FINAL REPORT

# ANALYSIS OF RULES AND REGULATIONS FOR STEEL COIL TRUCK TRANSPORT

## Project VB-H1, FY 93


Prepared by
W. B. Cross and S. J. Hanna
Department of Civil Engineering
and
N. Panahshahi and R. Romick-Allen
Department of Mechanical and Industrial Engineering
Southern Illinois University at Edwardsville



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16. Abstract

Flatbed trucks transporting steel coils are known to have been involved in several serious incidents resulting in property damage as well as loss of life. However, due to a lack of consistent incident reporting, little is known about the frequency of steel coil securement failure. Additionally, when incidents are reported, it is difficult to determine the root causes of the securement failure from the records of non-technically trained observers. This research will develops a methodology to obtain statistically sound samples of steel coil securement methods, and obtains data for the development of frequency statistics. Additionally, the research analytically and experimentally examines the current IDOT regulations for steel coil securement, and makes recommendations for changes to the regulations.

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## Analysis of Rules and Regulations for Steel Coil Truck Transport

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## DISCLAIMER

# CHAPTER 1: INTRODUCTION

## 1.1 Motivation

Flatbed trucks transporting metal coils are known to have been involved in several serious incidents resulting in property damage as well as loss of life (IDOT 1991). However, due to a lack of consistent incident reporting, little useful documentation exists regarding the frequency of steel coil securement failure. Additionally, when incidents are reported, it has been difficult to determine the root causes of the securement failures from the records of non-technically trained observers. This research develops a methodology to obtain statistically sound samples of steel coil securement methods, and obtains some data for the development of frequency statistics. Additionally, the research analytically and experimentally examines the current IDOT regulations for steel coil securement, and makes recommendations for changes to the regulations.

IDOT has proposed rules and regulations for the securement of steel coils based on the Federal Motor Carrier Safety Regulation, 49 CFR Part 393, Subpart I: Protection Against Shifting or Falling Cargo (IDOT 1982). It is currently unknown to what extent these regulations are being followed. Even if the standards are being followed, it is unclear whether or not these recommendations are adequate to provide for safe cargo securement in routine maneuvers. With the current lack of information regarding the frequency of steel coil cargo failures, as well as the absence of technical reports detailing the configuration and strength of failed securement methods, it has been difficult to assess the severity of the problem from a technical and regulatory standpoint.

The research described herein begins with a review of the existing literature. Additionally, a statistically sound methodology has been developed for the collection of data regarding steel coil securement practices. As part of the work performed, data has been gathered from observation sites at IDOT weigh stations. An in-depth survey of vehicle operators, state police, specialty carrier firms, and state and federal agencies was undertaken to determine knowledge of the current recommended practice for steel coil securement. As part of this survey, questions were asked to determine the types of securement failures that have occurred.

With the information gained in the first phases of the proposed project, an analytical model is developed to determine the likely failure modes for recommended securement configurations, with special attention paid to the requirements of the existing regulation. In order to verify some of the parameters in the analytical study, experiments on scale model assemblies are performed. Also, the relative strengths of different securement configurations are investigated.

## 1.2 Objectives and Scope of the Work

Chapter 2: Literature Survey and Summary - Review of literature regarding steel coil transport. This will include a review of published literature on the modeling and analysis of transport systems.

Chapter 3: Statistical Sampling Plan - A statistical methodology for sampling steel coil transporters is developed and implemented, with attention paid to securement method. Field observation is performed at weigh stations and highway check points.

Chapter 4: Current Knowledge Review - This chapter presents a survey of sources to determine the level of knowledge of securement methods, and for data indicating failure of securement methods. Sources for this information includes vehicle operator organizations, state police, specialty carrier firms, and state and federal agencies.

Chapter 5: Engineering Dynamic Studies - These are performed in three phases: first, an initial rigid body dynamic analysis; second, an experimental study to verify significant aspects of the rigid body dynamic analysis; and third, an advanced finite element analysis of the coil-truck interaction problem. The primary goal of these studies will be to determine the forces, displacements, etc., on the securement system in the currently recommended procedure.

Chapter 6: Securement Recommendations - After careful consideration of the information produced by Chapters 2 through 5, recommendations are made for modifications to the IDOT regulations. These are in the form of a parallel commentary to the 49 CFR 393.

## CHAPTER 2: Review of Previous Investigations of the Metal Coil Securement Problem

Although problems with metal coils are well-known anecdotally in the trucking industry, where the eye transverse configuration for coils is known as the "suicide position", very little documentation of securement problems is available. As part of this study, the investigators reviewed data for metal coil accidents in Illinois, and undertook a literature review to determine what research regarding cargo securement has been performed in the past. The findings from this work will be described in this chapter.

### 2.1 Past Performance of Metal Coils During Transport

Metal coil securement failures have been only sporadically documented. Securement failures that cause fatalities have drawn the attention of investigators, but those that do not are often only logged as cargo accidents and little or no data is gathered regarding the securement failure.

A review of 49 accident reports for 1992/93 involving vehicles transporting metal coils shows 21 (43%) occurred on a ramp or during a turning maneuver. Of these 8 involved rollovers of the whole unit or trailer. Of the 28 (57%) which occurred on tangent lines, 16 involved a collision (one with a bull), an avoidance maneuver or a sudden stop. Twenty-six of the 49 reports either did not state a cause, were listed as unknown or the description of the accident in the report did not permit a determination of the cause. Thirty-two of the forty-nine reports indicated that coils were released. The data indicate that forces in directions other than just longitudinal need to be considered in the evaluation of proper load securement.

| Location | No. of Incidents | Cause Indicated | | | | | |
|---|---|---|---|---|---|---|---|
| | | Too Fast | Rapid Stop | Avoidanc e Maneuver | Collision | Unknown or not in Report | Rollover |
| Ramp | 13 | 2 | 1 | 1 | 4* | 9 | 5 |
| Tangent | 19 | | 3 | 3 | | 9 | 4 |
| Turning | 2 | 1 | | | | 1 | 2 |
| Total | 34 | 3 | 4 | 4 | 4 | 19 | 11 |

*one collision involved an impact with a bull

Table 2.1-1: Summary of IDOT Metal Coil Accident Reports - 1992 (Full Year)

| Location | No. of Incidents | Cause Indicated | | | | | |
|---|---|---|---|---|---|---|---|
| | | Too Fast | Rapid Stop | Avoidance Maneuver | Collision | Unknown or not in Report | Rollover |
| Ramp | 6 | 1 | | | | 4 | 1 |
| Tangent | 9 | | | 1 | 4 | 4 | 2 |
| Turning | | | | | | | |
| Total | 15 | 2 | | 1 | 4 | 8 | 3 |

Table 2.1-2: Summary of IDOT Metal Coil Accident Reports - 1993 (January-June)

## 2.2 Cargo Securement Studies

Despite the large amount of cargo being transported throughout the U.S., relatively little has been written to describe securement problems and solutions. This lack of research extends to the metal coil securement area. In the past few years, some attention has been focused on cargo securement in general as a result of notable failures. Two detailed studies have been performed; one at the University of Michigan Transportation Institute (Gillespie 1987) and one at the Ontario Ministry of Transportation (Billing et al. 1993).

The study by Gillespie at the University of Michigan is notable, since it is the only technical report available that describes the mechanics of metal coil securement. The study was initiated to investigate 49 CFR Part 393, and observed that "the regulations relating to cargo restraint were often ambiguous and subject to different interpretations." Gillespie also notes that the regulations "do not necessarily reflect the current knowledge of vehicle dynamics and engineering design."

Gillespie recommends using design acceleration values of .75g for longitudinal motion and 1.0g for lateral motion. The longitudinal acceleration/deceleration value is justified by a discussion of the effects of braking on vehicles and the achievable amount of deceleration attainable. He notes that braking can be either in the forward or backward direction. The cargo securement should be at least capable of safely resisting the attainable braking accelerations. The recommended lateral acceleration is based on a discussion of vehicle rollover, tire traction, and body roll. It is conservative to assume that tire traction will limit the lateral acceleration (impact with obstacles such as curbs is *not* accounted for, since that would raise the design lateral acceleration to an unduly high level). Several alternative design codes are referenced (Australia, Sweden, BMCS, Canada, ANSI, United Kingdom), showing design longitudinal accelerations from .4g to 2.0g and lateral accelerations from .5 to 1.6.

Gillespie recommends a restraint safety factor of at least 2.0. It is assumed that such a safety factor should apply to the ultimate strength of the securement system. He also recommends using redundant chains in order to assure that the failure of one chain will not lead to the loss of the cargo.

Blocking is discussed in relation to the nailing requirements to prevent shifting of cargo. For example, in the *National Design Specification for Wood Construction* (NDS 1991), a 16d nail can take about 100 pounds of lateral force per nail or 300 pounds of lateral force per 8 inch spike. This would result in very large numbers of nails or spikes (eg. 400 nails for a 40,000 lb coil) used to restrain a coil against lateral motion, and therefore can not be recommended. The cargo securement regulations should make clear the number of spikes or nails required to safely restrain heavy objects.

Gillespie examines the effectiveness of over-the-top restraint of circular objects using chains or binders, and proposes some equations for forces on such securement. He does not examine through-the-eye restraint, as is common on metal coils.

In 1993, the Ontario Ministry of Transportation prepared *A Proposal to Provide a Technical Basis for a Revised National Standard on Load Security for Heavy Trucks* (Billing *et al.* 1993). The research proposed therein is currently underway, and should be complete by early 1996. It is an attempt to provide technical justification for standards related to load securement. The study is primarily experimental in nature, and will consider the following issues related to metal coils:

i. Effect of Friction
ii. Effect of Blocking
iii. Chain Securement, Eye Lateral
iv. Chain Securement, Eye Longitudinal
v. Coil with Eye Lateral in Cradle, Cradle Secured
vi. Coil with Eye Lateral in Cradle, Cradle Unsecured
vii. Coil with Eye Lateral in Cradle, with Chains, Cradle Unsecured
viii. Effect of Blocking Length for a Coil with Eye Longitudinal
ix. Coil with Eye Longitudinal, in Cradle, Various Securement Combinations
x. Coil with Eye Longitudinal, in Cradle, Steep Angle Chains
xi. Coil with Eye Longitudinal, in Cradle, Shallow Angle Chains
xii. Coil with Overwrap Chains and Webbing, Combination Block and Chain
xiii. Coil with Overwrap Chains and Two Way Blocking

All of the tests described will be performed on full scale coils. The tests will be static, and will not be able to reproduce any vehicle-load interaction, or other dynamic effects. It is clear that this study ~~is the most comprehensive investigation of metal coil securement ever attempted, and should yield~~ interesting results.

The State of New York prepared a report in 1993 that described the results of an intensive metal coil inspection effort (NYDOT 1993). New York has been plagued with a rash of securement failures in the past five years, some of which involved multiple fatalities. Most of the problems in New York have involved aluminum coil securement, but some have occurred during the transport of steel coils.

Most notably, as a result of their securement inspections, 449 (48.2%) of the 931 vehicles inspected were placed out of service due to "dangerously inadequate load securement". The authors of the 1993 report stated that their "inspections uncovered the fact that elements of the industry do not understand current regulations regarding cargo securement because they are confusing and therefore ineffective." They wrote that a major cause of the confusion was the difference between the federal breaking strength regulation and the commonly available CVSA securement calculators, which adhered to a working load limit standard. Their recommendations included changing the regulation to a working load limit procedure, and enacting training programs for proper load securement throughout the industry. They conclude by stating that after enacting a concentrated inspection/education program, the out of service rate for securement violations had decreased to 35.4%.

## 2.3 Tie-down Calculators

The Crosby Calculator (1991) provides an easy way of determining the number of chain tie-downs required for different cargo weights, ranging from 2600 lbs to 217,200 lbs, using different chain types, grades G30, G43, G70, and G80, using the working load limits. To illustrate the difference for the tie-down requirements computed based on the working load method and the ultimate strength method, the strength ratios of the breaking strength of the tie-down chains to 1.5 times of the cargo weight as well as the ratios of working load limit to 0.5 times the cargo weight, as given in the Crosby Calculator, are tabulated in Table 2.3-1. The National Association of Chain Manufacturer's "Welded Steel Chain Specifications," (1990) is used to obtain the minimum breaking and the working load limits of the chains. It is noted that for the 1/2 in. or smaller size High Test (G43) chains, the safety factor according to the ultimate strength method is compromised, while all tie-down chains meet the working load limit requirements.

| Chain Type | Minimum Breaking Force */ 1.5 Cargo Weight*** ( Working Load Limit** / 0.5 Cargo Weight***) | | | | | |
|---|---|---|---|---|---|---|
| | 1/4" | 5/16" | 3/8" | 7/16" | 1/2" | 5/8" |
| Proof Coil (G30) | 1.33 (1.0) | 1.19 (1.0) | 1.33 (1.0) | --------- | 1.33 (1.0) | 1.31 (1.0) |
| High test (G43) | 0.96 (1.0) | 0.82 (1.0) | 0.94 (1.0) | --------- | 0.93 (1.0) | 1.13 (1.0) |
| Transport (G70) | 1.28 (1.0) | 1.33 (1.0) | 1.25 (1.0) | 1.33 (1.0) | 1.23 (1.0) | 1.33 (1.0) |
| Alloy (G80) | ---------- | --------- | 1.33 (1.0) | -------- | 1.33 (1.0) | 1.33 (1.0) |

* According to Ultimate Strength Method (SCRA, 1988)
** According to Working Load Limit method (CVSA, 1991)
*** According to the Crosby Calculator (1991)

Table 2.3-1 Comparison of tie-down chain strength ratios using working load and ultimate strength methods

## CHAPTER 3: Field Survey of Metal Coil Transport Trucks

The project Technical Review Panel (TRP) agreed at its meeting on February 24, 1994, that the primary purpose of the project was to investigate the adequacy of the current steel coil securement regulations; the precise estimates of the numbers of metal coil transport vehicles on Illinois highways would not be necessary. It was also agreed that the purpose of Task B (the truck survey phase) was primarily to verify the coil sizes and securement configurations on typical coil-carrying trucks, along with determining the awareness level of the federal regulations by the truck operators. The possibility of a coil-spotting survey to be conducted in Chicago at the accident reporting station and/or at the intersection of US 6 and I-94 was discussed along with the availability of IDOT personnel for this survey. It was later decided that, based on the counts taken at weigh stations and the field study during Road Check 1994, the Chicago counts would not be required.

No historical traffic counts are available on the actual number of coil-carrying trucks operating within Illinois. In order to obtain estimates of the truck volumes, a decision was made in conjunction with the project TRP to request that counts of coil-carrying trucks at weigh stations be conducted by the Illinois State Police at six locations. These were 24-hour surveys (or for the time period that the station was open) during the period March 15 through April 15, 1994. Data recorded by the truck weight inspectors (TWI) included the date, time, and number of coils observed for each open flatbed truck. Since inspection of the trucks was not part of this survey, coils inside covered vehicles were not able to be counted.

The weigh stations selected were:

| | | | | | |
|---|---|---|---|---|---|
| ISP | D- 5 | Peotone Scale | SC13 | N/B, I-57 | @ MP 330 |
| ISP | D- 5 | Peotone Scale | SC23 | S/B, I-57 | @ MP 330 |
| ISP | D- 9 | Williamsville Scale | SC34 | S/B, I-55 | @ MP 107 |
| ISP | D-11 | Maryville Scale | SC31 | S/B, I-55 | @ MP 14 |
| ISP | D-12 | Brownstown Scale | SC15 | E/B, I-70 | @ MP 71 |
| ISP | D-12 | Marshall Scale | SC21 | W/B, I-70 | @ MP 151 |
| ISP | D-18 | Litchfield Scale | SC32 | N/B, I-55 | @ MP 56.5 |

Based on the truck weight inspectors' observations, the project Technical Review Panel decided that an in-depth field survey be conducted in conjunction with Road Check 1994, (June 6, 7, and 8). The Peotone Southbound Scale on I-57 was selected as the most appropriate location due to the volume of steel coil carrying vehicles passing through the area and its proximity to the steel coil producing area of East Chicago, Gary, Burns Harbor and Portage. The field survey coincided with the Level 1 inspections performed by the Illinois State Police and other agencies during Road Check 1994 permitting better control and coordination of the research survey. A letter to be given to each truck operator was prepared by the research team and signed by IDOT. This letter indicated the cooperation of IDOT and explained the purpose of the investigation (see Appendix A).

### 3.1 Truck Weight Inspectors Survey

The truck weight inspectors (TWI) visually observed trucks crossing their scales and recorded the date, time, and number of coils on each truck during the period March 15 through April 15, 1994. While coils carried in covered trailers (covered wagons) could not be observed, and problems resulted in shutdowns of over seven days at one scale, a total of 3,173 trucks were observed carrying steel coils during the 30-day period. Of these trucks, 28% carried one coil, 35.6% carried two coils, and 18.5% carried three coils (see Table 3.1-1). Almost one-third of the total observations occurred at the Peotone Southbound Scale on I-57. Table 3.1-1 presents a summary of the data collected at the weigh stations. Listed below is an average daily truck count on the selected fixed scales for 1994 as provided by the Illinois State Police:

**AVERAGE DAILY TRUCK COUNT**

| | |
|---|---|
| Peotone N/B | 1,249 |
| Peotone S/B | 1,309 |
| Williamsville | 1,766 |
| Maryville | 2,575 |
| Brownstown | 2,312 |
| Marshall | 2,057 |
| Litchfield | 884 |

A review of the data shows truck traffic in the near vicinity of the steel manufacturing plants is very much directional, as would be anticipated; however, there is also significant traffic in the other direction. For example, at the Peotone Southbound Scale there were over 1,024 coil-carrying trucks observed in the TWI count and 387 coil-carrying trucks observed at the Peotone Northbound Scale. It is interesting that northbound coil traffic even exists at this location since the steel manufacturing areas are located to the north and east of the Peotone scales. A possible explanation is that the coils have been transported to a processing location away from the main steel-producing areas and then shipped back northward to their final destination.

At the Brownstown Scale, which is eastbound at milepost 71 on I-70 (about 20 miles west of Effingham), the number of coil-carrying vehicles totalled 438; at the Marshall Scale, which is westbound at milepost 151 on I-70, the vehicles totalled 476. While there is a difference in the actual number of days involved in these counts and the interchange with I-57 is between these two locations, these numbers indicate evidence of significant movement of coil-carrying trucks in both directions on I-70. One explanation for this is that there is a galvanizing facility in the Granite City area from which coils are transshipped.

The average number of coil-carrying trucks per day was compared to the average daily truck counts for two locations. The percentage of coil-carrying trucks observed at the Brownstown Scale was 0.65% of the average daily truck traffic; at the Peotone Southbound Scale it was 3.7% of the average daily truck traffic. Further comparisons are not meaningful since all scales were not open 24 hours and various problems led to some shutdowns of the scales, including the 7+ days at the Litchfield Scale.

| LOCATION | NUMBER OF TRUCKS | | | | | TOTAL TRUCKS WITH COILS |
|---|---|---|---|---|---|---|
| | Coils Per Truck | | | | | |
| | 1 | 2 | 3 | 4 | 5 | |
| Peotone Scale N/B | 233 | 92 | 29 | 16 | 17 | 387 |
| Peotone Scale S/B | 170 | 412 | 227 | 117 | 98 | 1,024 |
| Williamsville Scale S/B | 79 | 277 | 185 | 90 | 46 | 677 |
| Maryville Scale S/B | 9 | 18 | 13 | 15 | 7 | 72 |
| Brownstown Scale E/B | 228 | 117 | 43 | 14 | 36 | 438 |
| Marshall Scale W/B | 131 | 184 | 70 | 39 | 52 | 476 |
| Litchfield Scale N/B* | 37 | 21 | 20 | 9 | 12 | 99 |
| **TOTAL TRUCKS:** | 887 | 1,131 | 587 | 300 | 268 | 3,173 |
| **PERCENTAGE:** | 28.0 | 35.6 | 18.5 | 9.4 | 8.5 | |

*Litchfield scales were down 7+ days.

TABLE 3.1-1 Summary of TWI Visual Observations of Steel Coil Transport Trucks
March 15 - April 15, 1994

### 3.2 Road Check 1994 Survey

As previously mentioned, it was decided that the Peotone Southbound Scale would be the most appropriate location for the in-depth survey of metal coil transport trucks. The SIUE field study was held simultaneously with the Illinois State Police's Road Check 1994, permitting interaction between the research group and the Road Check 1994 group. The survey performed by the Illinois State Police was a Level 1 inspection that took approximately 30-45 minutes for each vehicle. Coil-carrying trucks passing through the Peotone Southbound Scale were directed to the SIUE team during the survey. If the survey team had a backlog of vehicles (2 or 3) waiting to be inspected, other coil-carrying trucks were not required to stop for inspection. While a majority of the trucks were inspected by the survey team, a significant number were unable to be inspected. The SIUE evaluation took approximately 15-20 minutes, though the exact time for each inspection varied with the number of coils and the type of securement used. At a minimum, two investigators from SIUE were present during the entire survey. Terry Moore, IDOT, assisted with all field investigations.

### 3.2.1 Driver Data

Two recording forms were used (see Appendix A). The first recording sheet was used by Investigator Number 1 who handed the driver the introductory letter, asked the questions, recorded the answers on the form, and used a Polaroid camera to take a side photograph of the truck. This photograph was attached to the first page of the survey form and was used later to identify the truck. Investigator Number 2 took 35 mm slide pictures of the truck and coils from various angles and recorded the data collected by other investigators who obtained measurements for the dimensions. The location and size of the coils were determined in feet and inches. Securement and length dimensions of the chains were measured to the nearest 1/4". For measuring chain diameters a special tapered gauge was developed to obtain the chain size to the nearest 1/16". English units were used since the chains in use were identified by English units. Chain grades were obtained from the markings on the chain when present.

Over the three-day period, seventy-two (72) metal coil transport trucks were inspected by the research team and the operators interviewed. The results of the interviews are tabulated in Appendix B and are summarized as follows:

a. 75% of the vehicles were open flatbed trucks;
25% of the vehicles were covered flatbed trucks (covered wagons).

b. 42% of the drivers were owner/operators;
57% of the drivers were company drivers;
1% - unknown.

c. Of the 72 drivers interviewed, eight (8) had been hauling steel coils less than six months, and three of the drivers were hauling their first load. Drivers' experience ranged from "first day" to over 25 years. Approximately two-thirds of the drivers indicated that they had no idea of the grade of the tiedown chains; for the remaining one-third of the drivers, the most common answer was "about 10,000 lbs." A majority of the drivers indicated that they were not aware of the way chains were graded or what the grading indicated.

The destinations for all 72 vehicles are tabulated in Table 3.2-1. Nine states and thirty-two cities are listed. Twenty-one vehicles had destinations within Illinois, with Tennessee being the state with the second largest number of destination points (18 vehicles). The most popular destination point was Milan, Tennessee, with ten vehicles bound for that city. A review of the destinations revealed that, while a significant portion of the routes are on interstate highways, a significant portion is also on state-designated highways.

TABLE 3.2-1 Destinations by State and City (72 vehicles)

| | # of Trucks | Location |
|---|---|---|
| **ARKANSAS** | | |
| Little Rock | 1 | |
| Benton | 3 | 15 mi SE of Little Rock |
| Conway | 1 | 25 mi NW of Little Rock |
| Searcy | 3 | 45 mi NE of Little Rock |
| Stuttgart | 1 | 50 mi SE of Little Rock |
| Springdale | 1 | NW corner of Arkansas |
| **GEORGIA** | | |
| Dublin | 1 | 50 mi SE of Macon |
| **ILLINOIS** | | |
| Assumption | 3 | 36 mi S of Decatur |
| Albion | 1 | 8 mi N of I-64 at Indiana line |
| Carol Stream | 1* | 10 mi W of Elmhurst |
| Fairbury | 5 | 36 mi NE of Normal on US 24 |
| Granite City | 7 | Across river from St. Louis |
| Redbud | 1 | 50 mi SSE of St. Louis |
| West Salem | 3 | |
| **MISSOURI** | | |
| Kansas City | 2 | |
| St. Louis | 3 | |
| Fenton | 1 | 15 mi SW of St. Louis |
| Gerald | 2 | 55 mi SW of St. Louis |
| Sedalia | 2 | |
| Neosho | 1 | SW corner of Missouri |
| **KANSAS** | | |
| Kansas City | 1 | |
| Winfield | 1 | |
| **MISSISSIPPI** | | |
| Tupelo | 1 | |

*brought to scale for check of trailer; origin--Kentucky

(Table 3.2-1 continued on next page)

| | | |
|---|---|---|
| **OKLAHOMA** | | |
| Oklahoma City | 1 | |
| Muskogee | 2 | |
| **TENNESSEE** | | |
| Memphis | 7 | |
| Milan | 10 | ~100 mi NE of Memphis |
| Paris | 1 | 36 mi NE of Milan |
| **TEXAS** | | |
| Corsicana | 1 | 50 mi S of Dallas |
| Houston | 2 | |
| Schulenburg | 1 | ~75 mi W of Houston |
| Tyler | 1 | ~100 mi ESE of Dallas |

A comparison using the TWI survey information was also made for time of day at the Brownstown and Peotone scales for coil-carrying trucks. In summary:

| | | | |
|---|---|---|---|
| Brownstown E/B | | | |
| Midnight | to | 6 a.m. | - 23% |
| 6 a.m. | to | 12 noon | - 9% |
| 12 noon | to | 6 p.m. | - 25% |
| 6 p.m. | to | midnight | - 41% |
| Peotone S/B | | | |
| Midnight | to | 6 a.m. | - not available |
| 6 a.m. | to | 12 noon | - 15% |
| 12 noon | to | 6 p.m. | - 59% |
| 6 p.m. | to | midnight | - 26% |
| Peotone N/B | | | |
| Midnight | to | 6 a.m. | - 23% |
| 6 a.m. | to | 12 noon | - 53% |
| 12 noon | to | 6 p.m. | - 15% |
| 6 p.m. | to | midnight | - 9% |

Each location has a distinct time distribution pattern. For example, the majority of traffic at Peotone S/B occurs noon to 6:00 p.m. while at Peotone N/B the majority of traffic is in the 6:00 a.m. to noon time frame. On the other hand, the majority of traffic at Brownstown E/B occurred between 6:00 p.m. to midnight. The density of metal coil transport trucks by time of day is clearly dependent on location relative to origin.

### 3.2.2 Metal Coil Data

The survey team inspected the tiedowns on each coil recording the number of chains and/or straps, their grade or load rating, and tiedown geometry. Photographs of each coil were taken to assist in evaluating and cataloging the tiedown method. Results of the measurements and various tiedown methods were used in the computer modeling phase of the study. A total of 234 metal coils were examined on 72 trucks. A summary of the results of this survey appears in Appendix C.

Individual coil weights ranged from under 5,000 lbs. to over 40,000 lbs. Figure 3.2-1 graphically illustrates the weight distribution of the metal coils observed during the field study. A significant percentage (38.5%) of the coils weighed less than 5,000 lbs., with 38.9% of the coils weighing between 10,000 and 20,000 lbs.

During the survey, the coils and their securement were also examined by an IDOT Commercial Vehicle Safety Inspector. The original breaking strength federal regulation was used to verify the adequacy of the securement. Those coils, identified in Appendix C with a "Yes" in the Violation Column, did not meet the regulation requirements which included the interpretation that the *aggregate* number of chains have a total strength of 1.5 times the coil's weight. Thirty of the 72 trucks had at least one securement violation based on this interpretation. This is 42% of the total trucks examined. If the regulation requirement was interpreted to mean restrained by 1.5 times its weight in any direction, significantly more violations probably would have been observed.

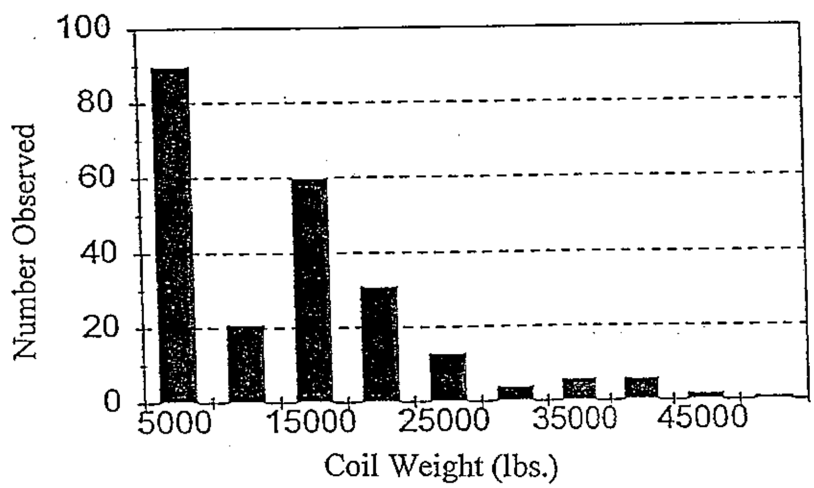



Figure 3.2-1 Coil Weight Distribution

## CHAPTER 4: Current Knowledge of Securement Systems

As a part of this study, the project Technical Review Panel requested that representative states be surveyed in order to determine the magnitude of the metal coil securement problem in other jurisdictions. This was accomplished by a telephone survey. In addition, the Illinois State Police were given a written questionnaire which is described in Section 4.3. Throughout the project, the investigators were in contact with other agencies, metal coil carriers, and chain manufactures, who provided data and expertise for the traffic survey, and the experimental and analytical portions of the project, where they are referenced.

### 4.1 Telephone Survey

In the Fall of 1994, a telephone survey was conducted in order to determine the current extent of concern regarding metal coil securement in several states, including Indiana, Michigan, Missouri, New York, Ohio, Pennsylvania, and West Virginia. Questions asked during the survey included:

1. Are you aware of any problems with metal coil securement in your state, such as securement failure or accidents due to inadequate securement?
2. Has your state collected data regarding the frequency of metal coil related accidents?
3. Do you have any data regarding the number of vehicles that are involved in metal coil transport, such as ADT's or % truck traffic?
4. What is your state's policy regarding metal coil securement? Are there any specific regulations?
5. Have you had any experiences with these regulations? Have they been difficult to enforce?
6. Who is responsible for cargo securement enforcement in your state?
7. Do you have any specific training for enforcers regarding cargo securement? How about metal coils in particular?
8. Do you have any training for drivers of cargo? Metal coils in particular?
9. Have you noted any weakness or concerns with the currently used securement procedures?
10. What modifications to the securement regulations for metal coils would you recommend?

### 4.2 Survey Results

The survey results are given in a summary form below.

*Missouri - Contact: Missouri State Highway Patrol, Commercial Vehicle Enforcement Division, Inspector Ronald D. Smith (314) 751-3313*

According to Mr. Smith, there have been no specific problems in Missouri related to cargo securement. Problems with cargo are more generally related to cargo shifting during cornering. He noted that one metal coil problem was related to the coil breaking through a trailer. Missouri has no data regarding metal coil related accidents, nor is it possible to determine the number of vehicles involved in metal coil transport.

The State of Missouri enforces the Federal Motor Carrier Safety Regulations without amendment. Mr. Smith has been inspecting cargo carriers for 30 years, and believes that the majority of drivers are conforming to the regulation. Isolated violations have occurred, and these have been mainly a result of a driver's misunderstanding of the regulation. The Commercial Vehicle Enforcement Division of the Missouri State Highway Patrol is responsible for enforcement of the cargo securement regulations.

Training for inspectors is given in a six week training program. No training program exists for drivers, but if a carrier requests it, the Missouri Department of Transportation will provide a training program.

Mr. Smith sees no weakness in the current regulation. He also believes that no modification to the current securement regulations is required.

*New York - Contact: New York State Dept. of Trans., Commercial Motor Vehicle Safety Bureau, Senior Transportation Official Tom Sweeney (518) 457-3406*

New York has had 3 fatal accidents involving metal coil transport in the past three years. Reports of these accidents are available and can be obtained from the NY DOT's "Freedom of Information Office" (contact James Del Principe at (518) 457-4440). Information regarding the frequency of metal coil related accidents in New York is also available at the same office. No particular information (ADT's or % truck traffic) regarding the volume of metal coil carrying traffic in New York is available.

Because of the severity of these accidents, New York has been actively petitioning the FHWA to update its motor carrier regulations. New York enforces the federal regulations with no local amendments. The experience has been that the regulation has not been difficult to enforce, and that there is adequate enforcement of the regulation. The main complaint that the New York DOT had with the federal regulation was that it was based on an ultimate strength criteria. In the past, there have been violations regarding the use of improper strength chain and the wrong number of chains. Now that the regulation has been modified to comply with a working load limit there is a feeling that it will be more easily understood by motor carriers.

The New York State DOT and the New York State Police are responsible for enforcing the cargo enforcement rules in New York. Training is provided via the "North American Standard" program administered by the CVSA. Program refreshers are attended by most inspection personnel every 3 years. There are no special securement training programs for drivers.

New York State recommended to the Federal Highway Administration that shippers share responsibility for cargo securement with drivers. They believe that shippers should be cited when a driver is given a securement violation.

*Ohio - Contact: Public Utilities Commission of Ohio, PUCO Trans. Enforcement Division, Jim Feddern (614) 466-3682*

Two major coil securement failures occurred in 1993 in which fatalities occurred. Both appeared to be related to welding chain links to the trailer, and failure of the chain at the weld led to the loss of the coils. Ohio does not directly collect metal coil securement failure data. It would have to be found in "safetynet" data that is collected for accidents in general. Also, no data exists regarding the number of vehicles that are involved in metal coil transport.

Ohio has adopted the Federal Motor Carrier Safety Rules without modification. Mr. Feddern noted that compliance is not a major problem, although he did state that many inspections reveal that an inadequate number, size, or grade of chain for coil securement is provided by the drivers. He mentioned that cargo securement within box trailers has been a problem. Inspections are performed randomly by the Public Utilities Commission of Ohio as well as by Ohio State Troopers. Inspectors are trained in the "North American Driver Vehicle Inspection Course," and no specific training regarding cargo securement is provided. Ohio has no state administered programs for educating drivers regarding metal coil securement.

Mr. Feddern stated a common concern that the current federal rules are unclear. Specifically, the blocking and bracing requirements are difficult to understand. He recommends that the regulation be re-written in a clearer, easier to understand form. Also he noted that chain marking requirements should be discussed in the federal regulation to aid inspectors.

*Pennsylvania - Contact: Penn DOT Center for Highway Services, Dan Smyser (717) 787-7445*

In 1992, a two fatality accident occurred that was related to metal coil securement failure. There have been a few metal coil related incidents, but no systematic data keeping procedure has been implemented. No data regarding ADT's or % truck traffic is kept for metal coil transport. Pennsylvania enforces the Federal Motor Carrier Regulations.

Some problems have been encountered when trying to determine chain grades in the field. Often, drivers believe that their unmarked chain is of a higher strength than the minimum value that must be assumed. Most securement inspections do not include a strength check (the items are inspected to determine if they are firmly secured). Inspections are performed by the Pennsylvania DOT, the Pennsylvania State Police, and the Public Utilities Commission of Pennsylvania. Most inspections of coil securement are made when the inspector believes there is a "probably cause" for a securement violation. Monthly systematic inspections (at a single site within the state) are performed that sometimes check securement. Inspectors are given the basic CVSA training program. When the tie-down calculators were made available, a 1-2 hour program was used to train inspectors in their use.

Mr. Smyser had no major problems with the federal regulation as written. He would like to see a more precise method for grading chains, especially those considered "unmarked."

*West Virginia - Contact: West Virginia Public Service Commission, Bob Brooks (304) 340-0453*

West Virginia has experienced some problems with metal coil securement. One fatality occurred about four years ago where a securement failure was probably related. Mr. Brooks was aware of several coil securement related incidents in the past few years. Also, during a labor dispute at an aluminum plant near Ravenswood, several complaints surfaced regarding inadequate metal coil securement. Coil securement violations were uncovered as a result of these complaints.

West Virginia does not specifically collect metal coil securement failure data, however, there are hardcopy reports for accidents investigated by the West Virginia Public Service Commission that can be scanned for information regarding metal coils. These include about 50% of all the post-accident investigations in West Virginia. This data goes back about four years. Inspection data for trucks is routinely collected that includes information regarding the commodity hauled. This could be scanned for "metal coils", and information regarding the amount of metal coil traffic in the state could be obtained.

West Virginia enforces the USDOT Federal Motor Carrier regulations regarding metal coil securement without amendment. Enforcement of the regulation is the responsibility of the West Virginia Public Service Commission and the State Police. It was noted that there are not enough personnel available to provide adequate enforcement of the regulations. Training in enforcement of the regulation is provided by attendance at the "North American Standard Course," of which about half the inspection personnel attend the full session. No state-supported training course for drivers of cargo is available, except that which is associated with the Commercial Driver's License. The City of Wierton, West Virginia and Wierton Steel have a special training program for cargo drivers which has been successful.

Mr. Brooks and his colleague Argel Stull commented that the federal regulations are subject to many different interpretations as currently written. One particular problem that they mentioned was the difficulty in enforcing cargo securement in box trailers, where cargo is often left unsecured. They suggested that some officially sanctioned material be provided to motor carriers so that the regulations could be more easily followed.

## 4.3 Illinois State Police Survey

In March of 1995, a survey was prepared that was distributed to members of the Illinois State Police that are active in metal coil enforcement activities. In total, 16 officers completed the questionnaire shown in Appendix D. The results of the survey are shown in Table 4.3-1.

It can be seen from the answers to Question 1 that the officers are almost all familiar with problems related to metal coil securement. Most (80%) are aware of accidents that resulted directly from a metal coil securement failure.

All of the officers were familiar with the correct regulations by reference. This is to be expected, since the officers surveyed were all directly responsible for cargo securement enforcement.

All of the officers said that they had experience enforcing securement regulations. Only three of the officers (18.75%) mentioned that they had trouble enforcing securement regulations. Most (15, or 93.75%) have had training in cargo securement regulations, though 3 (18.75%) mention no training for metal coils securement understanding or enforcement.

Eleven (68.75%) officers had performed more than 10 coil inspections in the past 12 months. Only one of these officers had performed no metal coil inspections. Most (13, or 87%) of the officers have written at least one citation for inadequate securement as a result of these inspections.

| | | |
|---|---|---|
| 1. Are you aware of any of the following problems with metal coils securement occurring in Illinois? | Actual securement failures (broken binders, chains, etc.) | 12 |
| | Inadequate securement (insufficient number of tie-downs, inadequate blocking, etc.) | 15 |
| | Accidents resulting *from* securement failures | 12 |
| | Accidents resulting *in* securement failures | 13 |
| 2. Name the cargo securement regulation applicable in Illinois | Correct responses | 16 |
| 3a. Have you had any experience in enforcing securement regulations? | Yes | 16 |
| | No | 0 |
| 3b. Are the regulations difficult to enforce? | Yes | 3 |
| | No | 13 |
| 4. Have you had specific training for (check all that apply): | Understanding cargo securement regulations | 15 |
| | Enforcing cargo securement regulations | 13 |
| | Understanding metal coil securement regulations | 13 |
| | Enforcing metal coil securement regulations | 13 |
| 5. In the past 12 months, how many coil inspections have you performed (check one)? | 0 | 1 |
| | 1-3 | 2 |
| | 4-10 | 2 |
| | 10+ | 11 |
| 6. In the past 12 months, how many citations have you issued based on inadequate securement as a result of the inspections? | 0 | 3 |
| | 1-3 | 2 |
| | 4-10 | 8 |
| | 10+ | 3 |
| 7. Do you feel the currently used securement regulations are adequate? | Yes | 14 |
| | No | 2 |

Table 4.3-1: Results of the Illinois State Police Survey

# CHAPTER 5: ENGINEERING DYNAMIC ANALYSES

The engineering dynamic analyses address the adequacy of the metal coil securement regulations. These analyses are divided into three sections. First, Section 5.1 Rigid Body Dynamic Analyses, presents simple models used to quickly evaluate the regulations. These models have limited scope, but their relative simplicity makes them attractive. Second, Section 5.2 Scale Model Testing, details the physical experimental testing to validate the analyses and to provide experimental parameters. Third and last, Section 5.3 Finite Element Model, discusses the advanced dynamic, structural, simulations based on dynamic, nonlinear finite element modeling of coils in transport.

## 5.1 Rigid Body Dynamic Analyses

The engineering analyses of coil restraints started with two rigid body models. These models, provided an initial understanding of the coil restraint loads. The rigid body models were instrumental in designing the scale model tests (Section 5.2). They also provided a check of the finite element models (Section 5.3).

### 5.1.1 Simple, Static Models

The first rigid body model was a two-dimensional, pseudo-static model. This model depicted in Figure 5.1-1, was used to approximate maximum chain forces for constant accelerations. These chain forces were needed to design the scale model test apparatus and test conditions.

The equations for this 2-D model are outlined below (Equations 5.1-1 through 5.1-3). The platform under the coil is assumed to be accelerated fore-aft ($x_b$). The coil equations of motion are based on relative motions between the platform and coil center. The relative motions are fore-aft (x) and angular rotation ($\theta$). If the coil relative motion is assumed to be pure rolling, then there is an additional kinematic constraint between the coil acceleration and angular acceleration (Equation 5.1-3). The coil also experiences forces due to the restraint chains and interface friction.

$$m(\ddot{x} + \ddot{x}_b) = F_{fx} + F_c \cos(\alpha)\sin(\psi) \qquad 5.1\text{-}1$$

$$J_{zz}(\ddot{\theta}_z + \ddot{\theta}_{zb}) = F_{fx}\frac{D}{2} \qquad 5.1\text{-}2$$

$$\ddot{x} + \frac{D}{2}\ddot{\theta}_z = 0 \qquad 5.1\text{-}3$$

For an applied platform acceleration, there are three equations with four unknowns. Thus, it is not possible to predict the coil response without considering the time history. A numerical simulation with starting conditions is needed to predict the behavior of a coil. Yet, it is possible to consider pseudo-static or limit response. For example, when a platform acceleration is suddenly applied, the chain forces do not change until the coil has moved, even a small amount. If the platform acceleration continues, the chain loads will adjust to arrest the relative motion. In this way, a bound on the chain forces can be approximated.

The maximum chain force occurs after the system has come to equilibrium. The net chain force becomes Fnet $=ma_b$, assuming that the acceleration is large enough to unload one set of chains. The chain force is then $Fc = ma_b/(2 \cos\alpha \sin\psi)$, where $\alpha$ is the fore-aft chain angle and $\psi$ is the lateral chain angle. Otherwise, for lower accelerations, the maximum chain force will be $Fc = F\text{-preload} + ma_b/(4 \cos\alpha \sin\psi)$. This is slightly larger force due to the preload force. For example, if a rearward base acceleration of 1 g is imposed on a coil weighing 500 lb with chain angles of $\alpha=45°$ and $\psi=30°$, the chain load will be 707 lbs on each forward leg. For a full size coil weighing 9,500 lbs, the chain forces would be 13,400 lbs.

One further note is that this rigid body model is for unblocked coils. This initial simple model was selected as a worst case to approximate the maximum chain loads in the scale model testing.

### 5.1.2 Three-Dimensional MatLab Model

The second rigid body model is a more sophisticated three-dimensional model developed and solved with MatLab (Math Works, 1992). This model is used to predict coil response motions for input platform motions. This model was used to help verify the finite element model (see Section 5.4). The equations of motion for this model are detailed in Appendix E and coil model idealization is depicted in Figure 5.1-2. The coil equations of motion were solved numerically with the Matlab function "ode45", which solves a system of ordinary differential equations by a 4-5 order Runga-Kutta scheme.

This model considers five degrees of freedom for each the coil and its platform (10 DOF total). Both the platform and coil have three displacement (x = fore-aft; y = vertical; z = left-right) and two rotations ($\theta_x$ = yawing or tipping; and $\theta_z$ = pitching or rolling). The equations of coil motion were developed as relative motion between the coil and platform. The model includes the additional forces of chain restraint forces, normal contact force, and interface friction. The friction force is assumed to be less than or equal to the friction coefficient times the normal contact force. When the friction limit is reached, the coil will slip on the platform. The frictional forces are considered in both the fore-aft and lateral directions. The chain forces are due to elastic extension. The chains are assumed to start with a preload.

In the unblocked configuration, the model can roll in the fore-aft direction or slide in the lateral direction. The equations of motion in MatLab include logical statements to determine if the coil is rolling or sliding. Additionally, the coil could separate from the platform in the vertical direction. However, to lose contact in the vertical direction requires that the downwards

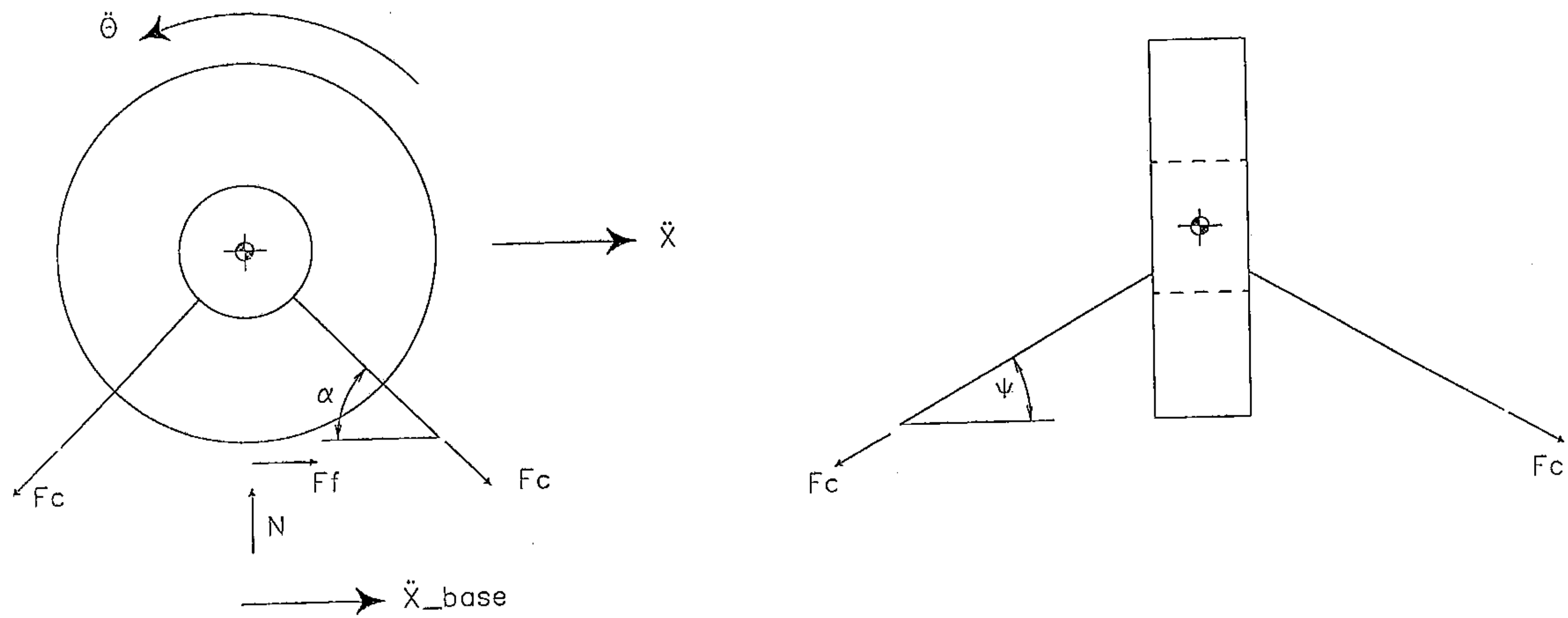



Figure 5.1-1 Two-dimensioanl rigid body coil model - free body diagram.

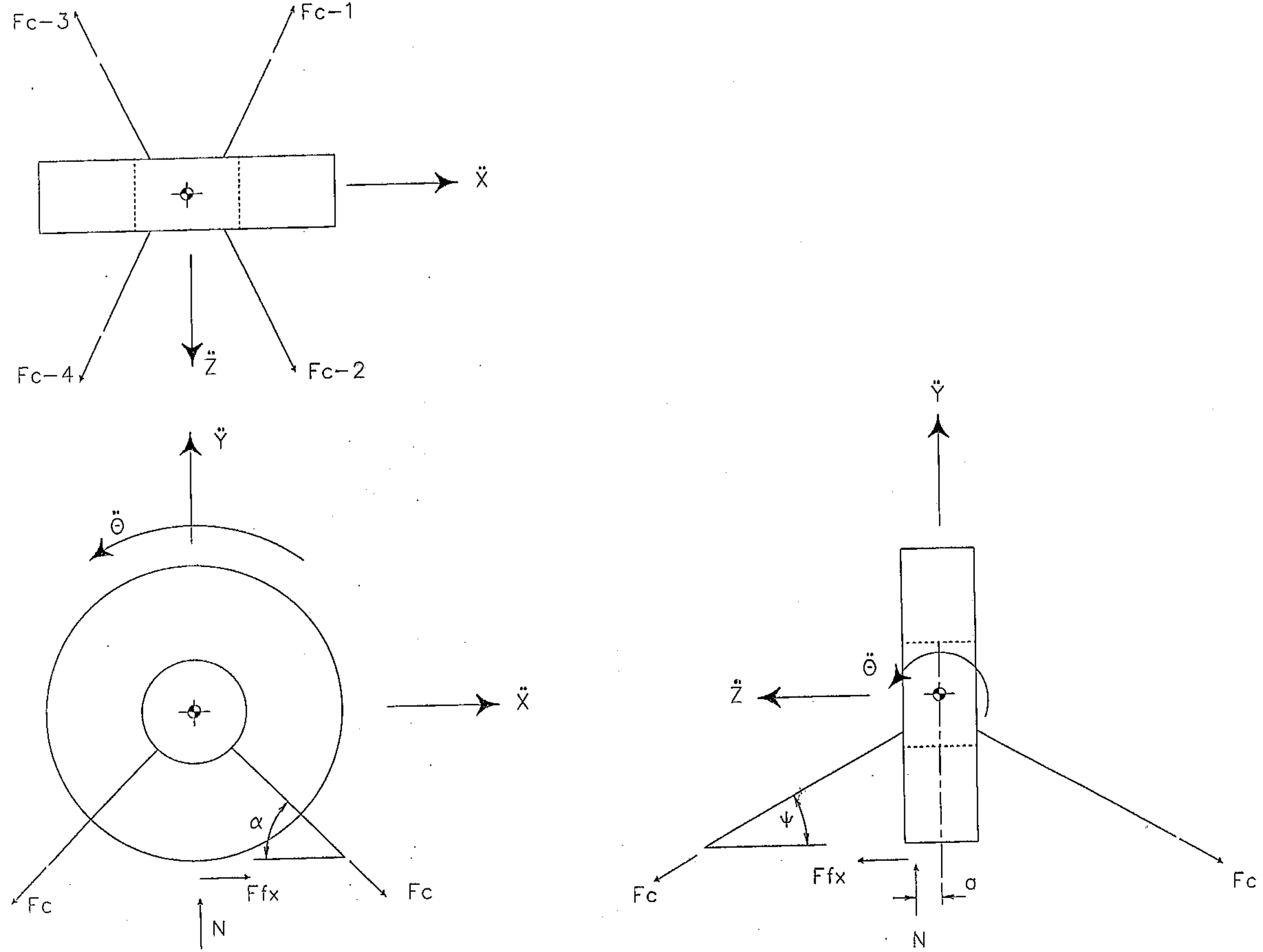



Figure 5.1−2 Three-dimensional rigid body coil model − 5 DOF each coil and base.

acceleration is large enough to exceed both the acceleration due to gravity and the chain restraint forces.

### 5.1.3 Observations - Rigid Body Models

The following observations are drawn from the two previously described rigid body models.

1. The coil must move, roll, or slide to change the forces in the restraint. The restraint chains act elastically and the coil's relative motion on the trailer is what causes the load changes. For the chains to fail, the coil has moved on the trailer due to dynamic loads (accelerations).

2. The simple 2-DOF rigid body model predicts that the two rearward legs of chain will each experience 1.42 times the weight of a single coil for a 1.0 g braking deceleration with chain angles of $\alpha = 45°$ (covered by regulations) and $\psi = 30°$ (not covered by regulations). This is assuming that there is enough coil motion to let the forward chains go slack. Otherwise the chain force will be even higher. If the lateral chain angle is steeper, say $\psi = 60°$, then the chain force falls to 0.82 times the coil weight. These chain forces are slightly lower than those predicted by the finite element simulations (see Section 5.4.2).

3. The three-dimensional Matlab rigid body model gave similar time history simulation results to those from the finite element modeling (See Section 5.3). Due to their similarity no specific model results are noted here, but this modeling exercise gives confidence in the finite element model.

## 5.2 Scaled Model Testing

The dynamic response of scaled coil specimens were experimentally investigated to provide further insight into their behavior. Also, the results are used to calibrate the analytical models.

The testing is divided into three sections. Experimental Planning (5.2.1) details the experimental test planning and preparation. Component Testing (5.2.2) describes the isolated component testing, i.e., chains, cable, and friction. Scaled Model Test Results (5.2.3) discusses the model coil tests. Then the overall test observations are summarized in Section 5.2.3.3.

### 5.2.1 Experimental Planning

The planning of the scaled model tests includes the selection of appropriate prototype steel coils, designing of the scaled coil specimens using similitude rules, designing of the test configuration and instrumentation, and selecting the test maneuvers.

5.2.1.1 Prototype Coils and Tie-down Chains

Two prototype steel coils are selected to cover a wide range of possible behavior of metal coils. The prototype "A", a tall and narrow coil that may have a tendency to tip to the side, is 9,690 lbs, 60 inches in diameter and 15 inches in length. The prototype "B" consists of a 39,250 lbs steel coil, 60 inches in diameter and 60 inches in length. Coil B is wide which is more likely to slide to the side. The diameter of the eye of both coils is 21 inches.

Each coil is positioned where the eye of the coil is crosswise with respect to the bed of the truck. The tie-down assembly passes through the eye of the coil which restricts forward and rearward motion. To satisfy the pre-1994 Federal Motor Carrier Regulation (49 CFR 393 1988) for aggregate breaking strength of 1.5 times the weight of the coil, two 1/4 in. and four 3/8 in. High Test (G4) chain tie-downs are used for prototype coil A and B, respectively. In both cases, the aggregate breaking capacities are 1.55 times that of the coil weight. However, the size difference between the coils results in a much shallower tie-down angle of Coil A in the lateral direction due to the narrower width of the coil (this angle is not covered by the regulation). The two coils are shown to scale in Figure 5.2-1.

The adequacy of the selected tie-down chains is also checked using the working load limit method. The tie-down chain working load limits are 0.54 and 0.55 times the weight of coils A and B, respectively, which are higher than the required value of 0.5 as specified by the post-1994 Federal Motor Carrier Regulation (49 CFR 393 1994).

5.2.1.2 Scaled Model Coil Specimens, Cable Tie Downs, and Test Platform

Two scaled model coil specimens are tested, as shown in Figure 5.2-2 and 5.2-3. Steel cables are used to attach the coil specimens to an adaptive timber platform which in turn is mounted on a truck. Due to very high density needed for a true replica model as specified by the similitude equations (up to 4000 pcf), the artificial mass (or added mass) simulation technique is utilized, as shown in Table 5.2-1 (Sabnis *et al.*, 1983). Consequently, lead can be used as the model material. It is important to note that the artificial mass modeling technique compensates for the relatively low model material density of lead (708 pcf) with a supplemental layer of lead added to the model coil so that the total mass of the model coil satisfies the true replica similitude requirement. This results in an "apparent" scale factor smaller than that of the "theoretical" scale factor. For construction convenience, the apparent scale factor of 3 and 5 are used for coil specimens A and B, respectively, resulting in a scaled coil weight of approximately 500 pounds. These apparent scale factors correspond to theoretical scale factor of 4.14 and 8.97 for model coil specimen A and B, respectively, which are used in similitude calculations. The details of the prototype and scaled coils are given in Table 5.2-2.

To satisfy the similitude requirement for the axial stiffness of the prototype tie-down chains, 3/32 in. uncoated stainless steel aircraft cables (type 9x73) are used as tie-downs for the model coils. This is verified experimentally where the axial stiffness of prototype tie-down chains and scaled model tie-down cables are measured, as given in Sections 5.2.2.1 and 5.2.2.2.

The timber and steel platform is designed to support the scaled coil in a "suicide" position, where the eye of the coil is crosswise with respect to the bed of the truck. The platform has an oak deck which is supported by wooden 4x4's and C8x11.5 steel channel beams, as shown in Figure 5.2-4. The scaled coil specimen is placed on the oak deck and the restraint cables are secured to the steel beams. The platform is designed to accommodate both scaled coils A and B, as shown in Figures 5.2-5 and 5.2-6.

To simulate properly the frictional characteristic at the interface of the scaled coil and the platform, a sheet metal skirt is attached to the lead coil specimen. The metal skirt (a sheet of can stock) is attached to the scaled coil specimen using contact cement adhesive and four screws. Also, steel end plates are used to prevent the restraint cables from biting into the soft lead at the eye of coil specimens.

The interface coefficient of friction between the platform deck and the steel jacketed coil specimen is measured (0.36) by a simple pull test (Section 5.2.2.3).

5.2.1.3 Instrumentation

The scale model tests were instrumented to monitor both acceleration and tie-down forces. Both the platform and sample coils were instrumented with accelerometers. The platform's complete three-dimensional motion was monitored with six accelerometers. That is, both the platform's displacements and rotations were monitored. The coil's motion was measured with four accelerometers. These four accelerometers monitored three displacements and one rotation of the coil. All ten accelerometers were PCB Piezotronics, Inc model 338A35 with a sensitivity of 100 mV/g. These accelerometers have a frequency range of 1 to 2000 Hz with a $\pm 5\%$ accuracy. The accelerometers were connected to PCB battery power supplies.

The platform accelerometers are configured as shown in Figure 5.2-7. There are three accelerometers in the vertical (Y) direction. These three are averaged to indicate the vertical acceleration. They also indicate tipping ( X axis rotation) - using Y2 and Y3 - and pitching or rolling ( Z axis rotation) - using Y4 and the average of Y2 and Y3. Then two accelerometers are in the fore-aft (X) direction. These two accelerometers also indicate the twisting (Y axis rotation). The remaining accelerometer is in the lateral (Z) direction.

The four accelerometers on the sample coils are configured as shown in Figure 5.2-8. Each sample coil has three accelerometers in the coil eye (center). These three accelerometers are approximately in-line with the coil's mass center. The remaining accelerometer is positioned at the top of the coil sample. The last accelerometer for coil A (tall, narrow sample) is in the lateral (Z) direction to sense lateral tipping rotation. Coil B (short, wide sample) is oriented in the fore-aft (X) direction to sense rolling motion.

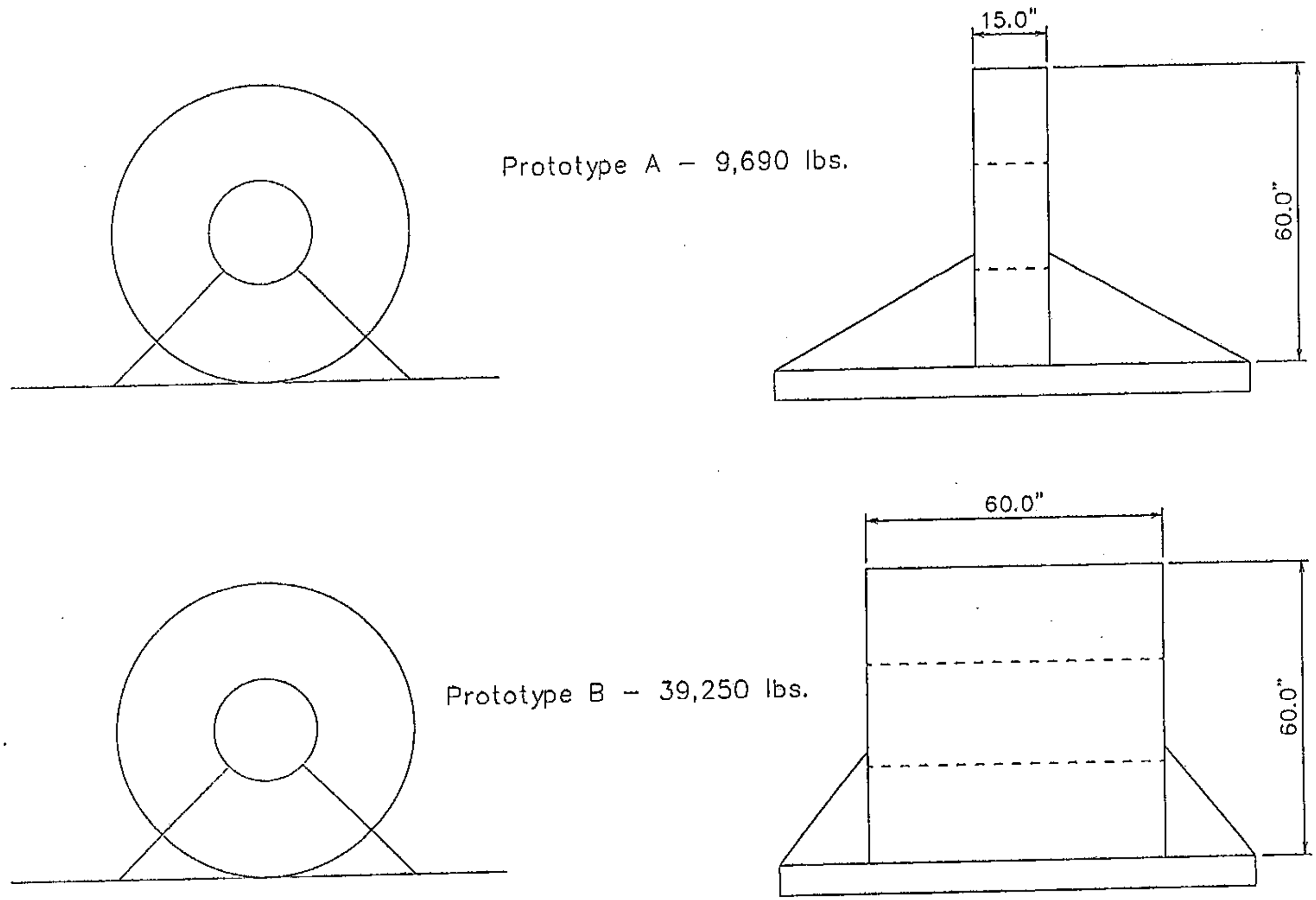



Figure 5.2-1 Prototype coils – to scale.

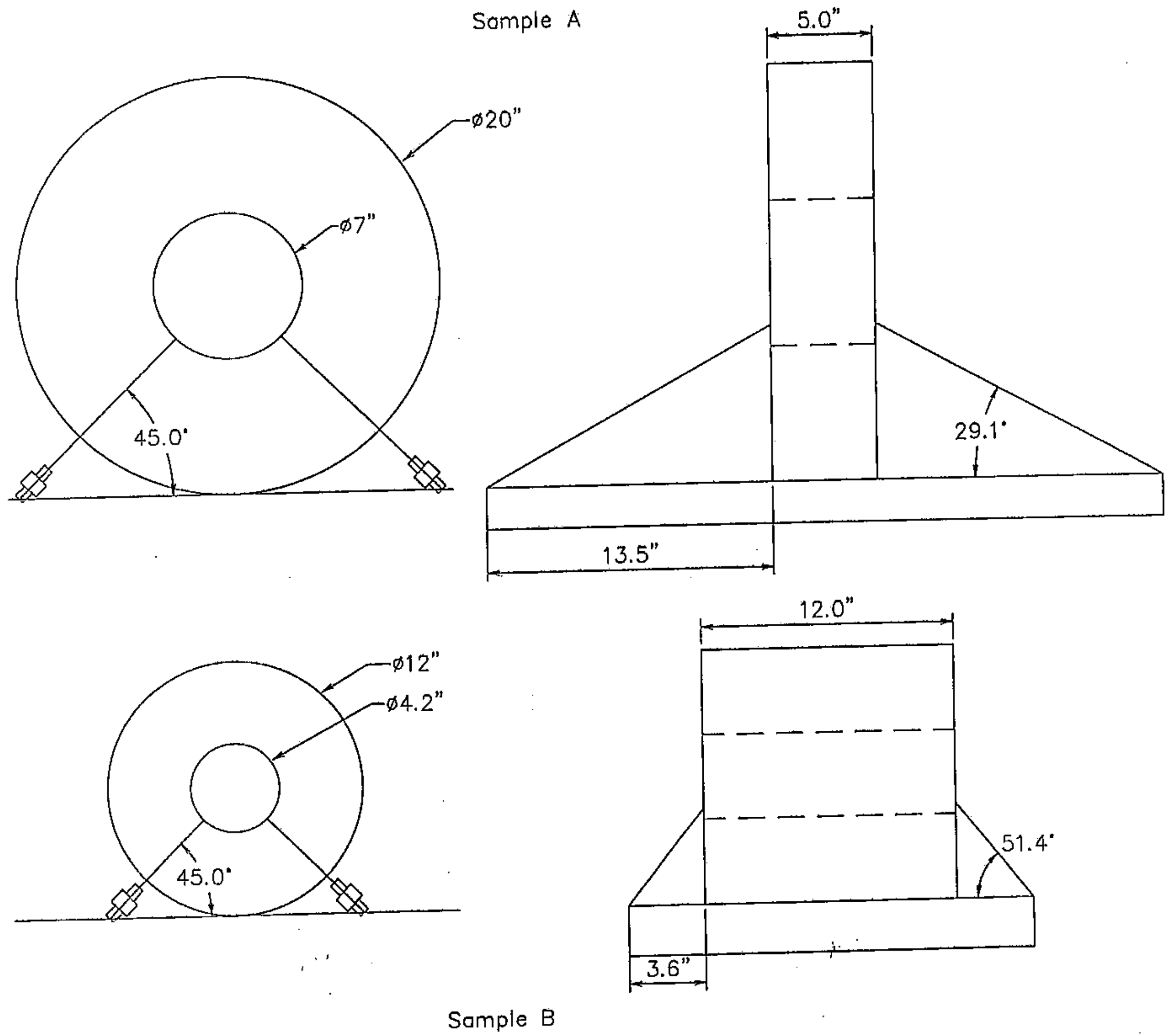



Figure 5.2-2 Scaled coil specimen for testing – to scale.

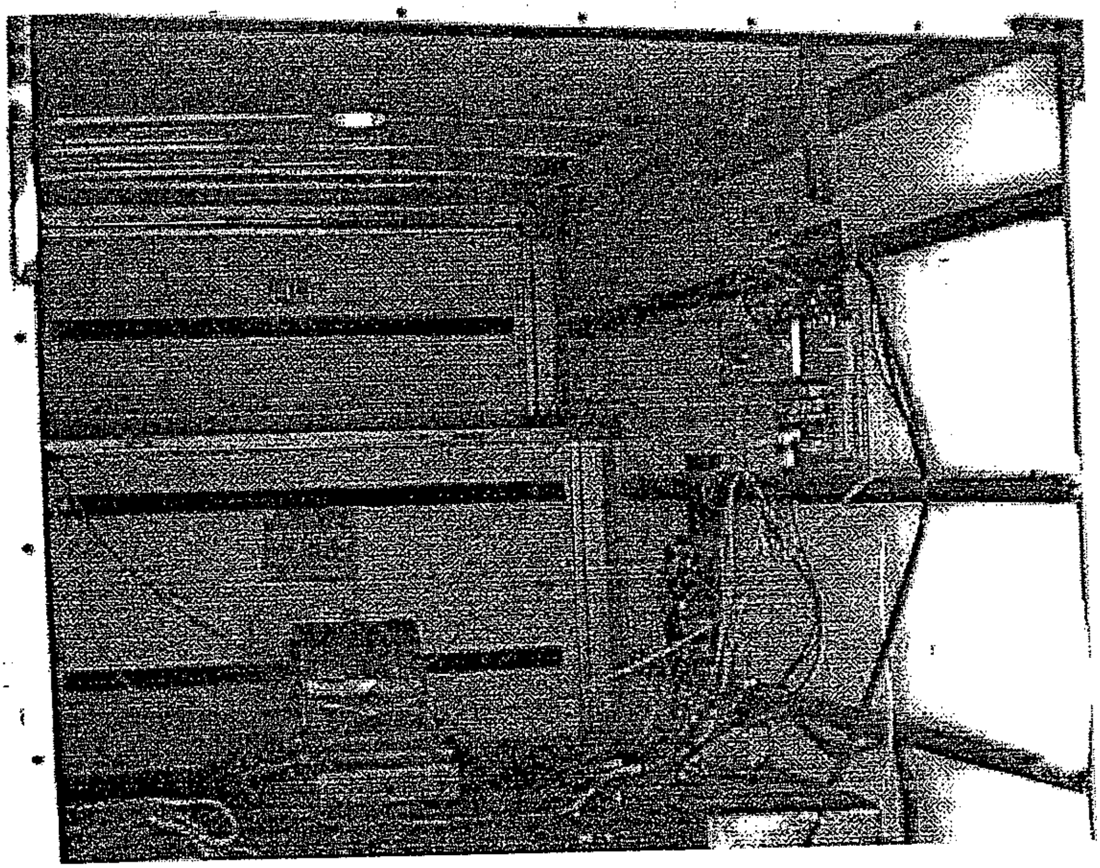


Figure 5.2-3 Test setup for the scaled coil specimens

| Group | Quantity | Dimension | True Model | Added Mass* |
|---|---|---|---|---|
| Loading | Force | F | $S_E S_l^2$ | $S_E S_l^2$ |
| | Acceleration | $LT^{-2}$ | 1 | 1 |
| | Time | T | $S_l^{1/2}$ | $S_l^{1/2}$ |
| Geometry | Linear dimension | L | $S_l$ | $S_l$ |
| | Displacement | L | $S_l$ | $S_l$ |
| | Frequency | $T^{-1}$ | $S_l^{-1/2}$ | $S_l^{-1/2}$ |
| Material properties | Modules of Elasticity | $FL^{-2}$ | $S_E$ | $S_E$ |
| | Mass Density | $FL^{-4}T^2$ | $S_E/S_l$ | * |

* Mass is added so that weight of the prototype = $(S_E)(S_l^2)$ weight of the model

Table 5.2-1 Similitude requirements (scale factors) for dynamic elastic models

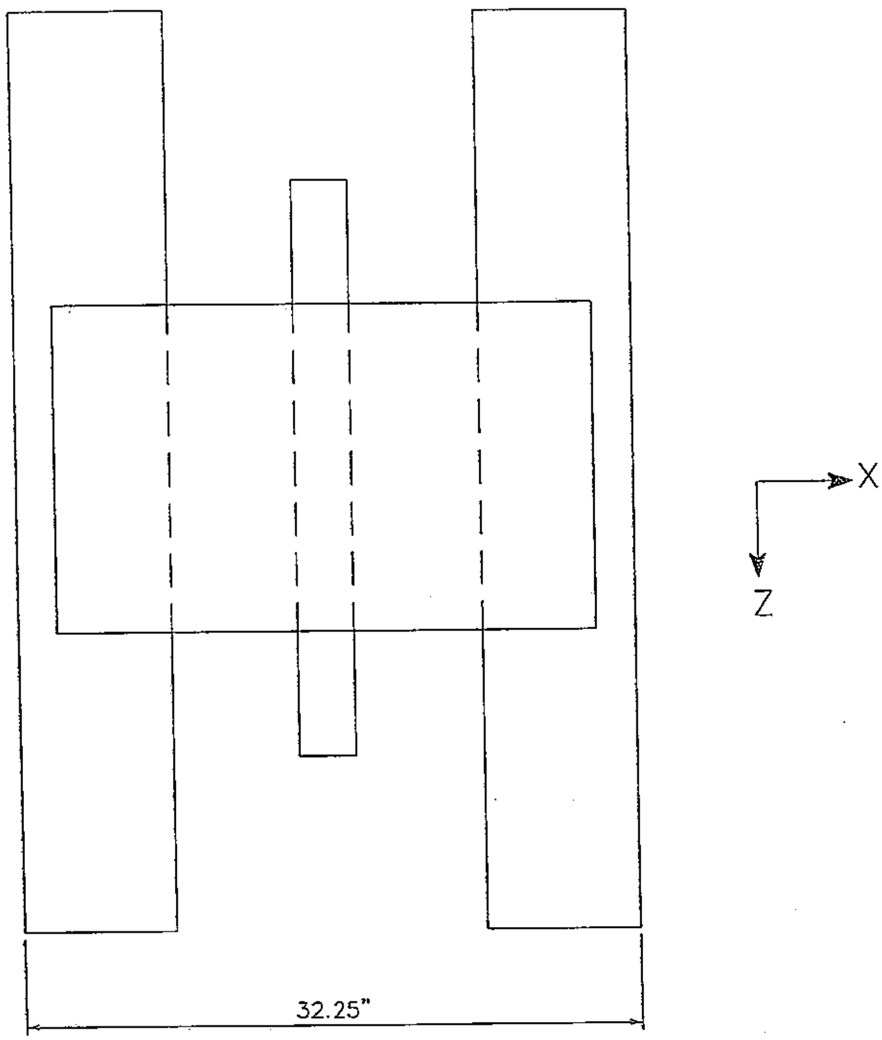
| | | Specimen A | | Specimen B | |
|---|---|---|---|---|---|
| Prototype | W (lbs) | 9,690 | | 39,250 | |
| | L (in) | 15 | | 60 | |
| | D (in) | 60 | | 60 | |
| | d (in) | 21 | | 21 | |
| | $\gamma$ (lb/ft$^3$) | 450 | | 450 | |
| | | (1)* | (2)** | (1)* | (2)** |
| Scaled*** Model | W (lb) | 565 | 565 | 488 | 488 |
| | L (in) | 5 | 3.62 | 12 | 6.69 |
| | D (in) | 20 | 14.5 | 12 | 6.69 |
| | d (in) | 7 | 5.07 | 4.2 | 2.34 |
| | $\gamma$ (lb/ft$^3$) | 708 | 1860.7 | 708 | 4088 |

* (1) Added mass

** (2) Theoretical

*** Specimen A: $S_{1\ \text{added mass}} = 4.14$ & Specimen B: $S_{1\ \text{added mass}} = 8.97$

Table 5.2-2 Prototype and scaled model geometry



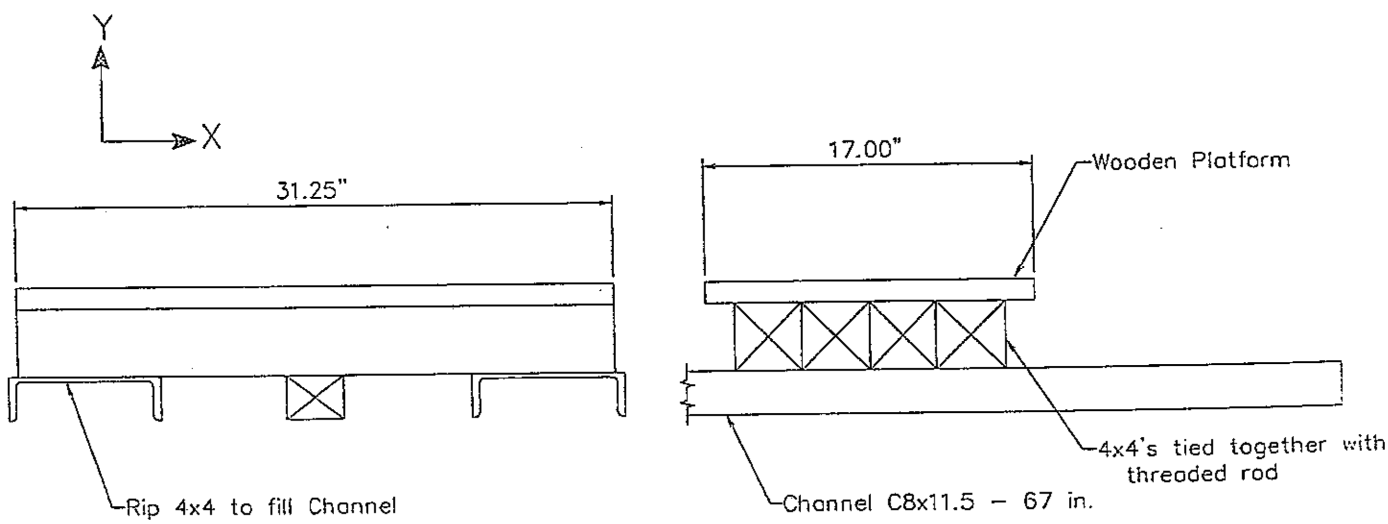




Figure 5.2-4 Coil test platform.

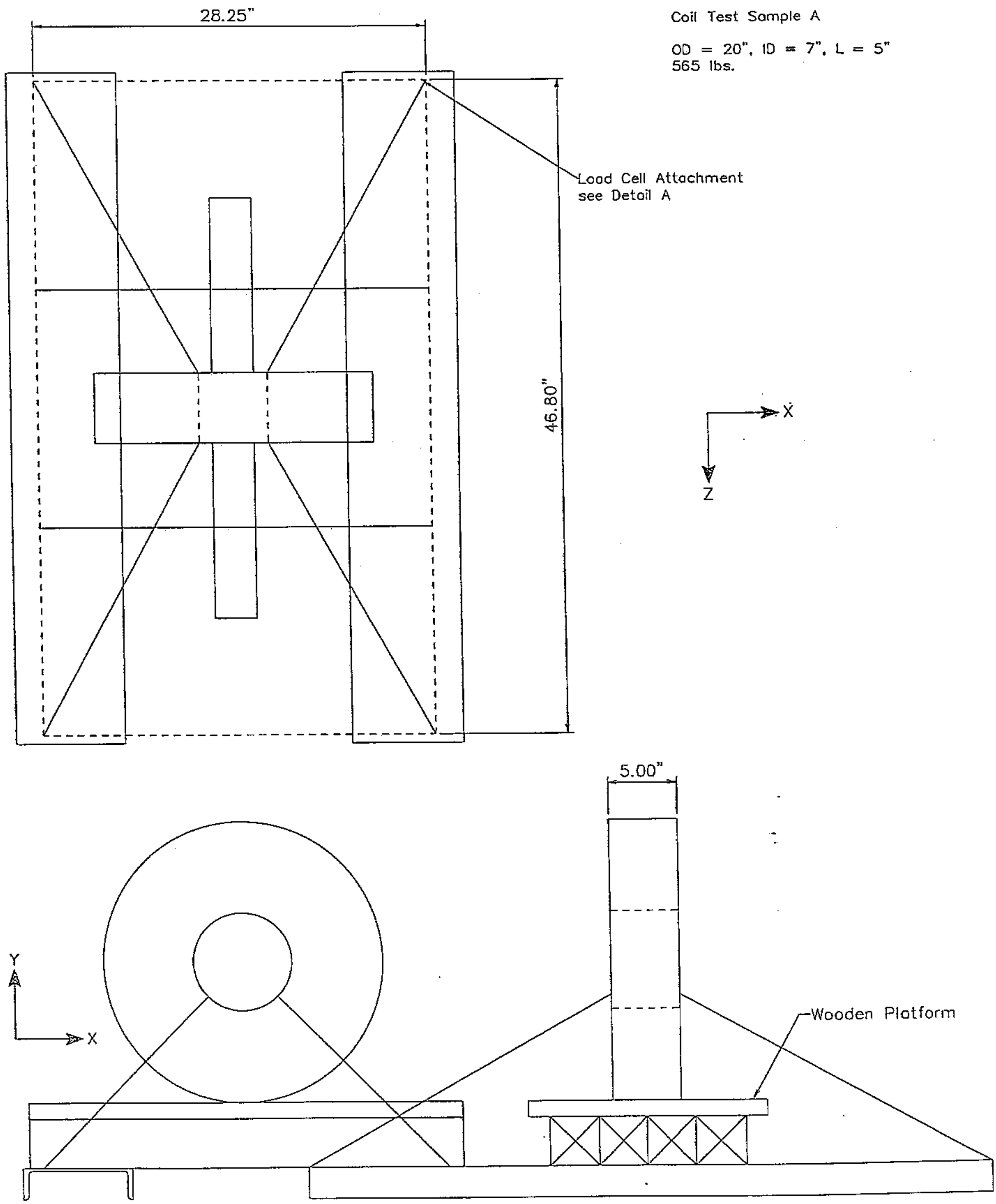



Figure 5.2–5 Scaled coil Specimen A on test platform.

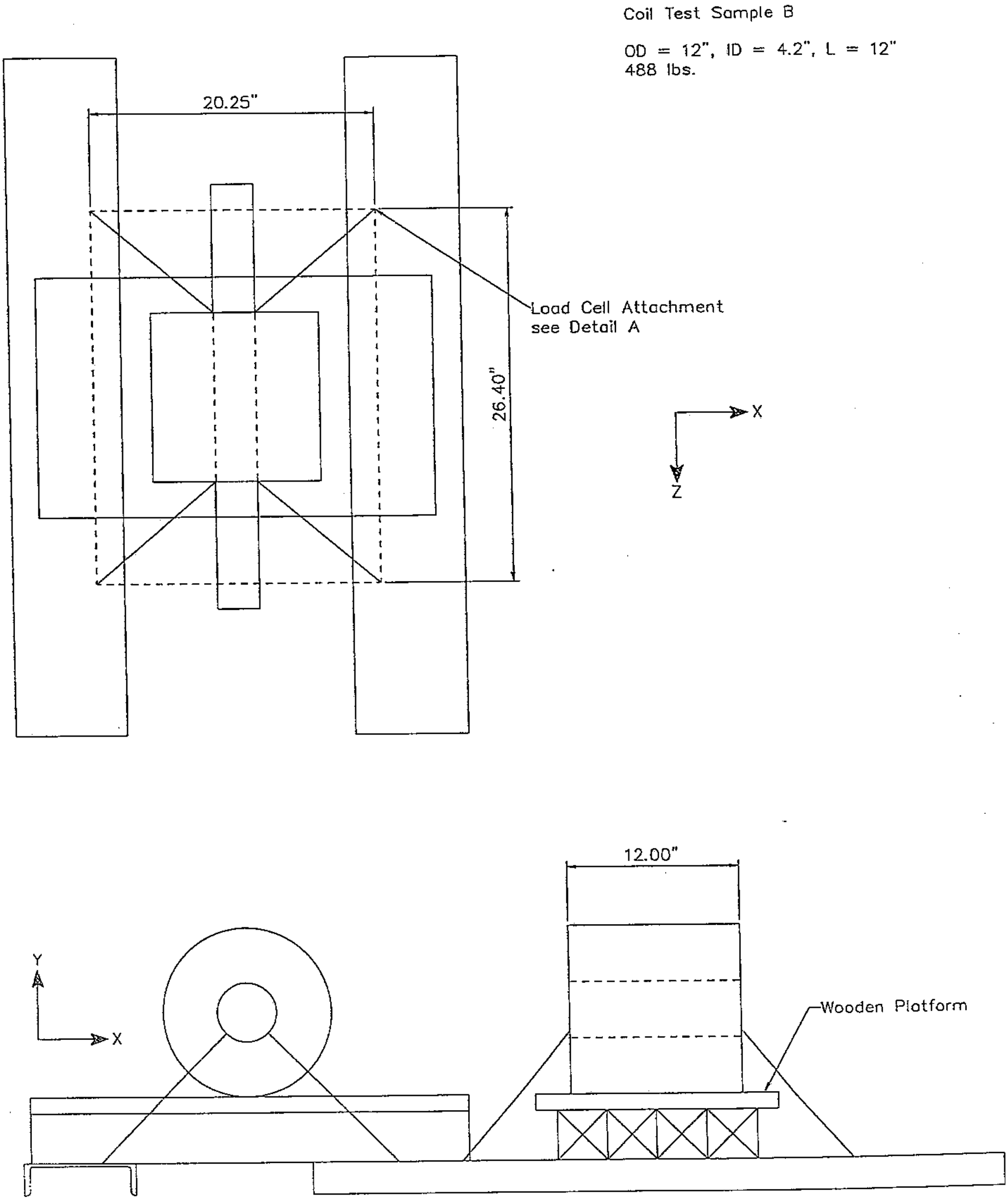



Figure 5.2-6 Scaled coil specimen B on test platform.

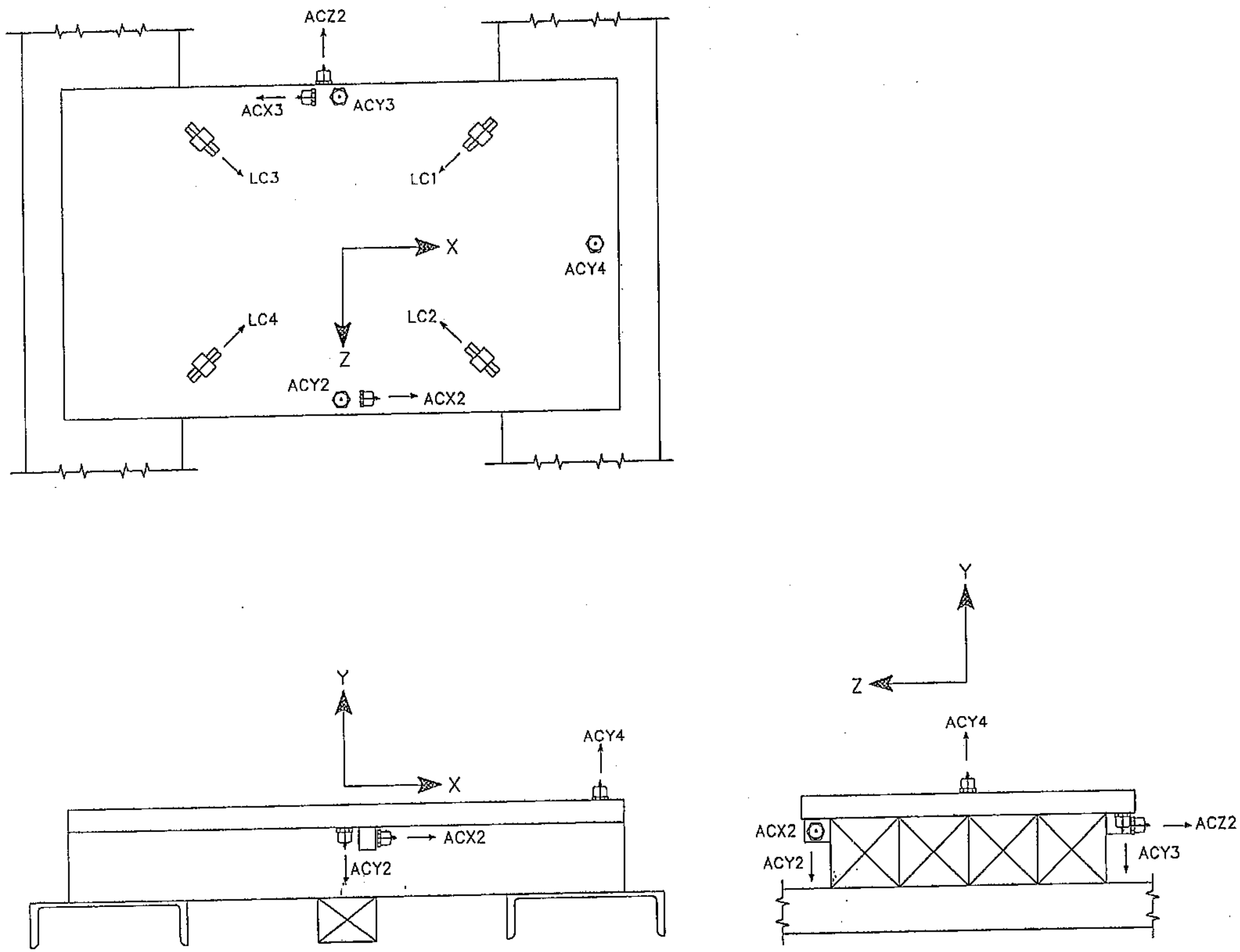



Figure 5.2-7 Accelerometer and load cell placement on test platform.

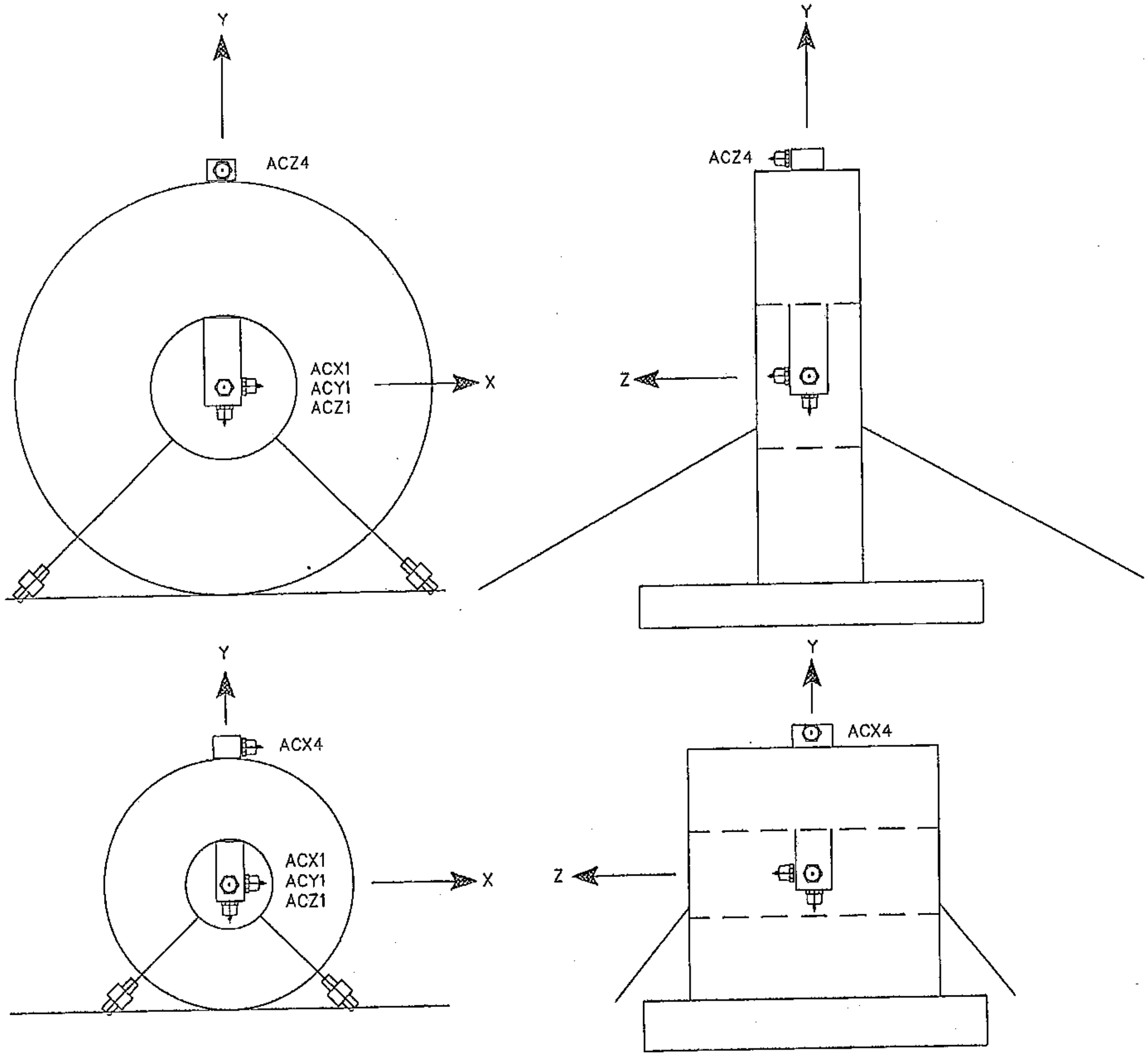



Figure 5.2-8 Accelerometer configuration on coil specimen.

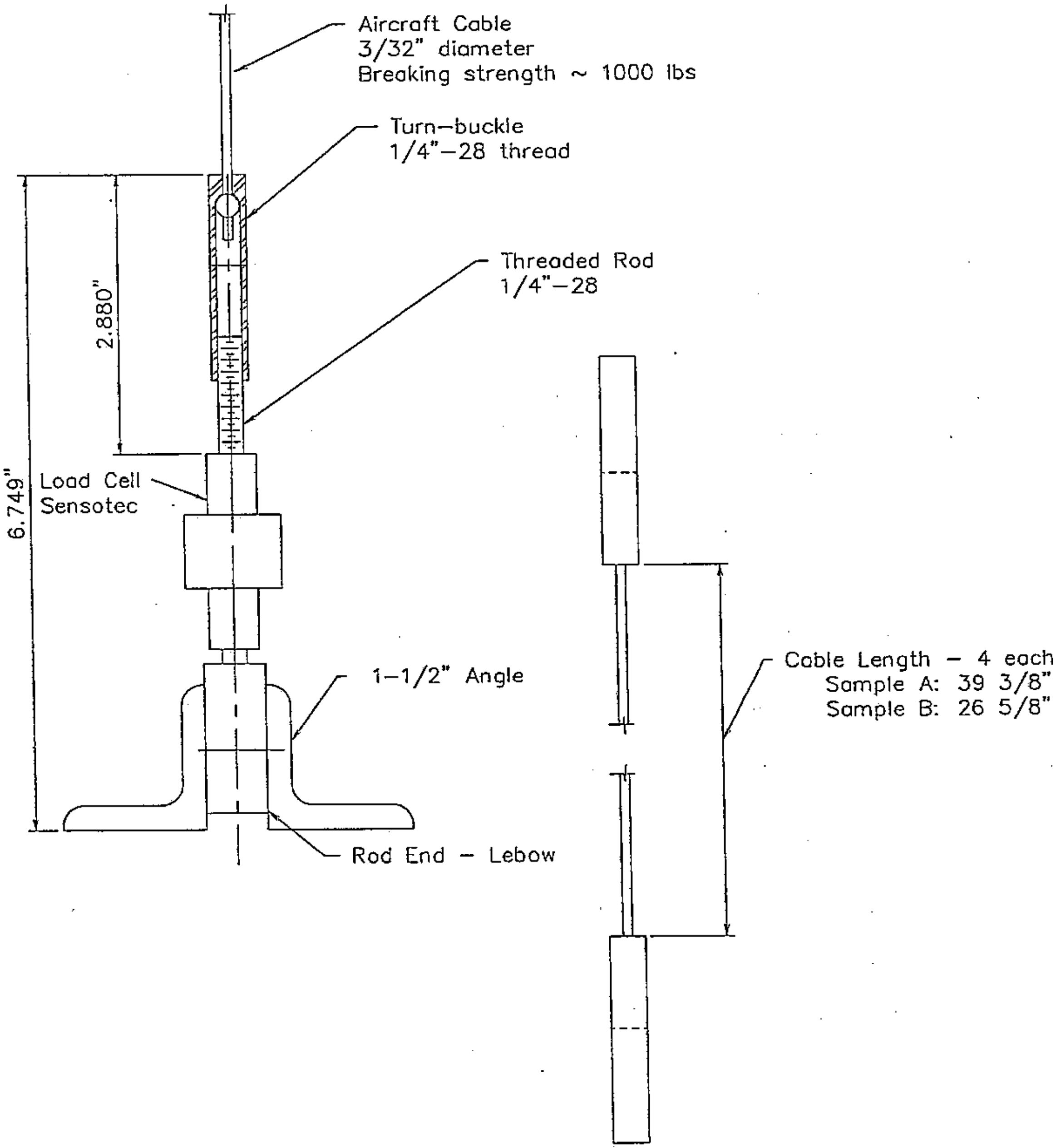



Figure 5.2-9 Load cell and turn-buckle configuration.

The restraint forces were monitored by load cells at the ends of the tie-down cables. The load in each end of the two restraint cables was measured by a load cell. The four load cells were configured as shown in Figure 5.2-9. The load cells are Sensotec Model 34 and connected to Model UV battery powered, in-line amplifiers. These load cells have a range of ±1,000 lbs. with a frequency range of DC - 5,000 Hz. The load cells were connected to the platform's support channels by rod ends and angle iron brackets. The brackets were bolted to the beams so that they can be repositioned to accommodate both coil samples. The load cells were attached to the restraint cables with a threaded stud and over-nut turn-buckle arrangement. The cables were custom made with the turnbuckle nuts and the cable preload was adjusted by turning the nut component.

The accelerations and loads were recorded with two eight-channel DAT (digital audio tape) recorders. The recorders were Sony model PC-108M, which when recording eight channels have a frequency range of 0 - 5 KHz (sample rate 12 K samples/sec. per channel). The recorder's 16 channels included 10 accelerations, 4 load cells, and two channels to synchronize the recorders. The two recorders were synchronized by recording reference event markers on one channel of each recorder. The synchronization scheme was to suddenly apply voltage at the start of a test and then turn it off at the end. A synchronization box was built with a 9 V battery, switch and two output cables.

5.2.1.4 Test Maneuvers and Test Site

The field tests were conducted outdoors in South Research Road on SIUE's campus in Edwardsville, as shown in Figure 5.2-10. The South Research Road is 390 ft long dead-end road with an end-circle, 100 ft. in diameter, as shown in Figure 5.2-11. The field tests were conducted using the following three maneuvers (driving courses shown in Figure 5.2-12).

1. Straight Line Braking Maneuver - where the moving truck attained a constant speed of about 30 MPH and was brought to a rapid, complete stop.

2. Q-Straight Braking Maneuver - where the truck attained a constant speed of about 20 MPH in a circle (driving radius of about 44 ft.), was turned into a connecting straight road, and then gradually brought to a complete stop; and

3. Q-Braking Maneuver - which was similar to the second maneuver except the truck was suddenly brought to a complete stop at the turn into the straight part of the road.

The selected speed for the straight line braking maneuver (30 MPH) corresponds to actual truck speeds of 61 MPH and 98 MPH for prototype coils A and B respectively. The selected turning speed of 18 MPH corresponds to actual speeds of 40 MPH and 50 MPH for prototype coils A and B respectively.

Each maneuver was repeated three times for the scaled coil specimens A and B, with and without timber blocking (cradle configuration). A total of 36 field truck tests were conducted.

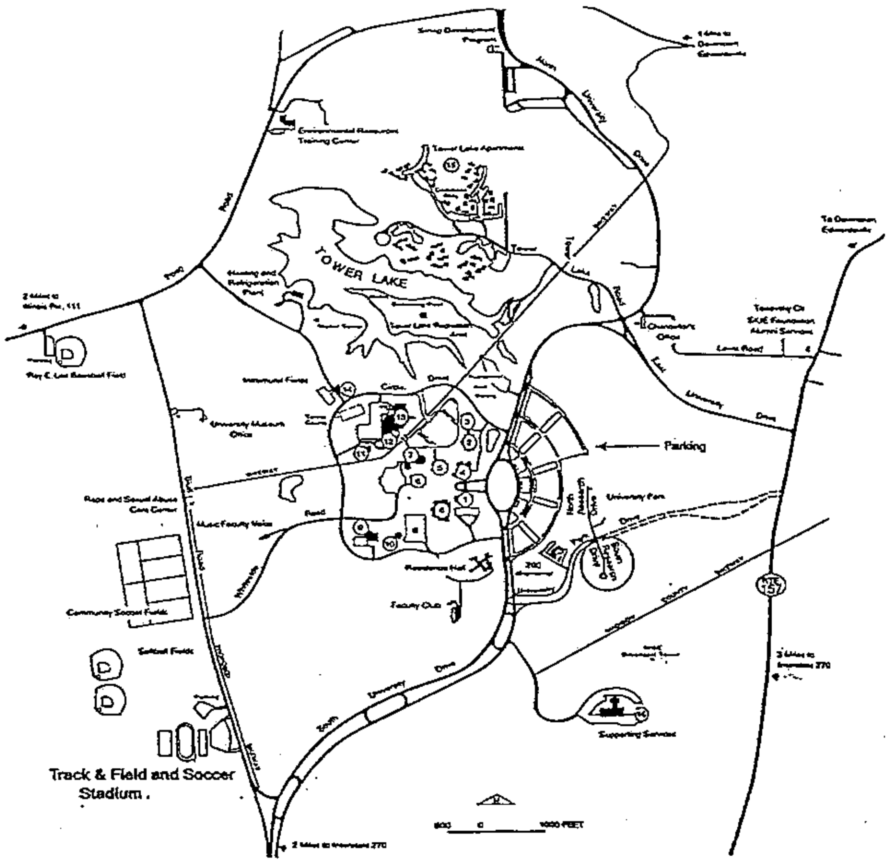
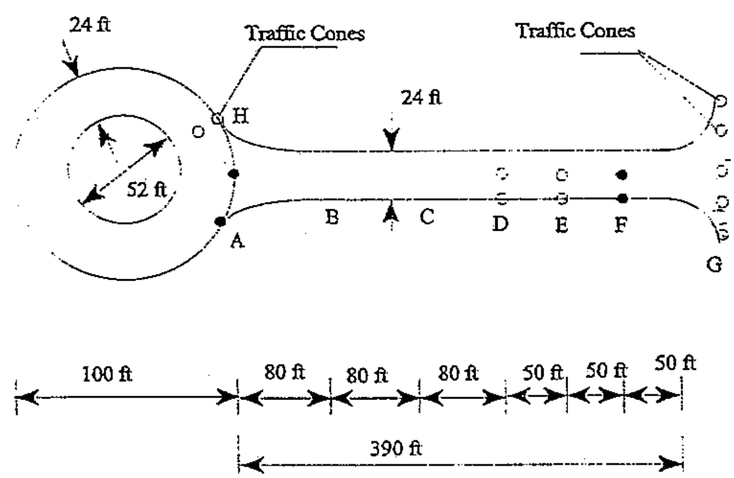
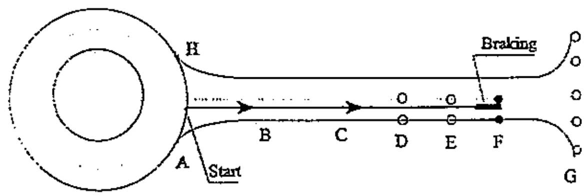



Figure 5.2-10 Location of the field testing site

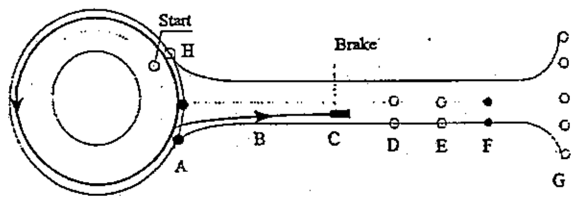



Driving Test Course Dimensions

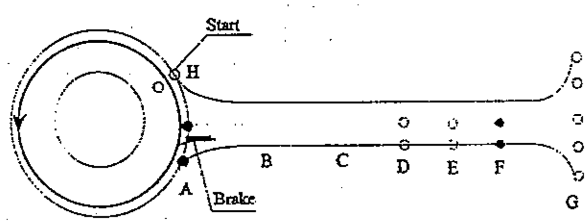
Figure 5.2-11 Field testing course gemoetry




—— Staight Line Braking Maneuver Course




—— Q Straight Braking Maneuver Course




—— Q Braking Maneuver Course

Figure 5.2-12 Course patterns for field test maneuvers

### 5.2.2 Component Testing

Before the field tests were run, the instrumentation was calibrated and a variety of component tests were performed. The component tests provide isolated component response characteristics for inclusion in the analytical models. The component tests include chain stiffness testing and theoretical predictions; cable stiffness and strength; and friction coefficient between the coil samples and platform.

#### 5.2.2.1 Chain (stiffness)

One of the essential components in the metal coil securement study is the tie-down chains. The chains are a complex elastic component and their load-deflection (stiffness) characteristic as well as strength was needed for analytical modeling. To this end, chain samples were obtained from LeClede Chain Manufacturing, Maryville, Mo. These chains were tested for stiffness.

Load restraint steel chain strength and dimensions are indicated in the industry standards. Two such standard are the Welded Steel Chain Specifications adopted by the National Association of Chain Manufactures (NACM), York, PA (1990), and the A 413-91 Standard for Carbon Steel Chain adopted by ASTM. These specifications cover the three grades of chain appropriate for cargo transportation, Grade 30 - Proof coil, Grade 43 - High test, and Grade 70 - Transport. Both specifications provide minimum dimensional specifications for links, minimum breaking strengths, and suggested working loads. They do not however provide any indication of the load-deflection stiffness of chains. A literature search failed to reveal any recent publications on chain stiffness. Thus, an analytical model and component tests were necessary to provide this information.

The analytical chain link stiffness model was developed based on Castigliano's theorem (energy method) (Boresi *et al.*, 1978). The chain link is idealized as shown in Figure 5.2-13 and the deflection equation was developed including bending and shear deformations. The analytical model is fully described and developed in Chai (1995). The final equation for the deflection per unit load (flexibility) of a single link is

$$\frac{\delta_w}{w}=\frac{1}{w}\frac{\partial U}{\partial w}=\frac{L}{EA}+P^2\frac{L}{EI}+1.33\frac{\pi}{4}\frac{L}{AG}-\frac{2}{EA}(P-R+\frac{\pi R}{4})+\frac{\pi}{4}\frac{R}{EA}$$

$$+\frac{A_m}{A(RA_m-A)E}[(P-R)^2\frac{\pi}{2}+2(P-R)R+R^2\frac{\pi}{4}] \qquad (5.2\text{-}1)$$

Where E and G are the Young's modulus and shear modulus, A is the cross sectional area, I the moment of inertial of the chain wire cross section, and the two derived geometric parameters P (due to moment B.C.) and $A_m$ (curved beam term) (Boresi *et al.*, 1978) are

$$P=\frac{\dfrac{1}{EA}-\dfrac{A_m(R-\frac{\pi}{2}R)}{A(RA_m-A)E}}{\dfrac{L}{EI}+\dfrac{\frac{\pi}{2}A_m}{A(RA_m-A)E}} \quad (5.2\text{-}2)$$

$$A_m=2\pi(R-\sqrt{R^2-r^2}) \quad (5.2\text{-}3)$$

This equation was verified by a finite element model (Chai, 1995).

Actual chain tests were performed on two chain specimens to verify the equations and the modeling of the chain. The chain samples tested were 1/4" Grade 70 and 5/16" Grade 43. The chain samples were pulled in tension in a 120 Kip Tinius Olsen universal test machine on a load range setting of 3 Kip. The chain samples were held in wedge grips and the displacement was measured with an 8 in. digital caliper across 5 links. The chain specimens were loaded to approximately 50% of the proof loading so as to not plastically deform the specimen. A summary of the test results compared with the analytical prediction is shown in Table 5.2-3.

| Chain Type | Equation 5.2-1 (Kip/in/in) | ABAQUS (Kip/in/in) | Experiment (Kip/in/in) |
|---|---|---|---|
| 1/4" G70 | 531 | 498 | 525 |
| 5/16" G43 | 888 | 844 | 974 |

Table 5.2-3 Comparison of chain stiffness by three methods

Note that this chain test does not conform to ASTM A 413-91 chain test specifications. Both the holding method and the number of links do not conform to the accepted test method. The number of links should have been 7, but this exceeded the capacity of the caliper available. This non-conformance with test standard in no way invalidates the test results. The chain samples were tested well below the working and ultimate strengths. Also the number of links is primarily for the statistical treatment of breaking strength and net elongation at rupture.

5.2.2.2 Cable (strength and stiffness)

The cable assemblies will restrain the scaled coil samples in the tests and their stiffness and strength must be verified. These tests verified the cable strength to ensure that the testing would be safe. Two cable assembles of the length for coil sample B were purchased for this destructive test.

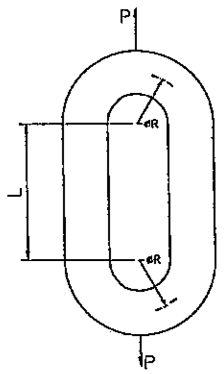



Figure 5.2-13 Chain link geometry

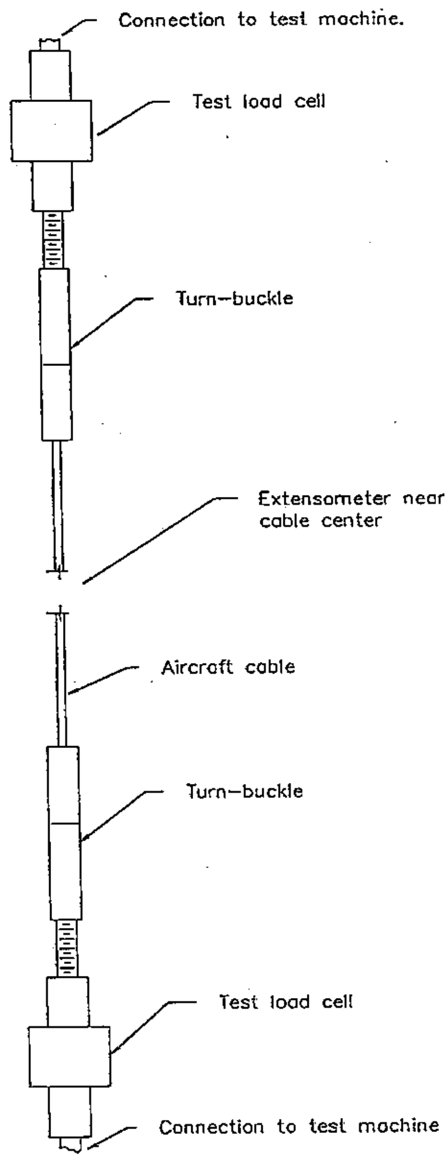



Figure 5.2-14 Configuration of cable test in tension test machine.

The cable test was configured as shown in Figure 5.2-14. The configuration includes the cable, load cells and turn buckles. This way the local cable stiffness was monitored as well as the macro stiffness of the whole restraint system. The cables were tested in a Tinius-Olsen 5 Kip universal test machine. The loads were measured by the test machine load cell as well as the two test load cells. Elongation was measured by an internal head displacement sensor in the test machine (total elongation) and an extensometer (2" gauge length , cable-only elongation). These results were recorded both on a X-Y pen plotter and Sony DAT recorder (5 inputs - 8 channel mode).

The breaking strength of the two cables were 1200 lb and 1230 lb. The average macro stiffness per unit length of the two cables were 72500 lb/in/in for a tangent stiffness (tangent to mid response) and 59100 lb/in/in for a secant stiffness (average stiffness for whole response). The macro stiffness is based on an overall length of 31 in. The cable only average stiffness per unit length is 69600 lb/in/in for the tangent stiffness and 53300 lb/in/in for the secant stiffness.

The cables did show significant nonlinear response as indicated by the difference between tangent and secant stiffnesses. The cable initially shows a hardening characteristic where the stiffness increases as the cable tension increases. This initial hardening is most likely due to the twisting of the cable fibers which takes out small slack in the cable. Then late in the response it softens where the stiffness decreases with increasing load. The late softening may be due to plastic deformation of the cable fibers. Besides the variation in the cable stiffness with load magnitude, the cables showed some hysteresis where the response loading was different than in unloading. The hysteresis is most likely due to friction of the cable fibers as they rub and twist against each other. One of the cables was cycled at a sub-critical load (just over half the breaking strength) and the hysteresis was repeatable. Thus, the hysteresis was not a proof phenomena, but a basic characteristic of the cables.

The cables are not a perfect analog for chains. Chains should not show the hardening or the hysteresis exhibited by the cables. Yet the cables are a reasonable and safe substitute for the scale test. The preloading of the cables will off-set some of their non-idealness. The cable will stay loaded slightly longer than a corresponding chain due to the hardening characteristic.

5.2.2.3 Friction (test coil on platform)

A simple interface friction test was performed to establish the approximate friction coefficient between the coil samples and the test platform. The friction test was a simple pull test where the force to cause a sample to slide was determined. The friction force was determined using lab weights to generate the sliding force. A sample was placed on the test platform with a cord attached. The cord extended over a pulley where the lab weights were suspended. Weights were added until sliding occurred.

The friction tests showed friction coefficients of 0.6 to 0.9 for lead on oak (depending on degree of wear and surface condition), 0.55 for mild steel on oak and 0.36 for the can stock on oak. These coefficients can be compared to published values of 0.49 for cast iron on oak and

0.95 for lead on mild steel (Avallone and Baumeister, 1978). The large magnitude and variability of the lead friction coefficients reinforced the use of the protective sheet metal layer at the contact interface. The can stock sheet metal was very smooth which accounted for the relatively low friction coefficient.

Note that the friction coefficient in the field may be significantly smaller than the values measured here. Many metal coils in transport are oily and truck beds are wet or oily. These oily and wet conditions will significantly lower the friction coefficient.

### 5.2.3 Scaled Model Test Results

#### 5.2.3.1 Free Vibration

A free vibration test was done to measure the initial dynamic characteristics of the scaled coil specimens A and B, secured with the tie-down cables to the test platform with and without cradles. The free vibration frequency tests were executed using simple hammer tests in the rolling direction. The average natural frequencies from three free vibration tests performed on each scaled coil specimen and the corresponding computed values for the prototype coil, using similitude relations, are given in Table 5.2-4. Damping values of 4.7% and 3.3% (of critical damping) are obtained for the scaled coil specimens A and B, respectively.

The natural frequencies of the prototype coils A and B (2.89 Hz and 3.67 Hz, respectively) increase significantly when the coils are placed on cradles (by a factor of 1.91 and 1.53 to 5.50 Hz and 5.61 Hz). This is expected since the cradles restrain the coil movements in rolling direction. This is pronounced especially in the case of coil A with diameter to length ratio of 4 (tall and narrow) and a higher center of gravity than coil B with diameter to length ratio of 1 (short and wide). Consequently, the natural frequency of both coils A and B approach the same value (within 2% to 5.50 Hz and 5.61 Hz, respectively) as the cradles are used. It is observed that changing the tie-down pre-load from 40 lbs to 70 lbs seems to have little influence on the natural frequencies. Also, the addition of cradles seems not to change the damping values significantly.

| Coil Configuration | Scaled (measured) | Prototype (computed) |
|---|---|---|
| A without cradle | 5.86 | 2.89 |
| B without cradle | 11.0 | 3.67 |
| A with cradle | 11.2 | 5.50 |
| B with cradle | 16.8 | 5.61 |

Table 5.2-4 Natural frequencies of coil specimens (Hz) in rolling direction.

5.2.3.2 Truck Maneuver

The scaled coils were subjected to base accelerations of 0.6g to 0.9g in the fore-aft direction in the straight line braking tests, and they were subjected to a lateral accelerations of 0.4g to 0.6g in the Q maneuvers.

In the securement configuration with the tie-down cables only (without blocking) both the scaled coil specimens rolled forward and then rolled back to the original place during the straight line braking maneuvers. In the Q maneuvers, the lateral accelerations caused specimen A to tip and then to return. However, specimen B behaved differently, where a lateral acceleration caused it to slide (about 1.25 in.) and not return. This cargo shift resulted in a net change in restraint pre-load after the maneuver. For scaled coil specimens A and B (without blocking), the maximum and the minimum cable forces in the tie-downs (normalized with respect to coil weight) are given in Tables 5.2-5 and 5.2-6.

In the securement configuration where the blocking (cradle) was added, there are two significant changes in the straight line braking. First, the maximum cable restraint force was significantly less than without the blocking. Second, both coil specimen slid forward and did not return to their original location. This cargo shift left the rear cables with more pre-load and the front cables with reduced pre-load. For scaled coil specimens A and B in the cradle configuration, the tie-down cable forces (normalized with respect to coil weight) are summarized in Tables 5.2-7 and 5.2-8.

The results in Tables 5.2-5 through 5.2-8 indicates that the maximum cable forces occurred in tie-down Cables 3 and 4 and was especially pronounced in the straight line braking and Q-braking maneuvers. For these maneuvers, the time-history response of the cable forces in all four tie-down legs are shown in Figures 5.2-15 through 5.2-22 for both coil specimens with and without cradles.

5.2.3.3 Observations and Concluding Remarks

By comparison of the tie-down cable responses as given in the previous section and summarized in Tables 5.2-5 through 5.2-8, the following observations are made:

1. The peak tie-down cable forces for coil specimen A and B without a cradle are obtained in the Q-braking maneuvers and they are almost identical (within 5%) in spite of the difference in geometry. The peak tie-down cable response in specimen A was about 25% higher than in specimen B for the straight line braking maneuvers. This moderate difference is due to higher level of coil accelerations observed in the tests for specimen A.

2. Using cradles effectively reduces the tie-down cable forces. The magnitude of reduction is affected by both the coil geometry and the type of test maneuvers. In the case of straight line breaking maneuvers, using cradles resulted in a 76% reduction in tie-down

cables forces for specimen A compared to the 41% reduction for coil specimen B. This is primarily due to the fact that the taller coil, specimen A, was restrained more effectively against the rolling motion in the fore-aft direction by the cradles. In the case of Q-braking maneuvers, the beneficial effect of the cradles on tie-down cable force reduction are more pronounced for coil specimen B (107% reduction) than coil specimen A (60%). This is mainly due to the fact that the cradles are less effective against twisting of the tall and narrow coil A than the short and wide coil B.

3. A maximum peak tie-down cable response in a single cable of 1.11 times the weight of coil Specimen A is obtained in Q-braking maneuver test without a cradle. This corresponded to a prototype chain force of 10,750. lbs which is 143% of the ultimate breaking force of the 1/4 in. High Test chain (7,500. lbs). Introduction of the cradle reduces the single cable response to 0.70 times the weight of the scaled coil specimen. This corresponds to 90% of the ultimate breaking force in the prototype chain considered. This value was 20% higher than that of straight line breaking maneuver test due to extra demand imposed by the lateral acceleration while turning and braking.

4. A maximum peak tie-down cable response in a single cable of 0.97 times the weight of coil specimen B is obtained in Q-braking maneuver test without a cradle. This corresponds to 125% of the ultimate breaking force of the 3/8 in. High Test chain considered. Introduction of the cradle reduces the cable response to 0.47 times the weight of the scaled coil specimen. Thus, the straight line braking maneuver becomes the critical loading for tie-downs (0.55W) with a cradle. This force corresponded to a 71% of the ultimate breaking force in the prototype chain considered.

After completion of all the planned test maneuvers, it was decided to conduct a few probing test maneuvers using another tie-down securement configuration where the tie-down cables were crossed through the eye of the coil specimen (i.e., cabled formed an X in the eye). This configuration was used by many drivers in the field survey. It was observed that the coil specimens slid significantly in straight line braking maneuvers and twisted in Q-braking maneuvers, even though cradles were used to block them. These observations clearly indicate that the effect of the crossed tie-downs on the response of the steel coils are different from previous cases studied. Further study is warranted to properly quantify this influence on the tie-down chain forces.

| | Cable No. | | Straight Line Braking | | | Q-Straight Braking | | | Q-Braking | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Cable Force/ Coil Weight | 1 | Max. | **0.33** | **0.45** | **0.49** | **0.46** | **0.43** | **0.46** | **0.51** | **0.61** | **0.56** |
| | | Min. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 2 | Max. | **0.34** | **0.46** | **0.50** | **0.38** | **0.35** | **0.39** | **0.41** | **0.45** | **0.57** |
| | | Min. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | 3 | Max. | **0.99** | **0.92** | **0.98** | **0.49** | **0.41** | **0.45** | **0.98** | **1.11** | **0.95** |
| | | Min. | 0.02 | 0.01 | 0.02 | 0.02 | 0.05 | 0.02 | 0.03 | 0.01 | 0.01 |
| | 4 | Max. | **0.90** | **0.84** | **0.90** | **0.37** | **0.33** | **0.46** | **0.68** | **0.65** | **0.81** |
| | | Min. | 0.02 | 0.00 | 0.02 | 0.04 | 0.05 | 0.03 | 0.01 | 0.01 | 0.01 |

Table 5.2-5 Tie-down cable response of scaled coil A without cradle

| | Cable No. | | Straight Line Braking | | | Q-Straight Braking | | | Q-Braking | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Cable Force/ Coil Weight | 1 | Max. | **0.22** | **0.26** | **0.37** | **0.17** | **0.28** | **0.47** | **0.51** | **0.26** | **0.36** |
| | | Min. | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.07 | 0.11 | 0.00 | 0.00 |
| | 2 | Max. | **0.18** | **0.21** | **0.32** | **0.12** | **0.24** | **0.63** | **0.52** | **0.28** | **0.29** |
| | | Min. | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.07 | 0.14 | 0.00 | 0.00 |
| | 3 | Max. | **0.68** | **0.71** | **0.80** | **0.25** | **0.27** | **0.59** | **0.79** | **0.64** | **0.97** |
| | | Min. | 0.03 | 0.02 | 0.02 | 0.08 | 0.04 | 0.05 | 0.28 | 0.09 | 0.04 |
| | 4 | Max. | **0.57** | **0.61** | **0.70** | **0.22** | **0.28** | **0.61** | **0.71** | **0.56** | **0.83** |
| | | Min. | 0.03 | 0.03 | 0.01 | 0.07 | 0.05 | 0.08 | 0.31 | 0.09 | 0.03 |

Table 5.2-6 Tie-down cable response of scaled coil B without cradle

| | Cable No. | | Straight Line Braking | | | Q-Straight Braking | | | Q-Braking | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Cable Force/ Coil Weight | 1 | Max. | **0.22** | **0.26** | **0.37** | **0.17** | **0.28** | **0.42** | **0.51** | **0.26** | **0.36** |
| | | Min. | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.07 | 0.11 | 0.00 | 0.00 |
| | 2 | Max. | **0.18** | **0.21** | **0.32** | **0.12** | **0.24** | **0.63** | **0.52** | **0.28** | **0.29** |
| | | Min. | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.07 | 0.14 | 0.00 | 0.00 |
| | 3 | Max. | **0.68** | **0.71** | **0.80** | **0.25** | **0.27** | **0.59** | **0.79** | **0.64** | **0.97** |
| | | Min. | 0.03 | 0.02 | 0.02 | 0.08 | 0.04 | 0.05 | 0.28 | 0.09 | 0.04 |
| | 4 | Max. | **0.57** | **0.61** | **0.70** | **0.22** | **0.28** | **0.61** | **0.71** | **0.56** | **0.83** |
| | | Min. | 0.03 | 0.03 | 0.01 | 0.07 | 0.05 | 0.08 | 0.31 | 0.09 | 0.03 |

Table 5.2-7 Tie-down cable response of scaled coil A with cradle

| | Cable No. | | Straight Line Braking | | | Q-Straight Braking | | | Q-Braking | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Cable Force/ Coil Weight | 1 | Max. | **0.18** | **0.21** | **0.23** | **0.36** | **0.37** | **0.41** | **0.36** | **0.41** | **0.28** |
| | | Min. | 0.01 | 0.01 | 0.01 | 0.00 | 0.03 | 0.05 | 0.02 | 0.10 | 0.03 |
| | 2 | Max. | **0.13** | **0.15** | **0.16** | **0.26** | **0.25** | **0.25** | **0.23** | **0.29** | **0.24** |
| | | Min. | 0.01 | 0.01 | 0.00 | 0.09 | 0.10 | 0.05 | 0.01 | 0.11 | 0.02 |
| | 3 | Max. | **0.50** | **0.54** | **0.55** | **0.34** | **0.36** | **0.39** | **0.47** | **0.47** | **0.41** |
| | | Min. | 0.13 | 0.18 | 0.16 | 0.18 | 0.19 | 0.09 | 0.17 | 0.23 | 0.14 |
| | 4 | Max. | **0.49** | **0.53** | **0.53** | **0.25** | **0.28** | **0.30** | **0.45** | **0.42** | **0.38** |
| | | Min. | 0.15 | 0.18 | 0.14 | 0.14 | 0.13 | 0.08 | 0.12 | 0.13 | 0.00 |

Table 5.2-8 Tie-down cable response of scaled coil B with cradle

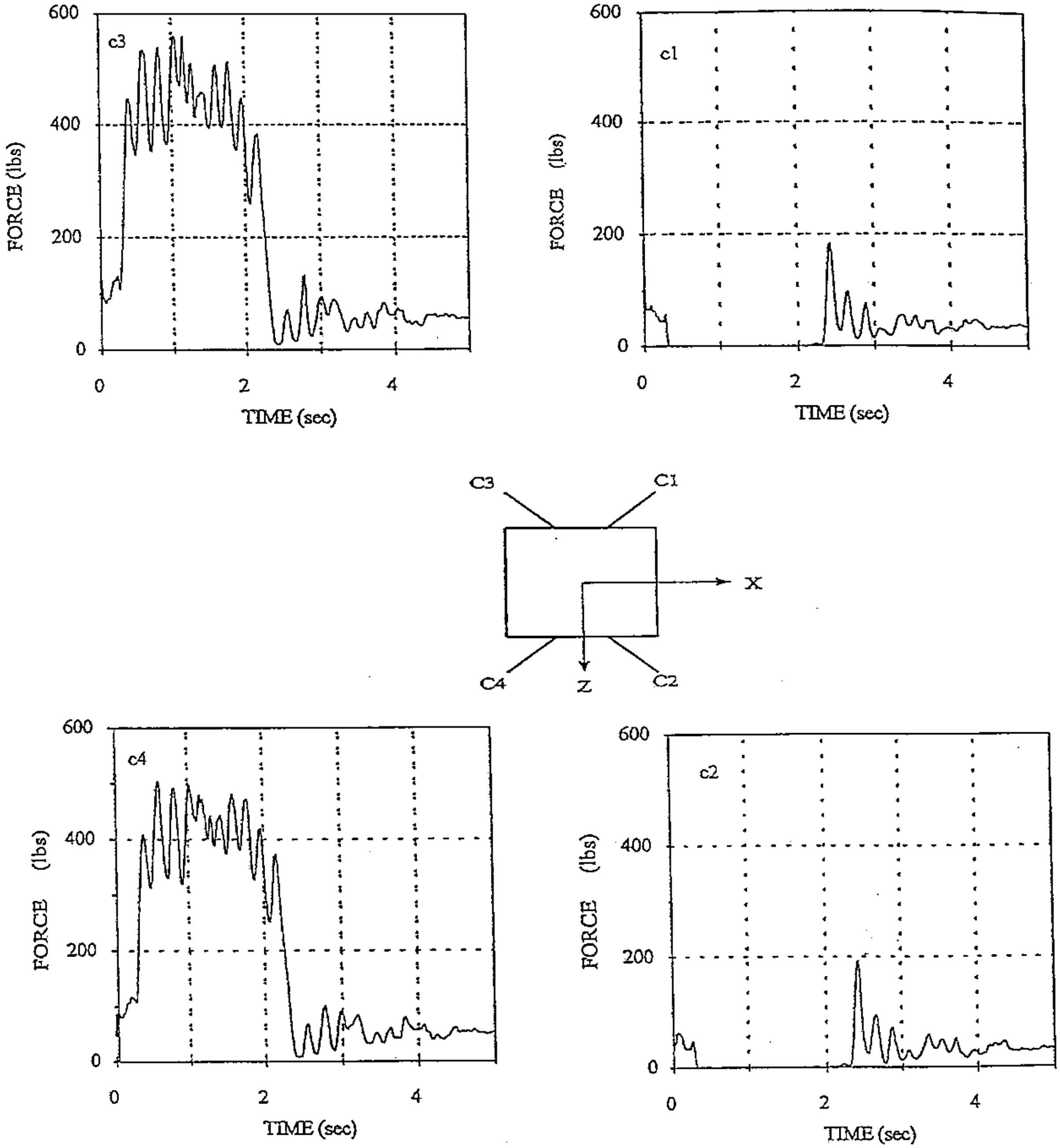



Figure 5.2-15 Cable force response history:
Specimen A without cradle in straight braking maneuver

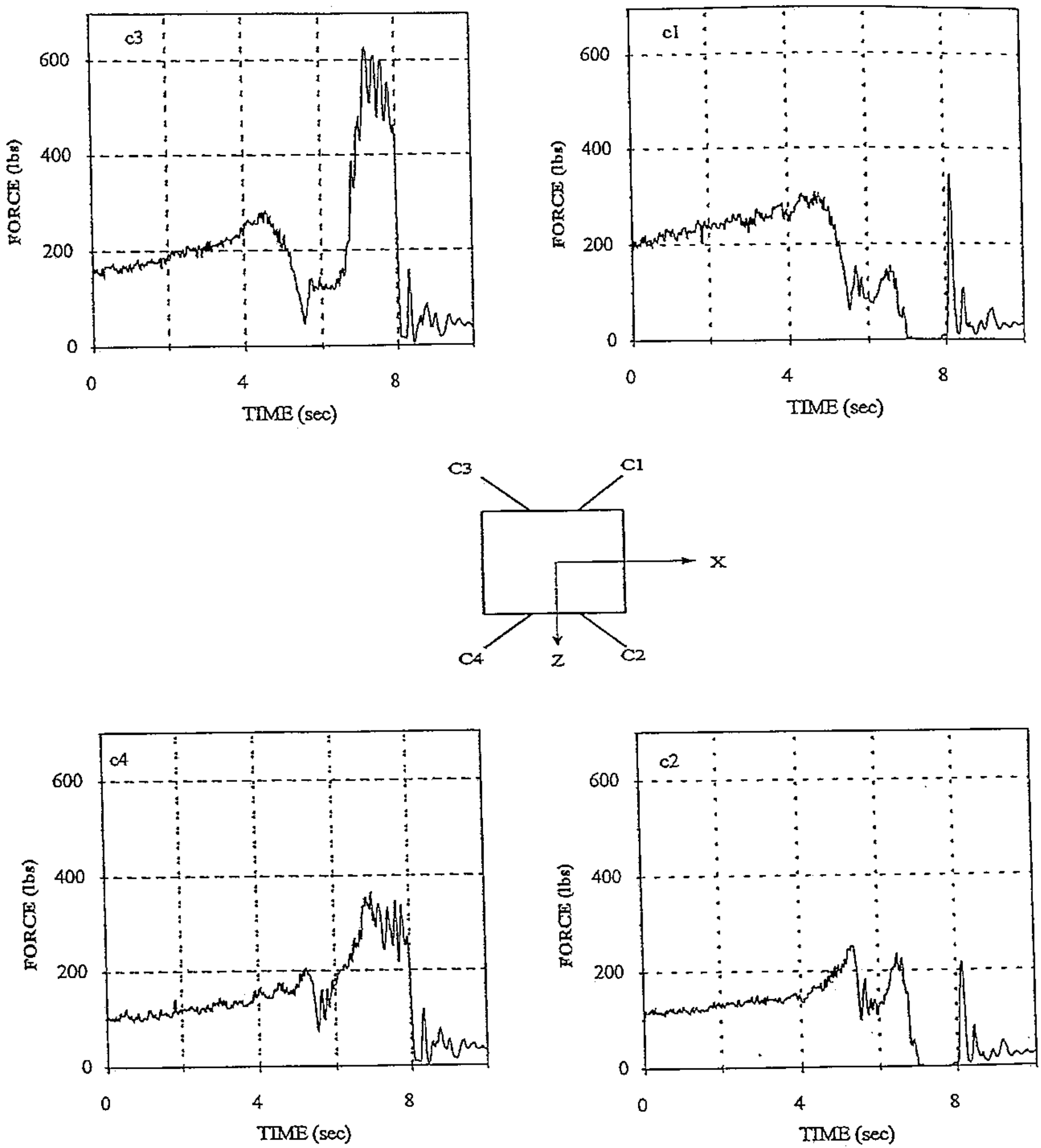



Figure 5.2-16 Cable force response history:
Specimen A without cradle in Q - braking maneuver

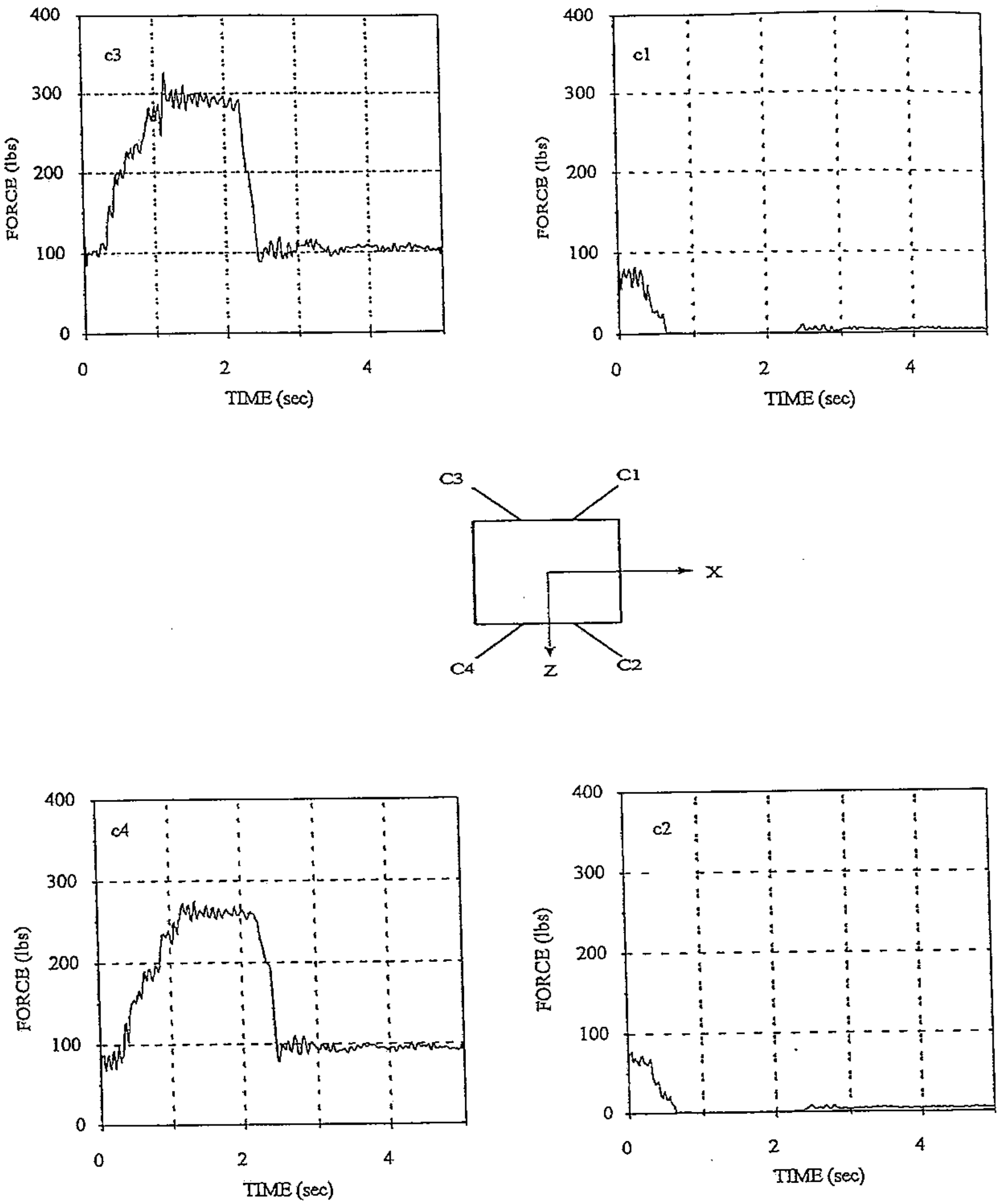



Figure 5.2-17 Cable force response history:
Specimen A with cradle in straight braking maneuver

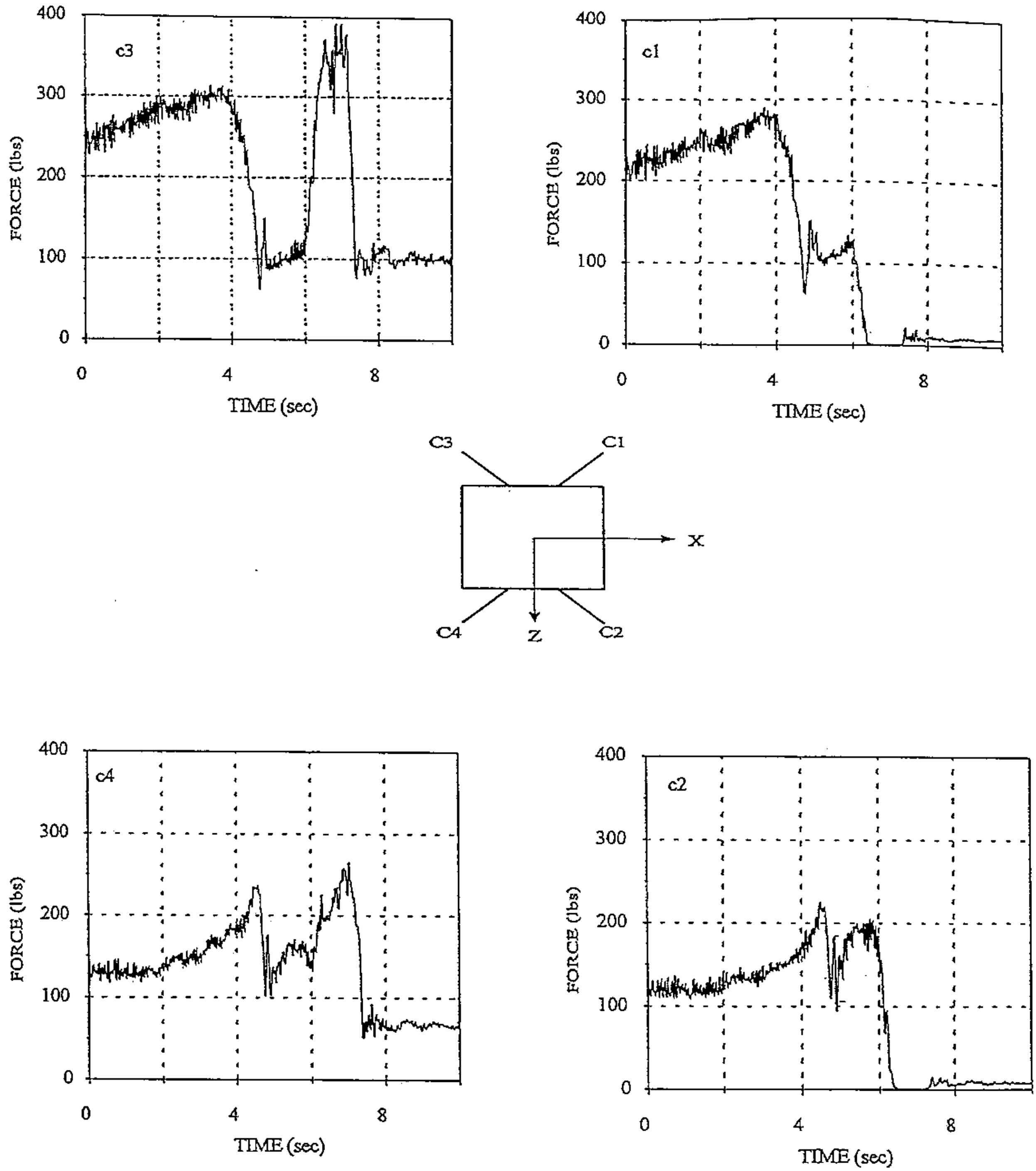



Figure 5.2-18 Cable force response history:
Specimen A with cradle in Q - braking maneuver

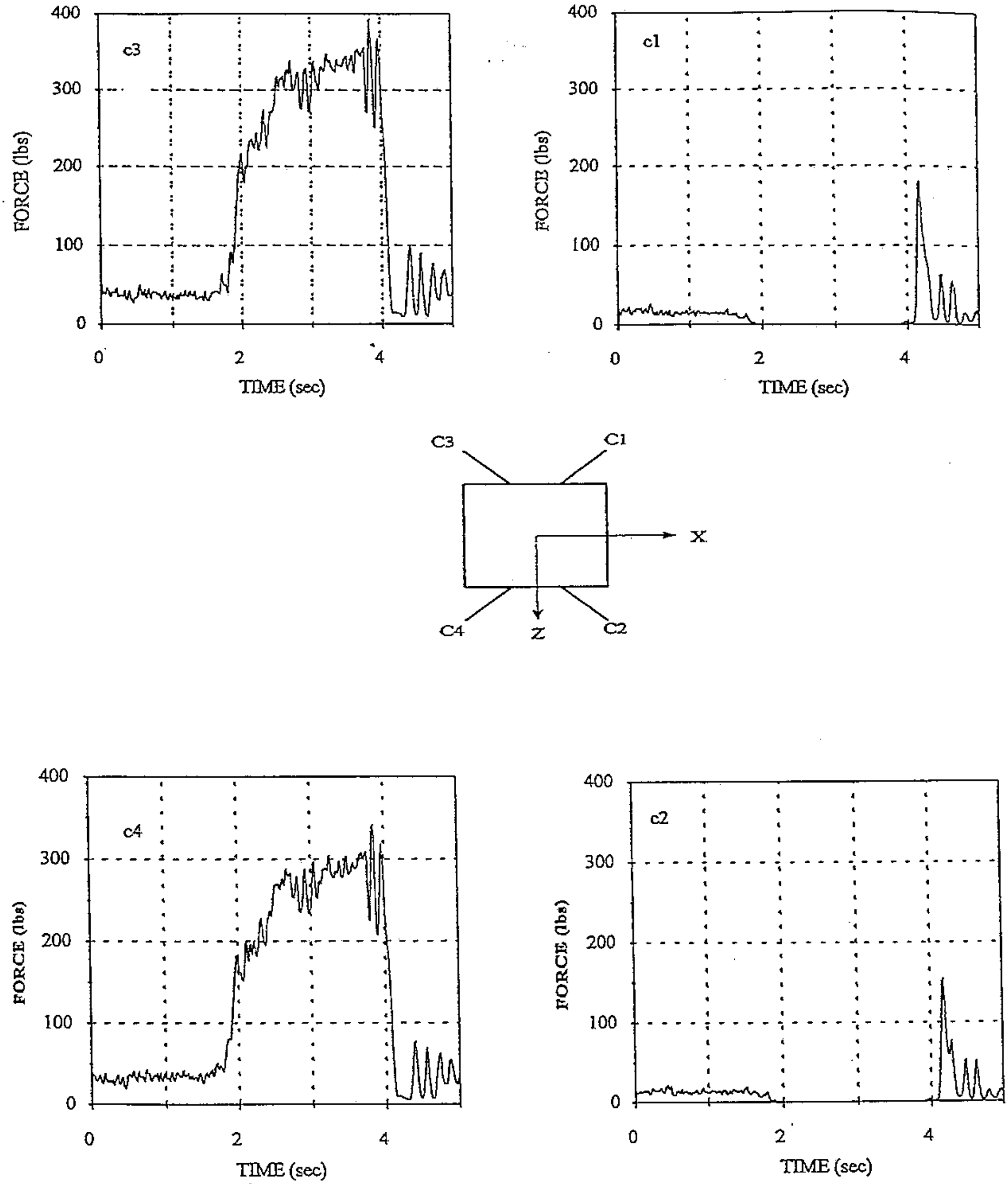



Figure 5.2-19 Cable force response history:
Specimen B without cradle in straight braking maneuver

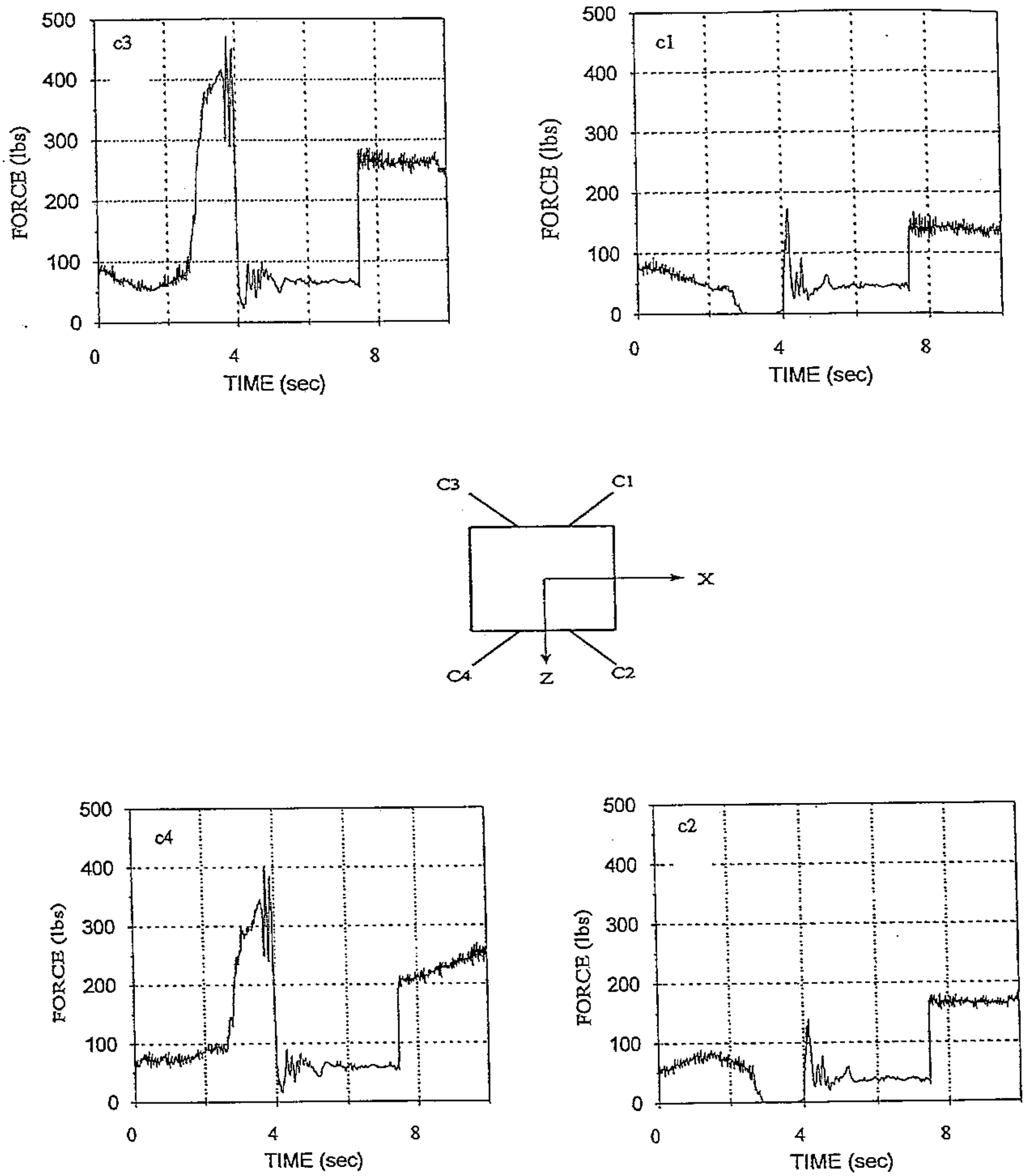



Figure 5.2-20 Cable force response history:
Specimen B without cradle in Q - braking maneuver

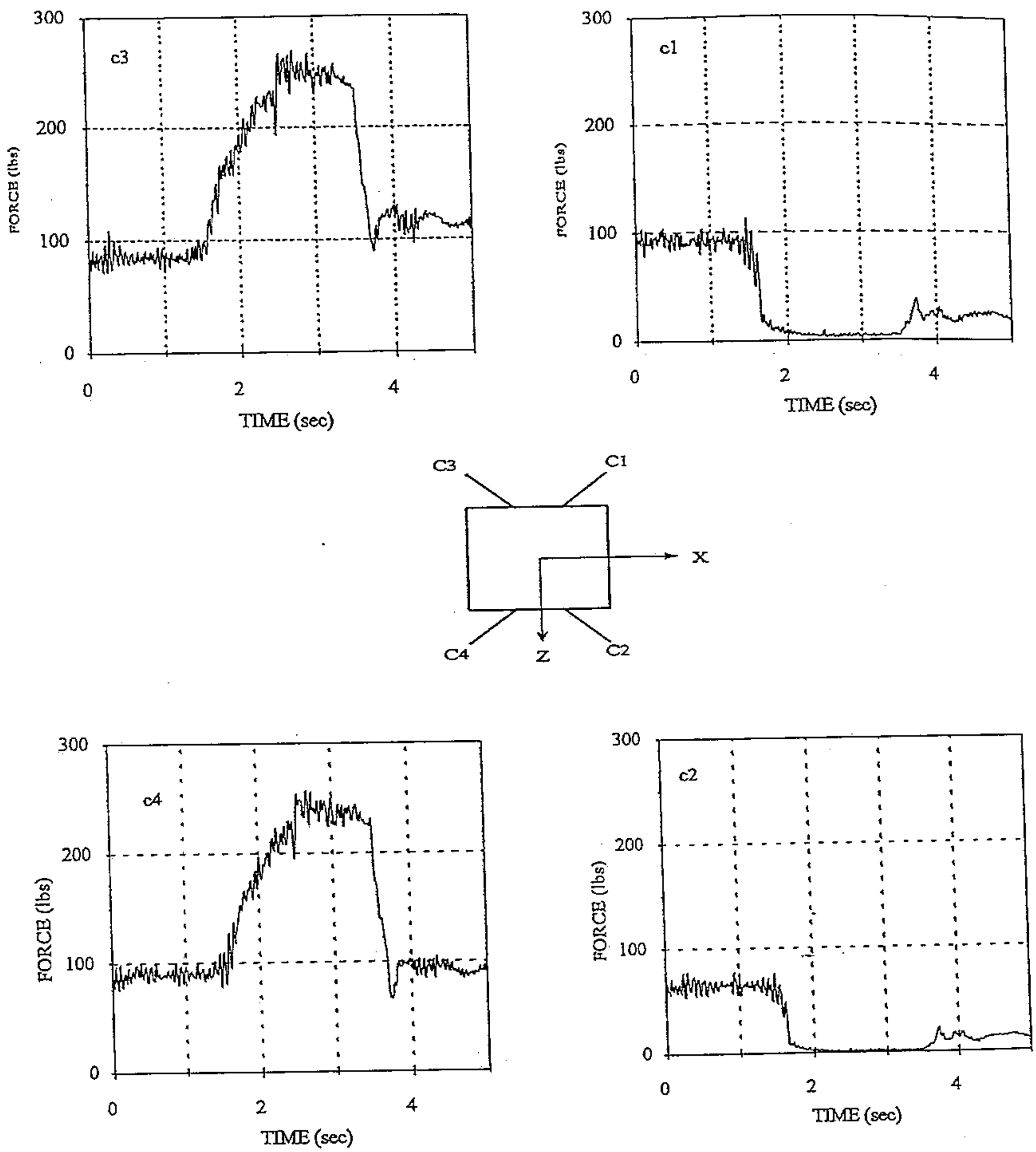



Figure 5.2-21 Cable force response history:
Specimen B with cradle in straight braking maneuver

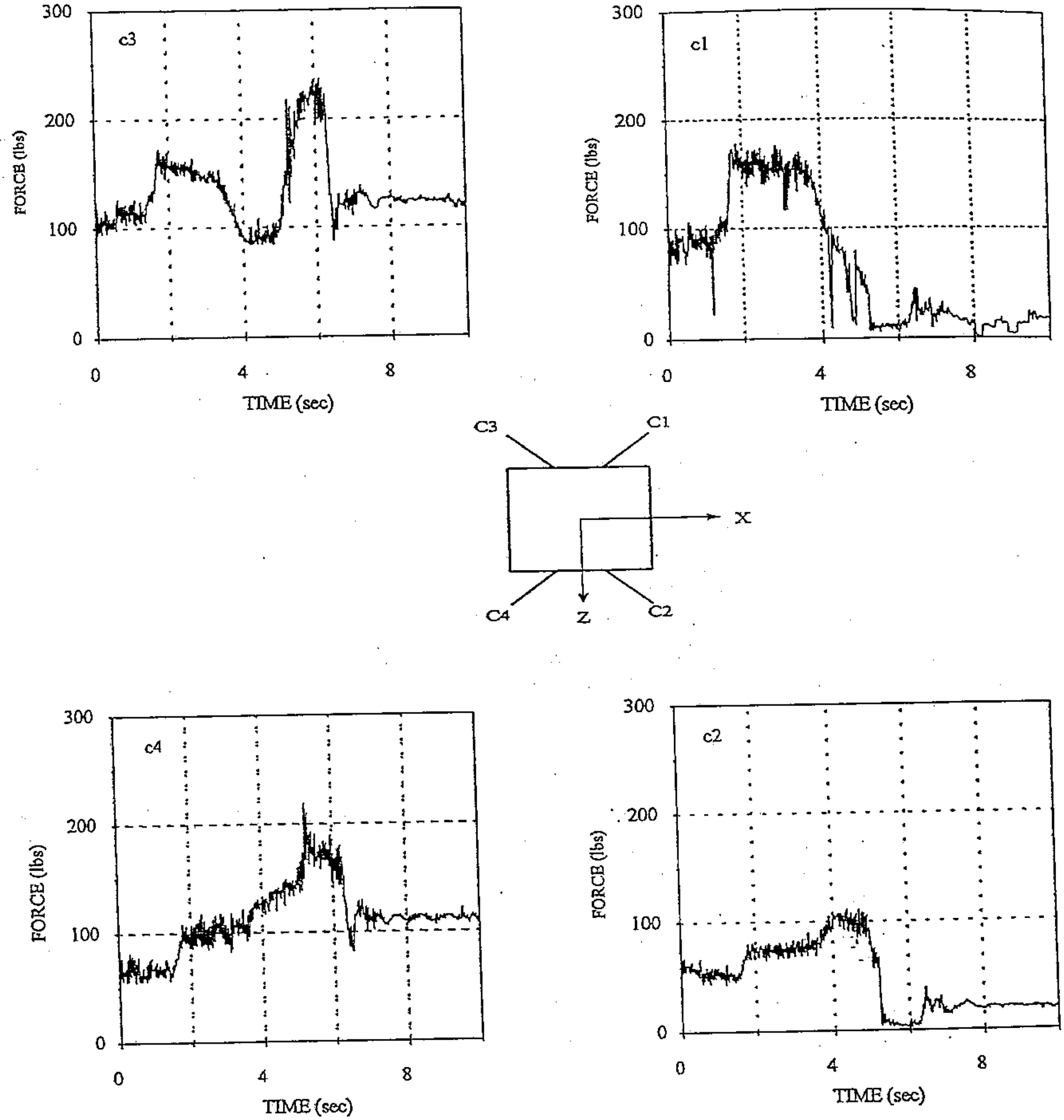



Figure 5.2-22 Cable force response history:
Specimen B with cradle in Q - braking maneuver

## 5.3 Finite Element Analytical Models

The experimental portion of this project has examined two prototypes using scale models designed using similitude theory. The aspect ratio of Prototype A was designed to study overturning behavior of the steel coil, while Prototype B was to examine sliding behavior of the steel coil. These scale models will also be examined analytically using the finite element program ABAQUS, so that comparisons between the experimental and the analytical results will be made.

### 5.3.1 Two-dimensional Finite Element Model

The objective of a finite element analysis is to closely approximate the behavior of the physical structure being analyzed. The degree of success in achieving this objective depends largely on the modeling techniques and assumptions. In this project, the chain responses during various driving conditions are the major concern. The coil-trailer system will be replaced by a simplified model which retains the essential features of the system for finite element analysis.

The assumptions in the ABAQUS analytical models are as follows:

(1) The trailer bed (support base) is treated as a rigid body without self weight (input accelerations are provided by motion of the trailer).
(2) The steel coil is represented by a rigid body with mass inertia and self weight.
(3) The steel coil can move in any direction on the truck base.
(4) The tie-down chains are modeled as spring elements with prestressing force and user-defined nonlinear behavior (i.e. no compression stiffness and finite tensile stiffness).

In this section, the 2-D analytical models for both prototypes will be developed, then the natural frequency and first mode shape will be predicted. The chain response under two types of input accelerations will be examined. In addition, hand calculations of simple rigid body models will be presented to help verify the ABAQUS output. In Section 5.3.2 a 3-D finite element model will be developed and analyzed.

#### 5.3.1.1 Model data for the 2-D models

The ABAQUS input contains model data and history data. Model data defines the geometric properties of the finite element model: the elements, nodes, element properties, material definitions, and all data that specify the model itself. The geometric properties of the Prototype A and B are shown in Table 5.3-1.

| | Prototype A | Prototype B |
|---|---|---|
| Self weight (lbs) | 9690 | 39250 |
| Outside Diameter (in) | 60 | 60 |
| Inside Diameter (in) | 21 | 21 |
| Width (in) | 15 | 60 |
| Steel Mass density (lbm/in$^3$) | 0.000683365 | 0.000683365 |

Table 5.3-1: Geometric properties of the prototypes

5.3.1.2 Nodes and elements specification

The shape and element pattern of a finite element model are entirely defined by the location of the nodes. Engineering accuracy and computational speed are two conflicting but desirable goals in a finite element analysis. In general, the accuracy of a finite element analysis is improved by increasing the number of nodes, whereas the speed of the solution decreases with more nodes.

Both the trailer base and the steel coil are modeled by a coarse mesh of nodes and elements (Figure 5.3-1). As mentioned before, the forces in the tie-down chains are the major concern, and not the stress and strain inside the steel coil and support base. Sufficient accuracy and reasonable analytical speed are obtained if the steel coil and support base are treated as two rigid bodies.

The steel coil is modeled by five plane strain 8-node biquadratic elements (Figure 5.3-1). Such higher order elements will normally increase computer processing time, however, only such a higher order element can provide the desired circular element edge instead of a straight edge. As a result, only five elements are required to model the circular shape.

The support base is modeled by only one rectangular quadrilateral, a plane strain 8-node biquadratic element. An 8-node element matches the bi-quadratic elements defined in the steel coil part. Using the same type elements facilitates the definition of the interface elements.

5.3.1.3 Material and spring properties definition

For the purpose of the ABAQUS model, the material behavior of the coil and base fall into the category of mechanical (stress) response. Therefore, density and elastic material properties need to be specified. The option ELASTIC is used to define linear elastic moduli. Both the steel coil and supporting base are assumed to be made of linear isotropic materials.

For the steel coil part of the models, gravity will be applied. The DENSITY option is needed to define the mass density, which will be converted to weight density by the program.

Material properties for the steel coil in the 2-D models:

| | |
|---|---|
| Young's modulus: | $29x10^6$ psi |
| Poisson's ratio: | 0.3 |
| Density: | $1.735x10^{-4}$ lbm/in$^2$ |

Material properties for the supporting base:

| | |
|---|---|
| Young's modulus: | $29x10^6$ psi |
| Poisson's ratio: | 0.3 |

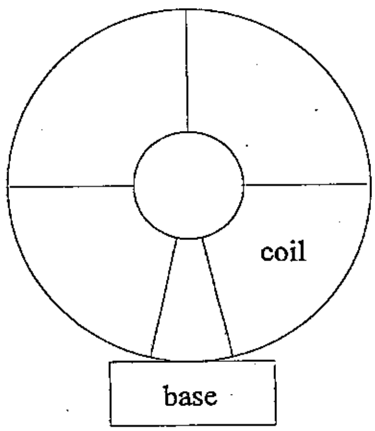



Figure 5.3-1: 2-D coil-base model

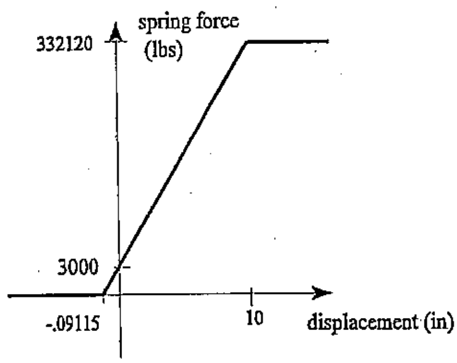



Figure 5.3-2: Spring properties definition

The examination of chain response during severe maneuvers is the most important objective of this project. For the finite element model, the chains are modeled by spring elements Spring elements are defined between two nodes, whose line of action is the line joining the two nodes. This line of action will rotate during a large displacement analysis. The chain is effective only in the tension state. To model such nonlinear behavior, the spring force is assumed to be a function of the relative displacement in the spring element. When the relative displacement is negative, the chain is in compression and has zero stiffness. Figure 5.3-2 is the nonlinear spring element load-displacement curve, which is defined by giving force and corresponding relative displacement values in an ascending order of relative displacement. The slope of this curve is the tangent stiffness (shown in Table 5.3-2). At zero relative displacement, a prestress tension force of 3000 lbs. is obtained. Given this prestress force, some negative relative displacement occurs before the chain goes slack (i.e., develops zero force). The force remains constant outside the given relative displacement ranges in order to model plastic behavior. Since plastic yield is not considered in this project, the tension yield force is specified to be much higher than the expected maximum tension. Such a force-relative displacement chart may be determined by the theoretical methods described in Z. Chai's Master's Thesis (1995).

| | Model A | Model B |
|---|---|---|
| Spring Stiffness (lbs/in) | 32912 | 183025 |
| Prestressed force (lbs) | 3000 | 3000 |

Table 5.3-2: Chain Properties

5.3.1.4 Interface properties and friction definition

ABAQUS provides a slide line interface element which is suitable for modeling the coil-trailer contact problem. When surfaces are in contact, they generally transmit shear as well as normal stress. ABAQUS provides a classical Coulomb friction model for the interface elements. Surfaces do not slide over each other as long as the shear stress magnitude is less than the product of the friction coefficient and the pressure stress between them. This corresponds to "static friction". When the shear stress magnitude attempts to exceed the product of the friction coefficient and the normal pressure, the object is "sliding" and a limiting shear force equal to the coefficient of friction times the normal pressure is applied at the interface. The friction coefficient used in the 2-D models is 0.5 (an additional friction coefficient of 0.1 is considered for the 3-D model in section 5.3.2). For further discussion, see Z. Chai's Master's Thesis (1995).

5.3.1.5 History data input

In ABAQUS, history data defines the sequence of events or loadings for which the model's response is sought. This history can be divided into a sequence of steps. For all the analytical models in this chapter, two nonlinear static steps will be used to define the initial conditions before the dynamic step or the eigenvalue step. Geometric nonlinearity will be included in all steps. In the first static step, the spring element prestressing force is applied by the user-defined spring properties (Figure 5.3-2). In the second static step, the self-weight (gravity load) of the steel coil is applied. Then, the third step will be either an eigenvalue analysis or dynamic time integration analysis.

5.3.1.6 Eigenvalue analysis (Natural Frequencies)

There are some restrictions related to eigenvalue analysis by ABAQUS. Due to those restrictions, the following factors will be considered to set up the eigenvalue analysis models.

(1) The prestressing force in the spring element has no impact on the frequency of the coil-base system. Only one fixed prestressed force is defined.
(2) Non-linear spring behavior will be ignored. No matter what kind of user-defined spring properties are defined, the spring element is treated as a simple linear spring element.

(3) Because the contact conditions can not change, the bottom node of the coil model can be pinned to the base model.

The first mode results for both models are shown in Table 5.3-3. The mode shape (a rolling mode) is displayed in Figure 5.3-3. The measured x-direction natural frequencies from Table 5.2-4 for the unblocked experimental models were 2.89 Hz for Specimen A and 3.67 Hz for Specimen B. The increase in frequency for the analytical model can be accounted for by the pinned base assumption, which effectively provides an infinite coefficient of friction. The real coil-base system had a measured coefficient of friction of .36.

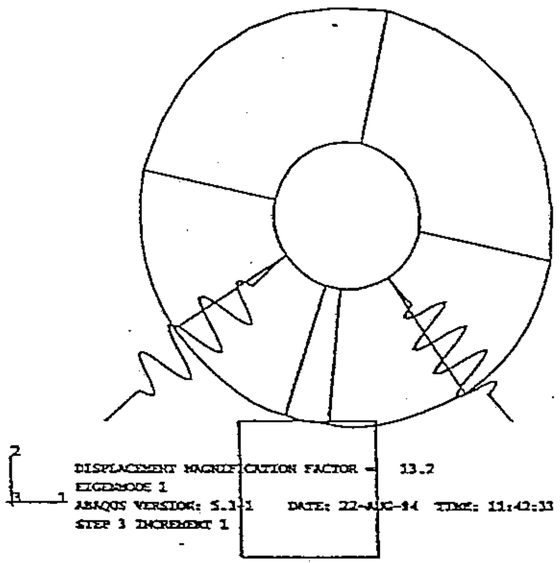



Figure 5.3-3: First mode shape for 2-D model

| | Prototype A | Prototype B |
|---|---|---|
| Frequency (cycles/second) | 4.59 | 5.42 |
| Period (second) | 0.217 | 0.185 |

Table 5.3-3: Eigenvalue analysis summary of the 2-D models

5.3.1.7 Dynamic analysis

In the dynamic analysis models, the DYNAMIC option in ABAQUS uses implicit integration to examine the time history response of the model. The interface between the steel coil and the base is modeled by interface elements. Such interface elements contact conditions may change from an open state to a closed state. An iterative solution using automatic time stepping will be performed.

In a time-history dynamic analysis, the AMPLITUDE option can define arbitrary time variations of loads, displacements or accelerations. In the coil-base models, this command defines the acceleration as a function of time. Figure 5.3-4 and Figure 5.3-5 are the input accelerations in the coil rolling direction (x-direction). The first acceleration input (Input One, Figure 5.3-4) is linear, and is meant to verify the solution with comparison to hand calculations. The second input (Input Two, Figure 5.3-5) is a sine wave acceleration. This changes direction to examine the tension-only spring assumption.

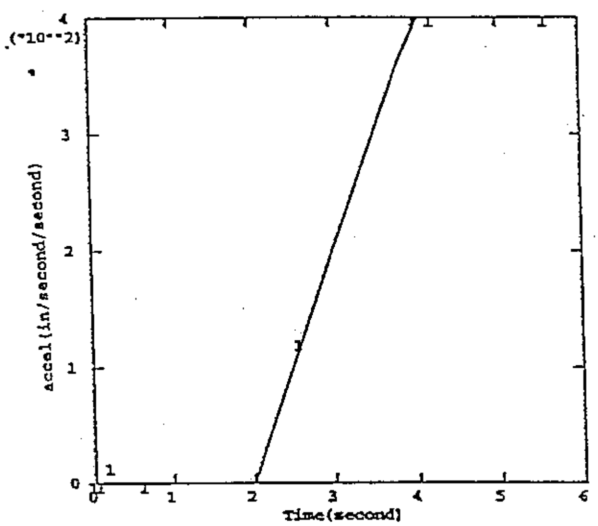



Figure 5.3-4: Acceleration Input One

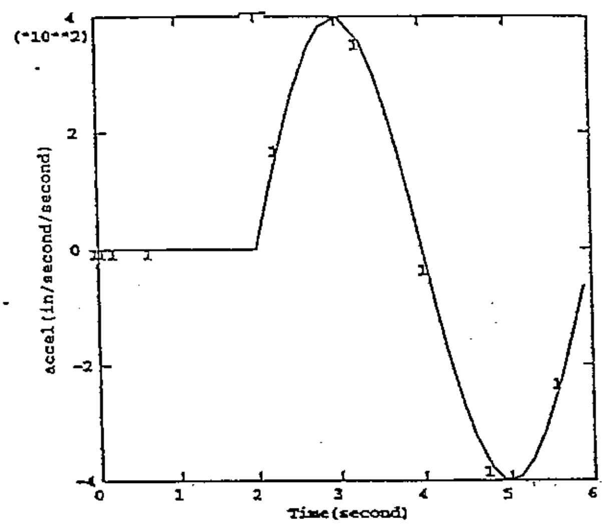



Figure 5.3-5: Acceleration Input Two

*ABAQUS solutions for Acceleration Input One*

If the nonlinear contact and dynamic effects are ignored, the following procedure can quickly predict the ratio of the spring force to steel coil self-weight at an acceleration of 400 in/second/second (1.037g). The chain is assumed to be oriented to make a 45 degree angle with the horizontal. The inertia force of the coil is assumed to act at its mass center, which corresponds to the line of action of the resultant spring force. If a=400 in/second/second (1.037 g), m=mass of steel coil, R=radius of steel coil, and F=spring force, then for equilibrium:

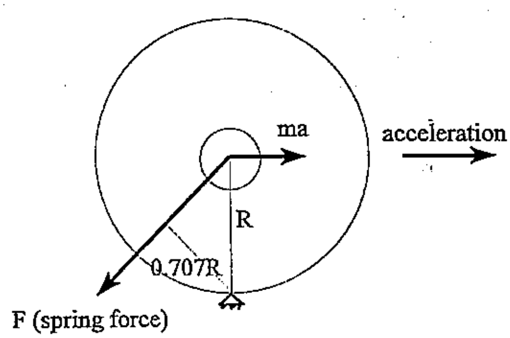



Figure 5.3-6: Hand Calculation Model

$$maR - .707\,RF = 0 \qquad (5.3\text{-}1)$$

$$1.037\,mg - .707\,F = 0 \qquad (5.3\text{-}2)$$

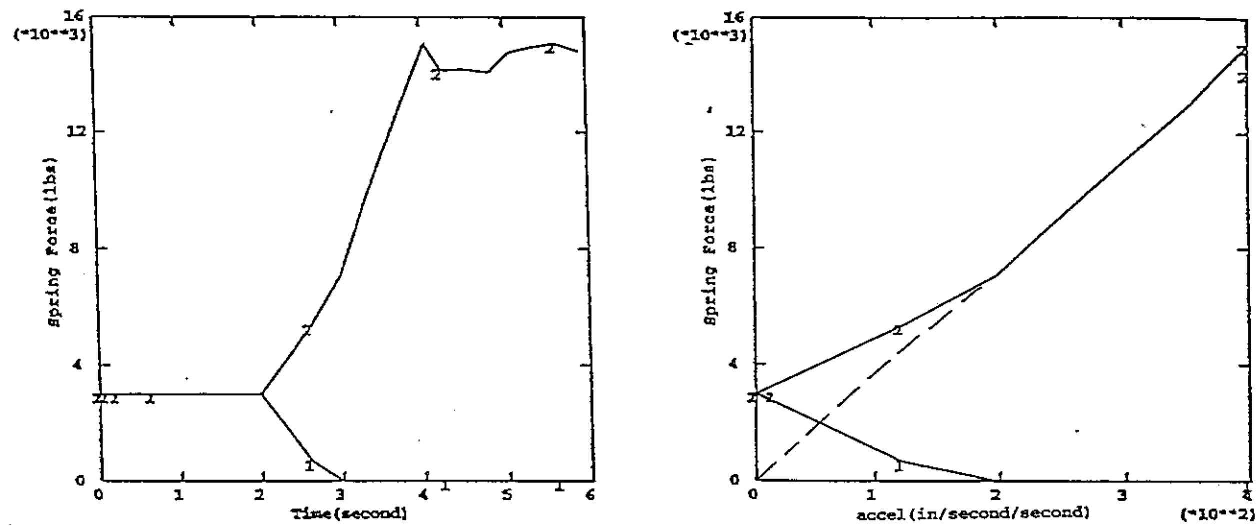
Thus the ratio of spring force in the two chains on one side to coil weight should be:

$$\frac{F}{mg} = 1.47 \qquad (5.3\text{-}3)$$

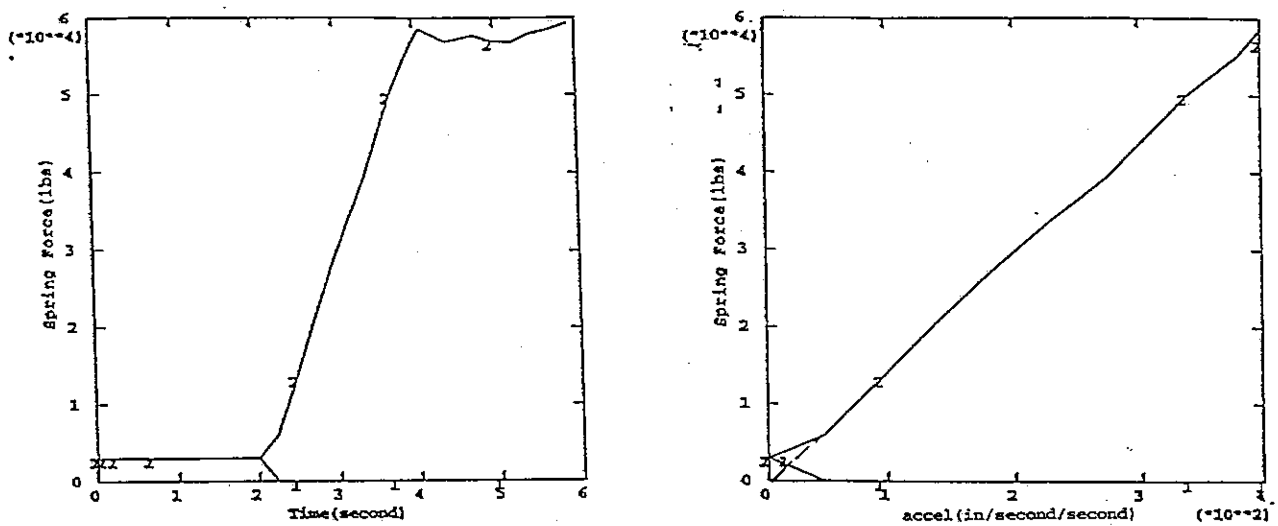
It should be noted that this force ratio is the force ratio *on one side* of the coil. In the federal regulations for coil securement (49 CFR 393), the breaking strength criteria was written such that the aggregate strength of all the securement chains equal 1.5 times the weight of the coil. If the chains are distributed evenly on each side of the coil, this would give a breaking strength of .75 times the weight of the coil on each side, which would be almost 50% of the required strength at 1.0g deceleration. The regulations have been rewritten in terms of a working stress criteria, but since the working stress is about 1/3 the breaking strength, and the regulation has been written to allow .5 times the weight of the coil in chain working strength, the results are essentially the same.

For purposes of comparing this result to output from ABAQUS, the effect of the prestressing force should be considered. The chains in this example are prestressed to 3000 lbs. Since the prestressing forces are in equilibrium with chains on both sides of the coil, they can effectively be ignored in the above equation.

The ABAQUS model using the nonlinear spring and interface elements was run to quantitatively compare results from the hand calculations to the results from the finite element approximation. This was done for both Specimen A and Specimen B. Under the applied base acceleration (Figure 5.3-4), Figure 5.3-7(a) and 5.3-8(a) show the spring response with respect to time. In these figures, 0 to 1 second is the first static step (prestressing applied), 1 to 2 seconds is the second static step (gravity applied), and 2 to 6 seconds is the dynamic step (acceleration applied). Figures 5.3-7(b) and 5.3-8(b) show the spring response with respect to the magnitude of base acceleration.




(a) Spring force vs. Time (b) Spring force vs. Acceleration
Figure 5.3-7: Spring Response of Model A due to Acceleration Input One




(a) Spring force vs. Time (b) Spring force vs. Acceleration
Figure 5.3-8: Spring response of Model B Due to Acceleration Input One

At the beginning of the dynamic step, the base acceleration is zero, the springs on both sides of the steel coil have the same prestress force (3,000 lbs), and both springs are in a tension state. With the increase of the base acceleration, the steel coil begins to roll on the base in the opposite direction of acceleration. Due to the coil rotation, the length of spring on one side increases, however, the length of the spring on the opposite side decreases. When the value of base acceleration reaches about 200 in/sec$^2$, the spring on the side opposite the direction of the base acceleration is in compression, and the force in this spring falls to zero.

The spring force in Table 5.3-4 is the maximum value from the ABAQUS output.

| | Spring force $F$ (lb) | Coil weight $mg$ (lb) | $F/mg$ by ABAQUS (one side) | $F/mg$ by hand calculation (one side) |
|---|---|---|---|---|
| Prototype A | 15000 | 9690 | 1.55 | 1.47 |
| Prototype B | 59000 | 39250 | 1.55 | 1.47 |

Table 5.3-4: Comparison of the Hand Calculation and Computer Output

It is clear that the results from the nonlinear procedure are slightly higher than the forces predicted by a hand calculation. Reasons for this include the following assumptions in the hand calculation:

(1) Dynamic effects are ignored.
(2) The steel coil is pinned to the base, i.e., sliding between the coil and the base is not possible
(3) The accelerations of the steel coil and base are identical.
(4) The steel coil and the base are perfectly rigid.

*ABAQUS solutions for Acceleration Input Two.*

The nonlinear spring behavior can be seen clearly in the figures below (5.3-9, 5.3-10). Notation 1 and 2 in the figures refer to the springs on each side of the steel coil. Under a reversing base acceleration (Figure 5.3-5), the springs on both sides change from a tension state to a compression state. The spring force varies with the relative spring displacement.

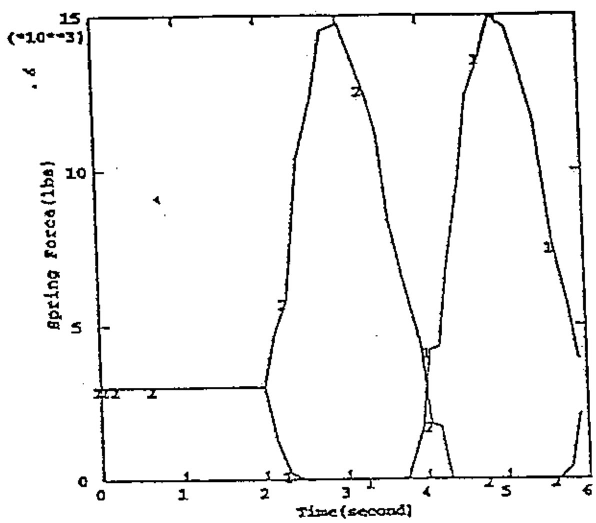



Figure 5.3-9: Spring Response of Model A

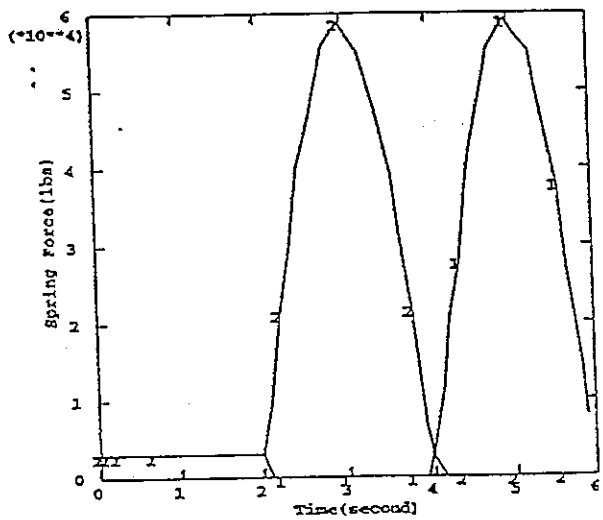



Figure 5.3-10: Spring Response of Model B

The two-dimensional model is useful for verifying the basic behavior of the coil, but to more closely approximate the behavior of the coil-trailer system, a fully three-dimensional model is required. This will be developed in the next section.

### 5.3.2 Three-dimensional Finite Element Model

To simulate the steel coil dynamic behavior during sudden starts and stops and quick turns, a three-dimensional ABAQUS finite element model was developed. In this 3-D model, the steel coil and trailer bed are modeled as rigid bodies, and the tie-down chains are modeled as flexible spring elements which were fully examined in Section 5.3.1. The friction and contact at the coil-spring interface is modeled using the ABAQUS slide line procedure (Z. Chai 1995).

Two scale-model specimens were tested experimentally to examine the steel coil overturning and sliding behaviors. Before the field test, the spring forces of these scale models were predicted by an ABAQUS dynamic analysis, in order to understand the behavior of the coils before the experiment. According to the ABAQUS solutions, the maximum testing acceleration used in the field test was approximated so as not to break the coil cables.

#### 5.3.2.1.1 Specimen A

In this section, the cable response of experimental Specimen A will be examined by the finite element method. The spring properties for the cable are shown in Figure 5.3-11, and the coil properties are shown in Table 5.3-5.

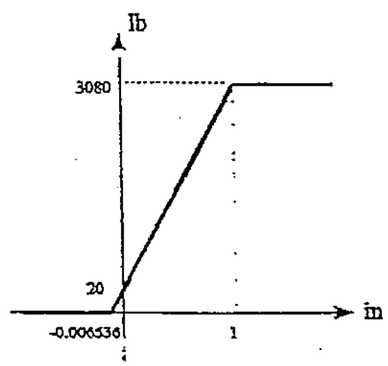



Figure 5.3-11: Spring Properties in Specimen A

| | Specimen A Properties (Lead) |
|---|---|
| Modulus of Elasticity of coil | $29 \times 10^6$ psi |
| Poisson Ratio | 0.3 |
| Friction Coefficient | 0.5 |
| Self weight | 565 lb |
| Outside Diameter | 20 in |
| Inside Diameter | 7 in |
| Width | 5 in |
| Mass density | 0.0010624 mlb/in$^3$ |

Table 5.3-5: Specimen A Properties

*Base acceleration in the X-direction*

For this case, the base acceleration is applied in the x-direction only (base input direction in Figure 5.3-12). Under this acceleration, the response of spring1 is the same as that of spring2, and the response of spring3 is the same as that of spring4. The response of Specimen A can be seen in Figure 5.3-16.

*Base acceleration in Z-direction*

The base acceleration is applied in the z-direction only (base input direction shown in Figure 5.3-13). Under this acceleration, the response of spring1 is the same as that of spring3, and the response of spring2 is the similar to that of spring4. The response of Specimen A can be seen in Figure 5.3-17.

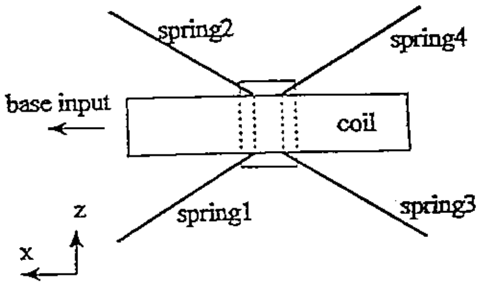



Figure 5.3-12: X-direction Acceleration Input

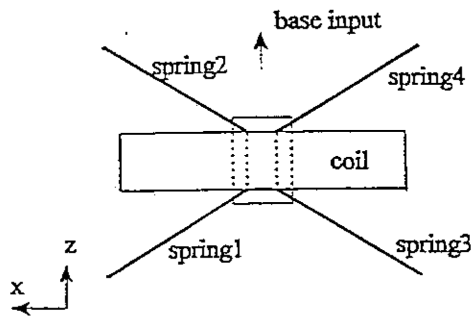



Figure 5.3-13: Z-direction Acceleration Input

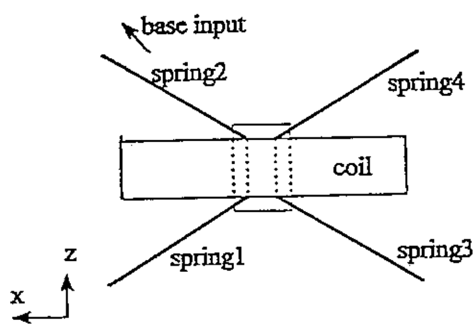



Figure 5.3-14: Acceleration Input in X and Z directions

*Base acceleration in two directions*

The base accelerations are applied in both the x and z directions (base input direction shown in Figure 5.3-14). Due to this combined acceleration, the response of the springs is not symmetric. The response of Specimen A can be seen in Figure 5.3-18.

5.3.2.1.2 Specimen B

*Geometric and material properties of Specimen B*

A similar dynamic analysis procedure is conducted for Specimen B. The coil properties for Specimen B are shown in Table 5.3-6. The nonlinear spring behavior for Specimen B is defined in Figure 5.3-15.

| | |
|---|---|
| Modulus of Elasticity of coil | $29x10^6$ psi |
| Poisson Ratio | 0.3 |
| Friction Coefficient | 0.5 |
| Self weight | 488 lb |
| Outside Diameter | 12 in |
| Inside Diameter | 4.2 in |
| Width | 12 in |
| Mass density (lead) | 0.0010624 mlb/in$^3$ |

Table 5.3-6: Specimen B Properties

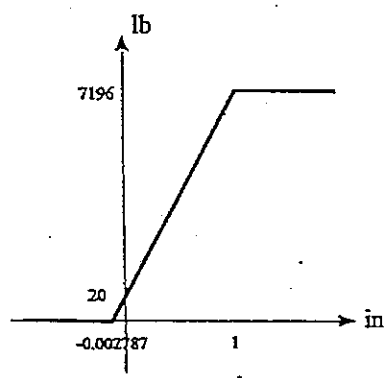



Figure 5.3-15: Spring properties for Specimen B

*Base acceleration in the X-direction*

For this case, the base input direction is shown in Figure 5.3-12. Due to symmetry, the responses of spring1 and spring2 are identical, and the responses of spring3 and spring4 are identical. Spring forces are shown in Figure 5.3-19.

*Base acceleration in Z direction*

For this case, the base input direction is shown in Figure 5.3-13. Due to symmetry, the responses of spring1 and spring2 are identical, and the responses of spring3 and spring4 are identical. Spring forces are shown in Figure 5.3-20.

*Base acceleration in two directions*

The base accelerations are applied in both the x and z directions (base input directions shown in Figure 5.3-14). Due to this combined acceleration, the response of the springs is not symmetric. The spring response for the added mass and true mass model is shown in Figure 5.3-21.

5.3.2.1.3 Result summary for Specimen A and Specimen B

| Acceleration direction | Max. Spring force (lbs) | Ratio of spring force to weight |
|---|---|---|
| X direction | 675 | 1.19 |
| Z direction | 260 | 0.46 |
| 45° angle | 600 | 1.06 |

Table 5.3-7: Specimen A, (Acceleration=385.83 in/sec$^2$ (1G))

| Acceleration direction | Max. Spring force (lbs) | Ratio of spring force to weight |
|---|---|---|
| X direction | 415 | 0.85 |
| Z direction | 160 | 0.33 |
| 45° angle | 310 | 0.64 |

Table 5.3-8: Specimen B, (Acceleration=385.83 in/sec$^2$ (1G))

*Eigenvalue Analysis*

In order to better understand the behavior of the experimental models, an eigenvalue analysis was performed to determine their frequencies and mode shapes. This will enable further calibration of the friction and stiffness characteristics of the models, as well as provide another point for comparison between the experiment and the analysis. The following steps were performed during the eigenvalue analysis:

Step 1: The spring prestressed force (50 lb) is applied.
Step 2: The gravity load is applied.
Step 3: Eigenvalue step. The first three modes and mode shapes are computed.

Specimen A and B have chain stiffnesses of 52.6 kips/in/in. For Specimen A, a linear spring stiffness of 3060 kips/in is used. For Specimen B, a linear spring stiffness of 7196 kips/in is used.

As can be seen in Table 5.3-9 to 5.3-12, the results from the analytical model correspond well with the experimental results for the rolling mode. It should be noted that the friction coefficient as measured in the experiment was .36, and the analytical model tried two different values, .1 and .5. The reason these friction values were used in the analysis was to bracket a low and high friction case. The actual response for an intermediate friction coefficient would theoretically be between the values recorded for .1 and .5.

For Specimen A, the analytical values for the frequency are within 20% of the measured value. For Specimen B, the accuracy increases to within 6%. These comparisons indicate that the mass and stiffness characteristics of the system are being reasonably approximated by the analytical model.

| Mode | Frequency (cycles/time) | Experimental Result (Hz)<br>Coefficient of Friction = .36 |
|---|---|---|
| Mode 1 (Twisting) | 4.322 | No Data |
| Mode 2 (Rolling - X) | 4.915 | 5.86 |
| Mode 3 (Sliding - Z) | 14.74 | No Data |

Table 5.3-9: Specimen A, Friction coefficient=0.1

| Mode | Frequency (cycles/time) | Experimental Result (Hz)<br>Coefficient of Friction = .36 |
|---|---|---|
| Mode 1 (Rolling - X) | 5.053 | 5.86 |
| Mode 2 (Twisting) | 8.405 | No Data |
| Mode 3 (Sliding - Z) | 20.07 | No Data |

Table 5.3-10: Specimen A, Friction coefficient=0.5

| Mode | Frequency (cycles/time) | Experimental Result (Hz) Coefficient of Friction = .36 |
|---|---|---|
| Mode 1 (Rolling - X) | 10.722 | 11.0 |
| Mode 2 (Sliding) | 17.646 | No Data |
| Mode 3 (Twisting - Z) | 20.48 | No Data |

Table 5.3-11: Specimen B, Friction coefficient=0.1

| Mode | Frequency (cycles/time) | Experimental Result (Hz) Coefficient of Friction = .36 |
|---|---|---|
| Mode 1 (Rolling - X) | 11.695 | 11.0 |
| Mode 2 (Sliding - Z) | 31.026 | No Data |
| Mode 3 (Twisting) | 33.922 | No Data |

Table 5.3-12: Specimen B, Friction coefficient=0.5

5.3.2.3 The Impact of the Friction Coefficient

In the 2-D dynamic analyses in Section 5.3.1, the friction coefficient was defined as 0.5 in all models. Using this coefficient of friction, Specimen A exhibits overturning behavior, and Specimen B shows sliding behavior. In an analysis not detailed herein, when the friction coefficient decreases from 0.5 to 0.1, Specimen B still displayed sliding behavior. In the following analysis, the friction coefficient is reduced to .1 for Specimen A. The motion will examined by dynamic analysis.

*Base acceleration in the X-direction*

The base input direction is shown in Figure 5.3-12. The displaced shapes of two models with different friction coefficients are shown in Figure 5.3-22 (displacements are magnified by a factor of 10). Both models display overturning (rolling) behavior. The forces output from these models are similar (Table 5.3-13).

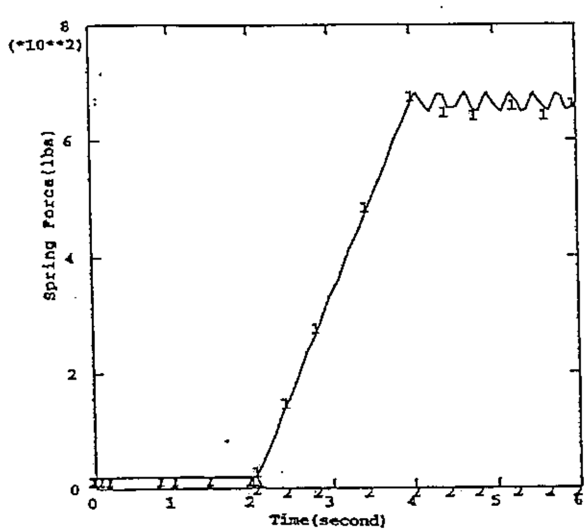
*Base acceleration in Z-direction*

The base input direction is shown in Figure 5.3-13. The displaced shapes are shown in Figure 5.3-23 (magnified by a factor of 10). The model with a 0.5 friction coefficient displays overturning behavior, but the model with a 0.1 friction coefficient displays sliding behavior. When acceleration increases to 385.83 in/sec$^2$ (1G), the spring forces of the two models are shown in Table 5.3-13.

| | Coefficient of Friction = 0.1 | | Coefficient of Friction = 0.5 | |
|---|---|---|---|---|
| Accel Direction | Spring Force(lbs) | Motion | Spring force(lbs) | Motion |
| X | 675 | overturning | 675 | overturning |
| Z | 295 | sliding | 260 | overturning |

Table 5.3-13: Friction Effects

The change of friction coefficient only has impact on the spring force output when the acceleration is applied in the Z direction. For acceleration in the rolling (X) direction, there is no major dependence on friction.



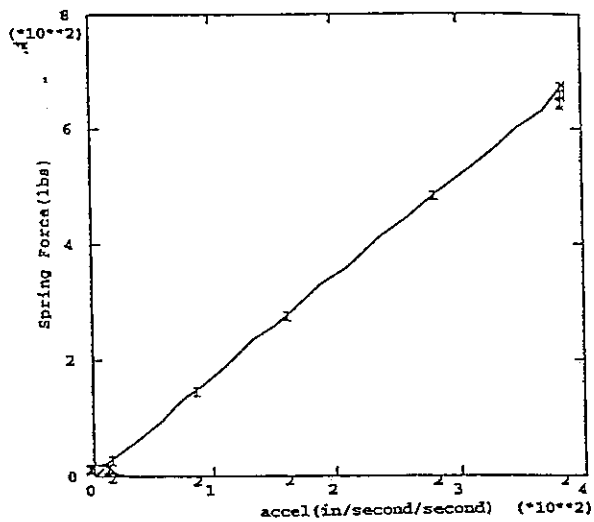
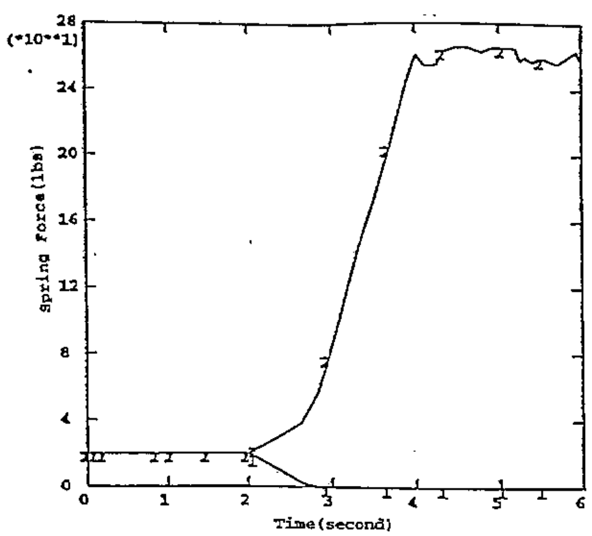




Figure 5.3-16: X-direction Acceleration, Specimen A



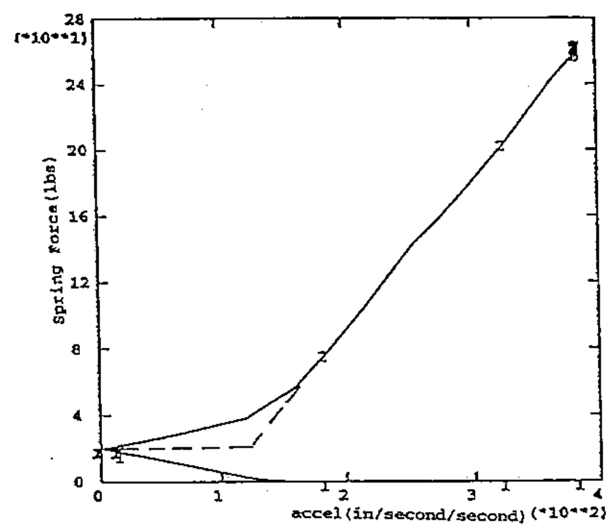




Figure 5.3-17: Z-direction Acceleration, Specimen A

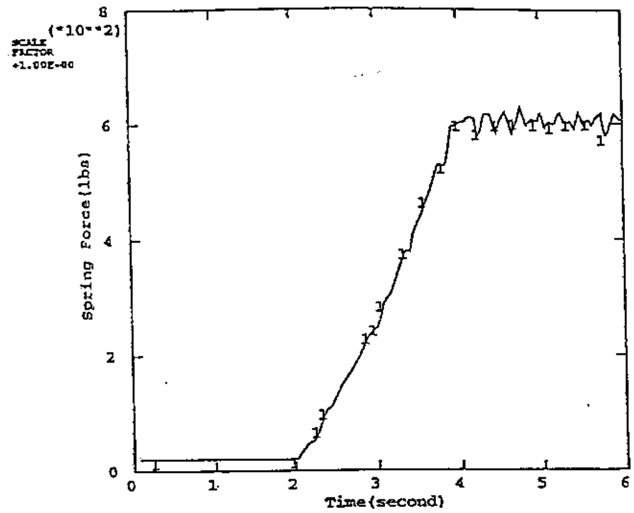
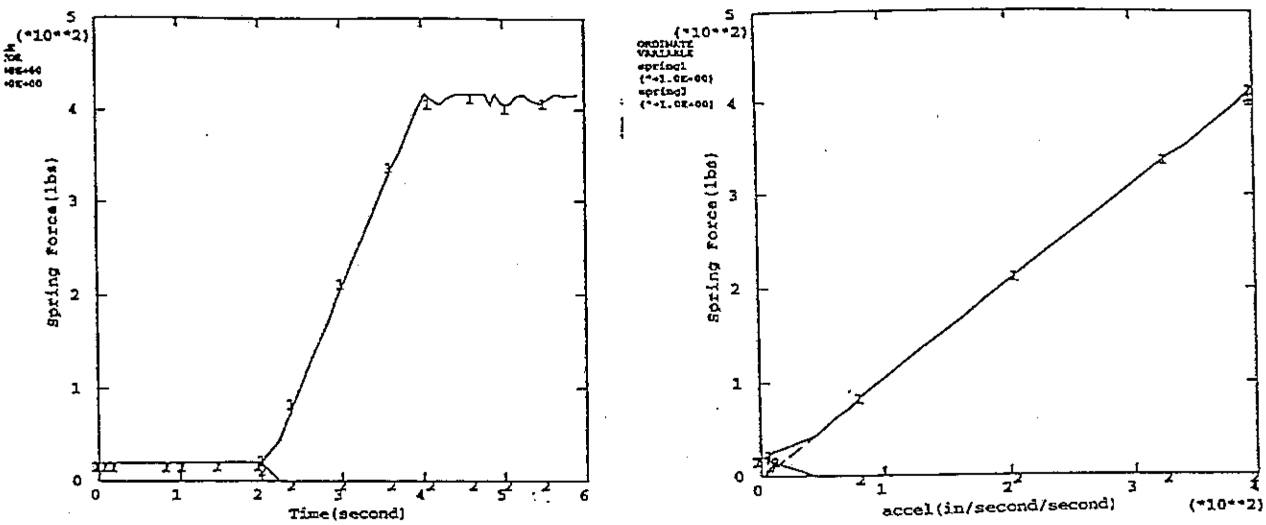


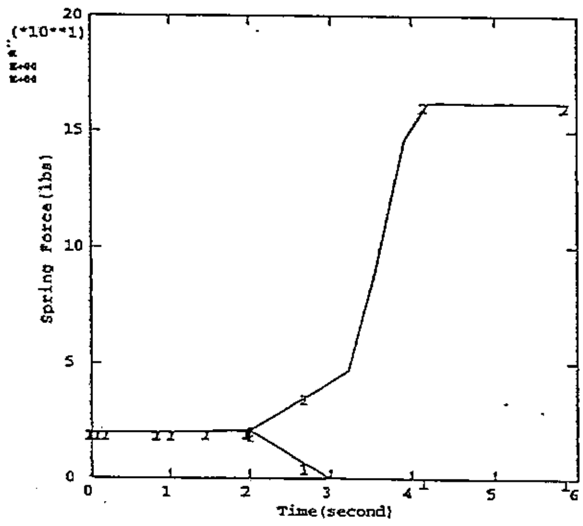

Figure 5.3-18: Acceleration at 45°, Specimen A



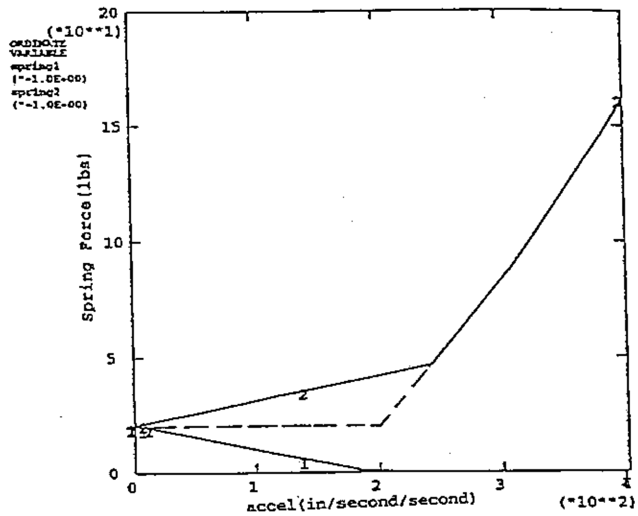

Spring force vs Time

Spring force vs Acceleration

Figure 5.3-19: X-Direction Acceleration, Specimen B

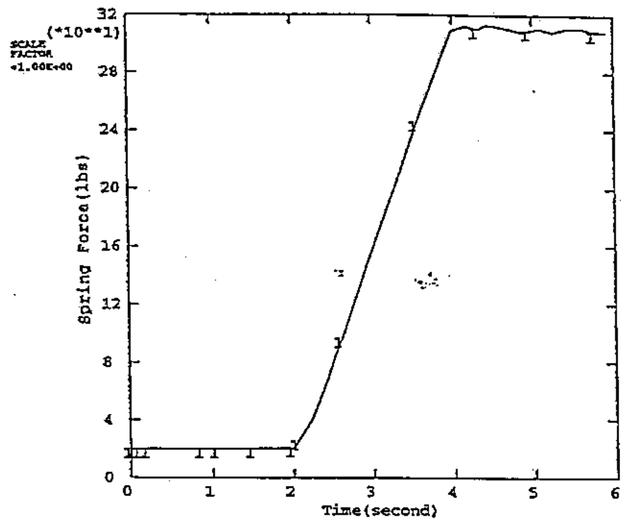



Spring force vs Time

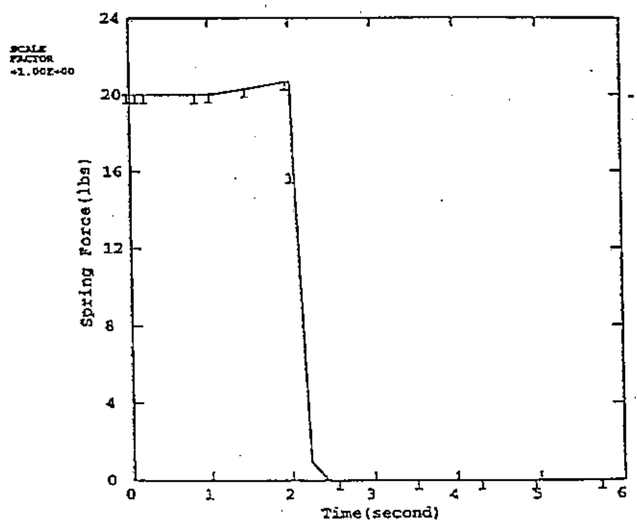



Spring force vs Acceleration

Figure 5.3-20: Z-direction Acceleration, Specimen B




Spring2
Spring force vs time




Spring3
Spring force vs time

Figure 5.3-21: Acceleration at 45°, Specimen B

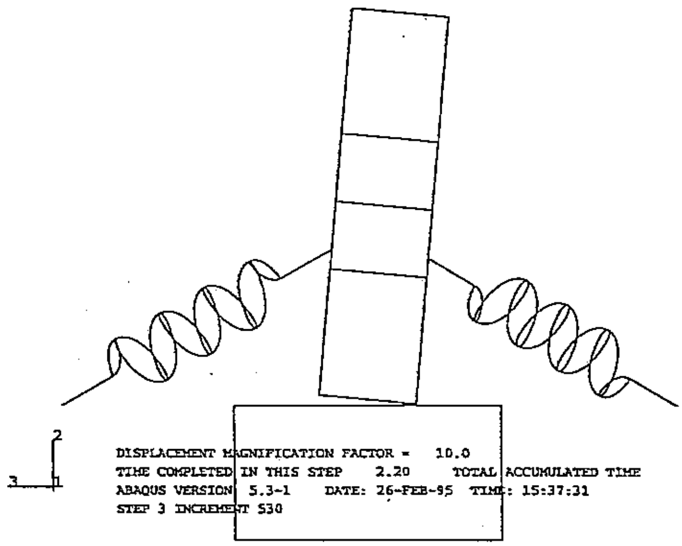



Figure 5.3-22: Specimen A Displaced Shape

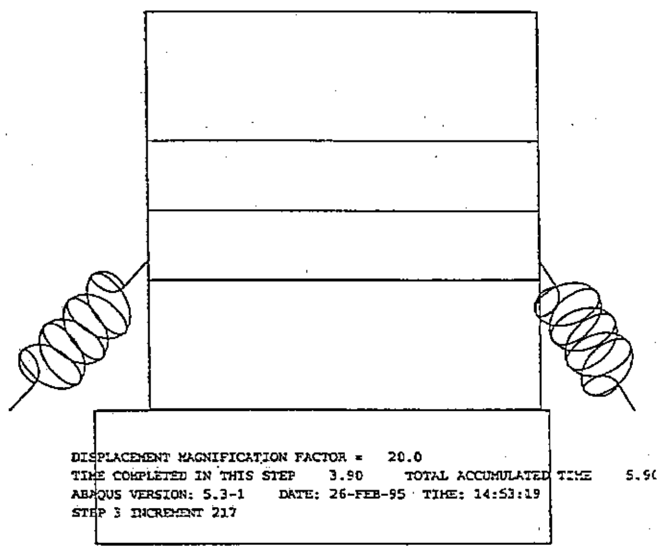



Figure 5.3-23: Specimen B Displaced Shape

#### 5.3.2.3 Finite Element Analysis of Prototypes

The geometric properties of Prototype A and Prototype B are shown in Table 5.3-14. A similar model setup and analysis procedure as described in earlier sections of this chapter have been employed for these prototypes. The nonlinear spring properties are also shown in Table 5.3-14.

| | Prototype A (weight: 9690 lbs) | Prototype B (weight: 39250 lbs) |
|---|---|---|
| Tie-down type (breaking strength) | 1/4" G70 (12,100 lbs) | 5/16" G43 (9700 lbs) |
| Unit chain stiffness | 525.5 kip/in/in | 974 kip/in/in |
| Tie-down length | 51.57 in | 36.65 in |
| Single tie-down stiffness | 10190 lb/in | 26576 lb/in |
| Tie-down quantity | 1 on each side | 3 on each side |
| Spring element stiffness | 10190 lb/in | 79727 lb/in |
| Prestress force | 2000 lbs | 2000 lbs |
| Chain deformation at zero force | -0.19627 in | -0.02509 in |
| Force at 10" chain displacement | 103900 lbs | 799270 lbs |

Table 5.3-14: Spring stiffness and prestress in the prototype models

The type and number of the tie-downs are determined by the coil weight (Crosby 1991). Four 1/4" G70 tie-downs are required for the Prototype A model and twelve 5/16" G43 tie-downs are required for the Prototype B model. In the 3-D prototype models, the coil is constrained by four spring elements, not two spring elements as in the 2-D models. As a result, each spring element represents one tie-down chain in Prototype A and three tie-down chains in Prototype B.

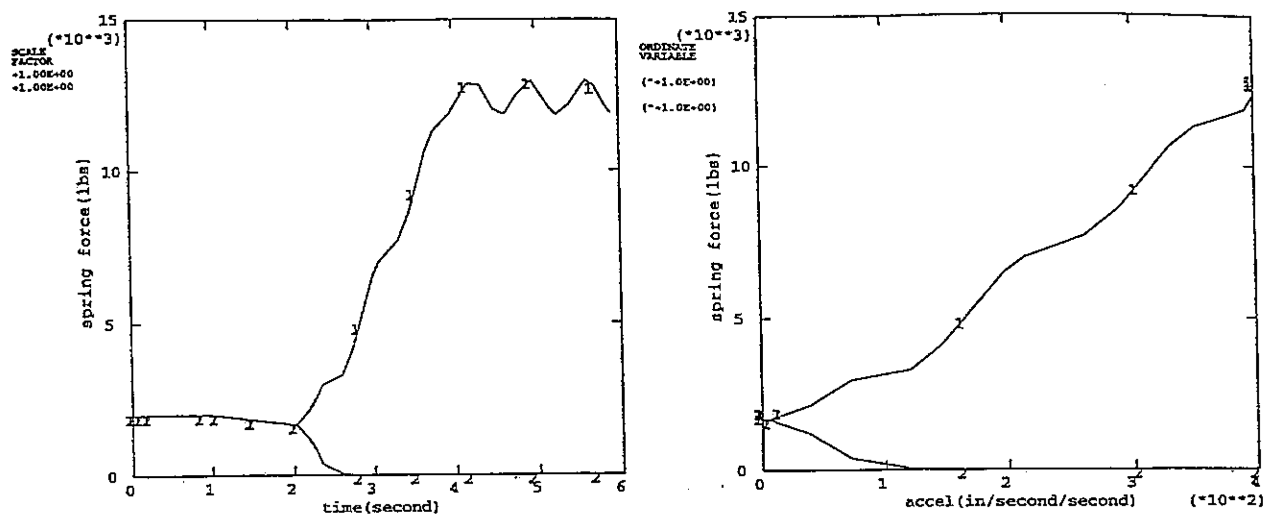
The prestress force of each spring element is defined to be 2000 lbs, which equals 8000 lbs total (there are four tie-down springs per coil). This tie-down prestress force is on the order of 10 to 20% of the breaking strength of the chain. In order to reduce the influence of elastic deformations due to this prestressing force, the coil modulus of elasticity has been increased to $100 \times 10^6$ psi.

For Prototype A, the spring response under X-direction acceleration is shown in Figure 5.3-24, the spring response under Z-direction acceleration is shown in Figure 5.3-25, and the response under a 45° acceleration is shown in Figure 5.3-26. The maximum chain forces are summarized in Table 5.3-15.

| | Acceleration Direction | | | | | |
|---|---|---|---|---|---|---|
| | X-direction | | Z-direction | | 45° direction | |
| | Peak Force (lbs) | % Breaking Strength | Peak Force (lbs) | % Breaking Strength | Peak Force (lbs) | % Breaking Strength |
| Prototype A | 13,000 | 107% | 4900 | 40.5% | 11,200 | 92.6% |
| Prototype B | 38,000 | 130.5% | 13,130 | 45.1% | 25,000 | 91.1% |

Table 5.3-15: Prototype Peak Chain Forces

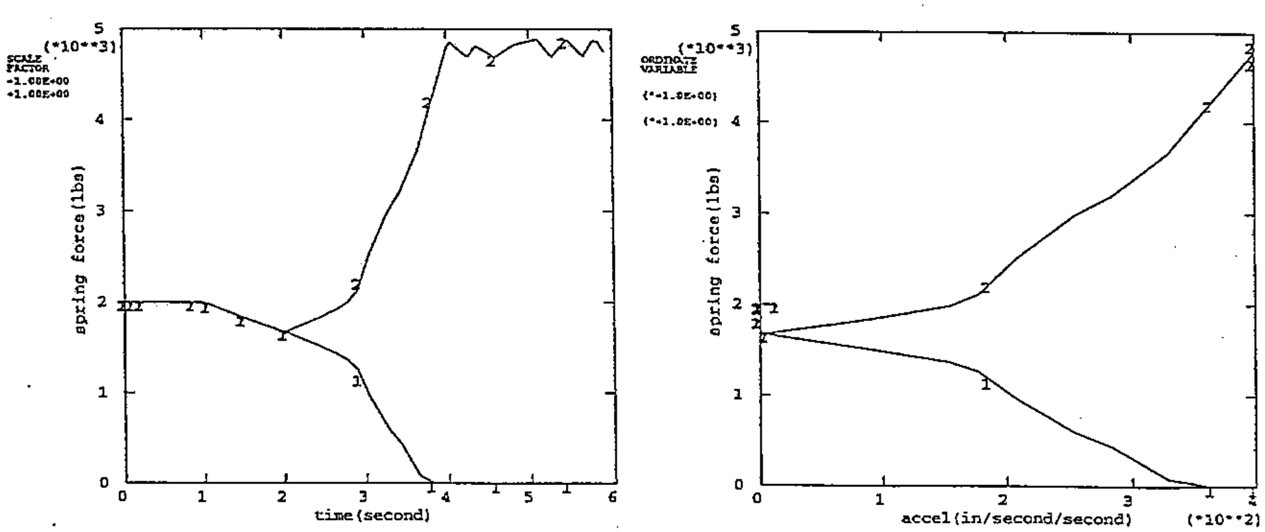
For Prototype B, the spring responses under three directions of accelerations are shown in Figure 5.3-27, Figure 5.3-28, and Figure 5.3-29. At an acceleration of 1G, the forces on the chains are summarized in Table 5.3-15. It can be seen that the forces in the chains are over the breaking strength of the chains for these unblocked prototypes. The X-direction acceleration is generally the worst case for this configuration.




Spring force vs Time

Spring force vs Acceleration

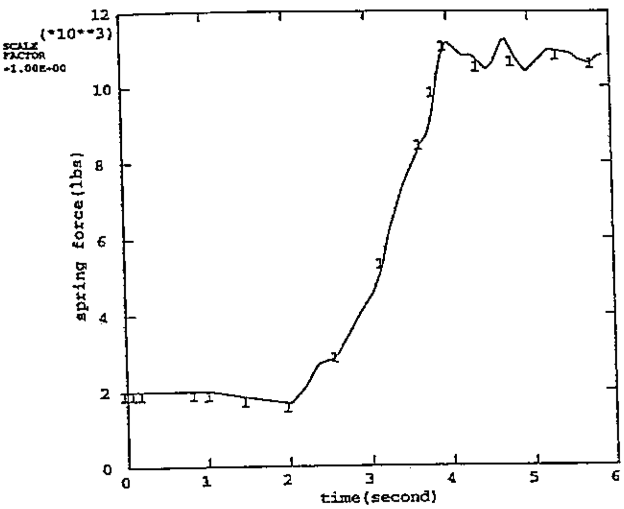
Figure 5.3-24: Prototype A, X-direction acceleration



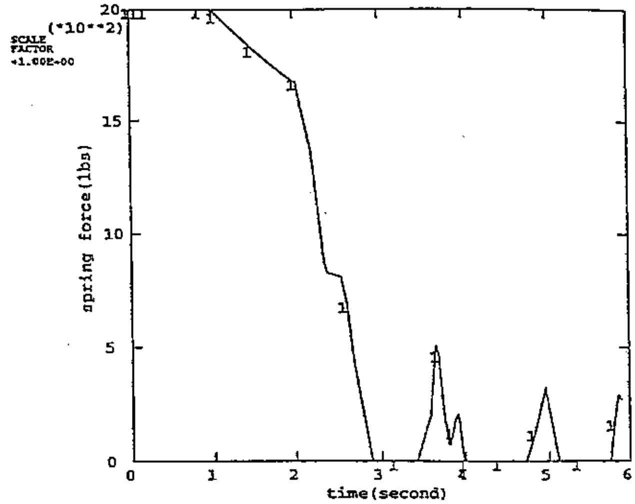

Spring force vs Time

Spring force vs Acceleration

Figure 5.3-25: Prototype A, Z-direction acceleration

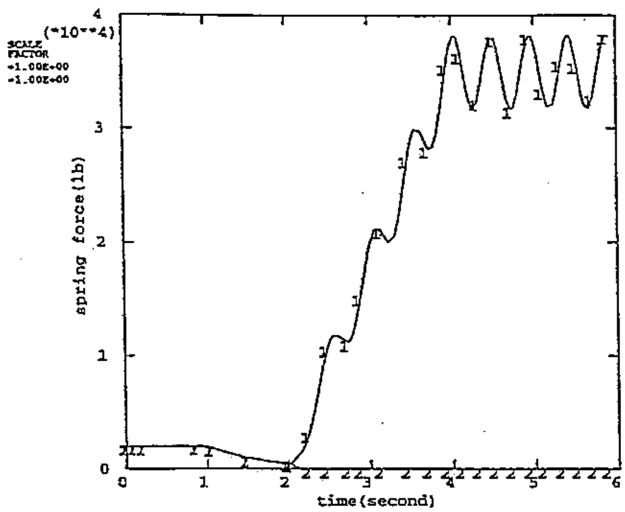



B. Spring2
Spring force vs time

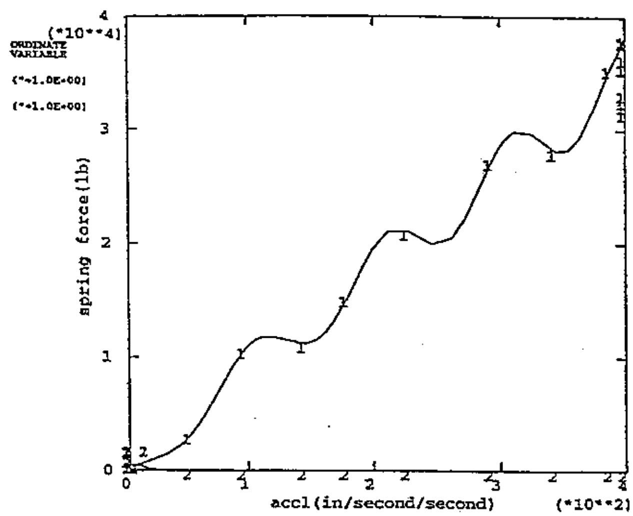



D. Spring4
Spring force vs time

Figure 5.3-26: Prototype A, 45° acceleration

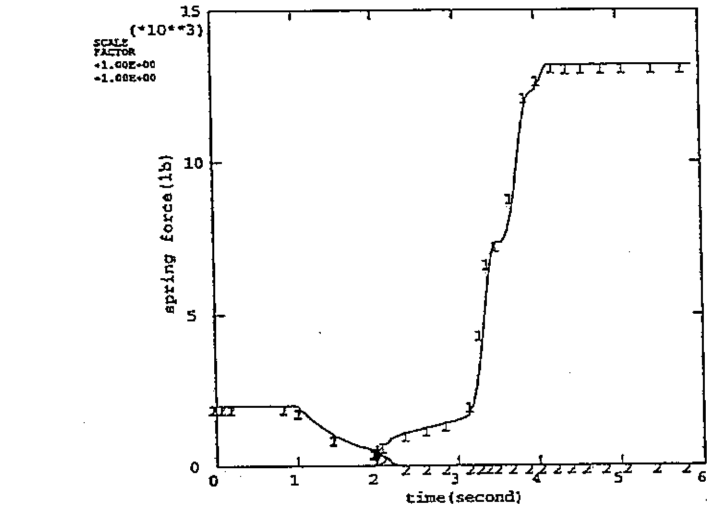



Spring force vs Time

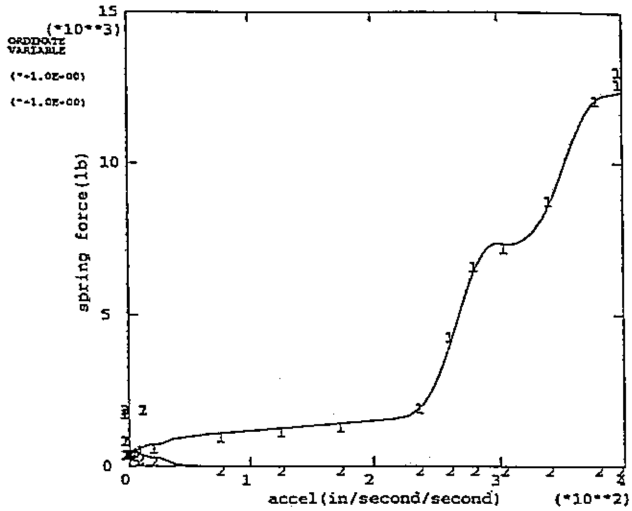



Spring force vs Acceleration

Figure 5.3-27: Prototype B, X-direction acceleration

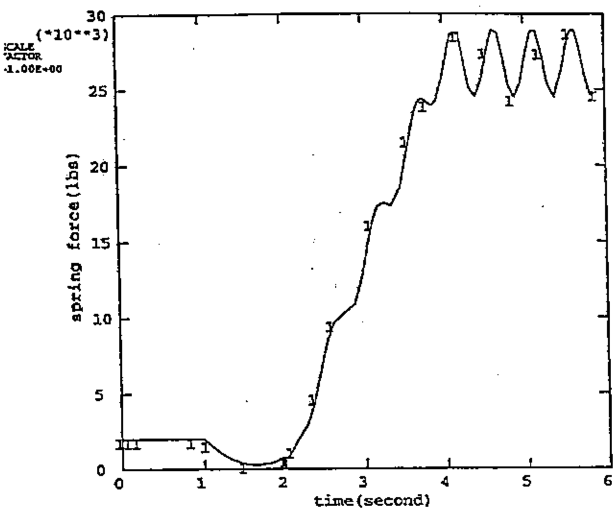



Spring force vs Time

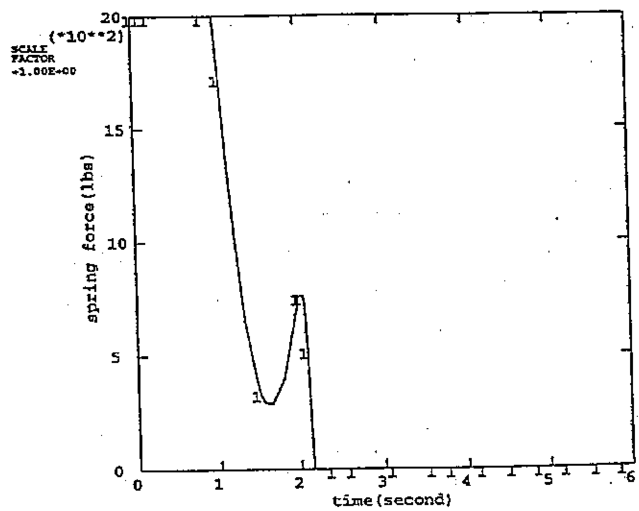



Spring force vs Acceleration

Figure 5.3-28: Prototype B, Z-direction acceleration




Spring2
Spring force vs time




Spring4
Spring force vs time

Figure 5.3-29: Prototype B, 45° Acceleration

## 5.4 Example Full Scale Coils

Using the data gathered during the truck survey described in Section 3.2.1, several "typical" metal coil securements were investigated using the finite element procedure described above. These securement configurations were based on the geometry of the actual coils and their securements, and modified so that they would always comply with the applicable federal regulations for the number of tie-down chains. The 1994 working load limit modification to 49 CFR 393 was used in the analysis in order to best comply with the current regulation.

### 5.4.1 Models

An average coil and securement configuration was selected for three coils weight 7100, 20480, and 45430 lbs. The configurations analyzed are shown in Table 5.4.1. The number of chains shown are the total number; these are placed symmetrically on coil so that one half are distributed on each side. This results in an even number of chains for each coil. It should be noted that where more than one tie-down location occurred, the dimensions were averaged in order to use a model with a single tie down location. This provides a reasonable approximation of the resultant securement location for multiple tie-downs. Chains were chosen to be typical of those used on trucks. For these analyses, the dimensions were limited to 1/4" G70 and 5/16" G43 chain. All of the securement configurations shown here meet or exceed the 1994 Federal Regulations (a minimum aggregate strength of .5 times the weight of the item being secured), with the exception of the requirement that all the chains make a 45 degree angle with the horizontal. The reason this particular requirement was not used for this analysis is because the condition for actual coils as transported has angles ranging from less than 45 to 90 degrees. The averages of the actual dimensions are used in the analysis, so that the angles are typically somewhat greater than 45 degrees.

The forces on the securement were developed for the "average" coils for two varying parameters. The coils were analyzed both blocked and unblocked, and with coefficients of friction .25 and .50. The unblocked configuration was examined in order to investigate the effect of blocking on the chain forces. As noted in Chapter 3, although blocking occurs for most metal coils with eyes not oriented vertically, it is often loose and may not always be effective in blocking rolling of the coil. For this reason, the unblocked condition is also checked.

The input accelerations for these models start at 0.0 and reach 1.0g over a 2 second interval. The direction of the force has been applied in the rolling direction (longitudinally), in the direction transverse to rolling (transverse), and at an angle of 45 degrees to each of these directions. As has been shown in the previous section, this will result in an essential static response of the coil-securement system. The results from the analyses are shown for .8g and 1.0g in Tables 5.4.2 through 5.4.5.

| Coil Weight (lbs) | Req'd Chains (per 1994) | Chain WLL (lbs/chain) | Chain Ultimate Strength (lbs/chain) | Total Chain WLL (lbs) |
|---|---|---|---|---|
| 7100 | 2-1/4" G43 | 2600 | 7500 | 5200 (.73W) |
| 20480 | 4-5/16" G43 | 3900 | 9700 | 15,600 (.76W) |
| 45430 | 6-5/16" G43 | 3900 | 9700 | 23,400 (.52 W) |

Table 5.4-1: Sample Coils and Securement

| Coil Weight (lbs) | Force at .8g Acceleration (kips) | | | | Force at 1.0g Acceleration (kips) | | | |
|---|---|---|---|---|---|---|---|---|
| | Long. | Trans. | 45° | Worst % Ultimate | Long. | Trans. | 45° | Worst % Ultimate |
| 7100 | 6.5 | 1.5 | 4.8 | 87% | 8.5 | 4.5 | 6.5 | 113% |
| 20,480 | 20.5 | 4.0 | 14.0 | 106% | 24.0 | 5.0 | 25.0 | 128% |
| 45,430 | 35.0 | 12.5 | 26.0 | 120% | 48.0 | 25.0 | * | 165% |

Table 5.4-2: Unblocked Coil Chain Forces at .5 Coefficient of Friction

| Coil Weight (lbs) | Force at .8g Acceleration (kips) | | | | Force at 1.0g Acceleration (kips) | | | |
|---|---|---|---|---|---|---|---|---|
| | Long. | Trans. | 45° | Worst % Ultimate | Long. | Trans. | 45° | Worst % Ultimate |
| 7100 | 1.9 | 1.5 | 3.1 | 41% | 3.9 | 2.4 | 4.5 | 60% |
| 20,480 | 5.0 | 3.0 | 6.0 | 31% | 11.0 | 5.9 | 14.0 | 72% |
| 45,430 | 7.5 | 10.0 | 18.5 | 64% | 15.0 | 14.0 | 25.0 | 86% |

Table 5.4-3: Blocked Coil Chain Forces at .5 Coefficient of Friction

| Coil Weight (lbs) | Force at .8g Acceleration (kips) | | | | Force at 1.0g Acceleration (kips) | | | |
|---|---|---|---|---|---|---|---|---|
| | Long. | Trans. | 45° | Worst % Ultimate | Long. | Trans. | 45° | Worst % Ultimate |
| 7100 | 6.0 | 2.5 | 5.0 | 80% | 8.0 | 3.1 | 7.6 | 100% |
| 20,480 | 21.0 | 5.9 | 14.0 | 108% | 25.0 | 8.8 | 22.0 | 129% |
| 45,430 | 36.0 | 18.0 | 28.0 | 123% | 45.0 | 25.0 | 44.0 | 154% |

Table 5.4-4: Unblocked Coil Chain Forces at .25 Coefficient of Friction

| Coil Weight (lbs) | Force at .8g Acceleration (kips) | | | | Force at 1.0g Acceleration (kips) | | | |
|---|---|---|---|---|---|---|---|---|
| | Long. | Trans. | 45° | Worst % Ultimate | Long. | Trans. | 45° | Worst % Ultimate |
| 7100 | 4.4 | 3.0 | 4.8 | 64% | 5.9 | 3.8 | 7.5 | 100% |
| 20,480 | 12.1 | 6.6 | 13.0 | 67% | 17.0 | 9.9 | 22.5 | 116% |
| 45,430 | 21.0 | 18.5 | 32.0 | 110% | 29.0 | 24.5 | 45.0 | 154% |

Table 5.4-5: Blocked Coil Chain Forces at .25 Coefficient of Friction

5.4.2 Observations

The results from these analyses confirm the nonlinear nature of the coil response to acceleration loading. Notice that for some of the coils, the chain force at 1.0g is more than twice the force at 0.8g (eg. blocked 20,480 lb. coil at .5 coefficient of friction with longitudinal acceleration). Therefore, simple linear models of the behavior of the coil may not describe the system with sufficient accuracy.

It can be clearly seen that, as expected, the chain forces are lower for the blocked case than for the unblocked case. The blocking helps to stabilize the coil, especially in the longitudinal direction. The blocking shifts the critical direction for the chain forces from the longitudinal to the 45 degree direction. It is interesting to note that if the blocking is not present, chain forces of about four times the blocked forces can be expected. Unfortunately, in many of the trucks observed during the field survey, the blocking was loose. This results from the use of standard size, non-adjustable blocking shoes. Metal coils come in all shapes and sizes which do not necessarily conform to the standard sizes, resulting in loose blocking.

With no blocking, forces as high as 120% ultimate for .8g and 165% ultimate for 1.0g were calculated for the 45,430 lb. coil. One of the reasons these forces are so high for this coil is that some of the chains exceeded the 45 degree angle with the horizontal required by the regulation. It is standard practice for drivers to attempt to meet the *number* of chain requirement in the regulation by providing some chains that loop at almost a 90 degree angle through the center of the coil. Unfortunately, the larger the coil, the greater the likelihood of this occurrence, because greater numbers of chains are required. This results in higher chain forces for the larger coils.

The 7100 lb coil has chains at an angle of slightly less than 45 degrees with the horizontal, and so it meets the federal regulation in all respects. Even though it meets the regulation, dangerously high forces are developed at low coefficients of friction in emergency maneuver situations. The 7100 lb. coil at .5 coefficient of friction, blocked, and with acceleration at 45 degrees has a chain force of 41% its ultimate breaking strength at .8g. At 1.0g, the worst ultimate force is 60%. These result in factors of safety just above and just below 2. It should be noted, however, that if the coefficient of friction drops to .25, the forces are 64% and 100% of ultimate for .8g and 1.0g, respectively. This is clearly unsafe. The coefficient of friction between wood and steel can vary in clean conditions from

.2 to .6 (Machinery's Handbook). In greasy or icy conditions the coefficient can become nearly zero, and the forces in the chains would increase even further.

The forces have been examined with reference to the ultimate breaking strength of the chains, in order to evaluate the federal regulations. Note that the working load limit requirements of the revised regulation are based on a factor of safety of about 3 against the ultimate breaking strength. It is clear that if the ultimate breaking strength of the chain is exceeded, the chain will break. The results from these analyses indicate that the chains are dangerously close to their ultimate strength, especially when the surface is contaminated by oil or ice, or the blocking is loose. Even with everything in perfect condition, the factor of safety is never as high as 3 for a 1.0g maneuver.

Unfortunately, it is difficult in practice to require truck drivers to keep the surface of their trailers clean. It is especially difficult given current practice to enforce the 45 degree angle requirement of the regulation. Since drivers already appear to understand the importance of blocking, more training to require the drivers to provide *tight* blocking will make the situation safer. The regulation should be updated to reflect the lack of safety in the current chain forces under typical driving conditions. The best way to do this would be to require more chains. This would partially make up for problems with the coefficient of friction and the lack of a 45 degree angle with the horizontal. If the current chain requirements were doubled, the average factors of safety would be about 4 for the blocked coil under clean conditions and about 2 for the blocked coil under more slippery (though still not greasy!) conditions. Although the factor of safety would be somewhat less than 2 when 1.0g maneuvers are required for the heavier coils, the large number of chains required for these coils would result in more system redundancy.

The problem with the current regulation is that the requirement that chains be required to restrain the coil *in any direction* is not understood by the drivers. The currently available Crosby Tie-Down calculator does not mention tieing down the coil against motion in every possible direction; it only indicates the total number of chains based on the working load limit of their aggregate strength. If the regulation is re-written to require chains to be evenly distributed on each side of the coil, making a 45 degree angle with the horizontal, the requirement that the coil be tied down against motion in any direction will essentially be met. Although the recommendation is to double the number of chains, essentially this will only require drivers to meet the current requirements of chaining down the coil in every direction.

Therefore, if the breaking strength requirement is used, the above results indicate that the aggregate strength of the chains on the coil should equal 3.0 times the weight of the coil, and be evenly distributed on each side of the coil. For the working load limit requirement, the aggregate strength of the chains should equal 1.0 times the weight of the coil. This will double the number of chains required by such securement aids as the Crosby calculator, but will keep the spirit of the regulation unchanged.

## CHAPTER 6: Securement Recommendations

The research described in the previous chapters was conducted with the aim of producing a reasonable analysis of the Federal Motor Carrier Safety Regulations as they apply to metal coil transport. In Section 6.1, some additional comments and conclusions on the research performed in this project will be discussed. Because of the general use of 49 CFR Part 393 by metal coil carriers, a side-by-side comparison between this regulation and the results of the research described herein will be presented in Section 6.2. Recommendations for changes to the regulation will be summarized in Chapter 6.3.

### 6.1 Summary and Conclusions

The objectives of the traffic analysis and field observation portion of this project were to obtain an estimate of the volume of coil-carrying trucks moving in Illinois, the type of securement used, and the level of knowledge of vehicle operators regarding the securement systems and regulations.

Coil destinations radiate primarily away from the steel making area in Northeastern Illinois and Northwestern Indiana with destinations as far away as Mississippi and Texas. However, metal coil movements on the Illinois interstates, while significantly directional, move in both directions on most of the interstate system as evaluated in the weigh station counts. Metal coil transport trucks were observed to make up more than 4% of the average daily truck traffic in the northeastern region of Illinois and specifically on I-57 southbound.

Review of 49 accident reports for 1992 and 1993 involving metal coil transport trucks in Illinois shows 43% of the accidents occurred on ramps or in turning movements. The review also indicates that forces other than just longitudinal must be considered in evaluation of coil securement. Additionally, it appears from a review of the accident reports that accident investigators could use some additional training regarding the evaluation of coil securement methods and resultant failures.

The distribution of coil weights varied from under 5,000 lbs to over 40,000 lbs. The coils weighing under 5,000 lbs accounted for 38.5% of the observed coils while 38.9% of the coils weighed between 10,000 lbs and 20,000 lbs. Visual counts at truck weigh stations showed approximately 28% of the observed coil-carrying trucks had one coil and approximately 54% of the trucks carried either two or three coil.

Based on field interviews with operators of 72 coil-carrying trucks, the operators did not appear to be knowledgeable about securement, chain or strapping strength, or federal regulations regarding securement. While there is some general knowledge of securement procedures, the fact that 42% of these vehicles had a violation further attests to either their lack of knowledge or deliberate actions which resulted in violations. Based on the field interviews, it appears most likely that there is a lack of knowledge regarding proper securement procedures as defined by the federal regulations or in an understanding of the federal regulations. In addition, the operators did not seem to have a clear understanding of chain code markings which identify the strength of a chain.

The results from the experiments and the analytical analyses confirm the nonlinear nature of the coil response to acceleration loading. For some of the coils, the chain force at an emergency maneuver acceleration of 386.4 in/sec$^2$ (1.0 times the acceleration of gravity, or 1.0g) is more than twice the force at 0.8g Therefore, simple linear models of the behavior of the coil may not describe the system with sufficient accuracy. Regulations should be based on nonlinear computer models backed up by experimental investigations.

It can be clearly seen that, as expected, the chain forces are lower for the blocked case than for the unblocked case. The blocking helps to stabilize the coil, especially in the longitudinal direction. It is interesting to note that if the blocking is not present, chain forces of about four times the blocked forces can be expected in the chains. Unfortunately, in many of the trucks observed during the field survey, the blocking was loose. This results from the use of standard size, non-adjustable blocking shoes, as can be seen in Figure 6.1-1. Metal coils come in all shapes and sizes which do not necessarily conform to the standard sizes, resulting in loose blocking. The coil in Figure 6.1-2 is effectively unblocked (note gap between timber and cradle on lower right side of coil).

Using cradles effectively reduces the tie-down cable forces. However, the magnitude of this reduction is affected by both the coil geometry and the type of test maneuvers. This can be seen in the results of the experiment. In the case of straight line braking maneuvers, using cradles resulted in 76% reduction in tie-down cables forces in Specimen A in comparison to the 41% reduction obtained in coil Specimen B. This is primarily due to the fact that the taller coil, Specimen A, was restrained more effectively against the rolling motion in the fore-aft direction by the cradles. The beneficial effect of the cradles in tie-down cable force reduction are more pronounced for the short, wide coil (107% reduction) than for the tall, narrow coil (60%). This is mainly due to the fact that the cradles are less effective against twisting of the tall and narrow coil A than the short and wide coil B.

A maximum peak tie-down cable response of 1.11 times the weight of the coil was obtained in the Q-braking maneuver test without a cradle. This corresponded to a prototype chain force of 10,750. lbs which is 143% of the ultimate breaking force of the 1/4 in. high test chain (7,500 lbs) considered. Introduction of the cradle in this test reduced the cable response to 0.70 times the weight of the scaled coil specimen. This corresponded to 90% of the ultimate breaking force in the prototype chain considered. This value was 20% higher than that of a straight-line braking maneuver test due to extra demand imposed by the lateral acceleration during turning at the time of braking.

With no blocking, chain forces as high as 120% the ultimate breaking strength for .8g and 165% ultimate for 1.0g were calculated in the computer analysis for the 45,430 lb. coil. Blocked forces for this coil were 110% and 154% of the ultimate breaking strength for .8g and 1.0g input acceleration, respectively. These compare reasonably well with the experimental values. Under this level of acceleration, the chains would most likely break. One of the reasons these forces are so high for this coil (and higher than any of the experimental values) is that some of the chains exceeded the 45 degree angle with the horizontal as required by the regulation. This coil is shown in Figure 6.1-2. The two outer chains approximately make an angle of approximately 45 degrees with the horizontal dimension (at least as viewed from the side), but the two inner chains are almost completely vertical, resulting in an angle with the horizontal of about 90 degrees. It is standard practice for drivers to attempt to meet the *number* of chains required in the regulation by providing some chains that loop at almost a 90 degree angle through the center of the coil, which ignores the requirement that chains be at an angle of no more than 45 degrees with the horizontal. Unfortunately, the larger the coil, the greater the likelihood of this occurrence, because greater numbers of chains are required. This results in higher chain forces for the larger coils. This condition is very common for larger coils, and it may be a violation of a strict interpretation of 49 CFR 393.100 (c) (3) (ii) (a).

Even for coils that meet the letter of the regulation, dangerously high forces could be developed at low coefficients of friction in emergency maneuver situations. The 7100 lb. coil at .5 coefficient of friction, blocked, and with acceleration at 45 degrees has a chain force of 41% its ultimate breaking strength at .8g. At 1.0g, the worst ultimate force is 60%. These result in factors of safety just above and just below 2. It should be noted, however, that if the coefficient of friction drops to .25, the forces are 64% and 100% of ultimate for .8g and 1.0g, respectively. This is clearly unsafe. The coefficient of friction between wood and steel can vary in clean conditions from .2 to .6 (Machinery's Handbook). In greasy or icy conditions the coefficient can become nearly zero, and the forces in the chains would increase even further.

The forces have been examined with reference to the ultimate breaking strength of the chains. The reason for this is because the ultimate breaking strength is defined as the strength at which the chain will break in the ASTM Standards. In other words, if the analysis indicates that the chain would develop more than 100% of its breaking strength, the chain would likely completely break during that maneuver. Note that the working load limit requirements of the revised regulation are based on a factor of safety of about 3 against the ultimate breaking strength. It is clear that if the ultimate breaking strength of the chain is exceeded, the chain will break. The results from these analyses indicate that the chains are dangerously close to their ultimate strength, especially when the surface is contaminated by oil or ice, or the blocking is loose. Even with everything in perfect condition, the factor of safety is never as high as 3 for a 1.0g maneuver.

Unfortunately, it is difficult in practice to require truck drivers to keep the surface of their trailers clean. It is especially difficult given current practice to enforce the 45 degree angle requirement of the regulation. Since drivers already appear to understand the importance of blocking, more training to require the drivers to provide *tight* blocking will make the situation safer. The regulation should be updated to reflect the lack of safety in the current chain forces under typical driving conditions. The best way to do this would be to require more chains. This would partially remedy problems with the coefficient of friction and the lack of a 45 degree angle with the horizontal. If the current chain requirements were doubled, the average factors of safety would be about 4 for the blocked coil under clean conditions and about 2 for the blocked coil under more slippery (though still not greasy!) conditions. Although the factor of safety would be somewhat less than 2 when 1.0g maneuvers are required for the heavier coils, the large number of chains required for these coils would result in more system redundancy.

The problem with the current regulation is that the requirement that chains be required to restrain the coil *in any direction* is not understood by the drivers. The currently available Crosby Tie-Down calculator does not mention tieing down the coil against motion in every possible direction; it only indicates the total number of chains based on the working load limit of their aggregate strength. If the regulation is re-written to require chains to be evenly distributed on each side of the coil, making a 45 degree angle with the horizontal, the requirement that the coil be tied down against motion in any direction will essentially be met. Although the recommendation is to double the number of chains, essentially this will only require drivers to meet the current requirements of chaining down the coil in every direction.

Therefore, if the breaking strength requirement is used, the above results indicate that the aggregate strength of the chains on the coil should equal 3.0 times the weight of the coil, and be evenly distributed on each side of the coil. For the working load limit requirement, the aggregate strength of the chains should equal 1.0 times the weight of the coil. This will double the number of chains required by such securement aids as the Crosby calculator, but will keep the spirit of the regulation unchanged.

In addition to these problems with the interpretation of the regulation, some of the allowed practices in the regulation are questionable. For example, blocking fore and aft is required for a coil with its eye oriented longitudinally if it only has one binder strap or chain over its top. However, no fore and aft blocking is required if two chains or binder straps go over the top of the coil. This situation is depicted in Figure 6.1-4. This configuration relies solely on friction between the coil and the trailer surface to restrain the coil from sliding fore or aft. Unfortunately, as discussed above, in icy or oil conditions the friction between the coil and the trailer surface may be very low or even zero. In those cases, the coil is effectively sitting on wooden skis that could slide off the end of the truck.

Another common situation is depicted in Figure 6.1-3. Here, the coil (in a covered wagon) is oriented with its eye longitudinal. The chains make an angle somewhat less than 45 degrees when viewed from the rear of the trailer. But when viewed from the side, the chains are almost at 90 degrees to the horizontal. This configuration will allow the coil to move fore and aft under acceleration and deceleration if the friction between the coil and the trailer surface is low.

The two experimental coil samples showed different characteristics under lateral accelerations (eye facing direction). The short and wide coil (B) tended to simply slide to the side when a threshold acceleration was reached. Then the tall and narrow coil (A) would tip to the side. This tipping could lead to a dangerous condition where a very narrow coil might "kick out" at the base. In practice (see field observations) such very skinny coils would be likely to be oriented in an eye up configuration. Yet, the Federal guidelines do not place any limits on coil dimension ratios in any restraint configuration. This decision is left up to the driver. After further study, some reasonable coil dimension ratio limits should be imposed for coils not in the eye up configurations.

The chains crossed through the eyes configuration (allowed in the regulation) was used by many truck drivers, as discovered in the field survey. It was observed that the experimental coil specimens with crossed chains slid in straight line braking maneuvers and twisted more in Q-braking maneuvers, even though cradles were used to block them. These observations clearly indicate that the effect of the crossed tie-downs on the response of the steel coils is different from the cases without crossed chains. Because the influence of crossing the chains appears to harmfully effect the coil system response, this configuration should not be currently allowed in the regulation. Further study is warranted to properly quantify this influence on the tie-down chain forces.

The restraint devices are elastic - chains, cables, and straps exhibit force-deflection characteristics. The coil must move relative to the trailer in order to change the load in these devices. The motions may be relatively small and not visually apparent. A change in the apparent preload (restraint force) on a coil may be due to several factors:

- Load settling - permanent deformation in the supporting structure, i.e., trailer bed, blocking face (coil "biting in"), or coil. Most of this settling should occur within the beginning of the transport - within the first 50 miles or less.

- Cargo shifting - sliding of the coil on the trailer. This is due to the imposed transport accelerations. Assuming no settling and initially tight restraints, the shifting both increases the preload in one set of restraint legs and decreases it in the other two legs. The appearance of loose or lower preload chain with a shift indicates that one chain will be "over tight" with a high preload. The driver should exercise caution when adjusting restraints of shifted coils. It may also be a good practice to mark the starting location of the coil to note any significant shift.

- Permanent deformation (plastic deformation) of restraint device or securement point on trailer. If the chain force exceeds the proof strength (approximately twice the working load limit - maximum recommended load - and half the minimum breaking strength) the chain will show permanent deformation that decreases the chain preload. Thus, a single severe maneuver can "loosen" the restraints by stretching the chains.

Technically, if a permanent elongation occurs due to an overload the chains should be replaced and taken out of service (CVSA Cargo Securement Tie-Down Guideline, 1992). Yet a moderate amount of deformation is not likely to be recognized as chain damage. Checking for and enforcing a rule to take chains out of service based on moderate levels of stretching may not be practical or enforceable. There are standards on chain size (ASTM A 413, 1991) but they provide only nominal and minimum dimensional specifications. Each chain manufacturer can make chains of differing dimensions so that it is not practical to inspect for moderate chain stretch even if it is in the best interest of transport safety. Further research should be performed to develop a method to evaluate chains in service.

Beyond the concern of permanent deformation, there is concern with wear, corrosion, and fatigue. Wear, nicks and cracks are indicated in the CVSA tie-down guidelines (1992) as reasons to take a restraint out of service. Yet, corrosion or rust which weakens a chain is not called out as a form of chain damage contributing to consideration to remove a chain from service. Corrosion is visible, but there are no standards to judge an acceptable chain from an unacceptable one. On the other hand, the issue of fatigue is even more difficult because fatigue damage is not apparent by a simple visual inspection. Fatigue is the formation of micro cracks that eventually grow to a macro crack and finally rupture due to repeated subcritical loads. Thus, a chain may rupture or break due to a load far less than the breaking strength if this load is repeated many thousands of times.

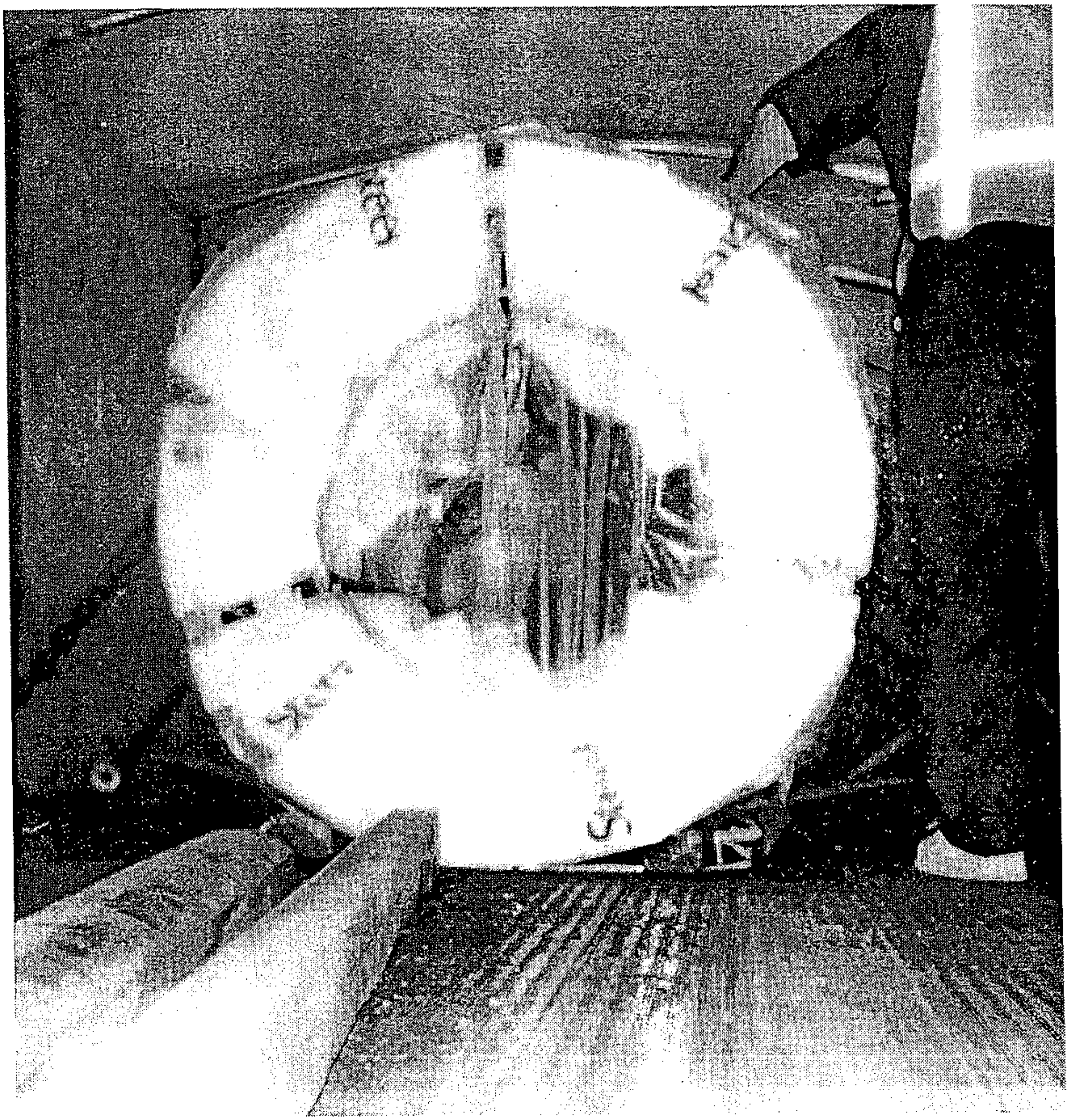


Figure 6.1-1 Coil A-10 with eye longitudinal (inside a covered wagon)

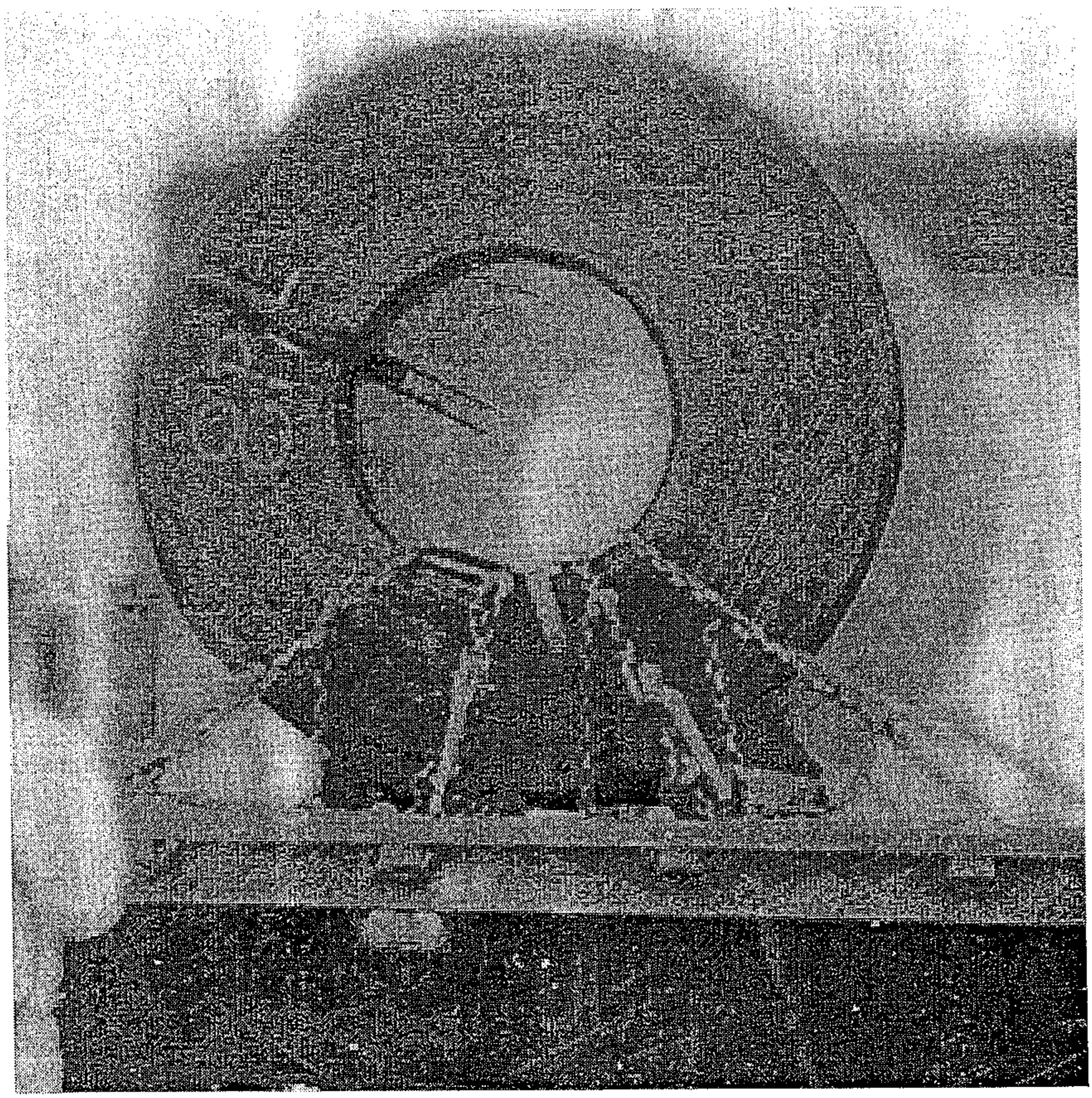


Figure 6.1-2: Coil A-1 with Eye Transverse and chains at greater than 45 degrees

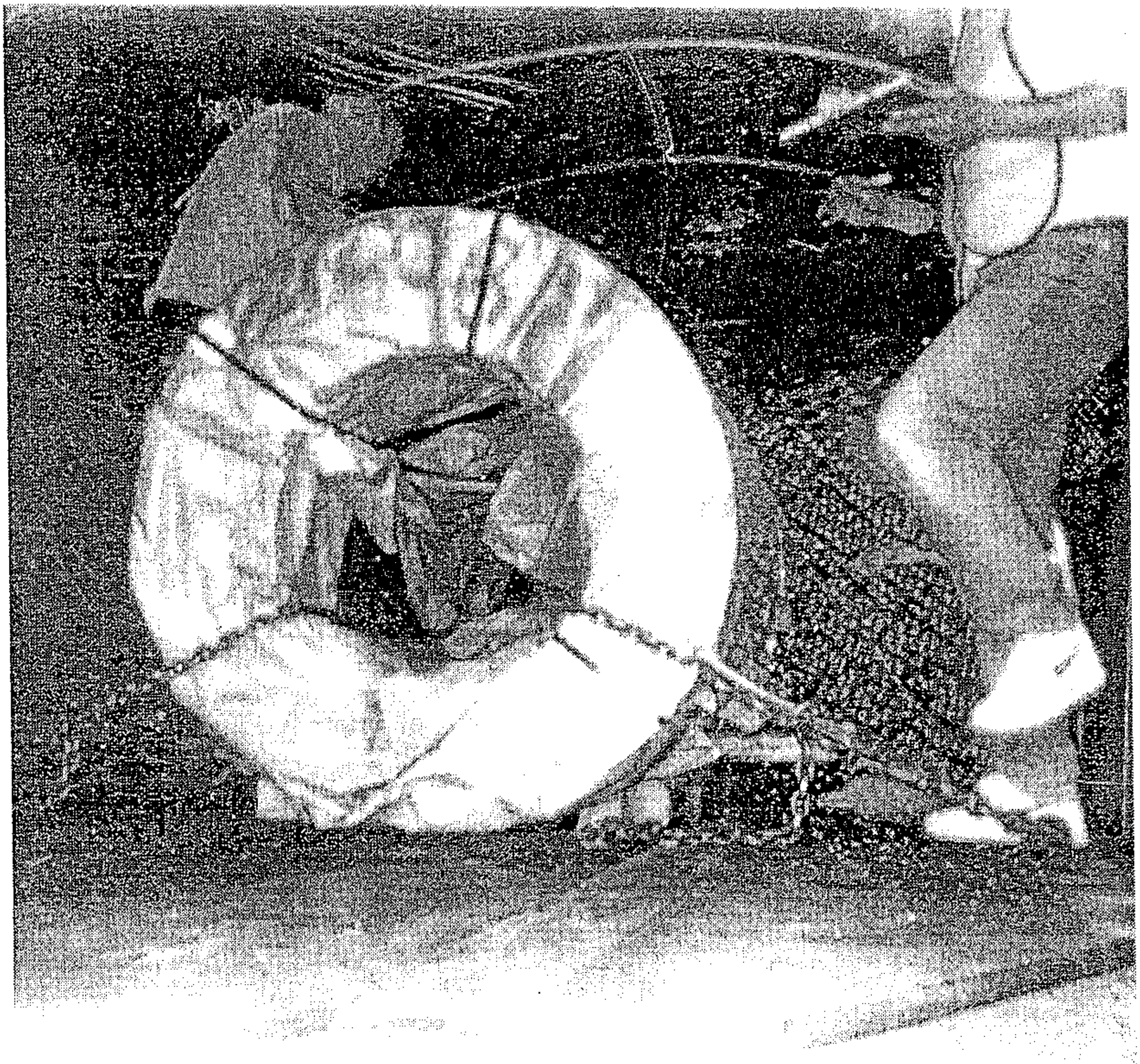


Figure 6.1-3 Coil A-14 with eye longitudinal

Figure 6.1-4 Coil A-9 with eye longitudinal and binding straps over the top

## 6.2 Federal Motor Carrier Safety Regulation Part 392, 393 and Commentary

**PART 392 --- DRIVING OF MOTOR VEHICLES** **COMMENTARY**

**Safe Loading of Motor Vehicles**

**392.9 Safe Loading.**

(a) *General.* No person shall drive a motor vehicle and a motor carrier shall not require or permit a person to drive a motor vehicle unless ---

(1) The vehicle's cargo is properly distributed and adequately secured as specified in 393.100-393.106 of this subchapter;

(2) The vehicles' tailgate, tailboard, doors, tarpaulins, its spare tire and other equipment used in its operation, and the means of fastening the vehicle's cargo are secure; and

(3) The vehicle's cargo or any other object does not obscure the driver's view ahead or to the right or left sides, interfere with the free movement of his arms or legs, prevent his free and ready access to accessories required for emergencies, or prevent the free and ready exit of any person from the vehicle's cab or driver's compartment.

(b) *Drivers of trucks and tractors.* Except as provided in subparagraph (4) of this paragraph, the driver of a truck or truck tractor must ---

(1) Assure himself that the provisions of paragraph (a) of this section have been complied with before he drives that vehicle;

(2) Examine the vehicles's cargo and its load-securing devices within the first 25 miles after beginning a trip and cause any adjustments to be made to the cargo or load-securing devices (other than steel strapping) as may be necessary to maintain the security of the vehicle's load; and

(3) Re-examine the vehicle's cargo and its load-securing devices periodically during the course of transportation and cause any adjustments to be made to the cargo or load-securing devices (other than steel strapping) as may be necessary to maintain the security of the vehicle's load. A periodic re-examination and any necessary adjustments must be made ---

(i) When the driver makes a change of his duty status; or

(ii) After the vehicle has been driven for 3 hours; or

(iii) After the vehicle has been driven for 150 miles, whichever occurs first.

(4) The rules in this paragraph do not apply to the driver of a sealed vehicle who has been ordered not to open it to inspect its cargo or to the driver of a vehicle that has been loaded in a matter that makes inspection of its cargo impracticable.

(c) *Buses.* No person shall drive a bus and a motor carrier shall not require or permit a person to drive a bus unless ---

(1) All standees on the bus are rearward of the standee line or other means prescribed in 393.30 or this subchapter;

(2) All aisle seats in the bus conform to the requirements of 393.91 of this subchapter; and

(3) Baggage, freight, or express on the bus is stowed and secured in a manner which assures ---

(i) Unrestricted freedom of movement to the driver and his proper operation of the bus;

(ii) Unobstructed access to all exits by any occupant of the bus; and

(iii) Protection of occupants of the bus against injury resulting from the falling or displacement of articles transported in the bus.

## PART 393 --- PARTS AND ACCESSORIES NECESSARY FOR SAFE OPERATION

### Subpart I --- Protection Against Shifting of Falling Cargo

#### 393.100 General rules for protection against shifting or falling cargo.

(a) *Application and scope of the rules in this section.* This section applies to trucks, truck tractors, semitrailers, full trailers, and pole trailers. Each of those motor vehicles must, when transporting cargo, be loaded and equipped to prevent the shifting or falling of the cargo in the manner prescribed by the rules in paragraph (b) of this section. In addition, each cargo-carrying motor vehicle must conform to the applicable rules in 393.102, 393.104, and 393.106.

(b) *Basic protection components.* Each cargo-carrying motor vehicle must be equipped with devices providing protection against shifting or falling cargo that meet the requirements of either subparagraph (1), (2), (3), or (4) of this paragraph.

(1) *Option A.* The vehicle must have sides, sideboards, or stakes, and a rear endgate, endboard, or stakes. Those devices must be strong enough and high enough to assure that cargo will not shift upon, or fall from the vehicle. Those devices must have no aperture large enough to permit cargo in contact with one or more of the devices to pass through it.

(2) *Option B.* The vehicle must have at least one tiedown assembly that meets the requirements of 393.102 for each 10 linear feet of lading or fraction thereof. (However, a pole trailer or an expandable trailer transporting metal articles under the special rules in paragraph (c) of this section is required only to have two or more of those tiedown assemblies at each end of the trailer.) In addition, the vehicle must have as many additional tiedown assemblies meeting the requirements of 393.102 as are necessary to secure all cargo being transported either by direct contact between the cargo and the tiedown assemblies or by dunnage which is in contact with the cargo and is secured by tiedown assemblies (tiedown assemblies or dunnage in contact with sufficient exterior (including topmost) pieces of the cargo and securely holding each interior or lower piece comply with this requirement).

(3) *Option C (for vehicles transporting metal articles only).* A vehicle transporting cargo which consists of metal articles must conform to either the rules in subparagraph (1), (2), or (4) of this paragraph, or the special rules for transportation of metal articles set forth in paragraph (c) of this section.

(4) *Option D.* The vehicle must have other means of protecting against shifting or falling cargo which are similar to, and at least as effective as, those specified in subparagraph (1), (2), or (3) of this paragraph.

(c) *Special rules for metal articles.* (1) *Scope of the rules in this paragraph.* The rules in this paragraph apply to a motor vehicle transporting cargo consisting of metal articles if that vehicle does not conform to the rules in subparagraph (1), (2), or (4) of paragraph (b) of this section.

(2) *Application of other sections.* A motor vehicle transporting property consisting of metal articles must, regardless of whether the rules in this paragraph apply to it, conform to the rules in 393.102 (relating to securement systems), 393.104 (relating to blocking and bracing of cargo), and 393.106 (relating to front-end structure requirements).

(3) *Coils.* Whenever a motor carrier transports one or more coils of metal which, individually or as a combination banded together, weigh 5,000 pounds or more, the coils shall be secured in the following manner:

This begins the special requirements for metal coils.

(i) Coils with eyes vertical: one or more coils which are grouped and loaded side by side in a transverse or longitudinal row must be secured by ---

For eyes vertical, the securement must restrain against:

(a) A tiedown assembly against the front of the coil or row of coils, restraining against forward motion;

(b) A tiedown assembly against the rear of the coil or row of coils, restraining against rearward motion; and

(c) A tiedown assembly over the top of each coil or transverse row of coils, restraining against vertical motion.

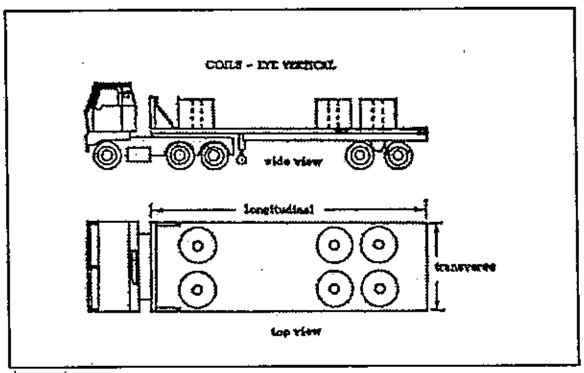
Forward motion;

Rearward motion;

Vertical Motion.

The same tiedown assembly shall not be used to comply with more than one of the requirements of (a), (b), or (c) of this subdivision.

Each direction must use a different tiedown; i.e., each coil or group of coils must have at least 3 tiedowns.




(ii) Coils with eyes crosswise: Each coil or transverse row of coils loaded side by side and having approximately the same outside diameters must be secured by ---

For crosswise eye (suicide position), each coil or transverse row of coils (transverse coils are oriented side by side) must be secured by:

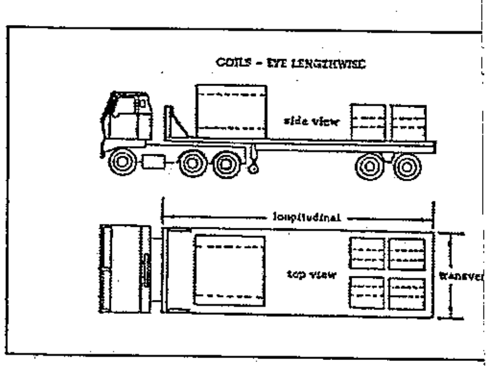
(1) One or more tiedown assemblies o
of each coil or transverse row; or

(2) Two or more tiedown assemblies t
eye of each coil or longitudinal row; or

(3) One or more tiedown assemblies, c
from one side of the vehicle to the other, thro
eye of each coil or longitudinal row of coils i
transverse row.

(b) Timbers having nominal cross sect
4 inches or more must be tightly placed again
sides of each coil or against the outboard side
transverse row of coils which are loaded side
that the timbers restrain against side-to-side n

(c) If, in accordance with (a) (1) of this
subdivision, only one tie-down assembly ove
each coil or transverse row of coils is used to
against side-to-side movement and fore-and-a
movement, timbers having a nominal cross se
4 inches or more and which are firmly secure
longitudinal blocking must be tightly placed a
front and back of each coil, each longitudinal
coils, and each transverse row of coils in a ma
which restricts forward and rearward moveme




(iv) Timber which is used for blocking r
sound lumber which is free of defects (such as
cracks) that materially reduce its strength.

(v) Timbers need not be used on vehicle
have depressions in the floor or are equipped v
other restraining devices which perform the fu
specified for timbers by the rules in this sectio

(vi) As used in this section, the term "no
when used to describe timber, means commerc
dressed sizes generally designated by the dime
indicated.

(a) A tiedown assembly through the eye of each coil, restricting against forward motion and making an angle of less than 45° with the horizontal when viewed from the side of the vehicle;

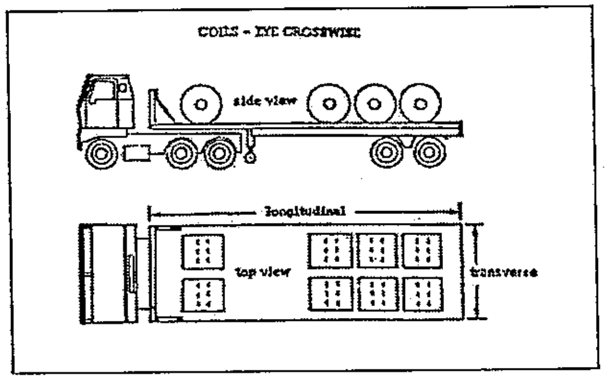
(b) A tiedown assemble through the eye of each coil, restricting against rearward motion and making an angle of less than 45° with the horizontal when viewed from the side of the vehicle; and

(c) Timbers, having a nominal cross section 4X 4 inches or more and a length which is at least 75 percent of the width of the coil or row of coils, tightly placed against both the front and rear sides of the coil or row of coils and restrained to prevent movement of the coil or coils in the forward and rearward directions.

(d) If coils are loaded to contact each other in the longitudinal direction and relative motion between coils, and between coils and the vehicle, is prevented by tiedown assemblies and timbers —

(1) Only the foremost and rearmost coils must be secured with timbers; and

(2) A single tiedown assembly, restricting against forward motion, may be used to secure any coil except the rearmost one, which must be restrained against rearward motion.




(iii) Coils with eyes lengthwise: A coil or transverse row of coils having approximately equal outside diameters and loaded side by side or a longitudinal row of coils having approximately equal outside diameters and loaded end to end must be secured as follows:

(a) The coil or coils must be restrained against side-by-side and fore-and-aft movement by —

Tiedown through the eye against forward motion. In practice, drivers will provide some chains at a greater than 45° angle in order to meet the number of chain requirements (for large coils 90° is not uncommon). Tiedown through the eye against rearward motion.

Timber blocking against forward or rearward motion.

Note that no direct vertical securement is required for coils with eyes crosswise.

For multiple coils in contact with eyes crosswise, securement only needs to prevent the forwardmost coil from moving forwards and the rearmost coil from moving rearwards. Timber blocking is also required. Note that vertical motion is still not explicitly prevented. It is also unclear what the phrase "relative motion between coils ... is prevented by tiedowns and timbers" actually means. Is contact sufficient? Should there be additional restraint? It seems like this section requires all coils to be restrained.

For coils with eyes lengthwise:

Restrain against side-to-side and fore-to-aft movement by:

(5) The rules in paragraphs (d) and (e) of this section do not apply to a motor vehicle manufactured before January 1, 1974.

(h) *Effective dates.* Cargo-carrying motor vehicles which are not exempted by paragraph (g) of this section must conform to the rules in this section as follows:

| If the vehicle was manufactured | It must conform to the rules in paragraph | On and After |
|---|---|---|
| Before January 1, 1974 | (a), (b), and (f) | October 1, 1973 or the date it was manufactured, whichever is later. |
| Before January 1, 1974 | (c) | January 1, 1975 |
| On or after January 1, 1974 | (a) through (f) inclusive | The date it was manufactured. |

Paragraphs (d) and (e) of this section do not apply to a motor vehicle that was manufactured before January 1, 1974.

POST 5 AUGUST 1994

PART 393-PARTS AND ACCESSORIES NECESSARY FOR SAFE OPERATION (AMENDED)

6.3 Recommendations for changes to 49 CFR 393

In summary, it is recommended that the following items be immediately considered in a review of 49 CFR 393:

1. The regulations should be clarified in relation to two terms: "aggregate strength" and "any direction." The coils should be restrained against motion in all three translational degrees of freedom. The research indicates that this could be accomplished if the working strength of all the tie-downs equalled the 1.0 times the weight of the coil and were distributed symmetrically on each side of the coil. Furthermore, *no* chains should be permitted to be at an angle of greater than 45 degrees.

2. Wood blocking should not be relied on alone to restrain the coil against lateral motion, since it is practically impossible to provide a sufficient number of nails to hold the blocking in place for a 5000 pound or greater coil. For coils with eyes longitudinal and more than one chain or binder over the top, fore-aft restraint should be provided by either chains or a specially designed securement system. Cradles with blocking do help when they are properly sized but they are not specifically allowed in the code. More research needs to be performed to specifically quantify the benefits of the cradle supports.

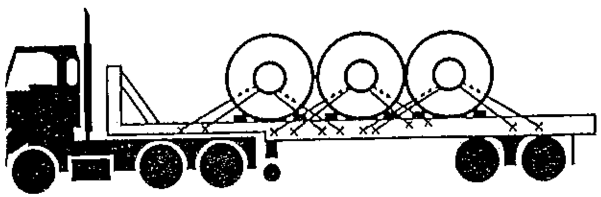
3. Crossed chains should not be allowed. They appear to cause system instability when used to restrain a coil that is experiencing high accelerations, and they have no beneficial effects.

4. The out-of-service criteria for chains and binders need to be seriously reconsidered in light of this research. Chains can be severely damaged in ways that are not visible to the naked eye. Corrosion and rust should also be considered as evidence of damage.

5. Some limits on coil dimensions and aspect ratios should be in the regulation. some large diameter, narrow coils need to be transported eyes up. The regulations do not currently specify any limits on the coil dimensions and their transportation configuration.

# APPENDIX A

# STEEL AND ALUMINUM COIL LOAD SECUREMENT



Illinois Department of Transportation
Division of Traffic Safety

To determine the extent of the load securement problem, the Illinois Department of Transportation (IDOT) has contracted the School of Engineering, Southern Illinois University at Edwardsville to conduct a Cargo Securement Research Project.

Part of the project will include gathering data from roadside inspections of motor carriers transporting metal coils. These short surveys will include measuring coils, identifying securement methods and brief driver interviews. This information will be used to gain better insight into the coil securement methods currently in use. Your company's and driver's cooperation with this survey is greatly appreciated.

**On November 20, 1990 on I-94 in Chicago, Illinois a 20,000 lb. steel coil broke free from its flat bed trailer securement and became a flying projectile. By the time it came to rest the coil had caused over $250,000 damage and temporary closure of two major transportation arteries.**

**On August 5, 1991, two aluminum coils fell off a U.S.-based motor carrier's trailer near Gananoque, Ontario, killing four members of a family in a passenger car, all U.S. residents. One of the deceased had just returned from service in Operation Desert Storm.**

**On October 5, 1992, several 7,000-pound steel coils fell off a motor carrier's trailer on I-190 near Buffalo, New York, striking several cars and killing four occupants.**

IDOT is advising motor carriers to pay particular attention to their load securement policies and practices. Specific attention should be paid to the number of tie-down assemblies, the condition and strength of the tie-downs and anchors, and any blocking or bracing that may be necessary. Webbing, chains, cables, and tie-down anchors must be inspected for wear and damage, and the blocking and bracing must be inspected for adequacy before any load is transported.

Sections 393.100 through 393.106 of the Illinois Motor Carrier Safety Regulations specify the load securement requirements applicable to motor carriers, and the Commercial Vehicle Safety Alliance (CVSA)/FHWA "out-of-service" criteria identify defects which will cause a carrier to be placed out-of-service. Carriers should acquaint themselves with both. In addition, the CVSA has developed "Cargo Securement Tie-Down Guidelines" and other related training materials.

If you would like more information on cargo securement regulations, please contact the Illinois Department of Transportation, Division of Traffic Safety, Commercial Vehicle Safety Section at (217) 785-1181 or 1-800-526-0844 (TDD only).

SIUE Southern Illinois University at Edwardsville

# TRUCK SURVEY(# )

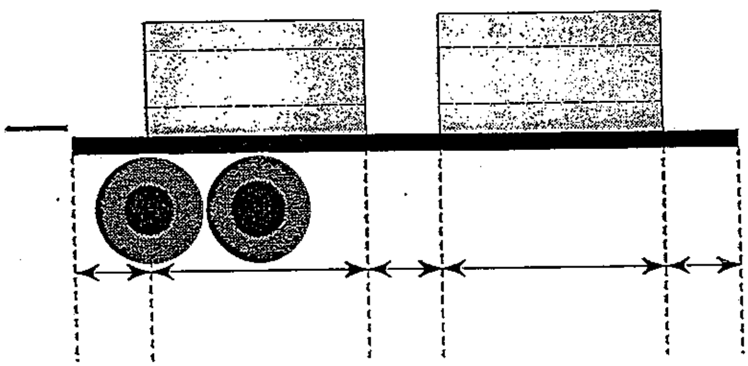
| | |
|---|---|
| DATE:<br>TIME: | LOCATION: |
| ORIGIN: | DESTINATION: |
| # OF COILS: | Wgt. OF COILS: |
| # OF TIE-DOWNS: | GRADE OF CHAINS: |
| TYPE OF CARRIER: | EXPERIENCE OF DRIVER( YEARS OF CARRYING COILS ): |

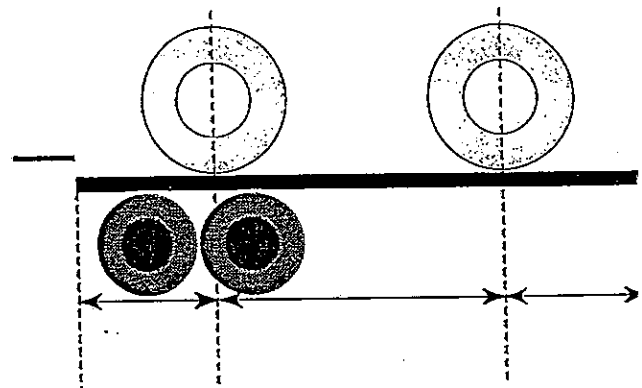
## PHOTO & COMMENTS:

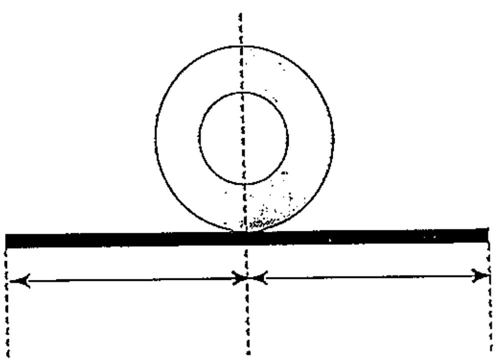
Southern Illinois University at Edwardsville

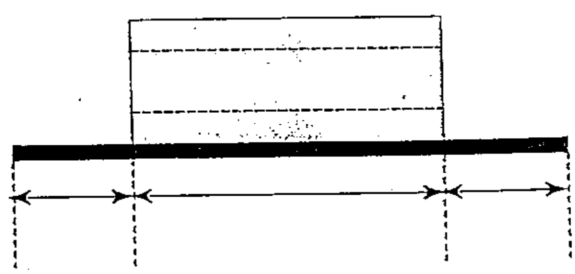
# TRUCK SURVEY(#          )

d = ______ D = ______ d = ______ D = ______ d = ______ D = ______ d = ______ D = ______





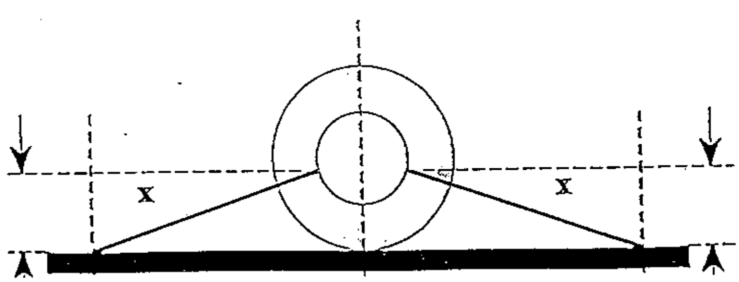


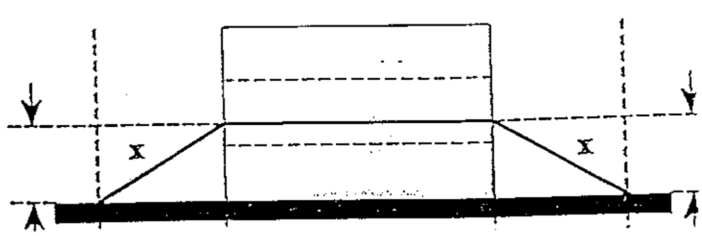


GRADE: ______

DIAMETER: ______

CHAIN LENGTH( x ) : ______



# APPENDIX B

# PEOTONE SCALES    I 57-SB

6/ 7/ 94

| TRUCK | ORIGIN | DESTINATION | No. of COILS | WEIGHT lb | SECUREMENT | TYPE of TRUCK | TYPE of CARRIER | EXPERIENCE years | GRADE OF THE CHAIN * FROM DRIVERS * |
|---|---|---|---|---|---|---|---|---|---|
| A-1 | Chicago Hts., IL | Gerald, MO | 1 | 45430 | 4 chains | FO | C | 19 | 16500 lb |
| A-2 | Portage, IN | Searcy, ARK | 3 | 17600,17570,11730 | 4 Chains+3 Straps | FO | C | 15 | 8000 lb or 9000 lb |
| A-3 | Burns Harbur, IN | Granite City, IL | 1 | 30800 | 3 Chains | FO | C | 6 | 7/8 in. |
| A-4 | South Holland, IL | West Salem, IL | 11 | about 4000 ea | - | - | C | 25 | No Chains |
| A-5 | Burns Harbor, IN | Searcy, ARK | 3 | 2@13000,1@16000 | 2 Chains ea | FO | O/O | 6-7 | G-7 |
| A-6 | Portage, IN | Muskogee, OKHA | 2 | 19000,20000 | 4 Chains | FO | C | 2 | Do Not Know |
| A-7 | E. Chicago, IL | Milan, TENN | 1 | 35000 | 2 Chains | FO | O/O | 10 | Do Not Know |
| A-8 | E. Chicago, IL | Milan, TENN | 1 | 36000 | 2 Chains+2 Straps | FO | O/O | 17 | Do Not Know |
| A-9 | Portage, IN | St. Louis, MO | 2 | 16000,21000 | 2 Straps | FO | O/O | 8 | Do Not Know |
| A-10 | Burns Harbor, IN | Assumption, IL | 3 | about 15000 ea | 2 Chains ea | CW | C | 14 | Do Not Know |
| A-11 | Indiana Harbor, IN | Milan, IN | 1 | 39500 | 2 Chains | FO | O/O | 6 months | Do Not Know |
| A-12 | Burns Harbor, IN | Granite City, IL | 1 | 32400 | 3 Chains over | FO | O/O | 25 | 4 or 6 |
| A-13 | Desdlains, IL | Stuttgart, ARK | 2 | 10000,11000 | 2 Chains ea | FO | O/O | 20 | Do Not Know |
| A-14 | Chicago, IL | Fairbury, IL | 3 | 13160,13600,14700 | 2 Chains ea | CW | C | 25 | Do Not Know |
| A-15 | Libertyville, IL | Memphis, TENN | 3 | 2@12000,1@13000 | 2 Chains ea | FO | C | 3 | 10-12000 lb |
| A-16 | Chicago, IL | Kansas City, KS | 8 pairs | 2@6500,6@4500 | 2 Chains thru+Straps | FO | C | 5-6 | - |
| A-17 | E. Chicago, IL | Sedalia, MO | 2 | 18000,22000 | 2 Chains ea-Over Top | FO | C | 8 | 10000 lb |
| A-18 | Chicago, IL | Houston, TX | 31 Boxes | 18500,20300 | Banded to Skids | CW | C | 10 | - |
| A-19 | Bride View, IL | Little Rock, ARK | 17 | 10185 | Straps Over - Eyes Up | FO | C | 13 | 10000 lb |
| A-20 | ? , IN | Fairbury, IL | 5 | ? | NONE - Eyes Up | CW | C | 2 | - |
| A-21 | E. Chicago, IL | Kansas City, MO | 3 | about 13000 ea | 2 Chains | CW | C | 10 | 3/8 in. |
| A-22 | Gary, IN | Rt. 24, IL | 5 | 43500 | Straps | FO | C | 6 months | - |
| A-23 | Chicago Hts., IL | Dublin, GA | 9 pallets | 44000 | Chains+Straps - Eyes Up | FO | O/O | 1 | Peerless 5/16 |
| A-24 | Chicago, IL | Cosacanna, TX | 12 pallets | 46000 | Chains+Straps - Eyes Up | FO | O/O | 5 | Peerless 5/16 |

# PEOTONE SCALES I 57-SB

6/ 8/ 94

| TRUCK | ORIGIN | DESTINATION | No. of COILS | WEIGHT lb | SECUREMENT | TYPE of TRUCK | TYPE of CARRIER | EXPERIENCE years | GRADE OF THE CHAIN * FROM DRIVERS * |
|---|---|---|---|---|---|---|---|---|---|
| B-1 | Homewood, IL | Tuepolo, MO | 2 | 21100,21720 | 2 Chains ea | FO | C | First Load | Do Not Know |
| B-2 | E. Chicago, IN | Milan, TENN | 1 | 29000 | 1 chain Over+2 Chains thru | CW | O/O | 1 | Do Not Know |
| B-3 | E. Chicago, IN | Houston, TX | 3 | 12000 ea | 2 Chains ea | FO | C | 5 | Do Not Know |
| B-4 | Gary, IN | Sedalia, MO | 2 | 17000,19000 | 2 Chains+Straps | FO | C | 10-12 | R70 |
| B-5 | Sak Trail, IL | St. Louis, MO | 2 | 16000,17000 | 1 Chain ea | CW | O/O | 1 | Do Not Know |
| B-6 | Portage, IN | Oklahoma City, OK | 3 | 13000 ea | 2 Chains on 1+2 Chains On 2 | FO | O/O | 7-8 | Do Not Know |
| B-7 | Gary, IN | Assumption, IL | 2 | 18000,19000 | 2 Chains over 1+1 Chains over 1 | CW | C | 1 week | Do Not Know |
| B-8 | New Carlyle, IN | Winfield, KS | 4 | 10200,11600 | 2 Chains ea | FO | C | 2.5 | Grade 70 |
| B-9 | Gary, IN | Albion, IL | 4 | 10500 ea | on Pallets+ top Straps | FO | O/O | 12 | Grade 5/16 and Grade 7 |
| B-10 | Gary, IN | West Salem, IL | 4 | 10000 ea | on Pallets+ top Straps | FO | C | 22 | Hi-Tensile |
| B-11 | Univ. Park, IL | Benton, ARK | 3 | 10000,13000,15900 | 2 Chains ea | FO | O/O | First Load | High Test |
| B-12 | Portage, IN | Paris, TENN | 2 | 21000,22000 | 1 Strap+2 Chains ea | FO | C | 11 | Do Not Know |
| B-13 | Gary, IN | Memphis, TENN | 1 | 34000 | 4 Chains | FO | C | 5 | 10000 lb |
| B-14 | E. Chicago, IN | Gerald, MO | 2 | 20160,20310 | 2 Chains ea | FO | C | 6 | 10-12000 lb |
| B-15 | E. Chicago, IN | Springdale, ARK | 2 | 38840 | Eyes Up | FO | C | 6-7 | G7 |
| B-16 | Riverdale, IL | Fairbury, IL | 6 Pallets | 3385-7315 max. | 1 Chain /Pallet | CW | C | 2.5 | Do Not Know |
| B-17 | E. Chicago, IN | Tyler, TX | 5 | 9000 ea | 2 Chains ea | FO | C | 4 | about 10000 lb |
| B-18 | Gary, IN | Granite City, IL | 3 | 10000,12000,26000 | 2 Chains ea | FO | C | 7 | Do Not Know |
| B-19 | E. Chicago, IN | Assumption, IL | 1 large,4 sma | 4670,4780,4960,15320,19950 | 1 Chain over ea | FO | O/O | 5 | Do Not Know |
| B-20 | Gary, IN | Redbud, IL | 3 | 13740,14190,14380 | 2 Chains ea | FO | C | 1 | 8000 lb |
| B-21 | Chicago Hts, IL | Neosho, MO | 5 | 3960,9520,9870,10185,10200 | Straps | FO | C | 4 | - |
| B-22 | South Bond, IN | Memphis, TENN | 1 | 32000 | 3 Chains+1 Strap | FO | O/O | 4 | Top Grade |
| B-23 | Chicago, IL | Benton, ARK | 2 | 18000,27000 | 2 Chains thru+3 Chains over | FO | O/O | 13 | Do Not Know |
| B-24 | Chicago, IL | Benton, ARK | 2 | 20000 ea | 2 Chains thru+Straps over | FO | C | 10 | 3/8 in. |
| B-25 | Chester, IN | Searcy, ARK | 3 | 1@11000,2@14000 | 2 Chains on 1+2 Chains thru 2 | FO | C | 33 | Do Not Know |
| B-26 | Portage, IN | Muskogee, OKLA | 3 | 15000,17000,19000 | Strapped-Eyes Up | FO | O/O | 10 | Do Not Know |
| B-27 | Burns Harbor, IN | Granite City, IL | 1 | 44000 | 2 Chains over top | FO | O/O | 23 | Do Not Know (2nd stop) |

# *PEOTONE SCALES I 57-SB*

*6/ 9/ 94*

| TRUCK | ORIGIN | DESTINATION | No. of COILS | WEIGHT lb | SECUREMENT | TYPE of TRUCK | TYPE of CARRIER | EXPERIENCE years | GRADE OF THE CHAIN * FROM DRIVERS * |
|---|---|---|---|---|---|---|---|---|---|
| C-1 | E. Chicago, IN | Milan, TENN | 1 | 37000 | 2 Chains thu+2 Chains over | FO | C | 10-12 | Heavy |
| C-2 | Bridge View, IN | St. Louis, MO | 3 | 12663,12691,13731 | Strapped | CW | C | 3 | Do Not Know |
| C-3 | E. Chicago, IN | Milan, TENN | 1 | 37520 | 3 Chains | CW | O/O | 3 | Do Not Know |
| C-4 | E. Chicago, IN | Milan, TENN | 5 | 74000 ea | 1 Chain ea | CW | C | 1 | Do Not Know |
| C-5 | South Holland, IL | West Salem, IL | 11 Skids | 3000-4000 ea | NONE | CW | C | 15 | Only carries coils on skids. |
| C-6 | E. Chicago, IN | Milan, TENN | 2 | 17000,17960 | 2 Chains ea | CW | O/O | 2 | Do Not Know |
| C-7 | Riverdale, IL | Fairbury, IL | 5 | 8400 ea | 2 Chains | CW | C | 7 | Do Not Know |
| C-8 | Gary, IN | Granite City, IL | 1 | 38000 | 2 Chains thru + 1 over | CW | O/O | 14 | 3/8 in. |
| C-9 | Chicago, IL | Memphis, TENN | 2 | 19100,19200 | 4 Chains+2 Straps ea | FO | C | 8.5 | Do Not Know |
| C-10 | E. Chicago, IN | Granite City, IL | 1 | 37337 | 4 Chains | FO | O/O | 4 | - |
| C-11 | Chicago, IL | Memphis, TENN | 2 | 19600,19840 | 2 Chains over ea | FO | O/O | 5 | Do Not Know |
| C-12 | Kentucky | Carol Stream, IL | 1 | 34000 | 4 Chains | CW | O/O | 40 | Do Not Know |
| C-13 | Portage, IN | Granite City, IL | 2 | 19600,27300 | 1 Strap ea | FO | O/O | 15 | 47 |
| C-14 | E. Chicago, IN | Milan, TENN | 1 | 38000 | 2 Chains+2 Straps | FO | C | 8 | 5/16 in. |
| C-15 | Chicago Hts., IL | Conway, ARK | 5 | 7110,7915,8600,10010,10175 | 2 Chains ea | FO | C | 6 months | G-7 |
| C-16 | Chicago Hts., IL | Schulenburg, TX | 3 | 9350,16550,20340 | 2 Chains | FO | O/O | 3 | Do Not Know |
| C-17 | Indiana Harbor, IN | Memphis, TENN | 2 | 18500,20600 | 1 Chain over ea | FO | O/O | First Load | 10000 lb |
| C-18 | Burns Harbor, IN | Fenton, MO | 2 | 21000 ea | 3 Chains over top | FO | O/O | 25 | Do Not Know |
| C-19 | Gary, IN | Kansas City, MO | 2 | 15000,19250 | 2 Chains + 1 Strap ea | FO | C | 6 months | Do Not Know |
| C-20 | Burns Harbor, IN | Memphis, TENN | 1 | 24650 | 4 Straps | FO | O/O | 4 | 7000 lb - Straps |
| C-21 | Indiana Harbor, IN | Milan, TENN | 1 | 38040 | 2 Chains thru + 2 Chains over | FO | - | 3-4 | G-70 |

# APPENDIX C

# TRUCK SURVEY( 6/ 7/ 1994 )

| # TRUCK | TRUCK TYPE | EYE ORIENTATION | # COILS | Wgt.(lb) COILS | CHAINS: # OVER TOP | CHAINS: # THROUGH EYE | CHAINS: GRADE | CHAINS: DIA(in) | STRAPS: # USED | STRAPS: WID.(in) | STRAPS: WLL(lb) | TIE-DOWN: TOTAL FOUND | TIE-DOWN: VIOLATION | BLOCKING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-1 | OPEN | CROSSWISE | 1 | 45,430 | 0 | 3 | *G-3 | 3/8 | 0 | NONE | 0 | 4 | YES | YES |
| | | | | | | 1 | C | 3/8 | | | | | | |
| A-2 | OPEN | LONGWISE | 3 | 17,000 | 0 | 2 | G-70 | 5/16 | 1 | 4 | 12,000 | 3 | NO | YES |
| | | | | 11,000 | 0 | 2 | G-70 | 5/16 | 1 | 4 | 12,000 | 3 | NO | YES |
| | | | | 17,000 | 0 | 2 | G-70 | 5/16 | 1 | 4 | 12,000 | 3 | NO | YES |
| A-3 | OPEN | LONGWISE | 1 | 30,800 | 3 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 3 | NO | YES |
| A-4 | COVERED | UPAWARD | 11 | 4,000( each ) | 0 | 0 | NONE | 0 | 0 | NONE | 0 | 0 | NO | PALLETS |
| A-5 | OPEN | LONGWISE | 3 | 13,000 | 0 | 2 | G-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 13,000 | 0 | 2 | G-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 16,000 | 0 | 2 | G-70 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| A-6 | OPEN | UPWARD | 2 | 19,000 | 1 | 1( SIDE ) | G-70 | 5/16 | 0 | NONE | 0 | 2 | NO | PALLETS |
| | | | | 20,000 | 1 | 1( SIDE ) | G-70 | 5/16 | 0 | NONE | 0 | 2 | NO | PALLETS |
| A-7 | OPEN | LONGWISE | 1 | 35,000 | 2 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 2 | YES | YES |
| A-8 | OPEN | LONGWISE | 1 | 36,000 | 0 | 2 | *G-3 | 5/16 | 2 | 4 | 24,000 | 4 | YES | YES |
| A-9 | OPEN | LONGWISE | 2 | 16,000 | 0 | 0 | NONE | 0 | 2 | ( 2 ) 3-3/4 | 24,000 | 2 | NO | YES |
| | | | | 21,000 | 0 | 0 | NONE | 0 | 2 | ( 2 ) 3-3/4 | 24,000 | 2 | YES | YES |
| A-10 | COVERED | LONGWISE | 3 | 15,000( each ) | 2 | 0 | *G-3 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| A-11 | OPEN | LONGWISE | 1 | 39,500 | 0 | 2 | G-43 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| A-12 | OPEN | LONGWISE | 1 | 32,400 | 3 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 3 | NO | YES |
| A-13 | OPEN | CROSSWISE | 2 | 10,000 | 0 | 2 | *G-3 | 5/16&3/8 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 11,000 | 0 | 2 | *G-3 | 5/16&3/8 | 0 | NONE | 0 | 2 | NO | YES |
| A-14 | COVERED | LONGWISE | 3 | 14,700 | 0 | 2 | A | 3/8 | 0 | NONE | 0 | 2 | ? | YES |
| | | | | 13,600 | 0 | 2 | G-28 | 3/8 | 0 | NONE | 0 | 2 | ? | YES |
| | | | | 13,600 | 0 | 2 | G-28 | 3/8 | 0 | NONE | 0 | 2 | ? | YES |
| A-15 | OPEN | CROSSWISE | 3 | 12,000 | 0 | 2 | G-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 12,000 | 0 | 2 | G-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 13,000 | 0 | 2 | G-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| A-16 | OPEN | LONGWISE | 8 | 6,500( 2 coils ) | 0 | 2 | *G-3 | 5/16&3/8 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 4,500( 6 coils ) | 0 | 2 | *G-3 | 5/16&3/8 | 6 | 2 | 36,000 | 8 | NO | YES |
| A-17 | OPEN | LONGWISE | 2 | 18,000 | 2 | 0 | G-70 | 0.35&5/16 | 1 | 2 | 6,000 | 3 | NO | YES |
| | | | | 22,000 | 2 | 0 | G-70 | 0.35&5/16 | 1 | 2 | 6,000 | 3 | NO | YES |

NOTICE: *G-3 indicates the unmarked chains.

| # TRUCK | TRUCK TYPE | EYE ORIENTATION | # COILS | Wgt.(lb) COILS | CHAINS | | | | STRAPS | | | TIE-DOWN | | BLOCKING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | # OVER TOP | # THROUGH EYE | GRADE | DIA(in) | # USED | WID.(in) | WLL(lb) | TOTAL FOUND | VIOLATION | |
| A-18 | COVERED | UPWARD | 31 | 15-18,500 & | 0 | 0 | NONE | 0 | 0 | NONE | 0 | 0 | YES | PALLETS |
| | | | | 16-20,300 | 0 | 0 | NONE | 0 | 0 | NONE | 0 | 0 | YES | PALLETS |
| A-19 | OPEN | UPWARD | 7 | 10,185( each ) | 0 | 2 | G-70 | 5/16 | 1 | 4 | 12,000 | 9 | NO | PALLETS |
| A-20 | COVERED | UPWARD | 5 | NO DATA | 0 | 0 | NONE | 0 | 0 | NONE | 0 | 0 | ? | PALLETS |
| A-21 | COVERED | LONGWISE | 3 | 13,000( each ) | 0 | 2 | *G-3 | 3/8 | 0 | NONE | 0 | 2 | NO | YES |
| A-22 | OPEN | UPWARD | 5 | 43,500( total ) | 0 | 0 | NONE | O | 5 | 4 | 60,000 | 5 | YES | PALLETS |
| A-23 | OPEN | UPWARD | 9 | 44,000( total ) | 0 | 2 | G-70 | 5/16 | 7 | 4 | 84,000 | 9 | NO | PALLETS |
| A-24 | OPEN | UPWARD | 12 | 46,000( total ) | 0 | 0 | NONE | 0 | 12 | 4 | 144,000 | 12 | NO | PALLETS |

NOTICE: *G-3 indicates the unmarked chains.

# TRUCK SURVEY( 6/ 8/ 1994 )

| # TRUCK | TRUCK | EYE POSITION | # COILS | Wgt.(lb) COILS | CHAIN # OVER TOP | CHAIN # THROUGH EYE | CHAIN GRADE | CHAIN DIA(in) | STRAP # USED | STRAP WID.(in) | STRAP WLL(lb) | TIE-DOWN TOTAL FOUND | TIE-DOWN VIOLATION | BLOCKING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-1 | OPEN | CROSSWISE | 2 | 21,720 | 0 | 4 | G-7 | 5/16 | 1 | ( 1 ) 4 | 12,000 | 5 | NO | YES |
| | | | | 21,100 | | 4 | G-7 | 5/16 | 1 | ( 1 ) 4 | 12,000 | 5 | NO | YES |
| B-2 | COVERED | LONGWISE | 1 | 29,000 | 1 | 2 | G-43 | 3/8 | 0 | NONE | 0 | 3 | NO | YES |
| B-3 | OPEN | CROSSWISE | 3 | 12,000( each ) | 0 | 2 | G-7 | 5/16 | 1 | 4 | 12,000 | 3 | NO | YES |
| B-4 | OPEN | LONGWISE | 2 | 17,000 | 0 | 2(through both | G-70 | 5/16 | 1 | 4 | 12,000 | 2 | NO | YES |
| | | | | 19,000 | 0 | of the coils) | G-70 | 5/16 | 1 | 4 | 12,000 | 2 | NO | YES |
| B-5 | COVERED | LONGWISE | 2 | 16,000 | 1 | 0 | C-7 | 5/16 | 0 | NONE | 0 | 1 | YES | YES |
| | | | | 17,000 | 1 | 0 | C-7 | 5/16 | 0 | NONE | 0 | 1 | YES | |
| B-6 | OPEN | LONGWISE | 3 | 13,000(2 coils) | 0 | 1(through both) | G70&L7 | 5/16 | 0 | NONE | 0 | 2-1/2(each) | NO | YES |
| | | | | | | + 2(on each) | & P7 | 5/16 | | | | | | |
| | | | | 13,000 | 0 | 2 | *G-3 | NO DAT. | 0 | NONE | 0 | 2 | ? | |
| B-7 | COVERED | LONGWISE | 2 | 18,000 | 1 | 0 | *G-3 | 3/8 | 0 | NONE | 0 | 1 | YES | YES |
| | | | | 19,000 | 2 | 0 | *G-3 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| B-8 | OPEN | CROSSWISE | 4 | 10,200(2 coils) | 0 | 2 | C-70 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 11,200(2coils) | 0 | 2 | C-70 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| B-9 | OPEN | UPWARD | 4 | 10,500( each ) | 0 | 0 | NONE | 0 | 1 | 4 | 12,000 | 1 | YES | PALLETS |
| B-10 | OPEN | UPWARD | 4 | 10,000( each ) | 0 | 0 | NONE | 0 | 1 | 4 | 12,000 | 1 | YES | PALLETS |
| B-11 | OPEN | LONGWISE | 3 | 13,000 | 0 | 2 | T-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 15,900 | 0 | 2 | T-7 | 5/16 | 0 | NONE | 0 | 2 | NO | |
| | | | | 16,000 | NO DAT. | NO DAT. | NO DAT. | NO DAT. | NO DAT. | NO DAT. | NO DAT. | ? | ? | YES |
| B-12 | OPEN | LONGWISE | 2 | 21,000 | 0 | 2 | L-4 | 3/8 | 1 | 4 | ,12000 | 3 | NO | YES |
| | | | | 22,000 | 0 | 2 | L-4 | 3/8 | 1 | 4 | ,12000 | 3 | NO | |
| B-13 | OPEN | CROSSWISE | 1 | 34,000 | 0 | 3 | G-4 | 3/8 | 0 | NONE | 0 | 4 | NO | YES |
| | | | | | | 1 | G-70 | 5/16 | | | | | | |
| B-14 | OPEN | CROSSWISE | 2 | 20,160 | 0 | 1 | G-7 | 5/16 | 0 | NONE | 0 | 2 | YES | YES |
| | | | | | 0 | 1 | G-3 | 5/16 | | | | | | |
| | | | | 20,130 | 0 | 1 | G-7 | 5/16 | 0 | NONE | 0 | 2 | YES | |
| | | | | | 0 | 1 | G-3 | 5/16 | | | | | | |
| B-15 | OPEN | UPWARD | 2 | 38,840(TOTAL) | 0 | 1 + | G-70 | 5/16 | 0 | NONE | 0 | 1-1/2(each) | YES | PALLETS |
| | | | | | | 1(through both) | | 5/16 | | | | | | |
| B-16 | COVERED | UPWARD | 6 | 7,315-3,385 | 1(each) one coil with no securement | 0 | G-70 | 5/16 | 0 | NONE | 0 | 5 | YES | PALLETS |

NOTICE: *G-3 indicates the unmarked chains.

| # | | EYE | # | Wgt.(lb) | CHAIN | | | | STRAP | | | TIE-DOWN | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TRUCK | TRUCK | POSITION | COILS | COILS | # OVER TOP | # THROUGH EYE | GRADE | DIA(in) | # USED | WID.(in) | WLL(lb) | TOTAL FOUND | VIOLATION | BLOCKING |
| B-17 | OPEN | CROSSWISE | 5 | 9,000 | 0 | 1 | G-70 | 5/16 | 1 | 4 | 12,000 | 2 | NO | YES |
| | | | | 9,000 | 0 | 1 | G-70 | 5/16 | 0 | NONE | 0 | 1 | NO | YES |
| | | | | 9,000 | 0 | 1 | G-70 | 5/16 | 1 | 4 | 12,000 | 2 | NO | YES |
| | | | | 9,000 | 0 | 1 | *G-3 | 5/16 | 1 | 4 | 12,000 | 2 | NO | YES |
| | | | | 9,000 | 0 | 1 | G-70 | 5/16 | 1 | 4 | 12,000 | 2 | NO | YES |
| B-18 | OPEN | CROSSWISE | 3 | 10,000 | 0 | 2 | *G-3 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| | | | | 12,000 | 0 | 2 | *G-3 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| | | | | 26,000 | 0 | 2 | *G-3 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| B-19 | OPEN | LONGWISE | 5 | 19,950 | 2 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 15,320 | 1 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 1 | YES | YES |
| | | | | 4,960 | 1 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 1 | NO | YES |
| | | | | 4,780 | 1 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 1 | NO | YES |
| | | | | 4,670 | 1 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 1 | NO | YES |
| B-20 | OPEN | CROSSWISE | 3 | 42,300(TOTAL) | 0 | 2 | G-70 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| B-21 | OPEN | UPWARD | 1 | 3,960 | 0 | 0 | NONE | 0 | 2 | 4 | 12,000 | 2 | YES | YES |
| | | LONGWISE | 4 | 9,520 | 0 | 0 | NONE | 0 | 2 | 4 | 12,000 | 2 | YES | YES |
| | | | | 9,870 | 0 | 0 | NONE | 0 | 2 | 4 | 12,000 | 2 | YES | YES |
| | | | | 10,185 | 0 | 0 | NONE | 0 | 2 | 4 | 12,000 | 2 | YES | YES |
| | | | | 10,200 | 0 | 0 | NONE | 0 | 2 | 4 | 12,000 | 2 | YES | YES |
| B-22 | OPEN | CROSSWISE | 1 | 32,000 | 0 | 3 | G-70 | 5/16 | 1 | 4 | 12,000 | 4 | NO | YES |
| B-23 | OPEN | LONGWISE | 2 | 18,000 | 1 | 0 | *G-3 | NO DAT. | 1 | 1' 2" | 3,000 | 2 | ? | YES |
| | | | | 27,000 | 2 | 0 | *G-3 | 5/16&3/8 | 1 | 1' 2" | 3,000 | 3 | YES | YES |
| B-24 | OPEN | LONGWISE | 2 | 20,000( each ) | 0 | 2 | *G-3 | 5/16 | 1 | 4 | 12,000 | 3 | YES | YES |
| B-25 | OPEN | LONGWISE | 3 | 11,000 | 0 | 1 | *G-3 | 5/16 | 0 | NONE | 0 | 1 | YES | YES |
| | | | | 14,000 | 0 | 2 | G-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 14,000 | 0 | 1 | *G-3 | 5/16 | 1 | 4 | 12,000 | 2 | YES | YES |
| B-26 | OPEN | UPWARD | 3 | 15,000 | 0 | 0 | NONE | 0 | 1 | 4 | 12,000 | 1 | YES | PALLETS |
| | | | | 17,000 | 0 | 0 | NONE | 0 | 1 | 4 | 12,000 | 1 | YES | PALLETS |
| | | | | 19,000 | 0 | 1(in front) | *G-3 | 5/16 | 1 | 4 | 12,000 | 2 | YES | PALLETS |
| B-27 | OPEN | LONGWISE | 1 | 44,000 | 2 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 4 | YES | YES |
| | | | | | 0 | 2 | *G-3 | 5/16 | 0 | NONE | 0 | | | |

NOTICE: *G-3 indicates the unmarked chains.

# TRUCK SURVEY( 6/ 9/ 1994 )

| # TRUCK | TRUCK TYPE | EYE ORIENTATION | # COILS | Wgt.(lb) COILS | CHAINS # OVER TOP | CHAINS # THROUGH EYE | CHAINS GRADE | CHAINS DIA (in) | STRAPS # USED | STRAPS WID.(in) | STRAPS WLL(lb) | TIE-DOWN TOTAL FOUND | TIE-DOWN VIOLATION | BLOCKING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C-1 | OPEN | LONGWISE | 1 | 37,000 | 1 | 2 | G-70 | 5/16 | 0 | NONE | 0 | 4 | NO | YES |
| | | | | | 0 | 1 | *G-3 | 5/16 | 0 | NONE | 0 | | | |
| C-2 | COVERED | UPWARD | 3 | 12,663 | 1 | 0 | G-70 | 5/16 | 1 | 4 | 12,000 | 1 | YES | PALLETS |
| | | | | 12,691 | 1 | 0 | C-3 | 3/8 | 2 | 4 | 24,000 | 1 | YES | PALLETS |
| | | | | 13,731 | 1 | 0 | C-3 | 3/8 | 2 | 4 | 24,000 | 1 | YES | PALLETS |
| C-3 | COVERED | LONGWISE | 1 | 37,520 | 0 | 1 | L3 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| | | | | | 0 | 1 | L4 | 3/8 | | | | | | |
| C-4 | COVERED | UPWARD | 5 | 7,400( each ) | 1 | 0 | G-70 | 5/16 | 0 | NONE | 0 | 1 | YES | PALLETS |
| C-5 | COVERED | UPWARED | 11 | 3,000-4,000 | 0 | 0 | NONE | 0 | 0 | NONE | 0 | 0 | NO | PALLETS |
| C-6 | COVERED | LONGWISE | 2 | 17,000 | 0 | 2 | G-70 | 5/16 | 0 | NONE | 0 | 2 | YES | YES |
| | | | | 17,960 | 0 | 1 | *G-3 | 5/16 | 0 | NONE | 0 | 2 | YES | YES |
| | | | | | 0 | 1 | HT | 5/16 | 0 | NONE | 0 | | | |
| C-7 | COVERED | LONGWISE | 5 | 8,400( each ) | 0 | 2 | G-70 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| C-8 | COVERED | LONGWISE | 2 | 38,000 | 0 | 2 | *G-3 | 3/8 | 0 | NONE | 0 | 3 | YES | YES |
| | | | | | 1 | 0 | T-4 | 3/8 | 0 | NONE | 0 | | | |
| C-9 | OPEN | LONGWISE | 2 | 19,100 | 0 | 2 | G-70 | 5/16 | 2 | 4 | 24,000 | 4 | NO | YES |
| | | | | 19,200 | 0 | 2 | G-70 | 5/16 | 2 | 4 | 24,000 | 4 | NO | YES |
| C-10 | OPEN | CROSSWISE | 1 | 37,337 | 0 | 4 | G-70 | 5/16 | 0 | NONE | 0 | 4 | NO | YES |
| C-11 | OPEN | LONGWISE | 2 | 19,600 | 2 | 0 | *G-3 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| | | | | 19,840 | 2 | 0 | L4 | 3/8 | 0 | NONE | 0 | 2 | YES | YES |
| C-12 | COVERED | LONGWISE | 1 | 34,000 | 4 | 0 | *G-3 | NO DATA | 0 | NONE | 0 | 4 | YES | YES |
| C-13 | OPEN | LONGWISE | 2 | 19,600 | 0 | 0 | NONE | 0 | 1 | 4 | 12,000 | 1 | YES | YES |
| | | | | 27,300 | 0 | 0 | NONE | 0 | 1 | 4 | 12,000 | 1 | YES | YES |
| C-14 | OPEN | LONGWISE | 1 | 38,000 | 0 | 2 | G-70 | 5/16 | 2 | 4 | 24,000 | 4 | NO | YES |

NOTICE: *G-3 indicates the unmarked chains.

| # TRUCK | TRUCK TYPE | EYE ORIENTATION | # COILS | Wgt.(lb) COILS | CHAINS # OVER TOP | CHAINS # THROUGH EYE | CHAINS GRADE | CHAINS DIA (in) | STRAPS # USED | STRAPS WID.(in) | STRAPS WLL(lb) | TIE-DOWN TOTAL FOUND | TIE-DOWN VIOLATION | BLOCKING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C-15 | OPEN | CROSSWISE | 5 | 7,110 | 0 | 2 | G-7 | NO DATA | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 7,915 | 0 | 2 | G-7 | NO DATA | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 8,600 | 0 | 1 | G-7 | NO DATA | 0 | NONE | 0 | 1 | NO | YES |
| | | | | 10,010 | 0 | 2 | *G-3 | NO DATA | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 10,175 | 0 | 2 | *G-3 | NO DATA | 0 | NONE | 0 | 2 | NO | YES |
| C-16 | OPEN | CROSSWISE | 3 | 9,350 | 0 | 2 | G-4 | 3/8 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 16,550 | 0 | 2 | G-4 | 3/8 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | 20,340 | 0 | 1 | C-7 | 5/16 | 0 | NONE | 0 | 2 | NO | YES |
| | | | | | 0 | 1 | *G-3 | 5/16 | | | | | | |
| C-17 | OPEN | LONGWISE | 2 | 18,500 | 1 | 0 | P-8 | 3/8 | 1 | 4 | 12,000 | 2 | NO | YES |
| | | | | 20,600 | 1 | 0 | P-8 | 3/8 | 1 | 4 | 12,000 | 2 | NO | YES |
| C-18 | OPEN | LONGWISE | 2 | 21,000 | 1 | 0 | G-4 | 5/16 | 0 | NONE | 0 | 3 | NO | YES |
| | | | | | 1 | 0 | G-43 | 5/16 | 0 | NONE | 0 | | | |
| | | | | | 1 | 0 | *G-3 | 5/16 | 0 | NONE | 0 | | | |
| | | | | 21,000 | 0 | 2 | G-70 | 1/4 | 0 | NONE | 0 | 3 | NO | YES |
| | | | | | 0 | 1 | *G-3 | 5/16 | 0 | NONE | 0 | | | |
| C-19 | OPEN | CROSSWISE | 2 | 15,000 | 1 | 0 | C-4 | 3/8 | 2 | 4 | 24,000 | 4 | NO | YES |
| | | | | | 1 | 0 | G-7 | 5/16 | | | | | | |
| | | | | 19,250 | 1 | 0 | C-4 | 3/8 | 2 | 4 | 24,000 | 4 | NO | YES |
| | | | | | 1 | 0 | G-7 | 5/16 | | | | | | |
| C-20 | OPEN | LONGWISE | 1 | 24,650 | 0 | 0 | NONE | 0 | 4 | 4 | 48,000 | 4 | NO | YES |
| C-21 | OPEN | LONGWISE | 1 | 38,040 | 2 | 2 | G-7 | 5/16 | 0 | NONE | 0 | 4 | NO | YES |

NOTICE: *G-3 indicates the unmarked chains.

# APPENDIX D

## ITRC/IDOT Metal Coil Securement Project

Illinois State Police Survey

This survey is being conducted by the Illinois Department of Transportation and Southern Illinois University at Edwardsville as part of a study to investigate metal coil securement during truck transport. Please answer the following questions regarding metal coil transport in Illinois.

1. Are you aware of any of the following problems with metal coil securement occurring in Illinois (check all that apply)?
   _____ Actual securement failures (broken binders, chains, etc.)
   _____ Inadequate securement (insufficient number of tie-downs, inadequate blocking, etc.)
   _____ Accidents resulting *from* securement failures
   _____ Accidents resulting *in* securement failures

2. Name the cargo securement regulation applicable in Illinois ________________________.

3. Have you had any experience in enforcing securement regulations? _____ yes _____ no
   If yes, are they difficult to enforce? _____ yes _____ no

4. Have you had specific training for (check all that apply):
   _____ understanding cargo securement regulations
   _____ enforcing cargo securement regulations
   _____ understanding metal coil securement regulations
   _____ enforcing metal coil securement regulations

5. In the past 12 months approximately how many coil inspections have you performed (check one)?
   _____ 0
   _____ 1-3
   _____ 4-10
   _____ 10+

6. In the past 12 months, approximately how many citations have you issued based on inadequate securement as a result of the inspections?
   _____ 0
   _____ 1-3
   _____ 4-10
   _____ 10+

7. Do you feel the currently used securement procedures are adequate? _____ yes _____ no
   If no, what modifications would you suggest? Use the space below.

# APPENDIX E

Used in MatLab simulation model. Refer to section 5.1.2 for model details and assumptions. Coordinates as shown in Figure 5.1-2. All the equations developed for relative motion of the coil on the platform.

Note: I, J, K are unit vectors in the gobal x, y, and z directions

Chain (tie-down) forces determined based on pre-load and motion of the coil center

$$F_{chain_i} = F_{Preload} + K*\left(\left(\vec{\delta} + (\vec{\theta} \times \vec{R})\right) \cdot \vec{e}_i\right)$$

$$M_{chain_i} = \vec{O}_i \times \vec{F}_{chain_i}$$

where $\bar{\delta}$ is the vector of the coil center displacements, $\bar{\theta}$ is the vector of the coil angular rotations, $\bar{R}$ is the vector from the coil contact point and the coil center, $\bar{O}_i$ is the vector from the coil center to the start of the chain at the coil eye, and $\bar{e}_i$ is the unit vector of the chain.

The individual chain forces are summed vectorally (if positive - zeroed if go slack). The total chain moment is also summed vectorally. These results, $F_{chain}$ and $M_{chain}$, are used in the following equations of motion.

Vertical Direction - Y

For the coil in contact with the platform ($\ddot{y} = 0$)

$$m\ddot{y}_b = F_n + \vec{F}_{chain} \cdot \vec{J} - mg$$

Else if the contact with the platform is lost ($F_n = 0$)

$$m(\ddot{y} + \ddot{y}_b) = \vec{F}_{chain} \cdot \vec{J} - mg$$

Rolling Direction - Fore-Aft - X

When coil is rolling without sliding ( $\ddot{x} + D/2\, \ddot{\theta}_z = 0$ - kinematic constraint)

$$m\left(\ddot{x} + \ddot{x}_b - \frac{D}{2}\ddot{\theta}_{zb}\right) = F_{fx} + \vec{F}_{chain} \cdot \vec{I}$$

$$J_{zz}(\ddot{\theta}_z + \ddot{\theta}_{zb}) = \frac{D}{2}F_{fx} + \vec{M}_{chain} \cdot \vec{K}$$

Check if the coil slips: $F_{fx} \geq \mu_s F_n$ ; if this condition exits, modify equations for slipping.

Lateral Direction - Left-Right - Z

No relative motion - No Tipping of Slipping; ( $z^{\cdot\cdot} = 0$ and $\theta^{\cdot\cdot}_x = 0$)

$$m(\ddot{z}_b + \frac{D}{2}\ddot{\theta}_{xb}) = F_{fz} + \vec{F}_{chain}\cdot\vec{K}$$

$$J_{xx}\ddot{\theta}_{xb} = -\frac{D}{2}F_{fz} - aF_n + \vec{M}_{chain}\cdot\vec{I}$$

Slipping, but No Tipping ($\theta^{\cdot\cdot}_x = 0$; $|a| < L/2$; and $|F_{fz}| = \mu_d F_n$)

$$m(\ddot{z} + \ddot{z}_b + \frac{D}{2}\ddot{\theta}_{xb}) = -\mathrm{sgn}(\dot{z})\mu_d F_n + \vec{F}_{chain}\cdot\vec{K}$$

$$J_{xx}\ddot{\theta}_{xb} = \frac{D}{2}\mathrm{sgn}(\dot{z})\mu_d F_n - aF_n + \vec{M}_{chain}\cdot\vec{I}$$

Tipping, but No Slipping ( $|a| < L/2$; and $z^{\cdot\cdot} - D/2\ \theta^{\cdot\cdot}_x = 0$ - kinematic constraint)

$$m(\ddot{z} + \ddot{z}_b + \frac{D}{2}\ddot{\theta}_{xb}) = F_{fz} + \vec{F}_{chain}\cdot\vec{K}$$

$$J_{xx}(\ddot{\theta}_x + \ddot{\theta}_{xb}) = -\frac{D}{2}F_{fz} - \frac{L}{2}\mathrm{sgn}(\theta)F_n + \vec{M}_{chain}\cdot\vec{I}$$

General Motion - Both Tipping and Slipping ( $|a| < L/2$; and $|F_{fz}| = \mu_d F_n$)

$$m(\ddot{z} + \ddot{z}_b + \frac{D}{2}\ddot{\theta}_{xb}) = -\mathrm{sgn}(\dot{z})\mu_d F_n + \vec{F}_{chain}\cdot\vec{K}$$

$$J_{xx}(\ddot{\theta}_x + \ddot{\theta}_{xb}) = \frac{D}{2}\mathrm{sgn}(\dot{z})\mu_d F_n - \frac{L}{2}\mathrm{sgn}(\theta)F_n + \vec{M}_{chain}\cdot\vec{I}$$

# APPENDIX F

**REFERENCES**


ABAQUS (1994), Hibbitt, Karlsson, and Sorenson, Providence, RI.

Avallone, Eugene A., and Baumeister, Theodore (1978), *Mark's Standard Handbook for Mechanical Engineering,* 9th Edition, McGraw-Hill, NY.

Billing, J.R., Mercer, W.R.J, and Cann, W. (1993) "Revised National Standard on Load Security for Heavy Trucks" Transportation Technology and Energy Branch, Ontario Ministry of Transportation, Ontario, Canada.

Boresi, A.P., Schmidt, R. J., and Sidebottom, O.M. (1993) *Advanced Mechanics of Materials,* 5th Edition, John Wiley and Sons, Inc., NY.

CFR 393 (1988, 1994) "Parts and Accessories Necessary for Safe Operation," Federal Highway Adminsitration, Department of Transportation, Washington, DC.

Chai, Z. (1995), *Finite Element Analysis of Steel Coil Tie-Down Securement Systems,* Master's Thesis, Southern Illinois University at Edwardsville, Edwardsville, IL.

Commercial Vehicle Safety Alliance (1992) *Cargo Securement Tie-Down Guidelines.*

The Crosby Group, Inc. (1991) "Tie Down Calculator"

Culled, C. Anderson, R.L., and Wesson, L.E. (1978) "Effect of Cargo Shifting on Vehicle Handling," Dynamic Science, Inc. A Subsidiary of Talley Industries, Inc. Phoenix, Arizona.

Gillespie, T.D. (1987) "Engineering Analysis of Cargo Restraint on Commercial Highway Trucks," The University of Michigan Transportation Research Institute.

Illinois Department of Transportation (1991) "Commercial Vehicle Inspection Report," IDOT, Division of Traffic Safety, Springfield, Illinois.

Illinois Department of Transportation (1982) "Securement of Steel Coils and Other Objects on Flatbed Vehicle," Part 558, Illinois Department of Transportation Rules and Regulations, IDOT, Springfield, Illinois.

National Association of Chain Manufacturers (1990) "Welded Steel Chain Specifications." York, PA.

*NDS National Design Specification for Wood Constrution* (1991), National Forest Products Association, Washington, DC.

New York Department of Transportation (1993), "1993 Annual Report, Commercial Vehicle Safety Bureau," State of New York Department of Transportation, Albany, N.Y.

Oglesby, C.H. (1975) *Highway Engineering,* Stanford University.

Plumbridge, W.J. and Knee, N. (1987) "Effect of heat treatment on fatigue crack growth in chain steels," *Materials Science and Technology,* Vol. 3.

Sabnis, G.M., Harris, H.G., White, R.N., and Mirza, M.S. (1983) *Structural Modeling and Experimental Techniques,* Prentice-Hall, Inc., Englewood Cliffs, N. J.

Sava Industries, Inc. "Design Guide for Precision Miniature & Small Cables, Assemblies, Pulleys, Fittings," Riverdale, New Jersey.

Specialized Carriers and Rigging Association (1988) "Cargo Securement on Motor Vehicles: Steel," SCRA, Alexandria, Virginia.

Tipton, S.M. and Shoup, G.J. (1992) "The Effect of Proof Loading on the Fatigue Behavior of Open Link Chain"