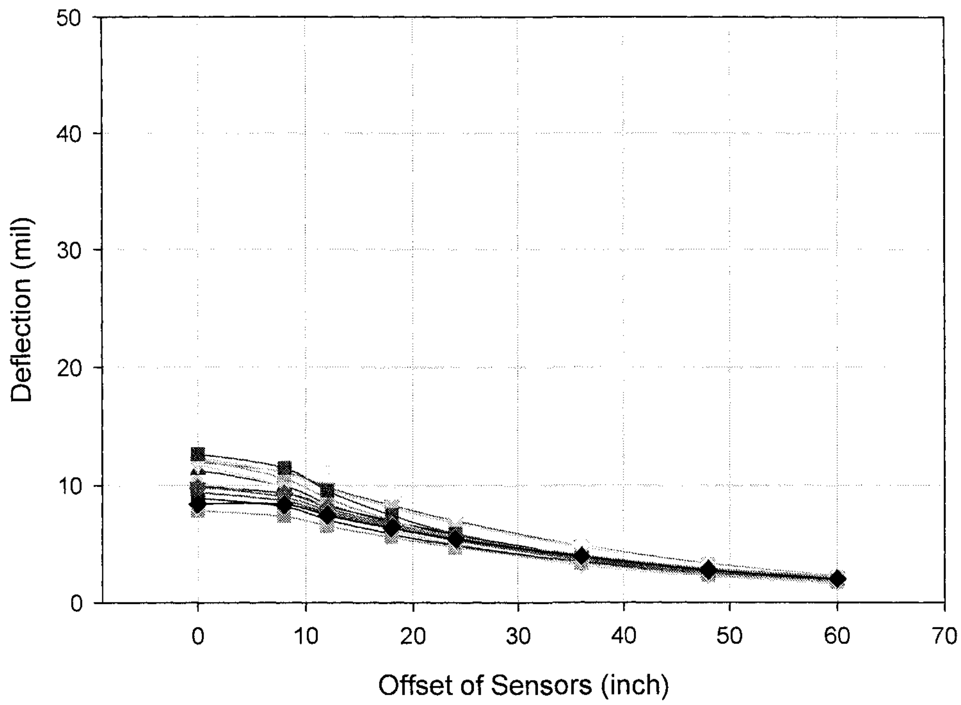
9
8
7
6
5
4
3
Log(Modulus, ksi)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Drops
HMA
CIR
FND

TamaV18a

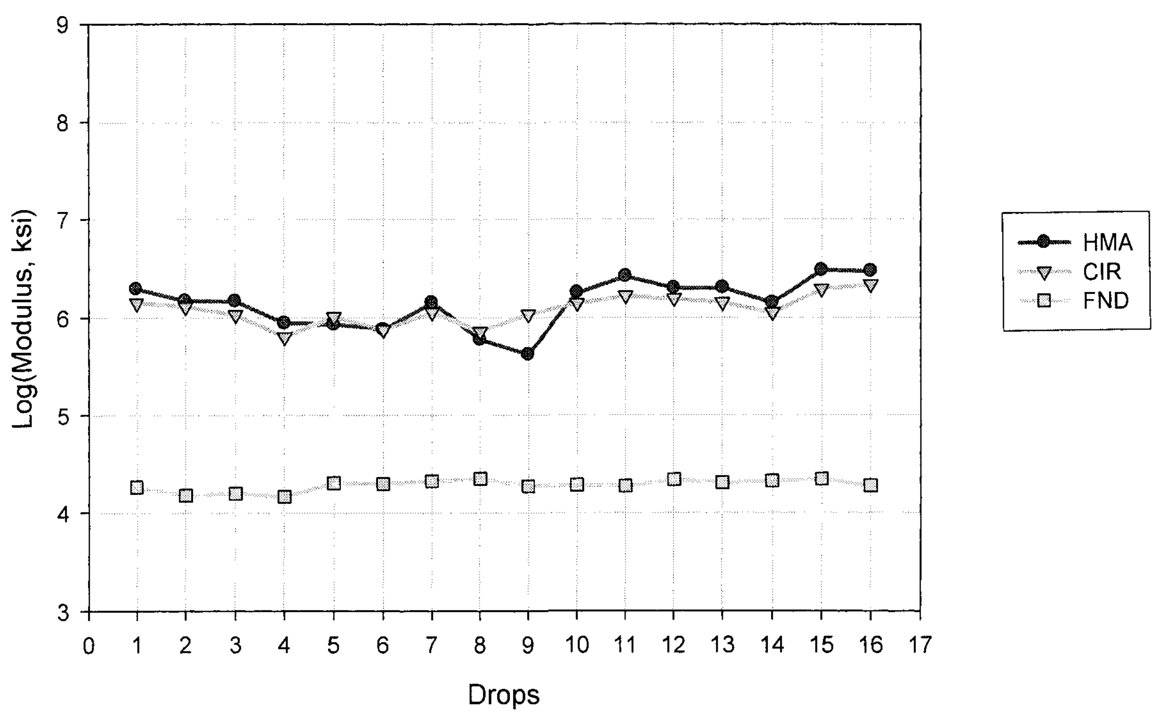

Deflection (mil)
Offset of Sensors (inch)
0
10
20
30
40
50
60
70


Log(Modulus, ksi)
Drops
HMA
CIR
FND

TamaV18b



50
40
30
20
10
0
Deflection (mil)
0
10
20
30
40
50
60
70
Offset of Sensors (inch)



9
8
7
6
5
4
3
Log(Modulus, ksi)
0
1
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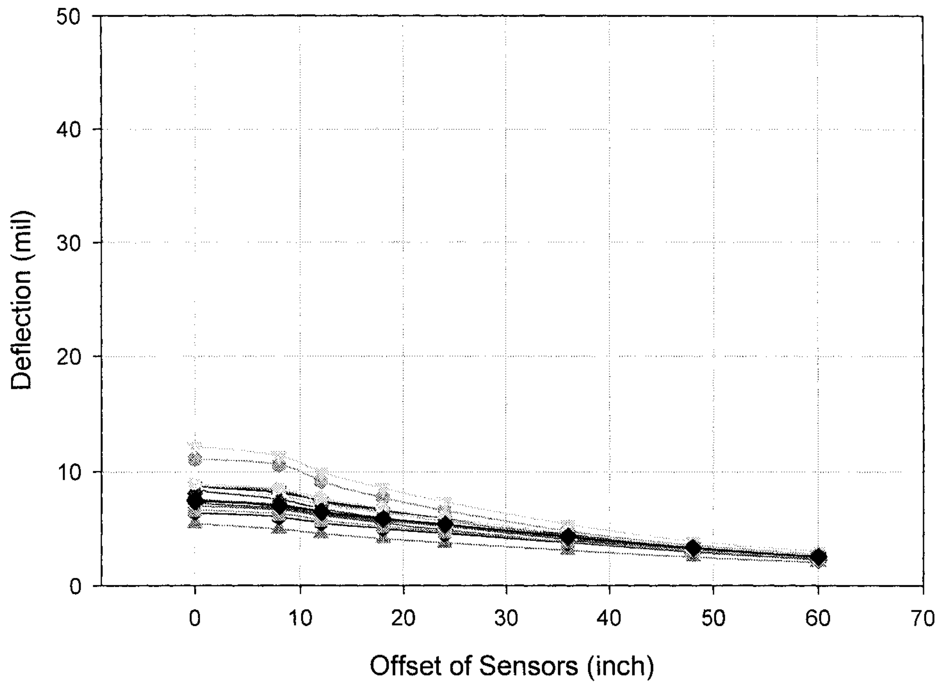
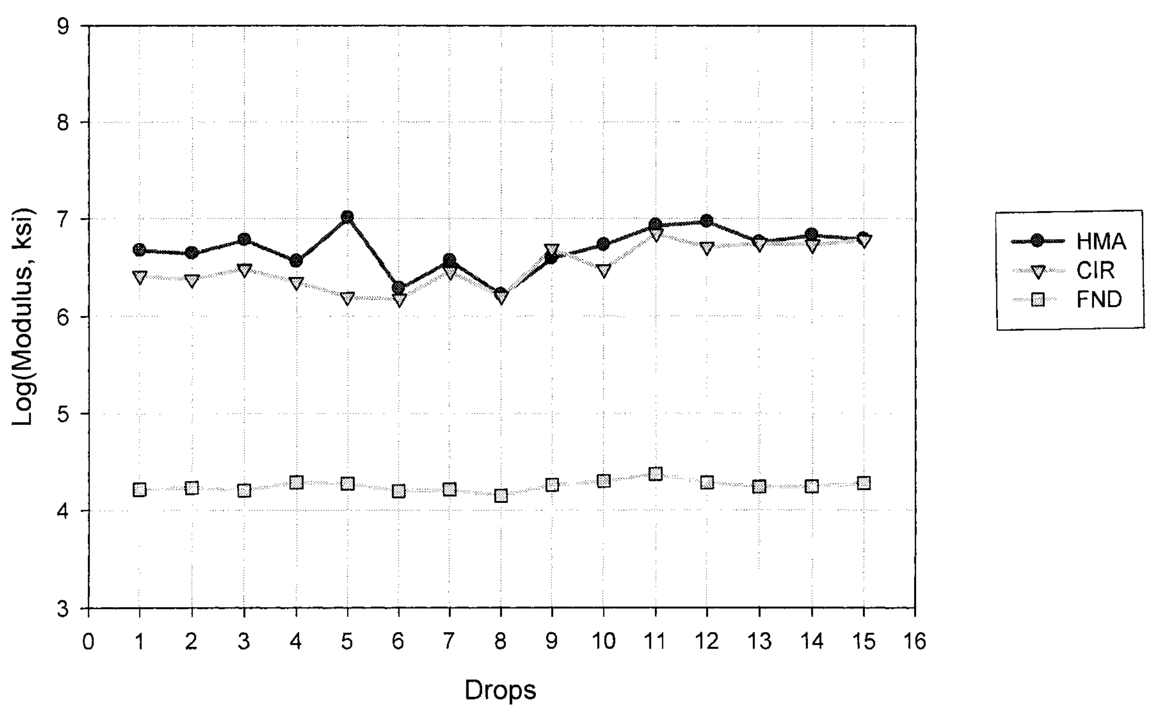
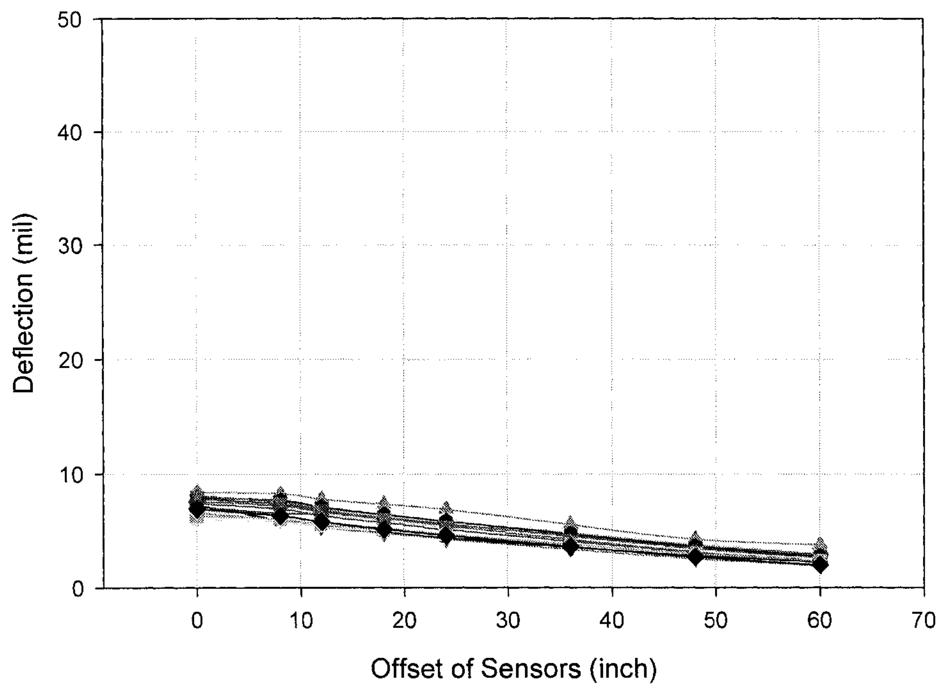
8
9
10
11
12
13
14
15
16
17
Drops
HMA
CIR
FND

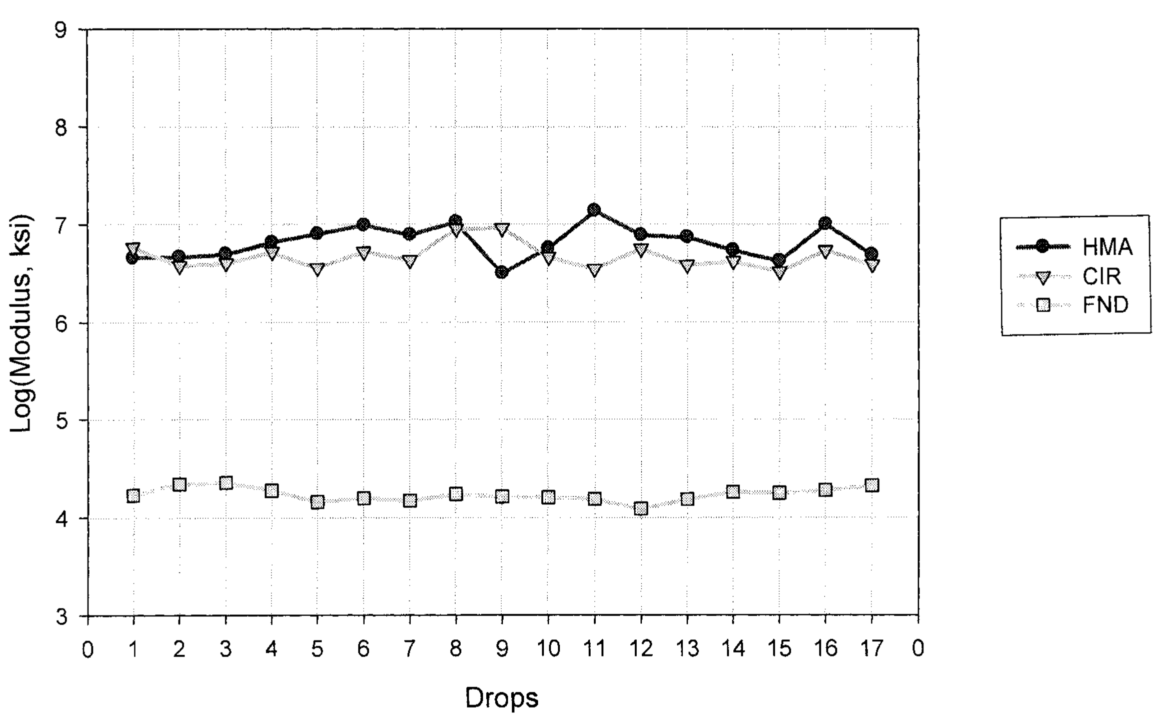
WinnebagoR34



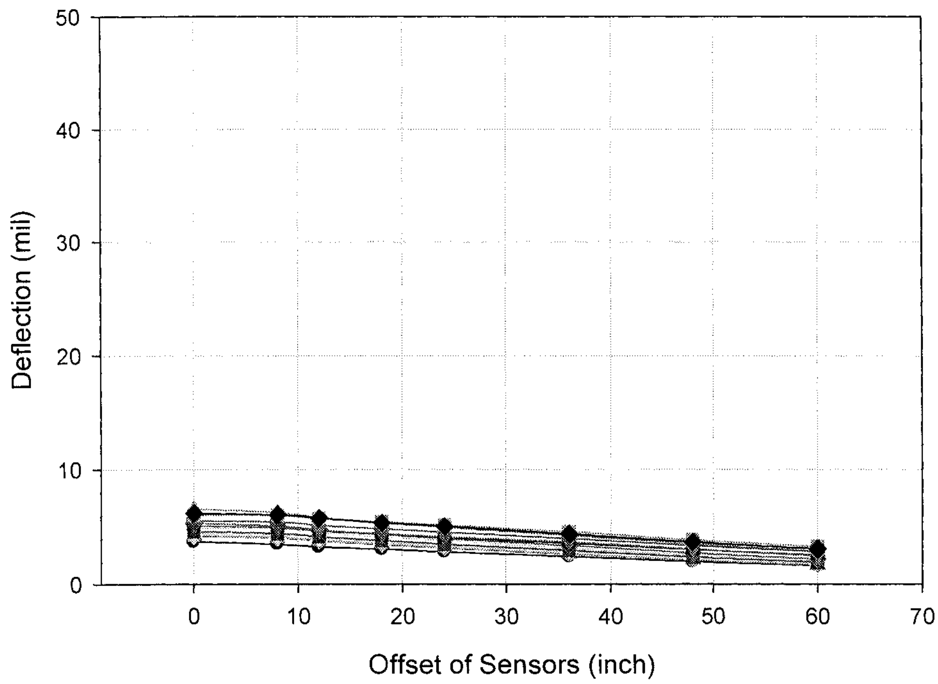


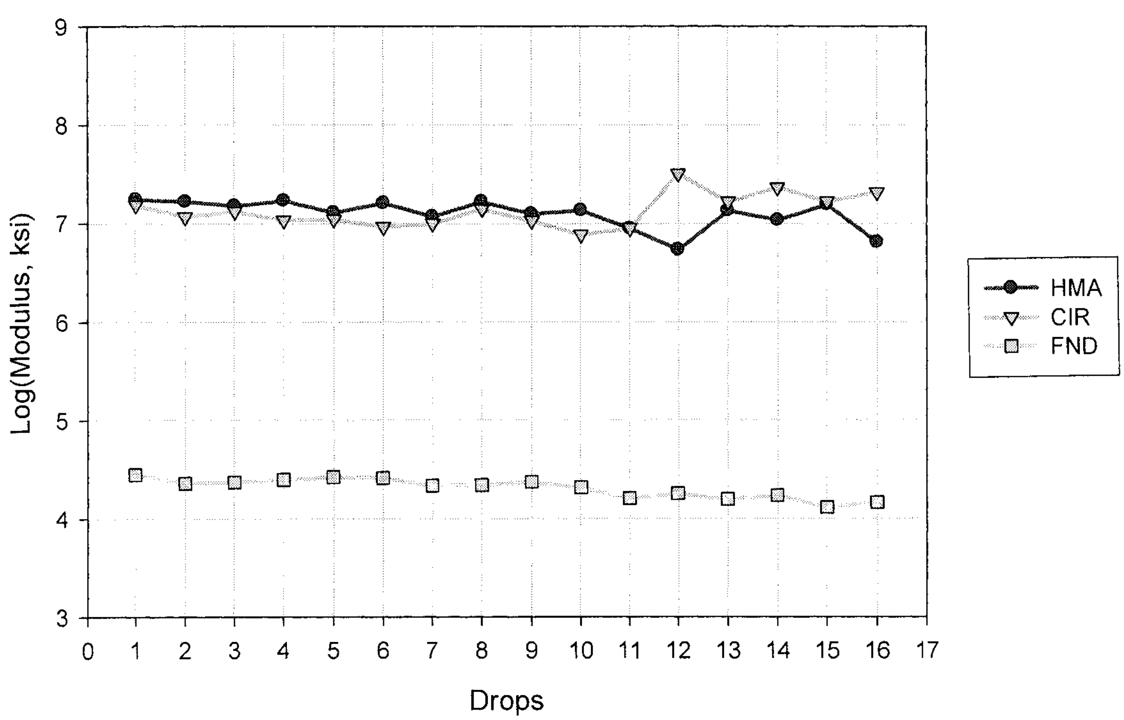
WinnebagoR34b





WinnebagoR60





APPENDIX G. SAS PROGRAM CODE AND SELECTED OUTPUT

1. SAS code for single-order models

```
## read external files (all 24 CIR roads, low traffic roads, and high traffic roads)
PROC IMPORT OUT= MYLIB.Cirsas
            DATAFILE= "C:\Documents and Settings\chdong\Desktop\Allcir.csv"
            DBMS=CSV REPLACE;
     GETNAMES=YES;
     DATAROW=2;
RUN;

PROC IMPORT OUT= MYLIB.Cirlow
            DATAFILE= "C:\Documents and Settings\chdong\Desktop\Cirlow.csv"
            DBMS=CSV REPLACE;
     GETNAMES=YES;
     DATAROW=2;
RUN;

PROC IMPORT OUT= MYLIB.Cirhigh
            DATAFILE= "C:\Documents and Settings\chdong\Desktop\Cirhigh.csv"
            DBMS=CSV REPLACE;
     GETNAMES=YES;
     DATAROW=2;
RUN;


## model selection for all 24 CIR roads
proc reg corr data=Mylib.Cirsas;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=f sle=0.05;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=b sls=0.1;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=stepwise sle=0.15 sls=0.15;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=rsquare sse cp;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=rsquare start=1 stop=4 best=2 sse mse aic cp;
                 title 'CIR: Model Selection';
run;


## develop the regression model for all 24 CIR roads based on model selection results
proc reg corr data=Mylib.Cirsas;
                 model RelativePCI = CumulativeTraffic CIRModulus Va;
                 title 'Single-order model: all 24 CIR Roads';
run;


## model selection for low traffic roads
proc reg corr data=Mylib.Cirlow;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=f sle=0.05;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=b sls=0.1;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=stepwise sle=0.15 sls=0.15;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=rsquare sse cp;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=rsquare start=1 stop=4 best=2 sse mse aic cp;
                 title 'CIR: Model Selection';
run;
```

```
## develop the regression model for low traffic roads based on model selection results
proc reg corr data=Mylib.Cirlow;
                model RelativePCI = CIRModulus IDTwet S;
                title 'Single-order model: low traffic CIR Roads';
run;

## model selection for high traffic roads
proc reg corr data=Mylib.Cirhigh;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=f sle=0.05;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=b sls=0.1;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=stepwise sle=0.15 sls=0.15;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=rsquare sse cp;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va IDTwet G S
Aggregate/selection=rsquare start=1 stop=4 best=2 sse mse aic cp;
                title 'CIR: Model Selection';
run;

## develop the regression model for high traffic roads based on model selection results
proc reg corr data=Mylib.Cirhigh;
                model RelativePCI = CumulativeTraffic CIRModulus Va;
                title 'Single-order model: high traffic CIR Roads';
run;
```

2. SAS code for higher-order models

```
## read external files (all 24 CIR roads, low traffic roads, and high traffic roads)
PROC IMPORT OUT= MYLIB.Cirsas
            DATAFILE= "C:\Documents and Settings\chdong\Desktop\Allcir.csv"
            DBMS=CSV REPLACE;
     GETNAMES=YES;
     DATAROW=2;
RUN;

PROC IMPORT OUT= MYLIB.Cirlow
            DATAFILE= "C:\Documents and Settings\chdong\Desktop\Cirlow.csv"
            DBMS=CSV REPLACE;
     GETNAMES=YES;
     DATAROW=2;
RUN;

PROC IMPORT OUT= MYLIB.Cirhigh
            DATAFILE= "C:\Documents and Settings\chdong\Desktop\Cirhigh.csv"
            DBMS=CSV REPLACE;
     GETNAMES=YES;
     DATAROW=2;
RUN;


## model selection for all 24 CIR roads
proc reg corr data=Mylib.Allcir;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=f sle=0.05;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=b sls=0.1;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=stepwise sle=0.15 sls=0.15;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=rsquare sse cp;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=rsquare start=1 stop=4 best=2 sse mse aic cp;
                 title 'CIR: Model Selection';
run;


## develop the regression model for all 24 CIR roads based on model selection results
proc reg corr data=Mylib.Allcir;
                 model RelativePCI = CumulativeTraffic CIRModulus Va3 Volume;
                 title 'Higher-order model: all 24 CIR Roads';
run;


## model selection for low traffic roads
proc reg corr data=Mylib.Cirlow;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=f sle=0.05;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=b sls=0.1;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=stepwise sle=0.15 sls=0.15;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=rsquare sse cp;
                 model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=rsquare start=1 stop=4 best=2 sse mse aic cp;
                 title 'CIR: Model Selection';
run;
```

```
## develop the regression model for low traffic roads based on model selection results
proc reg corr data=Mylib.Cirlow;
                model RelativePCI = CIRModulus IDTwet2 S;
                title 'Higher-order model: low traffic CIR Roads';
run;


## model selection for high traffic roads
proc reg corr data=Mylib.Cirhigh;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=f sle=0.05;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=b sls=0.1;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=stepwise sle=0.15 sls=0.15;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=rsquare sse cp;
                model RelativePCI = CumulativeTraffic CIRModulus FNDModulus Va3 IDTwet2 G2 S
Aggregate/selection=rsquare start=1 stop=4 best=2 sse mse aic cp;
                title 'CIR: Model Selection';
run;


## develop the regression model for high traffic roads based on model selection results
proc reg corr data=Mylib.Cirhigh;
                model RelativePCI = CumulativeTraffic CIRModulus Va3;
                title 'Higher-order model: high traffic CIR Roads';
run;
```

3. Selected SAS output for single-order models

CIR: Model Selection for all 24 CIR roads

Summary of Forward Selection

Step	Variable Entered	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	CIRModulus	CIRModulus	1	0.2274	0.2274	10.3459	6.18	0.0214
2	G	G	2	0.2367	0.4641	3.3560	8.83	0.0075

Summary of Backward Elimination

Step	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	S	S	7	0.0023	0.6291	7.0860	0.09	0.7737
2	Aggregate	Aggregate	6	0.0179	0.6112	5.7670	0.73	0.4078
3	IDTwet	IDTwet	5	0.0242	0.5870	4.6872	1.00	0.3329
4	FNDModulus	FNDModulus	4	0.0259	0.5611	3.6696	1.06	0.3166
5	G	G	3	0.0324	0.5287	2.9020	1.33	0.2638

Summary of Stepwise Selection

Step	Variable Entered	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)
1	CIRModulus		CIRModulus	1	0.2274	0.2274	10.3459
2	G		G	2	0.2367	0.4641	3.3560
3	CumulativeTraffic		CumulativeTraffic	3	0.0608	0.5249	3.0450

R-Square Selection Method

Number in Model	R-Square	C(p)	AIC	MSE	SSE	Variables in Model
1	0.2274	10.3459	104.8383	87.81632	1844.14266	CIRModulus
1	0.1199	14.4281	107.8340	100.03236	2100.67951	CumulativeTraffic
2	0.4641	3.3560	98.4255	63.96030	1279.20601	CIRModulus G
2	0.3988	5.8360	101.0696	71.75256	1435.05121	CIRModulus S
3	0.5287	2.9020	97.4708	59.21005	1124.99101	CumulativeTraffic CIRModulus Va
3	0.5249	3.0450	97.6538	59.68288	1133.97469	CumulativeTraffic CIRModulus G
4	0.5691	3.3660	97.4075	57.13687	1028.46371	CumulativeTraffic CIRModulus G Aggregate
4	0.5611	3.6696	97.8303	58.19685	1047.54328	CumulativeTraffic CIRModulus Va G

Single-order model: all 24 CIR Roads

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1312.31479	437.43826	7.77	0.0012
Error	20	1125.68521	56.28426		
Corrected Total	23	2438.00000			

Root MSE	7.50228	R-Square	0.5383
Dependent Mean	0	Adj R-Sq	0.4690
Coeff Var	.		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-8.35954	6.24829	-1.34	0.1959
CumulativeTraffic	CumulativeTraffic	1	-0.64808	0.24254	-2.67	0.0146
CIRModulus	CIRModulus	1	-1.33048	0.38058	-3.50	0.0023
Va	Va	1	2.05873	0.65330	3.15	0.0050

CIR: Model Selection for low traffic roads

The REG Procedure
Model: MODEL1
Dependent Variable: RelativePCI RelativePCI

No variable met the 0.0500 significance level for entry into the model.

Summary of Backward Elimination

Step	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	FNDModulus	FNDModulus	7	0.0035	0.5357	7.0229	0.02	0.8894
2	CumulativeTraffic	CumulativeTraffic	6	0.0161	0.5196	5.1277	0.14	0.7285
3	G	G	5	0.0214	0.4982	3.2668	0.22	0.6570
4	Aggregate	Aggregate	4	0.0032	0.4951	1.2874	0.04	0.8524
5	Va	Va	3	0.0108	0.4843	-0.6423	0.15	0.7104
6	IDTwet	IDTwet	2	0.1929	0.2914	-1.3867	2.99	0.1219
7	S	S	1	0.1771	0.1143	-2.2334	2.25	0.1679
8	CIRModulus	CIRModulus	0	0.1143	0.0000	-3.4893	1.29	0.2825

CIR: Model Selection

The REG Procedure
Model: MODEL3
Dependent Variable: RelativePCI RelativePCI

No variable met the 0.1500 significance level for entry into the model.

R-Square Selection Method

Number in Model	R-Square	C(p)	AIC	MSE	SSE	Variables in Model
1	0.1748	-2.6273	50.2230	56.49990	564.99895	IDTwet
1	0.1257	-2.3079	50.9160	59.85865	598.58650	CumulativeTraffic
2	0.3586	-1.8243	49.1984	48.79111	439.11995	CumulativeTraffic CIRModulus
2	0.3197	-1.5708	49.9056	51.75305	465.77741	CumulativeTraffic FNDModulus
3	0.4843	-0.6423	48.5819	44.13673	353.09380	CIRModulus IDTwet S
3	0.4643	-0.5120	49.0390	45.85012	366.80098	CIRModulus Va IDTwet
4	0.4971	1.2744	50.2804	49.19050	344.33348	CumulativeTraffic CIRModulus IDTwet S
4	0.4951	1.2874	50.3281	49.38619	345.70331	CIRModulus Va IDTwet S

Single-order model: low traffic CIR Roads

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	331.57286	110.52429	2.50	0.1331
Error	8	353.09380	44.13673		
Corrected Total	11	684.66667			

Root MSE	6.64355	R-Square	0.4843
Dependent Mean	4.66667	Adj R-Sq	0.2909
Coeff Var	142.36174		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-14.99778	10.12637	-1.48	0.1769
CIRModulus	CIRModulus	1	-1.33289	0.63001	-2.12	0.0673
IDTwet	IDTwet	1	0.67914	0.39265	1.73	0.1219
S	S	1	2.09766	1.15291	1.82	0.1063

CIR: Model Selection for high traffic roads

Summary of Forward Selection

Step	Variable Entered	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	CIRModulus	CIRModulus	1	0.4152	0.4152	-1.0161	6.39	0.0323

Summary of Backward Elimination

Step	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	IDTwet	IDTwet	7	0.0019	0.8026	7.0196	0.02	0.9015
2	Aggregate	Aggregate	6	0.0079	0.7947	5.1003	0.12	0.7520
3	G	G	5	0.0366	0.7581	3.4751	0.71	0.4458
4	S	S	4	0.0584	0.6997	2.0731	1.21	0.3218
5	FNDModulus	FNDModulus	3	0.0673	0.6324	0.7613	1.34	0.2904
6	CumulativeTraffic	CumulativeTraffic	2	0.1164	0.5160	-0.0472	2.22	0.1801
7	Va	Va	1	0.1008	0.4152	-1.0161	1.67	0.2329

Summary of Stepwise Selection

Step	Variable Entered	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)
1	CIRModulus		CIRModulus	1	0.4152	0.4152	-1.0161
2	S		S	2	0.1415	0.5567	-0.4636

R-Square Selection Method

Number in Model	R-Square	C(p)	AIC	MSE	SSE	Variables in Model
1	0.4152	-1.0161	48.5757	70.31624	632.84617	CIRModulus
1	0.3077	0.0844	50.4326	83.24737	749.22629	G
2	0.5567	-0.4636	47.5294	59.97055	479.76442	CIRModulus S
2	0.5518	-0.4139	47.6492	60.62725	485.01803	CIRModulus G
3	0.6609	0.4697	46.5805	52.42094	366.94661	CIRModulus FNDModulus S
3	0.6376	0.7081	47.3115	56.02289	392.16026	CIRModulus FNDModulus G
4	0.6997	2.0731	47.2453	54.16700	325.00200	CumulativeTraffic CIRModulus FNDModulus Va
4	0.6898	2.1744	47.6021	55.95280	335.71682	CIRModulus FNDModulus S Aggregate

Single-order model: high traffic CIR Roads

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	828.16702	276.05567	5.49	0.0242
Error	8	402.49965	50.31246		
Corrected Total	11	1230.66667			

Root MSE	7.09313	R-Square	0.6729
Dependent Mean	-4.66667	Adj R-Sq	0.5503
Coeff Var	-151.99559		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-8.35416	9.22017	-0.91	0.3914
CumulativeTraffic	CumulativeTraffic	1	-0.84438	0.53448	-1.58	0.1528
CIRModulus	CIRModulus	1	-1.56898	0.49298	-3.18	0.0129
Va	Va	1	2.37256	1.02245	2.32	0.0489

4. Selected SAS output for higher-order models

CIR: Model Selection for all 24 CIR roads

Summary of Forward Selection

Step	Variable Entered	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	CIRModulus	CIRModulus	1	0.2274	0.2274	11.0875	6.18	0.0214
2	Va3	Va3	2	0.1717	0.3991	6.4017	5.71	0.0268
3	CumulativeTraffic	CumulativeTraffic	3	0.1863	0.5854	1.1458	8.54	0.0087

Summary of Backward Elimination

Step	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	G2	G2	7	0.0024	0.6381	7.0920	0.09	0.7662
2	Aggregate	Aggregate	6	0.0032	0.6349	5.2163	0.13	0.7211
3	IDTwet2	IDTwet2	5	0.0116	0.6234	3.6665	0.51	0.4868
4	S	S	4	0.0121	0.6113	2.1372	0.55	0.4702
5	FNDModulus	FNDModulus	3	0.0259	0.5854	1.1458	1.20	0.2879

Summary of Stepwise Selection

Step	Variable Entered	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)
1	CIRModulus		CIRModulus	1	0.2274	0.2274	11.0875
2	Va3		Va3	2	0.1717	0.3991	6.4017
3	CumulativeTraffic		CumulativeTraffic	3	0.1863	0.5854	1.1458

R-Square Selection Method

Number in Model	R-Square	C(p)	AIC	MSE	SSE	Variables in Model
1	0.2274	11.0875	104.8383	87.81632	1844.14266	CIRModulus
1	0.1199	15.2730	107.8340	100.03236	2100.67951	CumulativeTraffic
2	0.3991	6.4017	101.0584	71.71750	1434.35005	CIRModulus Va3
2	0.3988	6.4131	101.0696	71.75256	1435.05121	CIRModulus S
3	0.5854	1.1458	94.5220	52.08521	989.61902	CumulativeTraffic CIRModulus Va3
3	0.5156	3.8632	98.0997	60.85136	1156.17580	CumulativeTraffic CIRModulus S
4	0.6113	2.1372	95.0384	51.54452	927.80135	CumulativeTraffic CIRModulus FNDModulus Va3
4	0.5934	2.8334	96.0726	53.91508	970.47145	CumulativeTraffic CIRModulus Va3 S

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1484.26099	371.06525	7.39	0.0009
Error	19	953.73901	50.19679		
Corrected Total	23	2438.00000			

Root MSE	7.08497	R-Square	0.6088
Dependent Mean	0	Adj R-Sq	0.5264
Coeff Var	.		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	3.92337	3.23301	1.21	0.2398
CumulativeTraffic	CumulativeTraffic	1	-0.34978	0.43815	-0.80	0.4346
CIRModulus	CIRModulus	1	-1.31106	0.35773	-3.66	0.0016
Va3	Va3	1	0.00648	0.00235	2.76	0.0124
Volume	Volume	1	-5.05944	5.50325	-0.92	0.3694

CIR: Model Selection for low traffic roads

The REG Procedure
Model: MODEL1
Dependent Variable: RelativePCI RelativePCI

No variable met the 0.0500 significance level for entry into the model.

Summary of Backward Elimination

Step	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	CumulativeTraffic	CumulativeTraffic	7	0.0016	0.5399	7.0103	0.01	0.9257
2	Va3	Va3	6	0.0022	0.5376	5.0248	0.02	0.8960
3	FNDModulus	FNDModulus	5	0.0030	0.5346	3.0445	0.03	0.8639
4	Aggregate	Aggregate	4	0.0030	0.5317	1.0641	0.04	0.8510
5	G2	G2	3	0.0059	0.5258	-0.8976	0.09	0.7760

The REG Procedure
Model: MODEL3
Dependent Variable: RelativePCI RelativePCI

No variable met the 0.1500 significance level for entry into the model.

R-Square Selection Method

Number in Model	R-Square	C(p)	AIC	MSE	SSE	Variables in Model
1	0.1312	-2.3161	50.8407	59.48412	594.84121	IDTwet2
1	0.1257	-2.2803	50.9160	59.85865	598.58650	CumulativeTraffic

2	0.3586	-1.8040	49.1984	48.79111	439.11995	CumulativeTraffic CIRModulus
2	0.3239	-1.5768	49.8314	51.43389	462.90504	CIRModulus Va3
3	0.5258	-0.8976	47.5749	40.58390	324.67117	CIRModulus IDTwet2 S
3	0.4669	-0.5121	48.9805	45.62739	365.01910	CIRModulus Va3 IDTwet2
4	0.5317	1.0641	49.4258	45.80905	320.66338	CIRModulus IDTwet2 G2 S
4	0.5299	1.0753	49.4697	45.97675	321.83726	CIRModulus IDTwet2 S Aggregate

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	359.99550	119.99850	2.96	0.0979
Error	8	324.67117	40.58390		
Corrected Total	11	684.66667			

Root MSE	6.37055	R-Square	0.5258
Dependent Mean	4.66667	Adj R-Sq	0.3480
Coeff Var	136.51177		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	5.27909	5.34823	0.99	0.3525
CIRModulus	CIRModulus	1	-1.53046	0.61336	-2.50	0.0372
IDTwet2	IDTwet2	1	-2580.12310	1297.56314	-1.99	0.0820
S	S	1	2.45289	1.13455	2.16	0.0626

CIR: Model Selection for high traffic roads

Summary of Forward Selection

Step	Variable Entered	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	CIRModulus	CIRModulus	1	0.4152	0.4152	9.1698	6.39	0.0323

Summary of Backward Elimination

Step	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	FNDModulus	FNDModulus	7	0.0093	0.9184	7.2572	0.26	0.6625
2	Aggregate	Aggregate	6	0.0304	0.8880	6.0965	1.12	0.3684
3	IDTwet2	IDTwet2	5	0.0268	0.8612	4.8368	0.96	0.3835

Summary of Stepwise Selection

Variable	Variable	Number	Partial	Model

Step	Entered	Removed	Label	Vars In	R-Square	R-Square	C(p)
1	CIRModulus		CIRModulus	1	0.4152	0.4152	9.1698
2	S		S	2	0.1415	0.5567	7.2584

R-Square Selection Method

Number in Model	R-Square	C(p)	AIC	MSE	SSE	Variables in Model
1	0.4152	9.1698	48.5757	70.31624	632.84617	CIRModulus
1	0.1782	15.7221	52.3178	98.80957	889.28614	S
2	0.5567	7.2584	47.5294	59.97055	479.76442	CIRModulus S
2	0.5270	8.0801	48.2431	63.99049	511.92394	CIRModulus Va3
3	0.6905	5.5592	45.5780	47.85480	334.98360	CumulativeTraffic CIRModulus Va3
3	0.6609	6.3758	46.5805	52.42094	366.94661	CIRModulus FNDModulus S
4	0.7654	5.4869	44.5287	42.31368	253.88207	CumulativeTraffic CIRModulus Va3 IDTwet2
4	0.7621	5.5771	44.6806	42.90206	257.41235	CumulativeTraffic CIRModulus FNDModulus Va3

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	879.83874	293.27958	6.69	0.0143
Error	8	350.82793	43.85349		
Corrected Total	11	1230.66667			

Root MSE	6.62220	R-Square	0.7149
Dependent Mean	-4.66667	Adj R-Sq	0.6080
Coeff Var	-141.90422		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	6.61065	6.98629	0.95	0.3717
CumulativeTraffic	CumulativeTraffic	1	-1.00656	0.52050	-1.93	0.0892
CIRModulus	CIRModulus	1	-1.32420	0.47354	-2.80	0.0233
Va3	Va3	1	0.00865	0.00319	2.71	0.0266