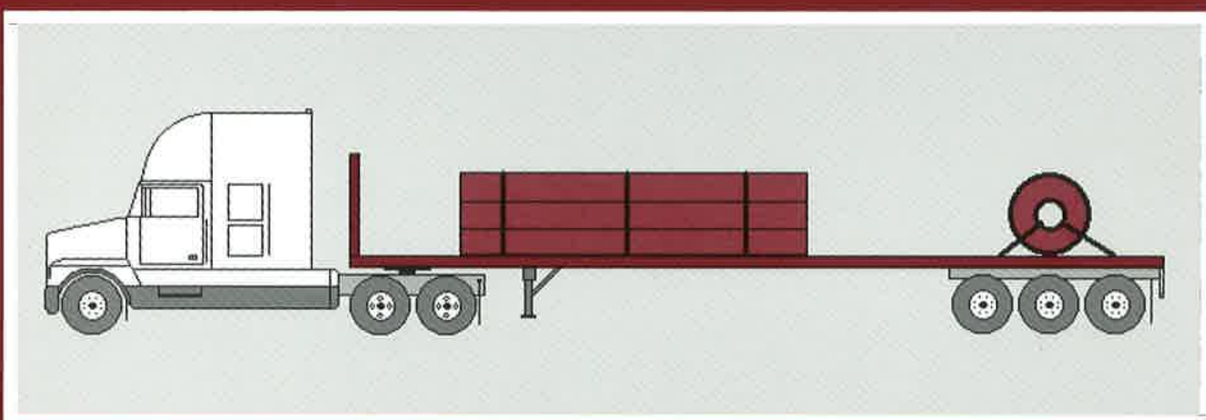
CCMTA Load Security Research Project

Report # 15

TESTS ON METHODS OF SECUREMENT FOR METAL COILS



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CANADIAN COUNCIL OF MOTOR TRANSPORT ADMINISTRATORS
CONSEIL CANADIEN DES ADMINISTRATEURS EN TRANSPORT MOTORISÉ

CCMTA Load Security Research Project

Report # 15

TESTS ON METHODS OF SECUREMENT FOR METAL COILS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

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North American Cargo Securement Standard

CCMTA is serving to coordinate the development of a revised North American Cargo Securement Standard. To this end the research results in this report are being reviewed and discussed by interested stakeholders throughout North America.

Those readers interested in participating in the development of the North American Cargo Securement Standard through 1997 are invited to visit the project Web site at www.ab.org/ccmta/ccmta.html to secure additional project information.

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Abstract

A series of full-scale tests were conducted to determine the individual and combined contributions of blocking, friction and tiedowns to securement of large metal coils, for eyes either longitudinal or lateral, and loads applied either longitudinally or laterally.

The tests found that unsecured blocking can pop out under extreme loads, whereas blocks placed in bunks to form a cradle provided reliable resistance that increased as the coil was placed more deeply in the well of the cradle. Resistance provided by tiedowns depended strongly on the orientation of the tiedown, but total resistance can be estimated well by combining the resistances available from the separate sources.

Recommendations are made regarding securement systems for large metal coils.

Executive Summary

A lack of understanding of the technical basis for existing regulations on cargo securement meant it was not possible to resolve differences between them to revise a cargo securement standard for Canada's National Safety Code. This process identified a number of research needs, which are now being addressed through the North American Load Security Research Project.

This preliminary work identified that there were significant concerns over methods of securement for large metal coils carried on flatbed trailers. The work reported here addresses these concerns through a series of full-scale static tests using three steel coils of different dimensions and weights. The tests were intended to determine the individual and combined contributions of blocking, friction and tiedowns to securement of large metal coils, for eyes either longitudinal or lateral, and loads applied either longitudinally or laterally, as outlined in Section 12 of the project proposal. The effects of oil, water and rubber compound materials at the interface between the coil and the blocking were also evaluated.

A force applied along the eye of the coil is described as a longitudinal pull, whereas a force transverse to the eye is described as a lateral pull. Coils in a longitudinal pull had a static coefficient of friction in the range 0.20-0.27, depending on the interface conditions. Friction was significantly increased by inserting rubber material between the coil and the blocks, though water or oil on the surface of this friction material drastically reduced the friction. The static friction coefficient for a longitudinal pull on a cradle formed from blocks placed in steel bunks on a dry deck was 0.34, and a rubber mat under the bunks increased this to 0.42, but oil reduced it by half. The rolling resistance of the coil was about 0.01. For a lateral pull, the static friction coefficient between the cradle and the dry deck was 0.31, and a rubber mat under the bunks increased this to 0.35. There was no improvement in resistance to a lateral pull by inserting friction material between the coil and the blocks.

Blocking provides resistance to a lateral pull as the coil must rise over the block, and the resistance depended on the block size, shape and spacing, and increased as the coil sat deeper in the well created by the blocking. Unsecured blocking always either was pushed along by the coil or popped out, allowing the coil to crash on the deck. Blocking secured by bunks to form a cradle always remained in place, and provided a resistance equivalent to an external acceleration in the range 0.30 to 0.80 g.

The resistance of a chain tiedown depended on the angle of the tiedown to the horizontal, for both lateral and longitudinal pulls. For example, for a lateral pull, a 90 deg (vertical) tiedown allowed large coil motions before it developed significant resistance when used alone, or added very little to securement when used in combination with chains at more effective angles. For a symmetric tiedown arrangement, with chains at equal and opposite tiedown angles, an initial tension higher than 20% of the chain working load limit resulted in significantly lower resistance

available before the chain reached its working load limit.

The resistance generated by combining a cradle and chain tiedowns could be computed fairly accurately as the sum of the resistances from each of these components. For an unsecured cradle with chain tiedown, the total lateral resistance is the sum of the chain resistance and the lesser of the blocking resistance and friction resistance between the cradle and deck interface, whereas the total longitudinal resistance is the sum of the chain resistance and the lesser of the friction resistance at the coil/block interface and the cradle/deck interface.

Webbing provides significantly less resistance to longitudinal and lateral pulls than chain tiedowns, and nailed wood blocking and cleats were not an effective way to restrain either blocking or the coil.

It is recommended that large a metal coil should only be transported on a cradle, that the cradle should preferably be immobilized, and the coil should also be immobilized so that it cannot slide along the blocks. Any desired level of lateral and longitudinal resistance can be delivered by making appropriate use of cradle dimensions, friction and chain tiedowns. It is expected that placing the cradle so that the coil has its eye laterally on the vehicle should, in general, provide the most reliable securement.

This report presents technical results from just one task in this project. The results may be limited by the scope of this task, but are placed in context in the summary report.

Acknowledgments

The work reported here is part of the Load Security Research Project conducted on behalf of the Canadian Council of Motor Transport Administrators (CCMTA) by Strategic Transportation Research Branch of Ontario Ministry of Transportation (MTO). This section recognizes the direct contributions of those who organized and conducted this part of the work, and also recognizes that there have been many indirect contributions.

The project was funded jointly by the following :

- Alberta Transportation and Utilities;
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- British Columbia Ministry of Transportation and Highways;
- Canadian Trucking Research Institute;
- Commercial Vehicle Safety Alliance;
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- Manitoba Highways and Transportation;
- Ministère des Transports du Québec;
- New Brunswick Ministry of Transportation;
- Newfoundland Ministry of Transportation and Public Works;
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- Transport Canada, Transportation Development Centre; and
- United States Department of Transportation, Federal Highway Administration.

The project was conducted under the guidance of the Load Security Research Management Committee, formed by CCMTA, with one representative of each of the funding partners, and chaired by Mr. M. Schmidt of Federal Highway Administration, Albany, New York. Sean McAlister provided administrative support from CCMTA.

Walter Mercer designed the test rig, and CCMTA contracted CSI Aerospace of Rexdale for detail design and manufacture. Bob Easter, Stan Fassaert and Reg Lorraine of Stelco Inc of Hamilton, Ontario, provided invaluable advice, and arranged loan of the steel coils. These were delivered by W. J. Deans Transportation of Delson, Quebec.

Testing was conducted at Taylor Steel in Stoney Creek, Ontario, with the assistance of Mike Ford and staff, by Norm Carlton, Gary Giles, Walter Mercer, Bill Stephenson and Mike Wolkowicz of Strategic Vehicle Technology Office of MTO.

1/ Introduction

Heavy truck cargo securement is a matter of public safety, subject to a body of industry practice and government regulation. Regulations are broadly similar across North America's many jurisdictions, but there are also some significant differences. When the Canadian Council of Motor Transport Administrators (CCMTA) came to revise a cargo securement standard for Canada's National Safety Code, a lack of understanding of the technical basis for existing regulations made it impossible to resolve differences between them, and a number of research needs were identified. Ontario Ministry of Transportation prepared a draft proposal for this research that was widely circulated for review through governments and industry. The proposal was revised and became the work statement for the North American Load Security Research Project [1]. It has three objectives :

- To determine how parts of cargo securement systems contribute to the overall capacity of those systems;
- To demonstrate the adequacy of parts, and the overall capacity, of cargo securement systems; and
- To develop principles, based on sound engineering analysis, that could contribute to an international standard for cargo securement for heavy trucks.

The goal is to supplement existing practice with these research findings, and to develop uniform North America-wide standards for cargo securement and inspection.

The research proposal identified significant concerns with securement of metal coils on flatbed trailers. The work reported here addresses these concerns through a series of full-scale static tests to determine the individual and combined contributions of blocking, friction and tiedowns to securement of metal coils, for eyes either longitudinal or lateral, and loads applied either longitudinally or laterally, as outlined in Section 12 of the project proposal [1]. The effects of oil, water and rubber compound materials in the interface between the coil and the blocking were also evaluated.

2/ Test Program

2.1/ Objective

The shape and weight of large metal coils make them a particular challenge for cargo securement systems, as a coil with its eye horizontal has different resistance to motion along its two horizontal axes. The objective of this series of tests is to examine and understand the separate effects of friction, and common methods of blocking and tiedowns, for coils placed with the eye either transversely or longitudinally on a truck deck, and subject to a force equivalent either to a longitudinal (braking) or lateral (turning) acceleration, then to examine and understand the combined effect of all these components of a cargo securement system.

2.2/ Scope

This series of tests examined the separate contributions of friction, blocking and tiedowns to securement of large metal coils, and the combined effect of these components of the cargo securement system. Some tests used tiedowns that met or were close to meeting typical current securement requirements for the coil that was used for the test [2]. This was coincidental. The purpose was to gain insights into the mechanics of securement of large metal coils, not to evaluate these particular rules.

This series of tests covered the following :

1/ Friction, for a lateral pull, and rolling, for a longitudinal pull;
2/ Resistance of blocking to a lateral pull;
3/ Resistance of chain securement to a lateral pull;
4/ Resistance of chain securement to a longitudinal pull;
5/ Friction of cradle for a lateral pull;
6/ Resistance of coil in cradle with chains to lateral pull;
7/ Friction of coil in secured cradle for a longitudinal pull;
8/ Friction of unsecured cradle for a longitudinal pull;
9/ Resistance of coil in cradle with steep angle chains to longitudinal pull;
10/ Resistance of coil in cradle with shallow angle chains to longitudinal pull;
11/ Resistance of coil in cradle with tiedowns over the coil; and
12/ Resistance of nailed wood blocking cradle.

3/ Procedures

3.1/ Test Apparatus

The tests were conducted on the test rig shown in Figure 1. It was mounted on a lowbed trailer for transportation, and the trailer was parked on a concrete floor inside a building, supported on wooden blocks, so that the deck of the test rig was level and as rigid as possible. The deck was constructed of 5x15 cm (2x6 in) rough oak planks bolted to a steel sub-frame. The rig provided a flat bed, approximately 2.4 m (8 ft) square, on which the test coil was placed. Rails on all four sides provided attachment points for tiedowns at 0.15 m (6 in) spacings, as seen in Figure 2. The trailer deck and rail holes were marked to provide consistent placement of the test specimen and tiedowns. A hydraulic actuator with a stroke of about 0.76 m (30 in), a load capacity of about 222 kN (50,000 lb), and controlled to pull at a constant speed of about 3.81 mm/s (0.15 in/s) under load, provided the capacity to pull a large coil. The actuator was placed horizontally inside a rectangular steel casing mounted on a trolley that rolled vertically on a reaction frame at the rear of the test rig, as seen in Figure 3. This allowed a true horizontal pull for different size metal coils, and compensated for the change in coil elevation as it pivoted around the edge of fixed blocking. The actuator assembly was counter-balanced, for ease of handling, and to minimize the resistance

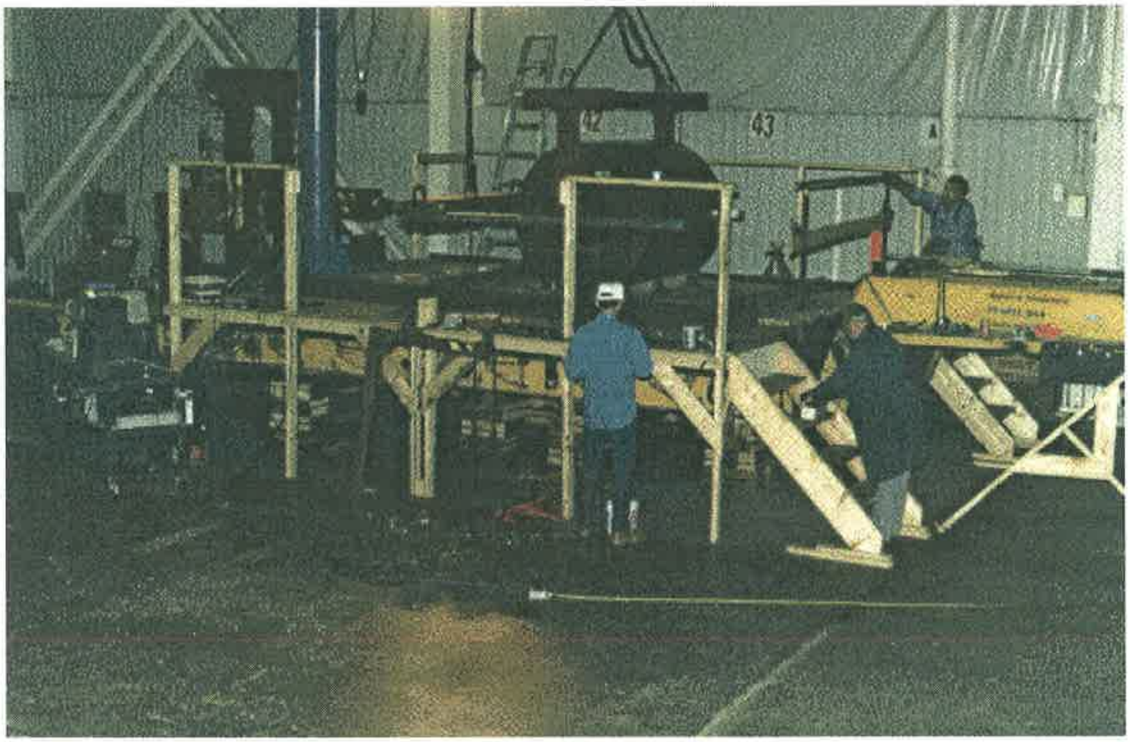


Figure 1/ General view of test rig

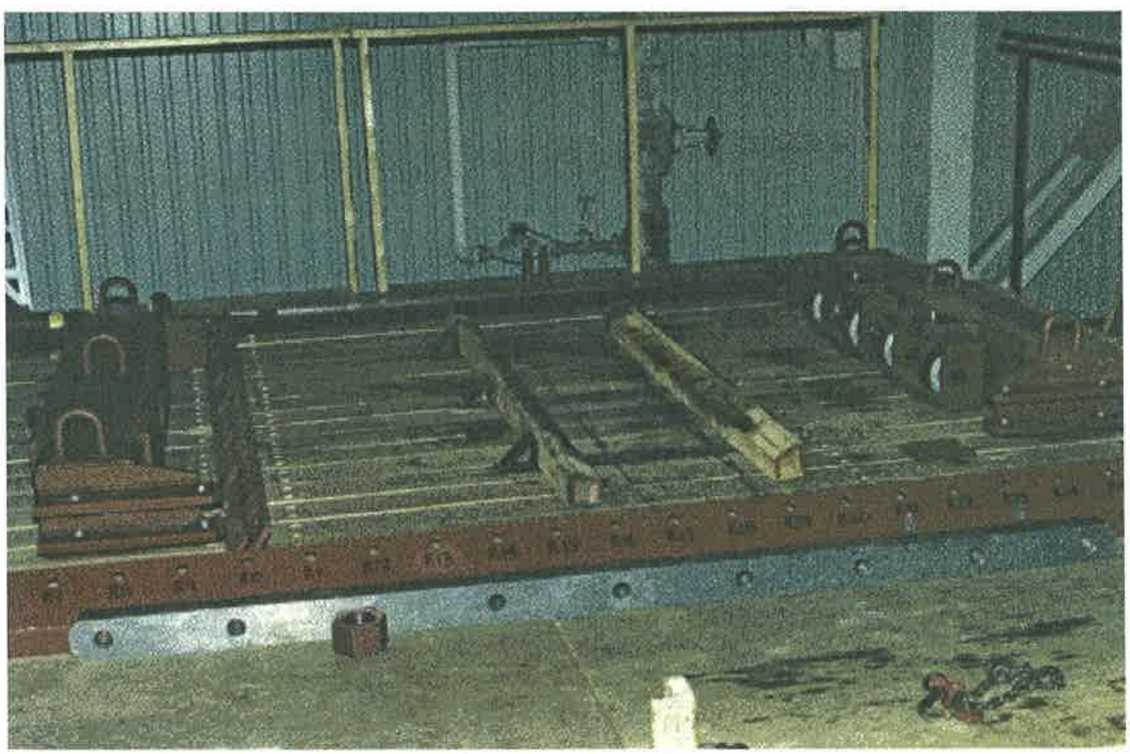


Figure 2/ Deck of test rig, showing side rails, cradle and crossmembers

to vertical motion during a pull. The actuator also pivoted on a vertical axis, so that there was no restriction to the coil slewing during a pull. The actuator head was fitted with a nut that took a 5.04 cm (2 in) threaded rod that served as a drawbar, also seen in Figure 3. The test rig was fitted with a jib boom with a rating of 1,361 kg (3,000 lb) for lifting and supporting test equipment of modest weight. The coils were placed in position using a high-capacity overhead crane installed at the test site.

Two pulling arrangements were used throughout the tests, referred to as longitudinal and lateral pulls. For a longitudinal pull, the eye of the coil was aligned with the hydraulic actuator, and for a lateral pull, the coil was placed with its eye at 90 deg, transversely across the test rig. A longitudinal pull corresponds to longitudinal acceleration, such as during braking, of a truck carrying a coil with its eye oriented longitudinally, and to lateral acceleration, such as during turning, of a truck carrying a coil with its eye lateral, the so-called "suicide" arrangement. A lateral pull corresponds to longitudinal acceleration of a truck carrying a coil with its eye lateral, or lateral acceleration of a truck carrying a coil with its eye longitudinal. Throughout this report, the terms "front" and "rear", "left" and "right", and "longitudinal" and "lateral" correspond to those directions for the trailer on which the test rig was mounted. Either type of pull actually moved the coil towards the rear.

Figure 4 shows the test rig set up for a longitudinal pull. The coil was placed in the middle of the deck, with its centre-line aligned with the hydraulic actuator. A long threaded drawbar was pushed through the eye of the coil, where it was supported by a semi-circular wooden former, and the other end was attached to the actuator. The jib boom lifted a crossmember over the drawbar at the front of the coil, and a retainig nut was placed on the drawbar to retain the crossmember, as shown in Figure 5. When the actuator pulled on the drawbar, this crossmember pulled the coil along the rig.

Figure 6 shows the test rig set up for a lateral pull. The coil was placed with its eye laterally across the middle of the deck with the midpoint of the coil aligned with the hydraulic actuator. A support roller assembly was placed on top of the coil. A crossmember with rollers facing to the rear was placed through the eye of the coil using the jib boom, and while it was held with its rollers at the same elevation as the centre of the coil, it was bolted to the support roller assembly to hold it in place. The short drawbar was attached to the actuator, the second crossmember, supported by the jib boom, was placed over the drawbar and held in place by the retaining nut. The side members were pinned in place between the two crossmembers, and the nut on the drawbar was adjusted to tighten up the drawbar. The crossmember through the eye of the coil pulled the coil along the rig, with the rollers bearing on the inside of the coil roughly along a horizontal diameter. Care was taken to orient coils so that the steel bands on the coil did not interfere with the support or crossmember rollers during a pull. The actuator produced smooth pulls, even when the coil was pulled against fixed blocking and the centre of the coil moved both rearward and upward. The trolley moved smoothly up the slide, maintaining a near-horizontal pull at all times, a design feature of the test rig.

Figure 3/ Actuator assembly

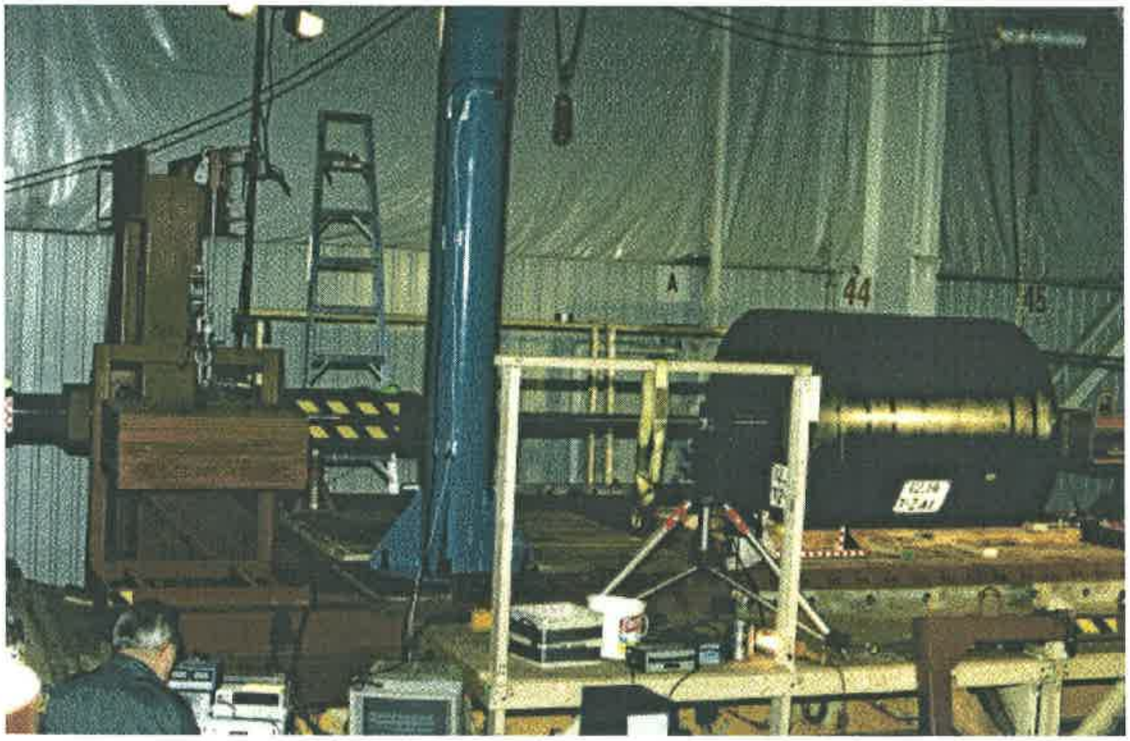


Figure 4/ Test rig set up for longitudinal pull

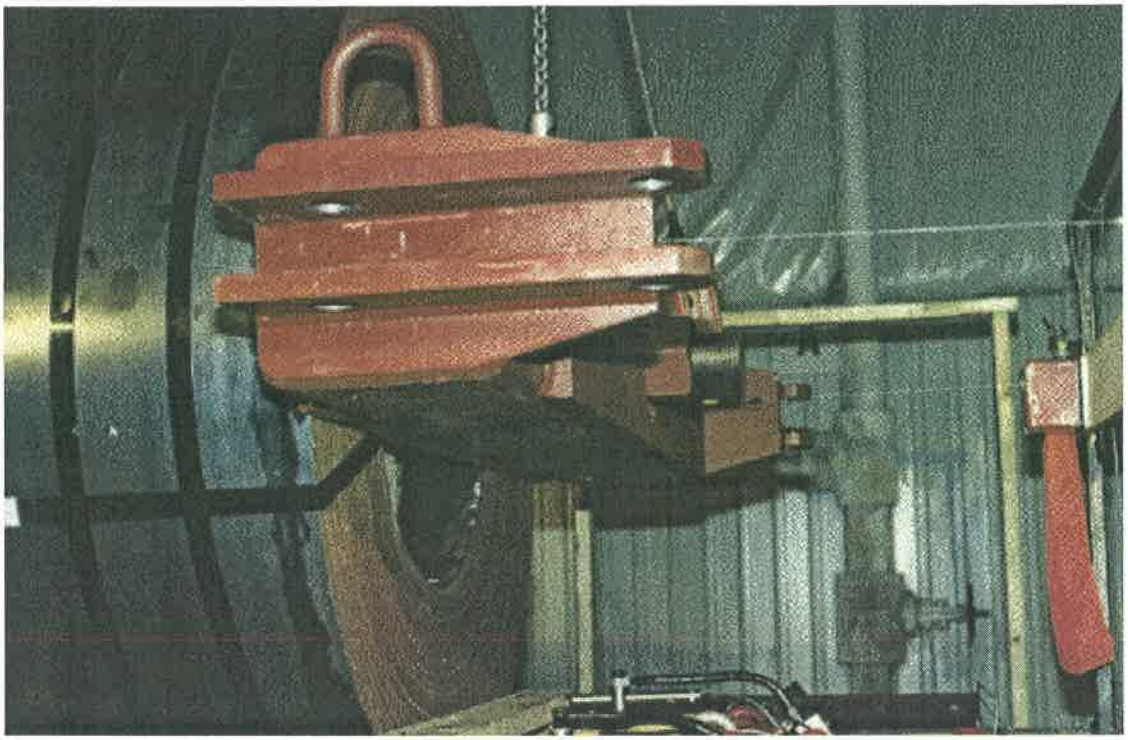


Figure 5/ Crossmember set up for longitudinal pull

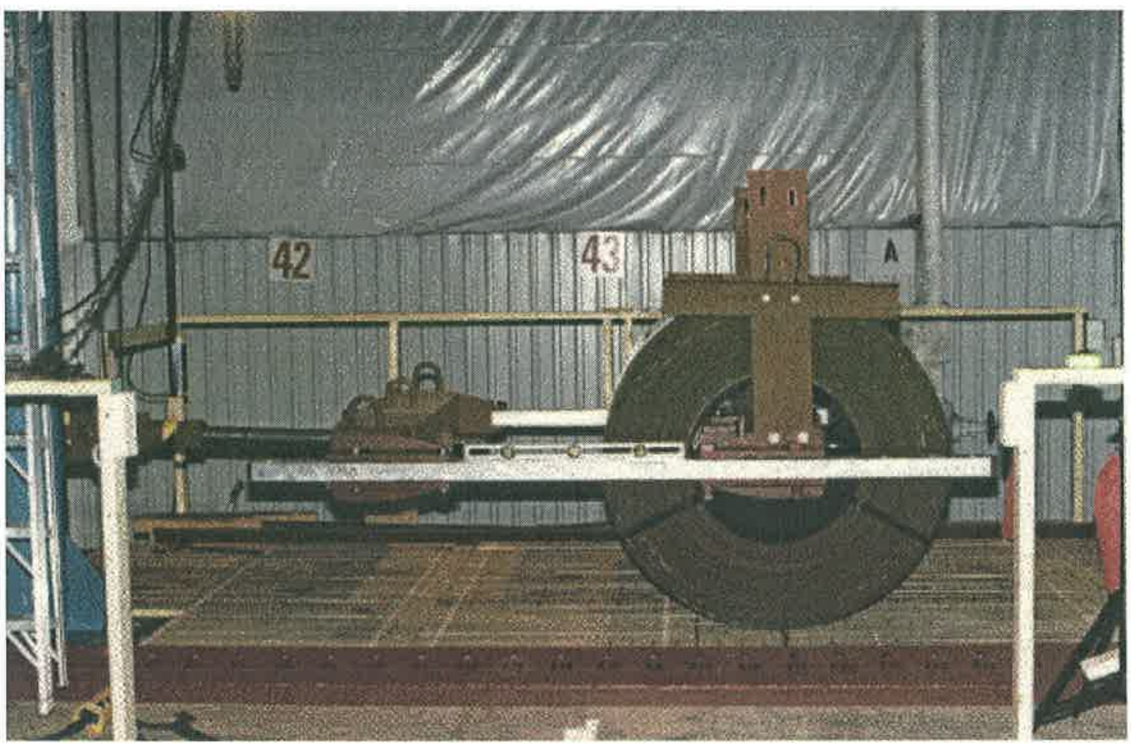


Figure 6/ Test rig set up for lateral pull

Table 1/ Properties of Coils Tested

Coil	Width		Outside diameter		Weight	
	m	in	m	in	kg	lb
1	1.78	70	1.07	42	8,264	18,220
2	1.52	60	1.24	49	10,523	23,200
3	1.22	48	1.75	69	20,139	44,400

Three steel coils were used for these tests, each with an eye internal diameter of 0.61 m (24 in). Their other principal properties are listed in Table 1. They are shown in Figure 7, and from left to right, are numbers 3, 1 and 2 from Table 1.

Rough maple timber with nominal dimensions of 10x10 and 15x15 cm (4x4 and 6x6 in) was used as blocking, some square, and others with a 22 deg bevel on the top. Bunks were made from 0.635x7.62 cm (1/4x3 in) steel plate with both ends folded inward and welded to form a 10 cm (4 in) high right angle triangle. The bunk was 0.69 m (27 in) between the verticals, for an overall length of 0.91 m (36 in). A cradle was formed from three bunks equally spaced on the deck, with one block placed laterally across the bunks against each of the verticals, as seen in Figure 2.

Tiedown equipment included 1/4 and 3/8 in grade 7 steel chains, with working load limits of 1,474 and 2,948 kg (3,250 and 6,500 lb) respectively, and 7.62 cm (3 in) wide synthetic webbing with a working load limit of 2,268 kg (5,000 lb).

3.2/ Instrumentation and Data Capture

A Strainsert model CPA-1.5 (SS)X0 clevis pin load sensor, rated at 133.5 kN (30,000 lb), and seen in Figure 8 joining the drawbar and actuator, was used to measure the pull force. Two Celesco model DV-301-150B pull cord transducers were attached to the front of the test rig, and their cords were attached to each end of the crossmember pulling the coil, as shown in Figure 9. The pull cord transducers allowed motion and yaw of the coil to be determined. Two Transtek DC-DC model 0245-0000 10.16 cm (4 in) stroke linear variable differential transformers (LVDT's) were attached to the bed, as shown in Figure 10, and were used to measure motion and yaw of the blocking or cradle. Tension in a tiedown was measured using a three link section of chain, with the middle link strain gauged in a four-arm bridge, and calibrated to become a load cell. One of these was attached by shackles between the side rail of the test rig and the end of a tiedown or binder, as shown in Figure 11.

Signals from the instruments were wired to a signal conditioning unit where they were amplified and filtered. They were digitized using the PC-based data acquisition system seen in Figure 12, and shown in real time on the screen. A sample rate of 1000 Hz was

Figure 7/ Coils used for tests

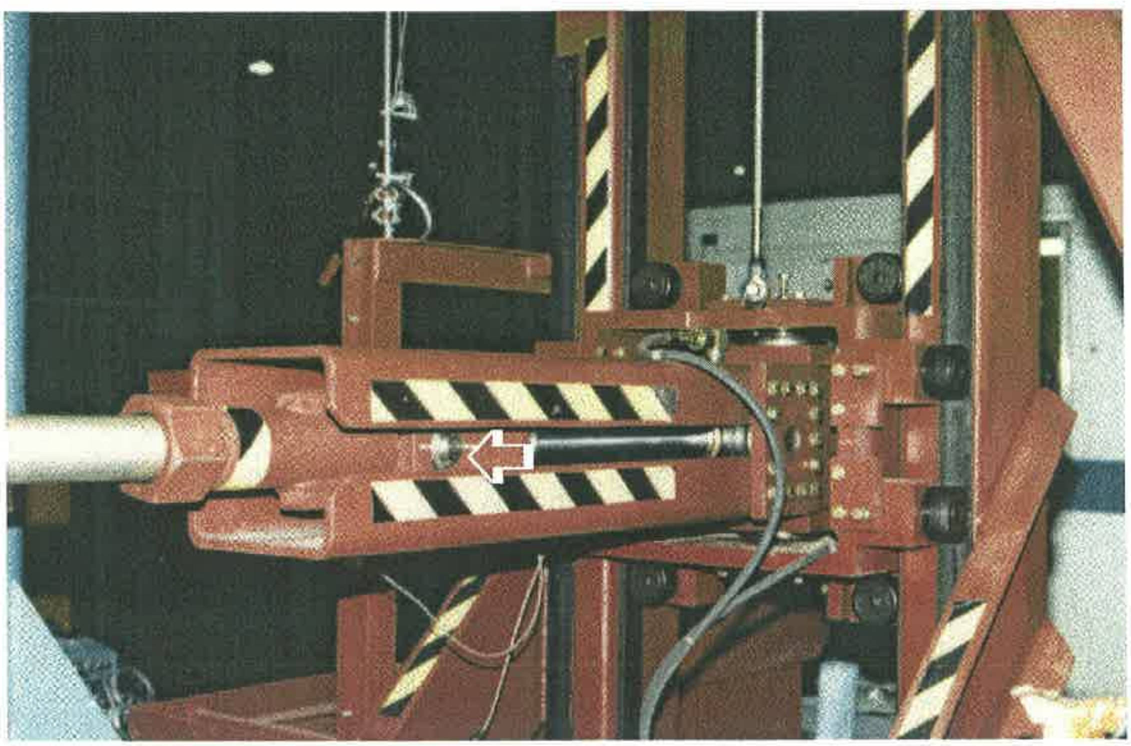


Figure 8/ Clevis pin load sensor

Figure 9/ Pull cord transducers

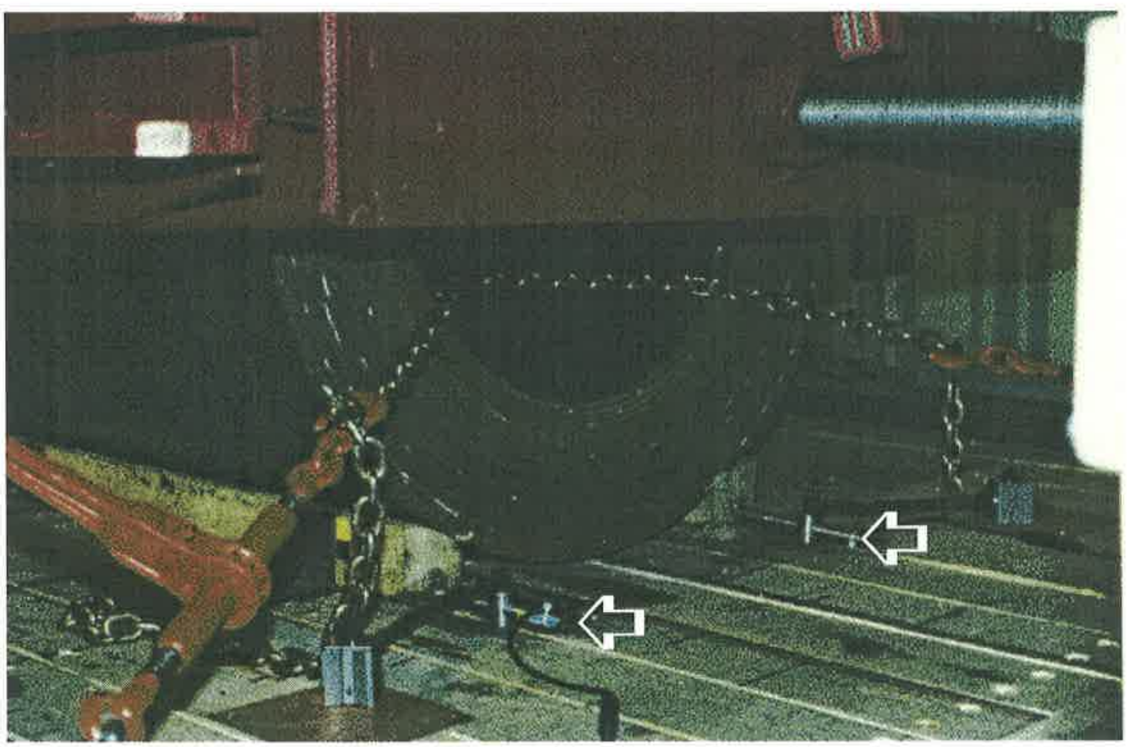


Figure 10/ Deployment of LVDTs

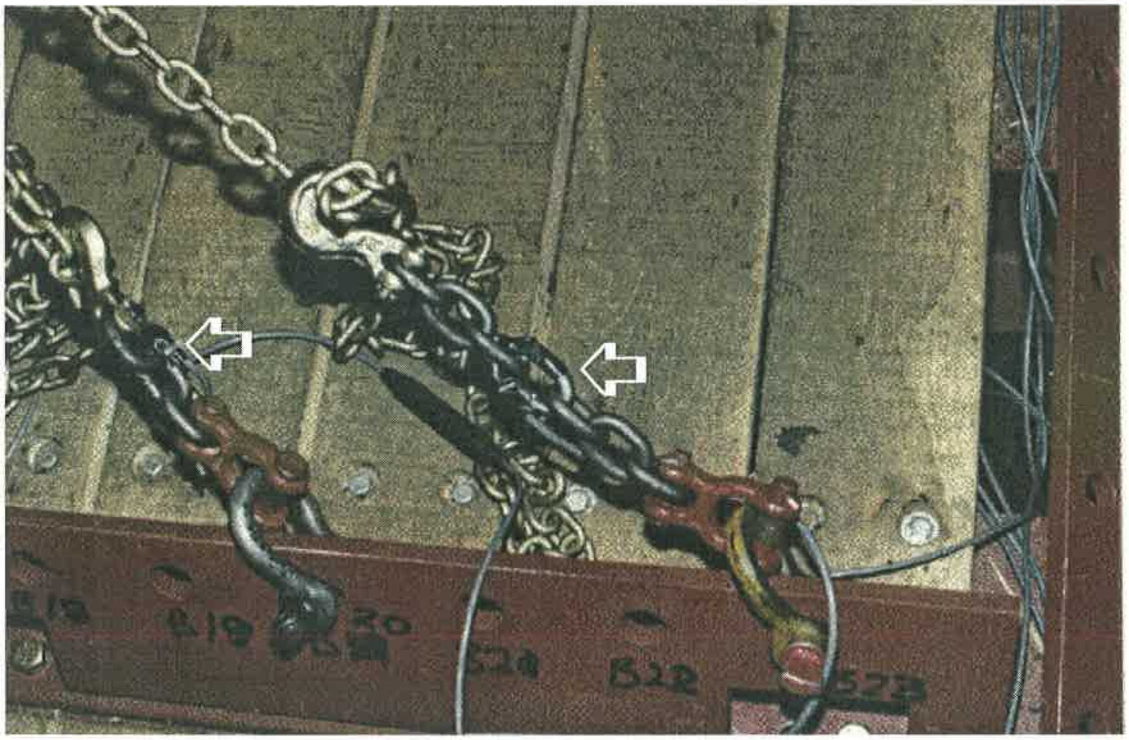


Figure 11/ Strain gauged chain links used as load cells

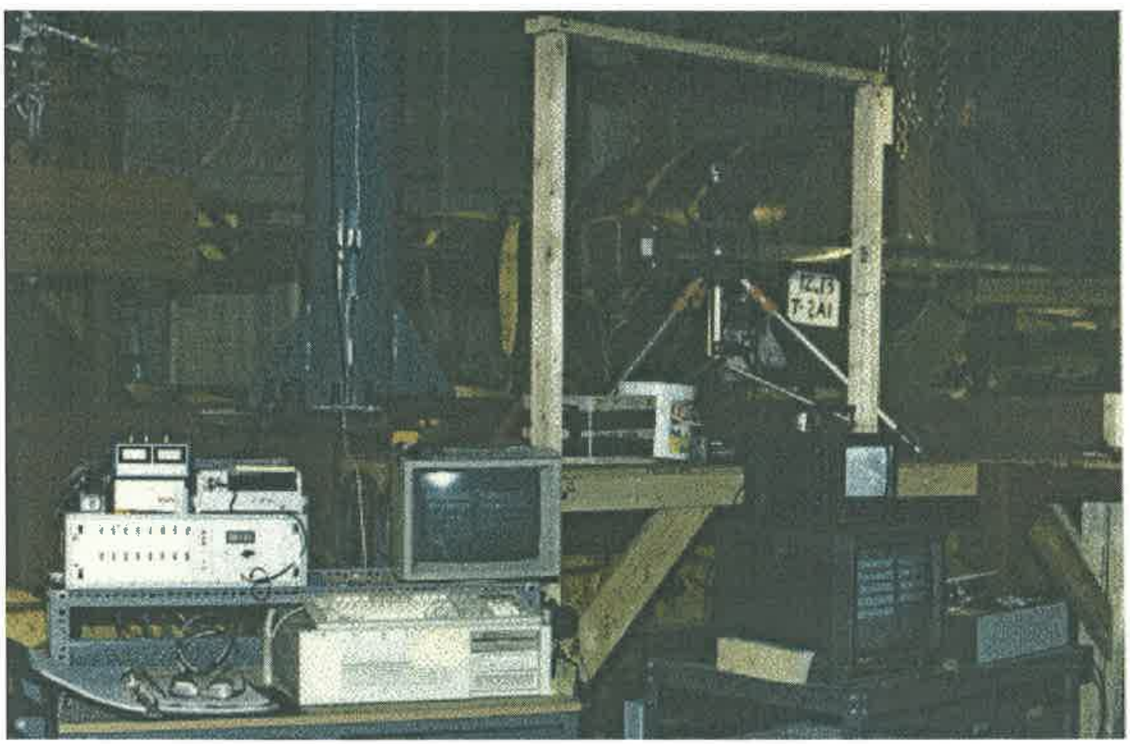


Figure 12/ PC-based data acquisition system

used with a 200 Hz low-pass filter for friction tests, and the rest of the tests used a sample rate of 100 Hz with a 20 Hz filter. The number of data channels varied from three (load cell and two pull cords) for friction tests, to 13 (load cell, two pull cords, two LVDT's and eight strain gauged chain links) for some of the tests that included a coil on an unsecured cradle with four tiedowns. Intermediate numbers were used for other tests, depending on the particulars of the test.

3.3/ Test Procedure

This section describes the setup and procedures used for most tests. For tests where the setup or procedure differed from this general description, the differences are described in the section presenting the results for those particular tests.

For each test series, any blocks or cradle were placed in the centre of the bed of the test rig, oriented according to the desired coil orientation. The coil was then lifted into place using the overhead crane, and the pull mechanism was assembled as described in Section 3.1. Any tiedowns were attached loosely. The pull cords were attached, on each side of the crossmember at the front of the test rig, and the LVDT's were put in place to measure movement of a block or cradle. The actuator was adjusted to relieve any tension in the drawbar.

Once the physical set up was complete, the transducer outputs were zeroed. The data acquisition system was started, and a three point calibration (zero, half-scale and full-scale) was recorded, followed by at least three seconds of zero data. Data acquisition was then stopped while final preparations for the test run were made. Each tiedown was tensioned using a ratchet binder, usually on the left-hand side for a lateral pull, or the front of the test rig for a longitudinal pull, to achieve the desired tension in the tiedown. This was usually within about 0.1 kN (25 lb) of that value. Whatever tension arose on the other side was accepted. When all was ready, data acquisition was re-started, and about three seconds later the hydraulic system was actuated to draw the coil rearward on the test rig. If the coil was not secured, it or its supports could move, and the pull continued typically while the coil moved about 15 cm (6 in), or until unsecured blocking popped out and the coil crashed on the deck. If the coil was secured by tiedowns or blocking, the pull continued until either the pull force reached the weight of the coil, any tiedown reached twice its working load limit, or the blocking failed or popped out. At this point, the hydraulic system was stopped, and data acquisition was also stopped.

The pull cords, LVDT's and tiedowns were removed, and the pull mechanism was disassembled as necessary for the next test.

The data in the PC were saved to a file on the hard disk, under the same file name as that recorded in the test log. The data were retrieved, and the calibrations were examined and adjusted if necessary. A quick look at the data was taken to ensure that the results were reasonable. If there was any question, the run was repeated, and sometimes adjustments were made to test conditions or fittings to ensure consistent and repeatable data. The file was then saved again, and a backup file was also saved immediately on a floppy disk.

Samples of equipment and test activity, and each pull, were recorded on video tape. Color still photographs and slides were taken of the tests, instrumentation and test activity. A detailed log of test activities and observations was maintained.

3.4/ Data Processing

A data processing procedure was developed within a specialized test data processing program written at MTO. This procedure took a single run, calibrated and detrended the data, and then presented the data for analysis. Key data were extracted from runs, and entered into spreadsheets for plotting and tabulation.

3.5/ Test Matrix

The matrix of tests conducted is summarized in each of the sections that presents the results below. There ended up being substantially fewer pulls than outlined in the project proposal [1], for several reasons, all anticipated at the time the proposal was developed. First, there were simply a number of duplicate conditions across various sections, which were included in the proposal for completeness, but did not need actually to be repeated as tests. Second, there were ranges of interface conditions that replicated some of the work done in the friction portion of this project [3]. Third, once a critical condition had been established, there were often a number of other conditions that did not need to be tested.

4/ Results

4.1/ Friction, for a Lateral Pull, and Rolling, for a Longitudinal Pull

4.1.1/ Scope

This test series examined the longitudinal and lateral frictional force between the coil and the deck, as outlined in section 12.2 of the proposal [1]. Two coils, those weighing 8,264 and 10,523 kg (18,220 and 23,200 lb), were used on the dry oak deck to conduct a total of four test conditions as follows:

1/ longitudinal pull with the 8,264 kg (18,220 lb) and 10,523 kg (23,200 lb) coils;
2/ longitudinal pull with the 8,264 kg (18,220 lb) coil wrapped with paper; and
3/ lateral pull with the 10,523 kg (23,200 lb) coil.

4.1.2/ Specialized Test Setup and Procedures

The longitudinal and lateral pull setups and procedures were as described in Section 3.1. Figure 13 shows the set up for a longitudinal pull, and Figure 14 shows the setup for a lateral pull, with the coil free to roll. Each test measured only drawbar load and coil displacement. Up to six separate pulls were conducted in a single run. The procedure, data processing and analysis followed that for the series of friction tests conducted as part of the larger project [3].

4.1.3/ Results

Figure 15 shows typical responses of drawbar force and coil displacement for a single longitudinal pull. The drawbar force rose rapidly to a peak just before the coil began to move, and settled to a sliding value, determined as the average during the subsequent slip-stick period, when the coil was pulled at a steady rate. Table 2 summarizes the peak and slide friction forces between the coil and oak deck, and gives equivalent coefficients of friction (μ), based on the coil weight plus 680 kg (1,500 lb) for test equipment. The static friction coefficients of the two coils are 0.25 and 0.26, with slide coefficients of about 0.21 each. These values are about half those found in the friction test, where a steel plate was pulled over a coarse oak deck [3]. However, the weight of the coil is highly concentrated in a narrow strip, which is more comparable to the loading of the steel pads or machine feet used in the friction test, which gave static friction coefficients of 0.26 and 0.29 respectively, on coarse oak [3]. When the 8,264 kg (18,220 lb) coil was wrapped with a coated high-friction paper, the longitudinal peak and slide forces were reduced, equivalent to friction coefficients of 0.21 and 0.17 respectively.

The resistance from the lateral pull with the 10,523 kg (23,200 lb) coil was only 1.21 kN (273 lb), equivalent to a rolling resistance of 0.01. It only took one person pushing to start the coil rolling.

Table 2/ Friction and rolling of coils on a dry oak deck

Coil weight kg (lb)	Resistance type	Resistance					
		Coil			Coil wrapped in paper		
		kN	lb	μ	kN	lb	μ
8,264 (18,220)	Static	23.10	5,193	0.263	18.71	4,204	0.213
	Slide	18.07	4,061	0.206	15.24	3,426	0.174
10,523 (23,200)	Static	27.43	6,164	0.250			
	Slide	23.58	5,300	0.215			
	Rolling	1.21	273	0.011			

4.1.4/ Conclusions

The static coefficient of friction of a typical dry steel coil on a dry oak deck subject to a longitudinal pull is in the range 0.25-0.26. This may be reduced if the coil is wrapped in some paper. Its rolling resistance is less than 0.01.

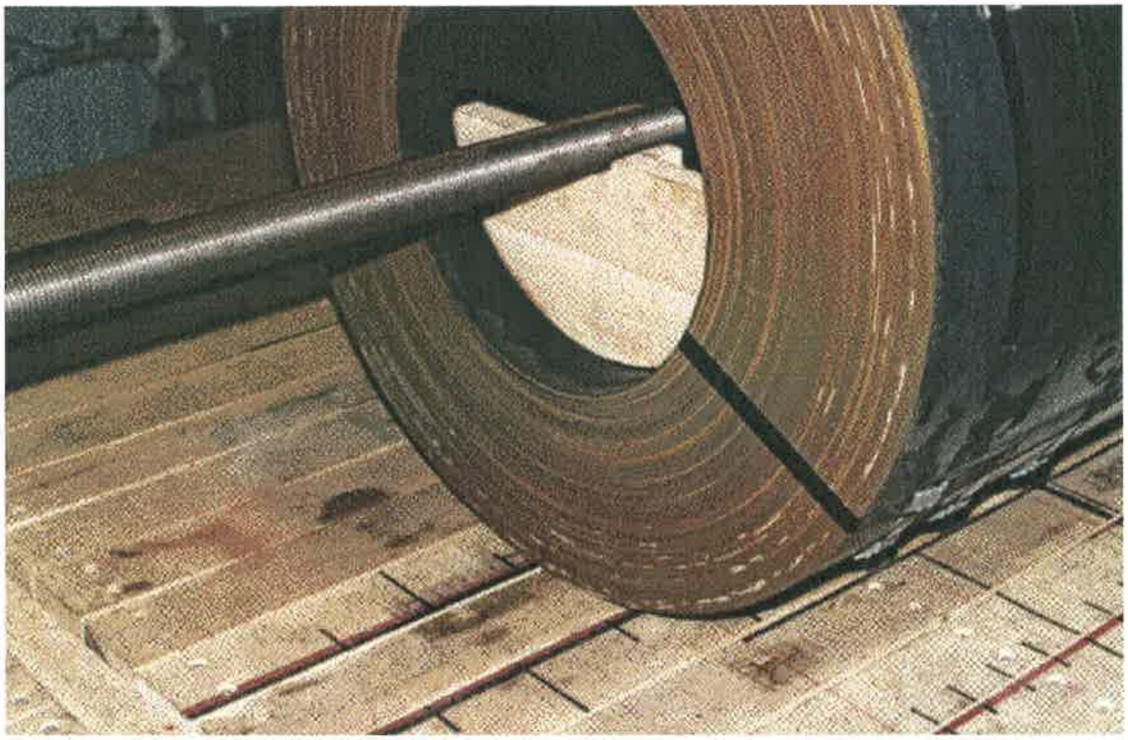


Figure 13/ 8,264 kg (18,220 lb) coil set up for longitudinal friction test

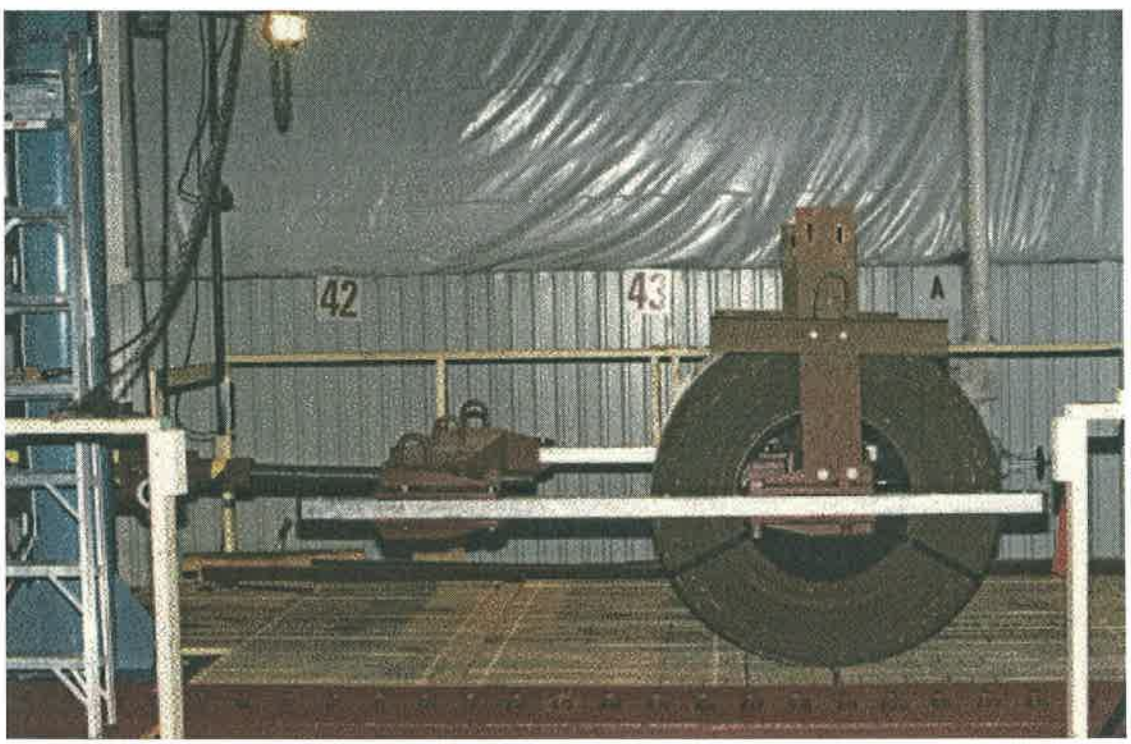


Figure 14/ 10,523 kg (23,200 lb) coil set up for rolling resistance test

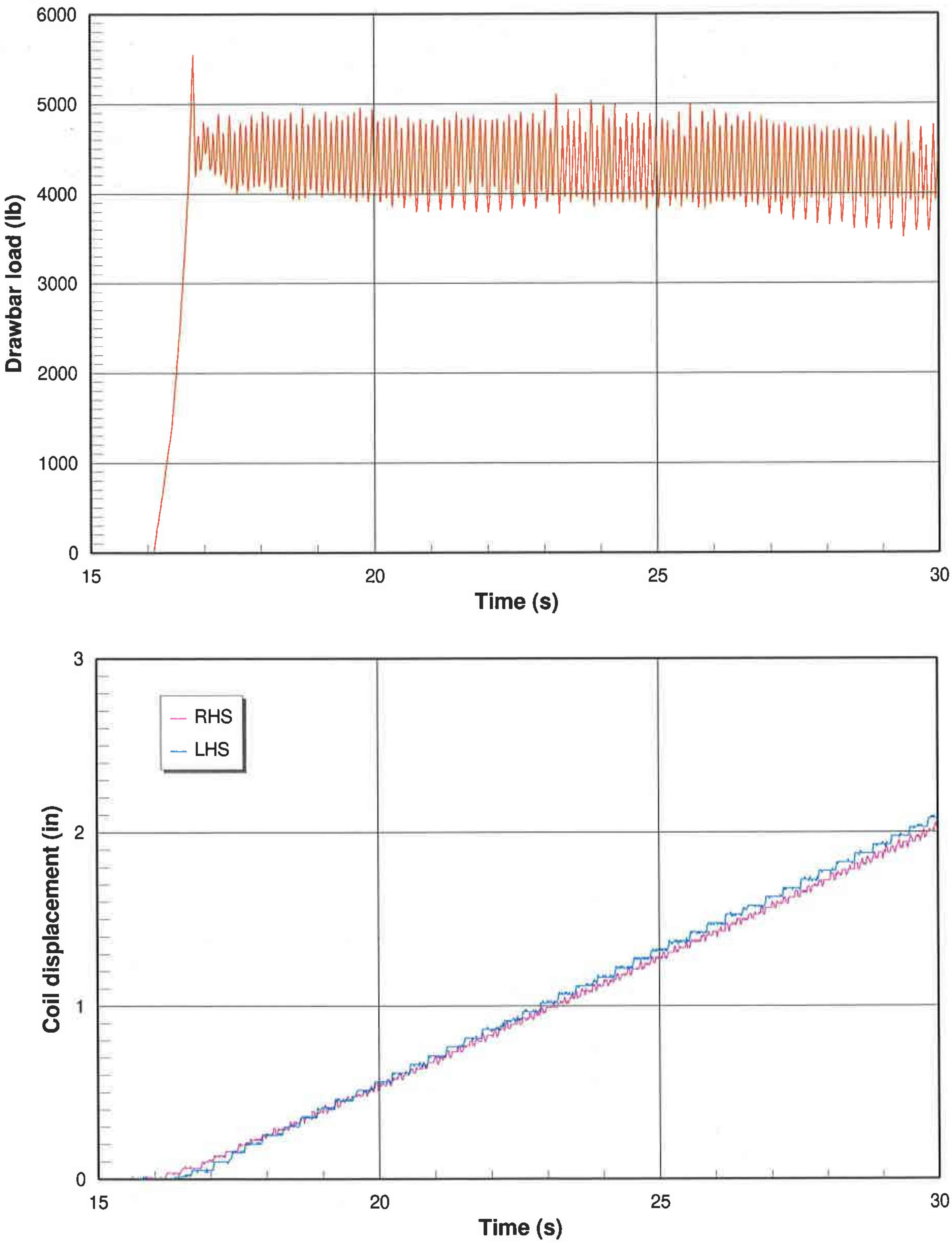


Figure 15/ Longitudinal pull of 8,264 kg (18,220 lb) coil on dry oak deck

4.2/ Resistance of Blocking to a Lateral Pull

4.2.1/ Scope

Hardwood blocks are commonly used to prevent metal coils from rolling. This test series examined the effect of size, shape, spacing and securement of hardwood blocks on resistance to a lateral pull, as outlined in section 12.3 of the proposal [1]. Nominal 10x10 and 15x15 cm (4x4 and 6x6 in) hardwood blocks were used, with the upper surface either flat, or bevelled at a nominal angle of 22 deg to the horizontal. The blocks were spaced to provide clearance of zero and 2.5 cm (0 and 1 in) between the coil and the deck. The 10,523 kg (23,200 lb) and 20,139 kg (44,400 lb) coils were used, with both unsecured and secured blocking. Table 3 shows the test matrix.

Table 3/ Test matrix for blocking with a lateral pull

Coil Weight kg (lb)	Blocking	Flat top		Bevelled top	
		Clearance (in)		Clearance (in)	
		0	1	0	1
10,523 (23,200)	10x10 cm (4x4 in) unsecured	X	X	X	X
	15x15 cm (6x6 in) unsecured	X	X	X	
20,139 (44,400)	10x10 cm (4x4 in) unsecured			X	
	15x15 cm (6x6 in) unsecured				
10,523 (23,200)	10x10 cm (4x4 in) secured	X	X	X	X
	15x15 cm (6x6 in) secured	X	X	X	X
20,139 (44,400)	10x10 cm (4x4 in) secured	X	X	X	
	15x15 cm (6x6 in) secured	X	X		

4.2.2/ Specialized Test Setup and Procedures

This test series used a lateral pull, as shown in Figure 16. The blocks were initially placed on the deck, away from the coil. For zero clearance, the overhead crane simply placed the coil on the deck, and a block was pushed against the coil. For a clearance of 2.5 cm (1 in), the crane held the coil that distance clear of the deck, blocks were pushed against the coil from each side, and the crane released the coil. Blocking was secured with a pair of spacers between the rear block and the lateral steel rail at the rear of the test rig. Drawbar load, coil and rear block displacement were measured.

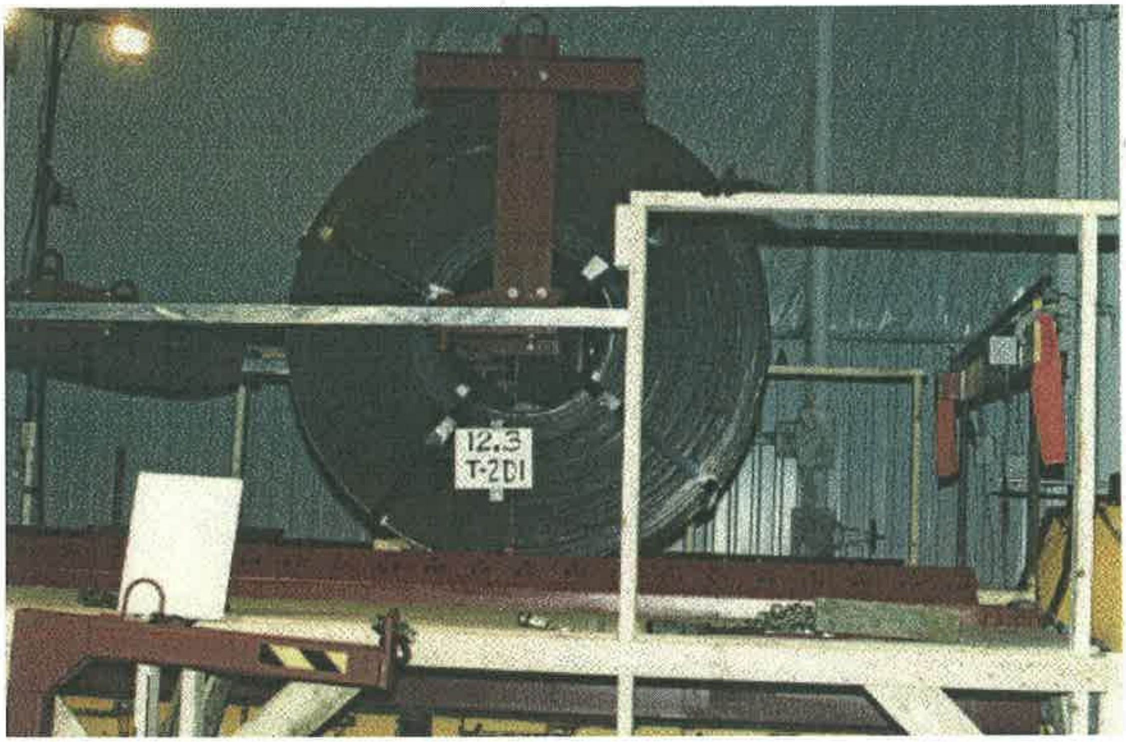


Figure 16/ Setup for blocking resistance

4.2.3/ Results

Figure 17 shows an example response of drawbar load, coil and block displacement for unsecured 10x10 cm (4x4 in) bevelled blocking with zero clearance. Initially, the drawbar load increased to about 4.45 kN (1,000 lb) as the coil attempted to move up the block, then dropped suddenly when the left side of the block slipped about 2.5 cm (1 in). The block held while the drawbar load climbed to about 35.6 kN (8,000 lb), when both sides of the block slipped. The coil continued to climb up the block, then finally the block slipped again and the coil crashed onto the deck.

Figure 18 shows the response for the same case, except that the rear block was now secured against movement in the pull direction. The drawbar load increased until the coil lifted off the ground, then it decreased gradually as the coil rotated about the edge of the block.

Table 4 summarizes the resistance of the various blocking configurations, in terms of maximum pull force reached, and an equivalent external acceleration, calculated by dividing the resistance by the mass of the coil plus 680 kg (1,500 lb), for the weight of test equipment it was supporting.

In all cases where the blocking was unsecured, the block was either pushed along by the coil, or popped out after the coil had climbed partially up the block, when the coil crashed onto the deck. In either of these cases, the block ended up loose. When the

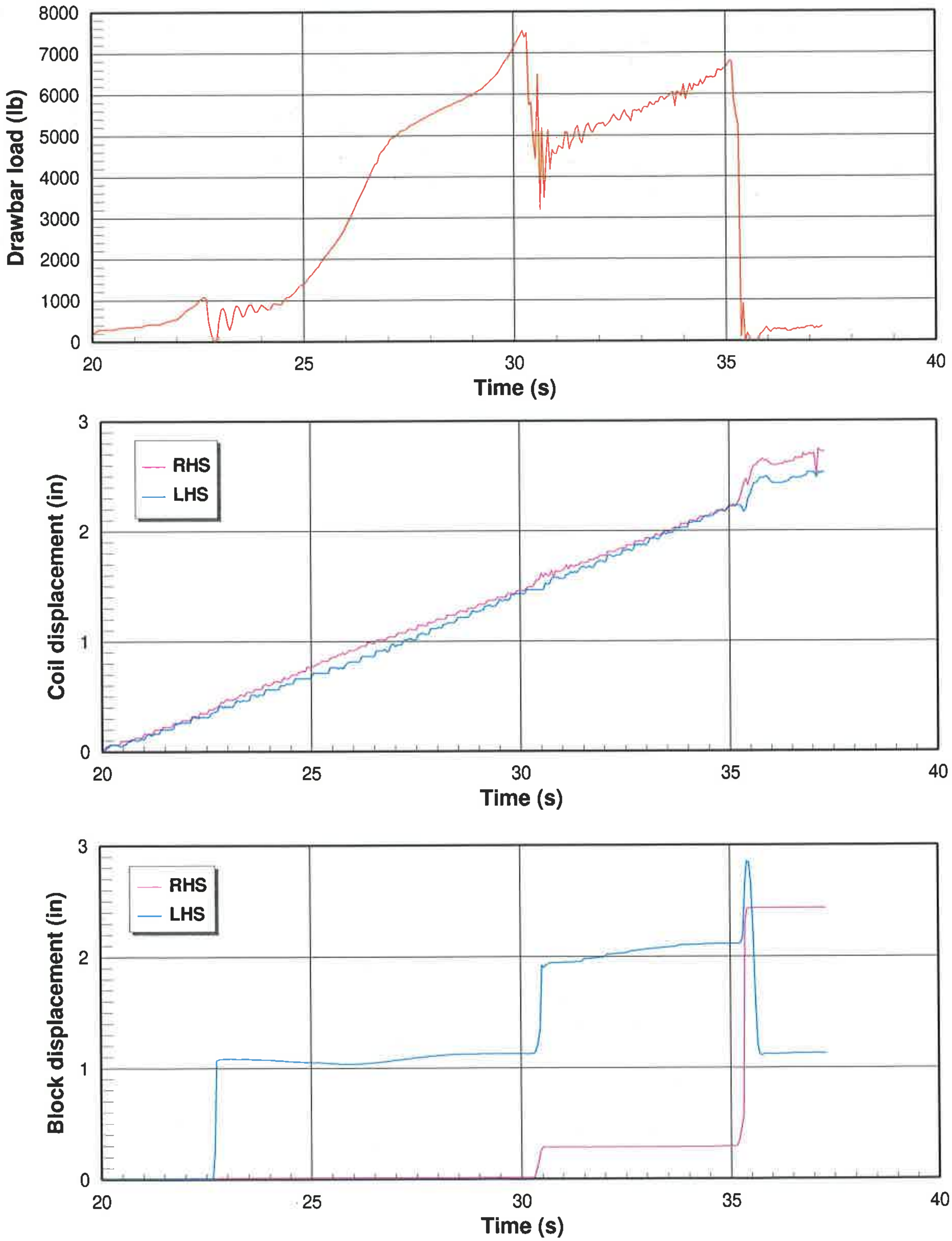


Figure 17/ Lateral pull of 10,523 kg (23,200 lb) coil
Unsecured 4x4 in bevelled block with zero gap clearance

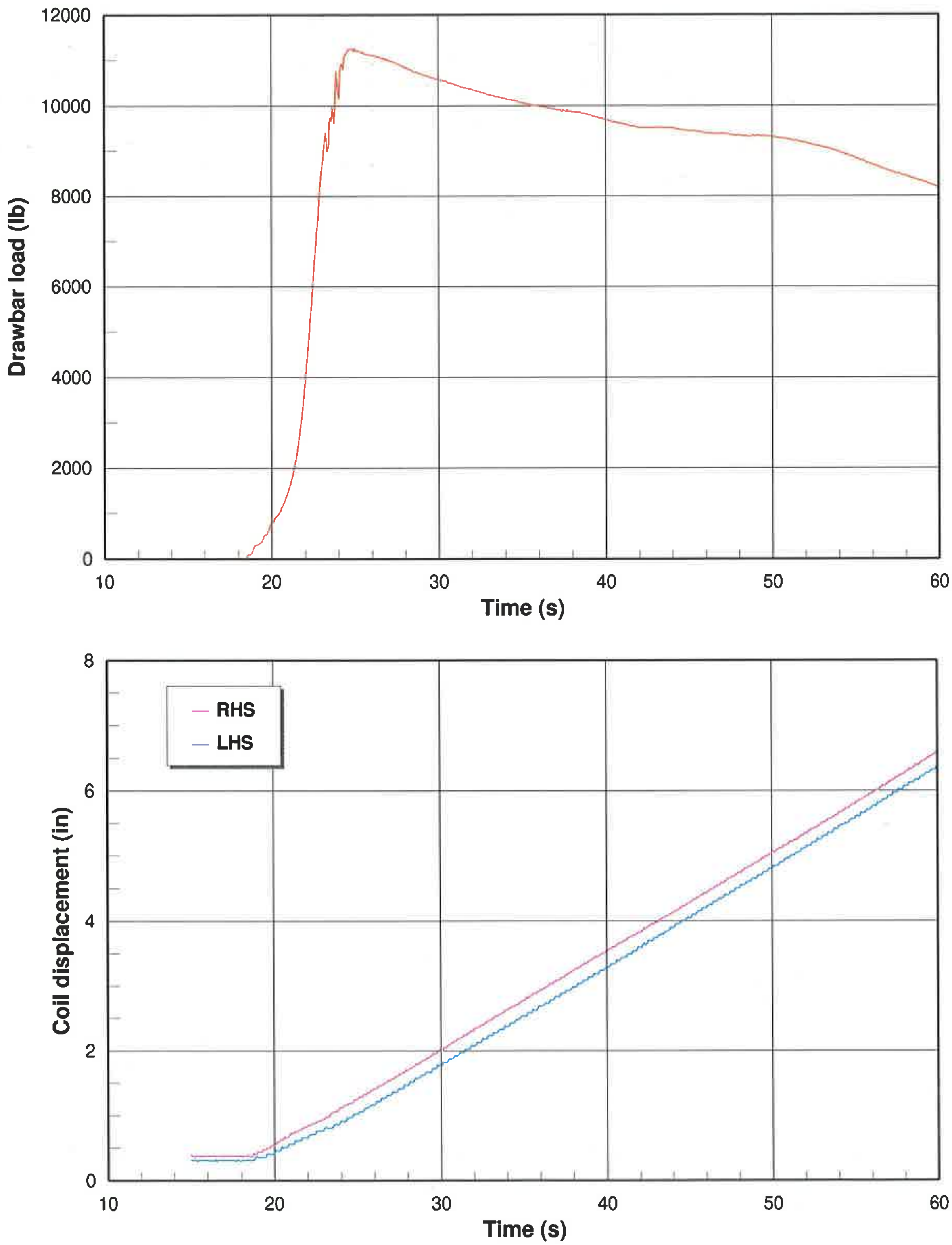


Figure 18/ Lateral pull of 10,523 kg (23,200 lb) coil
Secured 4x4 in bevelled block with zero gap clearance

Table 4/ Resistance of blocking for a lateral pull

Coil weight kg (lb)	Block	Resistance: Zero clearance kN	lb	g	Resistance: 1 in clearance kN	lb	g
10,523 (23,200)	4x4 flat unsecured	43.48	9,772	0.396	12.90	2,900	0.117
	4x4 bevelled unsecured	32.58	7,322	0.296	20.60	4,630	0.187
	6x6 flat unsecured	55.60	12,495	0.506	25.14	5,651	0.229
	6x6 bevelled unsecured	48.71	10,947	0.443			
20,139 (44,400)	4x4 bevelled unsecured	53.85	12,102	0.264			
10,523 (23,200)	4x4 flat secured	56.27	12,646	0.512	46.44	10,437	0.423
	4x4 bevelled secured	50.48	11,346	0.459	41.66	9,364	0.379
	6x6 flat secured	81.94	18,416	0.746	71.77	16,129	0.653
	6x6 bevelled secured	59.71	13,420	0.543	48.22	10,835	0.439
20,139 (44,400)	4x4 flat secured	82.12	18,456	0.402	62.96	14,150	0.308
	4x4 bevelled secured	77.87	17,501	0.381			
	6x6 flat secured	117.85	26,484	0.577	104.78	23,548	0.513

blocks were secured and could not pop out, the results were consistent, and always higher than with unsecured blocks. For the same gap clearance, the square block provided a higher resistance than a similar size bevelled block, and the resistance increased as the block size was increased. Resistance also increased as gap clearance was decreased. These were obtained by adjusting the spacing of the blocks, which generates the optimum resistance. Typically, block size, shape and spacing are fixed, and coil diameter varies, so resistance may vary with coil diameter.

4.2.4/ Conclusions

While some of these results indicate that unsecured blocking may provide significant resistance to an external acceleration equivalent to a lateral pull, the values were inconsistent as the block was either pushed along by the coil or popped out, allowing the coil to crash on the deck. The resistance of hardwood blocks was greater and consistently reliable when the blocks were secured. In this case, the resistance depends on the size, shape and spacing of the blocks, and increases as the coil sits deeper in the well created by the blocks.

4.3/ Resistance of Chain Securement to a Lateral Pull

4.3.1/ Scope

This test series examined the resistance of chain securement for a lateral pull, as outlined in section 12.4 of the proposal [1]. The first half examined the effect of chain tiedown angle on resistance, with one tiedown at an angle of 90, 75, 60 or 45 deg to the deck, then two, three and four tiedowns at these angles, all at an initial tension of 5% of tiedown working load limit (WLL). Table 5 shows the test matrix. The second half examined the resistance of tiedowns in pairs at equal and opposite angles, at initial tensions of 5, 20 or 50% of WLL. Table 6 shows this test matrix.

4.3.2/ Specialized Test Setup and Procedure

This test series was conducted with a lateral pull, as described in Section 3.1. The 20,139 kg (44,400 lb) coil was used, shown in Figure 19 with biassed 1/4 in grade 7 chain tiedowns with a WLL of 1,474 kg (3,250 lb). Balanced securement used the 10,523 kg (23,200 lb) coil, as shown in Figure 20, with either four 1/4 in or two 3/8 in grade 7 chain tiedowns, the latter with a WLL of 2,948 kg (6,500 lb). Drawbar load, coil displacement, and tension at both ends of each chain were measured.

4.3.3/ Results

Figure 21 superimposes drawbar load, coil displacement and tiedown tension for separate pulls of biassed single 1/4 in grade 7 chain tiedowns at angles of 45, 60, 75 and 90 deg. These show coil displacement was greater at a given tiedown tension as tiedown angle increased, or conversely, for a given coil displacement, the tiedown tension was reduced. The coil had to move about 15 cm (6 in) for the tiedown at 90 deg to reach its working load limit, while for the others it was only 3-5 cm (1.2-2 in). At that limit, resistance diminished rapidly as tiedown angle increased.

Figure 22 shows similar data for three 1/4 in grade 7 chains at angles of 90, 75 and 60 deg. The coil moved about 2.5 cm (1 in) before the chains tightened up and started taking significant load. The chain at 60 deg took over half the load, that at 75 deg took most of the rest, and the chain at 90 deg provided little resistance.

The effectiveness of chain arrangements was compared using the drawbar load at which the first chain of a group reached its working load limit, or twice its working load limit. Table 7 shows the resistance of the various biassed arrangements of 1/4 in grade 7 chain with a WLL of 1,474 kg (3,250 lb). Resistance decreased as tiedown angle increased. At the chain's working load limit, resistance ranged from only 3.42 kN (770 lb) at a 90 deg angle to 17.87 kN (4,016 lb) at 45 deg, more than five times higher than at 90 deg. The columns labelled "g" are an equivalent external acceleration, obtained by dividing the resistance by the mass of the coil. This column gives only relative values, as 1/4 in chain would not normally be used to secure such a heavy coil.

Table 5/ Test matrix for biassed chain securement with a lateral pull

Coil weight and tiedown size	Tiedown angle (deg)				Tiedown initial tension (% WLL)
	45	60	75	90	
20,139 kg (44,400 lb) coil with 1/4 in chain				X	5
			X		5
		X			5
	X				5
			X	X	5
		X	X		5
	X	X			5
		X	X	X	5
	X	X	X		5
	X	X	X	X	5

Table 6/ Test matrix for balanced chain securement with a lateral pull

Coil weight and tiedown size	Tiedown Angle (deg)				Tiedown initial tension (% WLL)
	45	75	-75	-45	
10,523 kg (23,200 lb) coil with 1/4 in chains	X	X	X	X	5
	X	X	X	X	20
	X	X	X	X	50
10,523 kg (23,200 lb) coil with 3/8 in chains		X	X		5
		X	X		20
		X	X		50
	X			X	5
	X			X	20
	X			X	50

When two chains were used, the resistance was governed by the chain with the higher tension, which was always the chain with the lowest tiedown angle. The resistance with tiedown angles of 60 and 45 deg was about three times that with tiedown angles of 90 and 75 deg. Similar results were found for three or four chains. At the working load

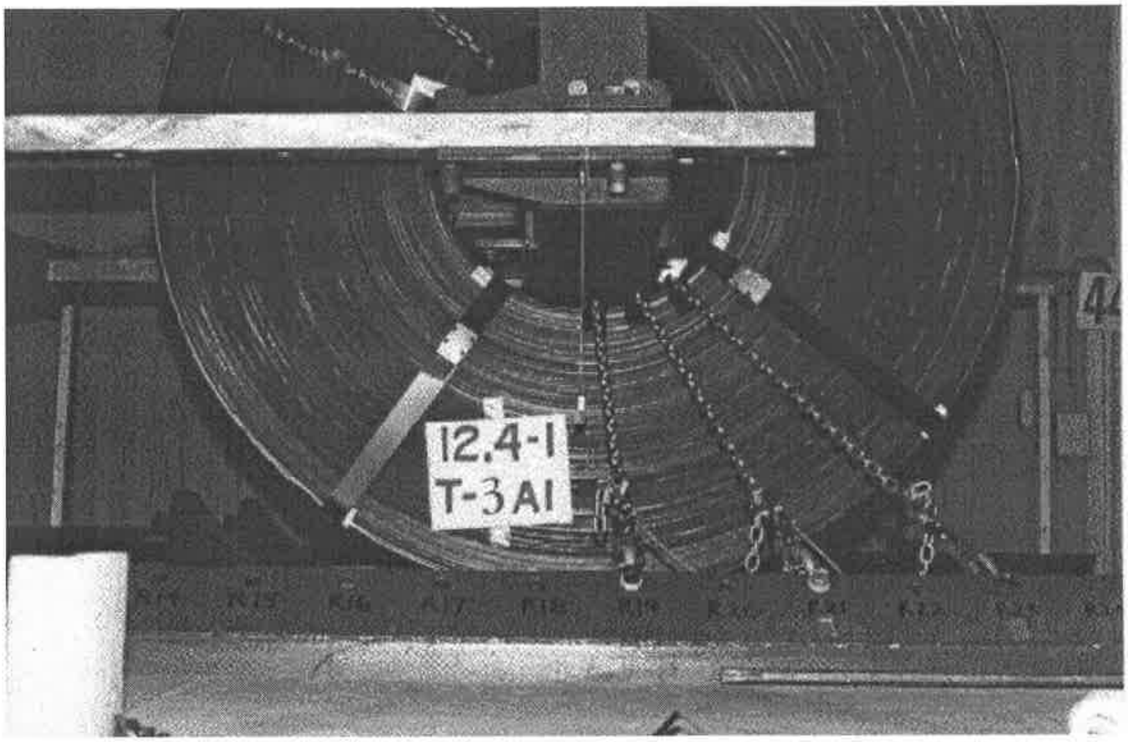


Figure 19/ Biassed chain securement setup
Lateral pull of 20,139 kg (44,400 lb) coil with three 1/4 in chains

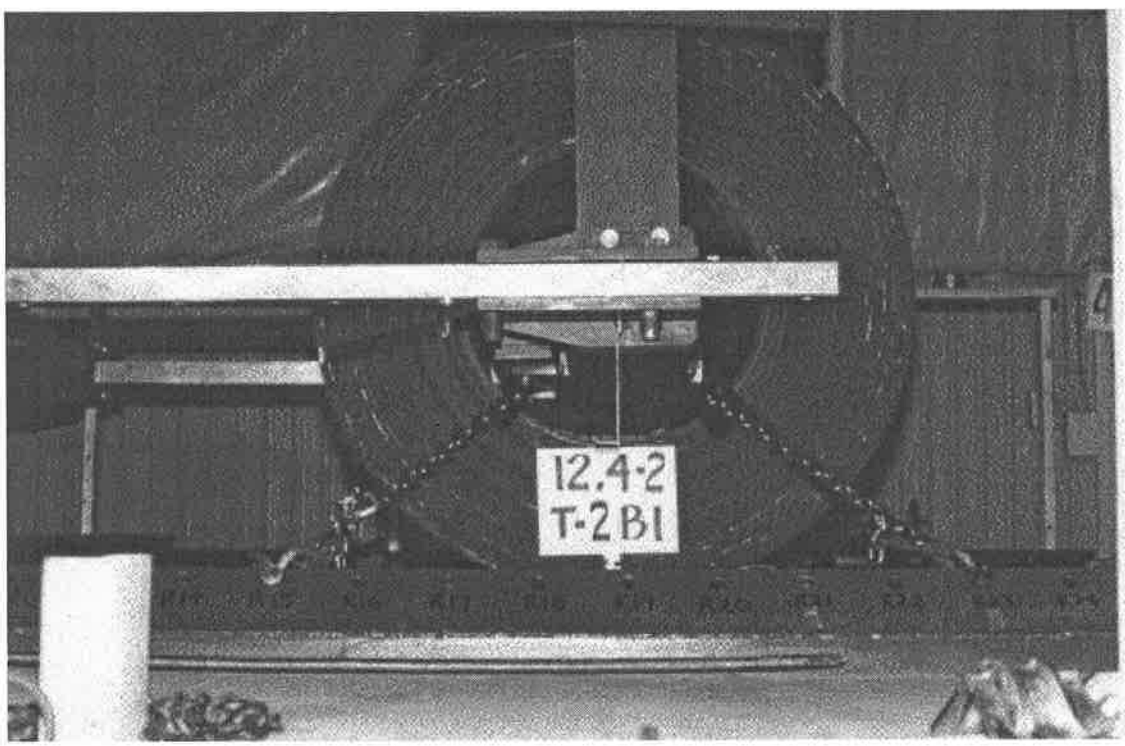
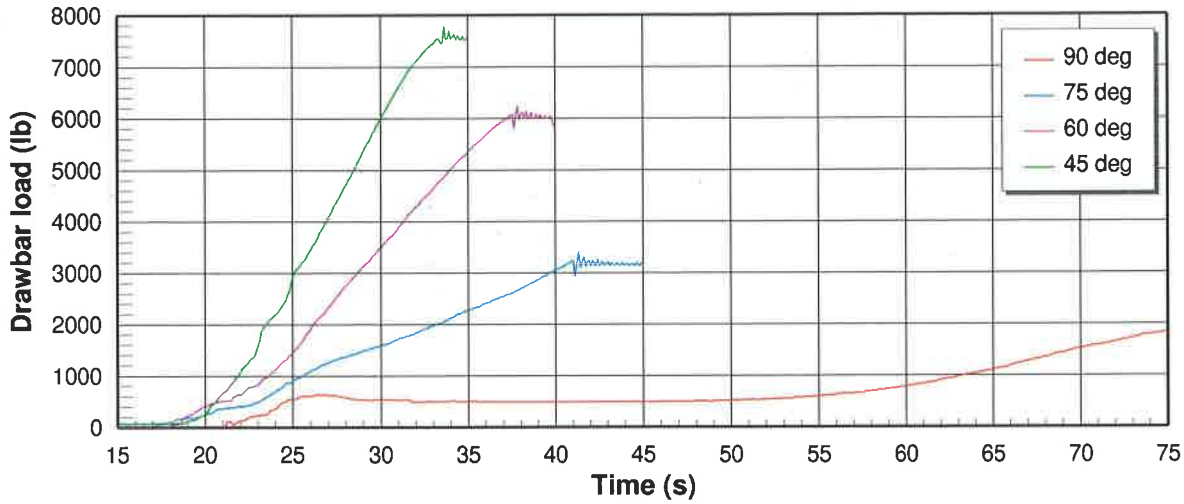
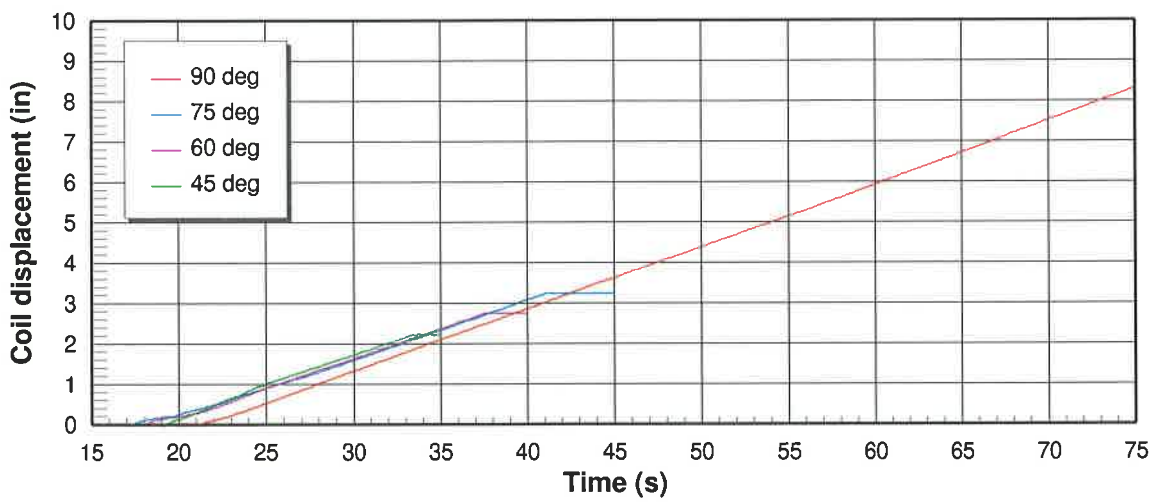


Figure 20/ Balanced chain securement setup
Lateral pull of 10,523 kg (22,300 lb) coil with two 3/8 in chains





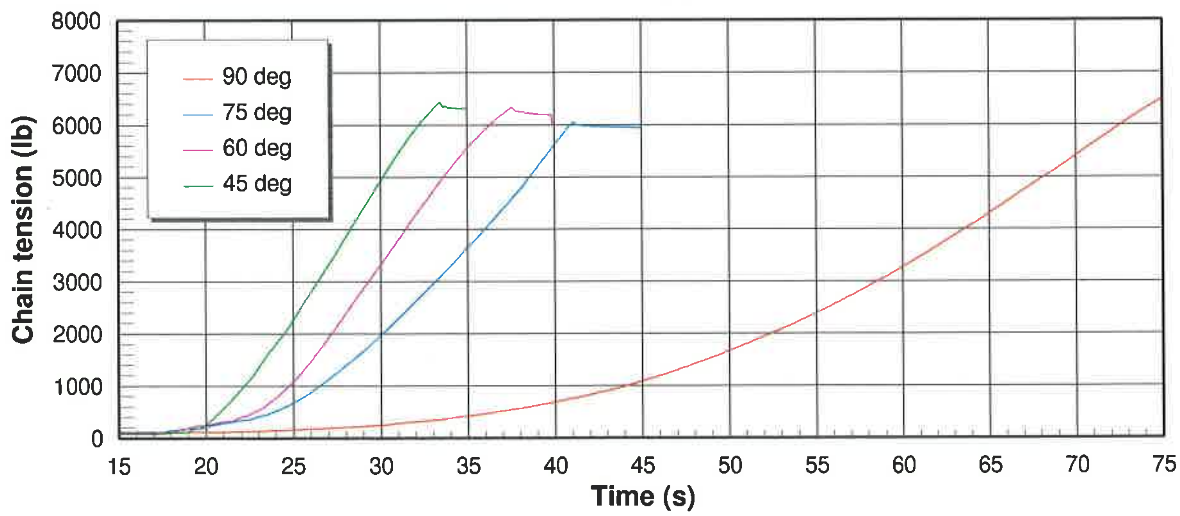


Figure 21/ Lateral pull of 20,139 kg (44,400 lb) coil on deck
Single 1/4 in grade 7 chains at 90, 75, 60 and 45 deg, initial tension of 5% of WLL

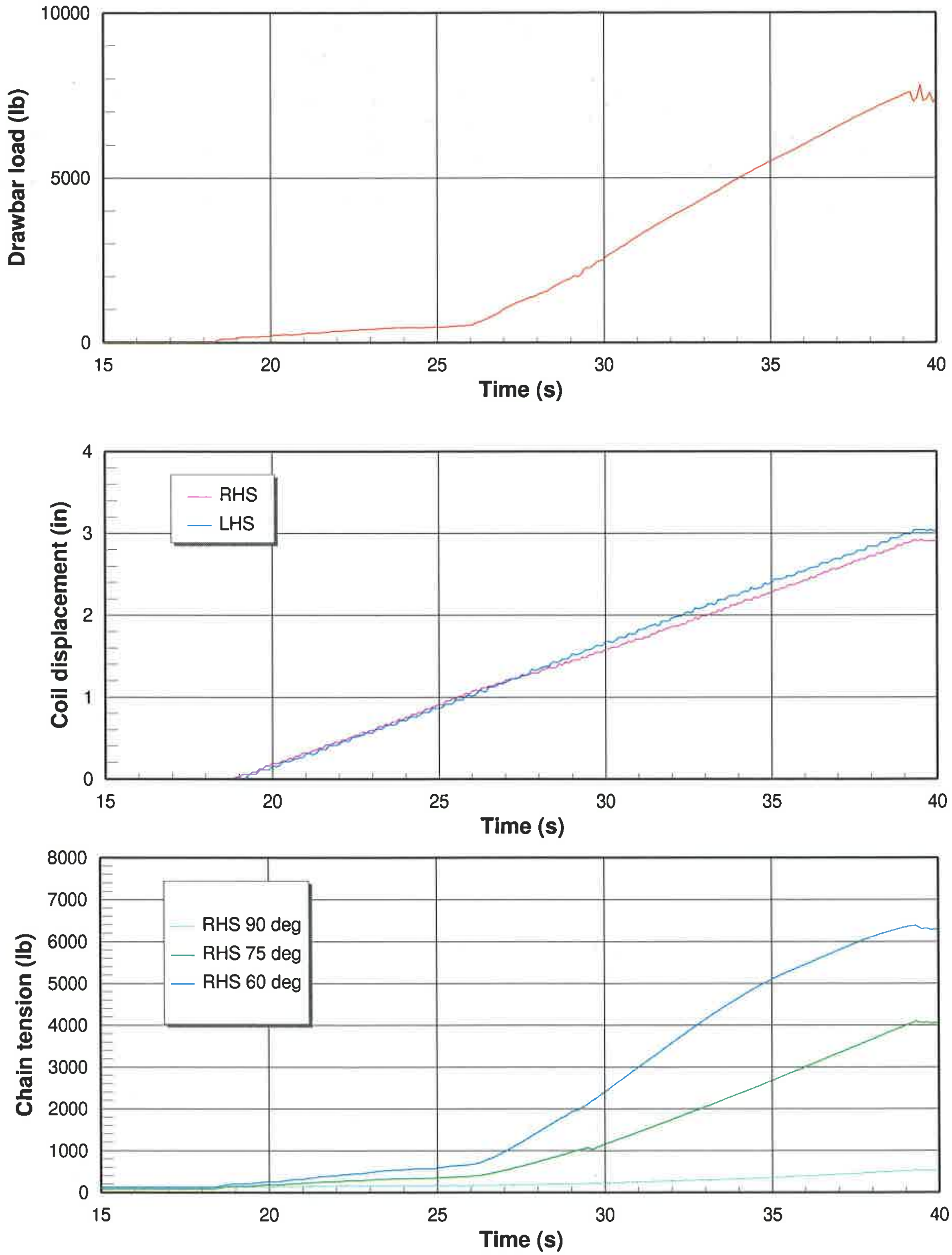


Figure 22/ Lateral pull of 20,139 kg (44,400 lb) coil on deck
Three 3/8 in grade 7 chains biassed at 90, 75 and 60 deg, initial tension of 5% of WLL

Table 7/ Resistance of biassed chain securement
Lateral pull on 20,139 kg (44,400 lb) coil for 1/4 in grade 7 chain

Chain - initial tension (% WLL)	Tiedown angle (deg)				Resistance at WLL			Resistance at 2xWLL		
	45	60	75	90	kN	lb	g	kN	lb	g
1/4 - 5%				X	3.42	770	0.017	8.13	1,828	0.041
1/4 - 5%			X		8.17	1,837	0.041	13.24	2,977	0.067
1/4 - 5%		X			15.30	3,440	0.077	26.19	5,886	0.133
1/4 - 5%	X				17.87	4,016	0.090	33.14	7,447	0.168
1/4 - 5%			X	X	7.97	1,791	0.040	15.48	3,748	0.084
1/4 - 5%		X	X		17.31	3,892	0.088	35.32	7,937	0.179
1/4 - 5%	X	X			25.56	5,746	0.129	52.45	11,788	0.265
1/4 - 5%		X	X	X	15.75	3,539	0.080	34.57	7,769	0.175
1/4 - 5%	X	X	X		28.81	6,475	0.146	62.12	13,960	0.314
1/4 - 5%	X	X	X	X	28.27	6,354	0.143	56.97	12,803	0.288

limit, chains at 75, 60 and 45 deg generated resistance of 28.81 kN (6,475 lb), almost twice the 15.75 kN (3,539 lb) of chains at 90, 75 and 45 deg. Surprisingly, four chains resulted in a slightly lower resistance than that from three chains, possibly because the chain at 45 deg was not quite as tight initially as the others. The chain at 90 deg never made a significant contribution to any of these cases.

Figure 23 shows the tiedown tensions and coil displacement for a complete pull, as drawbar load was applied and released, for balanced 3/8 in chain tiedowns with an initial tension of 50% of WLL at angles of 45 and -45 deg. The tensions in the chain at the front increased, and those in the other chain quickly decreased to zero. This test used formed steel corner protectors under the front chain to protect the edge of the eye from the chain. After the drawbar load was released, the coil had moved 2.5 cm (1 in) rearward, the chain at the rear had no tension, and the corner protector had crushed into the empty space between it and the coil, so the chain at the front lost most of its initial tension. Both chains were essentially loose.

Table 8 shows the resistance for pairs of 1/4 and 3/8 in grade 7 chains at balanced tiedown angles, for various initial tensions, in the same format as Table 7. For each of the three cases (four 1/4 in chains, two 3/8 in chains at 75 deg, and two 3/8 in chains at 45 deg), there was little difference in resistance at the chain's working load limit for initial tensions of 5% and 20% of WLL, but there was a significant drop for an initial

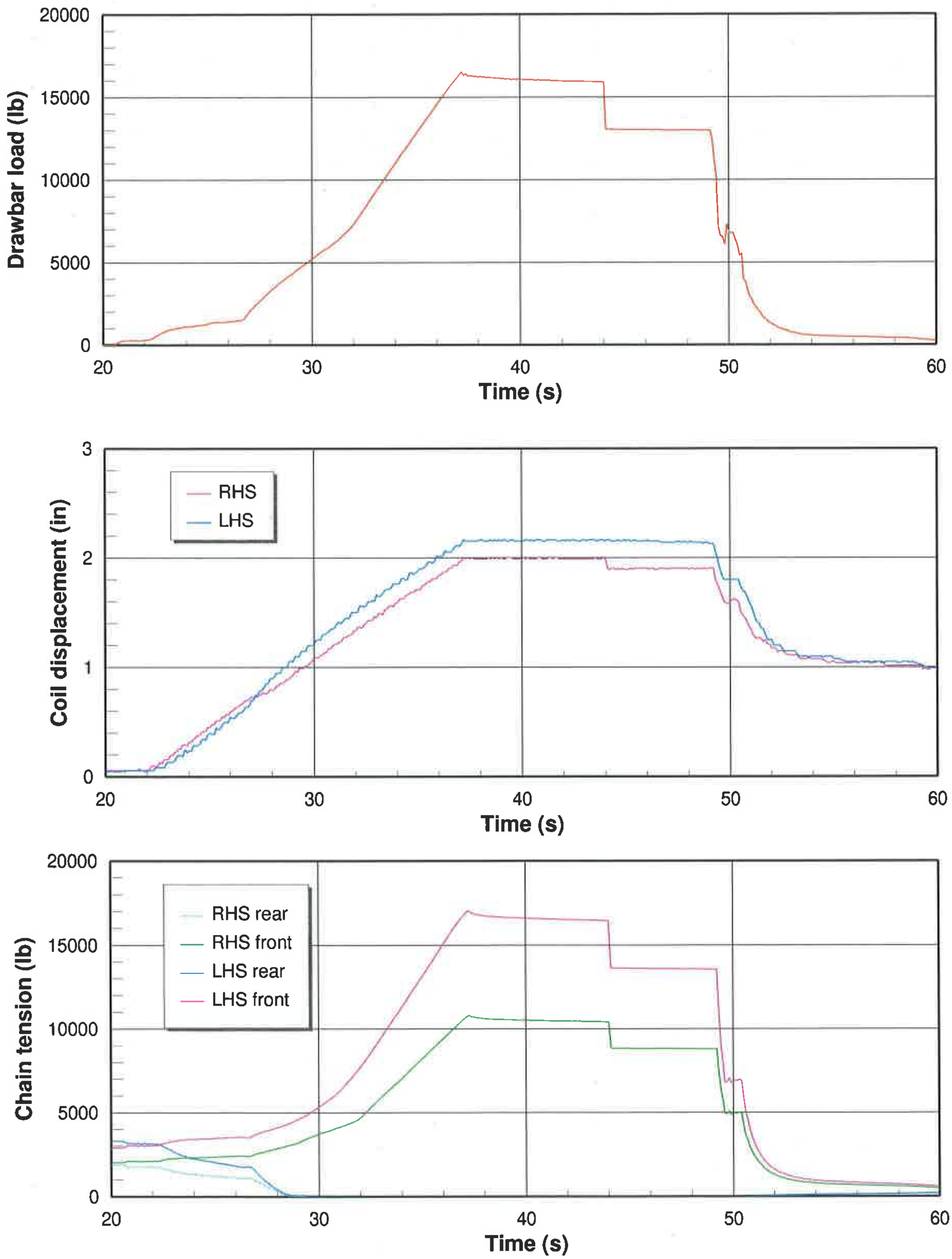


Figure 23/ Lateral pull of 10,523 kg (23,200 lb) coil on deck
Two 3/8 in grade 7 chains balanced at 45 deg, initial tension of 50% of WLL

Table 8/ Resistance of balanced chain securement
Lateral pull on 10,253 kg (23,200 lb) coil for grade 7 chains

Chain - initial tension (% WLL)	Tiedown angle (deg)				Resistance at WLL			Resistance at 2xWLL		
	45	75	-75	-45	kN	lb	g	kN	lb	g
1/4- 5%	X	X	X	X	27.56	6,193	0.267	53.93	12,118	0.522
1/4-20%	X	X	X	X	28.95	6,505	0.280	51.62	11,601	0.500
1/4-50%	X	X	X	X	20.76	4,665	0.201	47.78	10,738	0.462
3/8- 5%		X	X		25.46	5,721	0.247	48.24	10,841	0.467
3/8-20%		X	X		23.58	5,299	0.228	46.66	10,485	0.452
3/8-50%		X	X		20.06	4,508	0.194	46.85	10,529	0.454
3/8- 5%	X			X	28.72	6,455	0.278	63.36	14,240	0.58
3/8-20%	X			X	35.76	8,036	0.346	66.22	14,822	0.614
3/8-50%	X			X	25.11	5,644	0.243	61.49	13,819	0.596

tension of 50% of WLL. The reason for this was that when the tension in a chain opposite to the pull direction reached its working load limit, there was still significant tension remaining in its partner tied in the other direction. It is clear that a higher initial tension provides less margin for a tiedown to offer resistance up to some defined limit.

The tests reported in Table 8 were designed to gain insight into securement of metal coils by chains. All cases just exceed the requirement for aggregate tiedown working load limit for the coil tested [2]. The resistance is between 0.182 and 0.325 g at the working load limit. The upper limit is 80% higher than the lower limit, and is available simply by using the most effective tiedown angle and initial tension.

4.3.4/ Conclusions

The resistance provided by a chain tiedown on a metal coil depends on the angle of the tiedown to the horizontal. A tiedown at 90 deg (vertical) provides only 20% of the resistance of one at 45 deg, so the resistance for the effort required to secure a given chain may vary widely. For multiple chains, the resistance of each chain is related inversely to its tiedown angle. Where multiple small chains are used, and an extreme load occurs, the chain at the shallowest angle would break first, and the others would then be expected to break in sequence of increasing tiedown angle, a domino effect.

Corner protectors that can deform or crush under extreme load can leave the tiedowns loose after the extreme event is over.

4.4/ Resistance of Chain Securement to a Longitudinal Pull

4.4.1/ Scope

This test series examined the resistance of chain securement for a longitudinal pull, as outlined in section 12.5 of the proposal [1]. Using the 10,253 kg (23,200 lb) coil, longitudinal securement was provided by two 3/8 in grade 7 chains arranged symmetrically at roughly 45, 65, 85 and -45 deg angles to the horizontal across the coil, either straight through the coil or crossed, with a nominal initial tension of 20% of the chain working load limit. Table 9 shows the test matrix.

Table 9/ Test matrix for chain securement for a longitudinal pull

Configuration	Tiedown angle (deg)	Chain orientation
10,523 kg (23,200 lb) coil secured by two 3/8 in chains longitudinally with a nominal initial tension of 20% of WLL	45/-45	Straight
		Crossed
	65/-65	Straight
		Crossed
	85/-85	Straight
		Crossed
	-45/45	Straight
		Crossed

4.4.2/ Specialized Test Setup and Procedures

This test series used a longitudinal pull, with the coil simply placed on the deck without any blocking. The long threaded drawbar was replaced by a 1/2 in high-strength chain between the actuator and the crossmember adaptor, as shown in Figures 24 and 25. The crossmember was supported by the jib boom as shown in Figure 26, and was free to move in a horizontal plane. This setup allowed the coil to yaw as it was pulled, if it should be so inclined. Figure 27 shows a typical setup for this series, after a pull with the chains at a tiedown angle of 85 deg. The tiedowns were set with an initial tension of 20% of working load limit. The drawbar load, coil displacement and tension at each end of each chain were measured.

4.4.3/ Results

Figure 28 shows a typical time history response of drawbar load, coil displacement and

Figure 24/ Setup for longitudinal pull with chain securement 10,523 kg (23,200 lb) coil with two 3/8 in chains

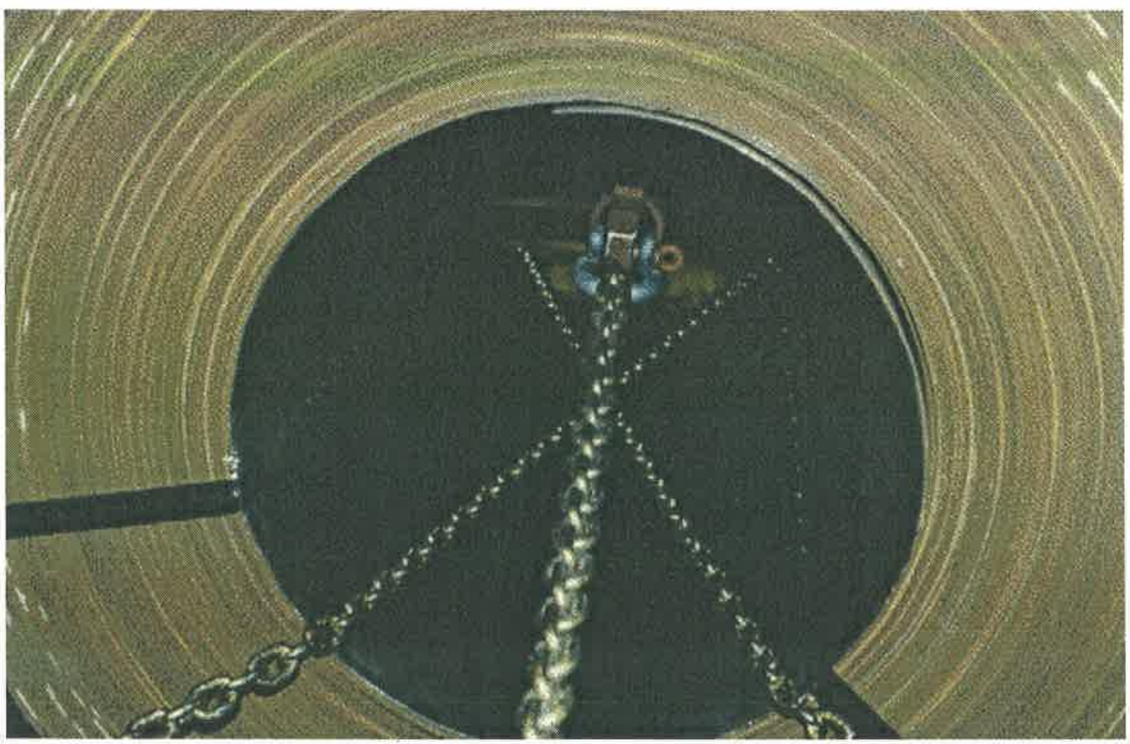


Figure 25/ Setup for longitudinal pull with chain securement 10,523 kg (23,200 lb) coil with two 3/8 in crossed chains

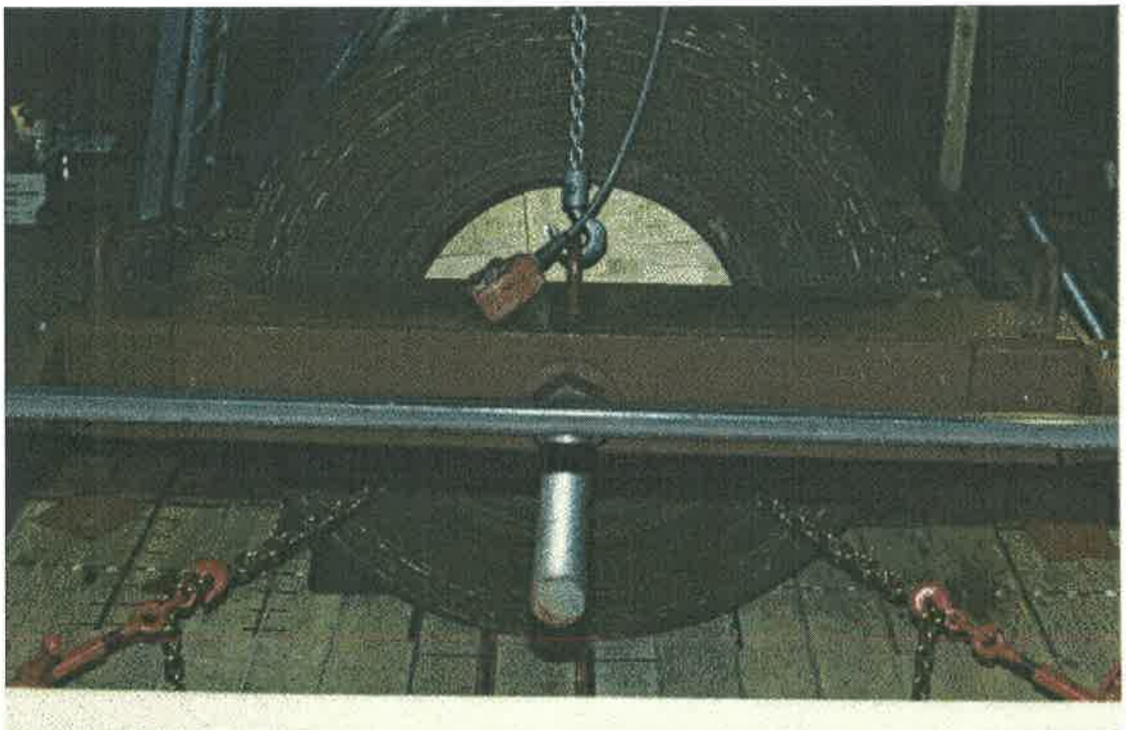


Figure 26/ Setup for longitudinal pull with chain securement
Vertical support of the front crossmember

Figure 27/ Setup after longitudinal pull with chain securement
10,523 kg (23,200 lb) coil with two 3/8 in chains at 85/-85 deg

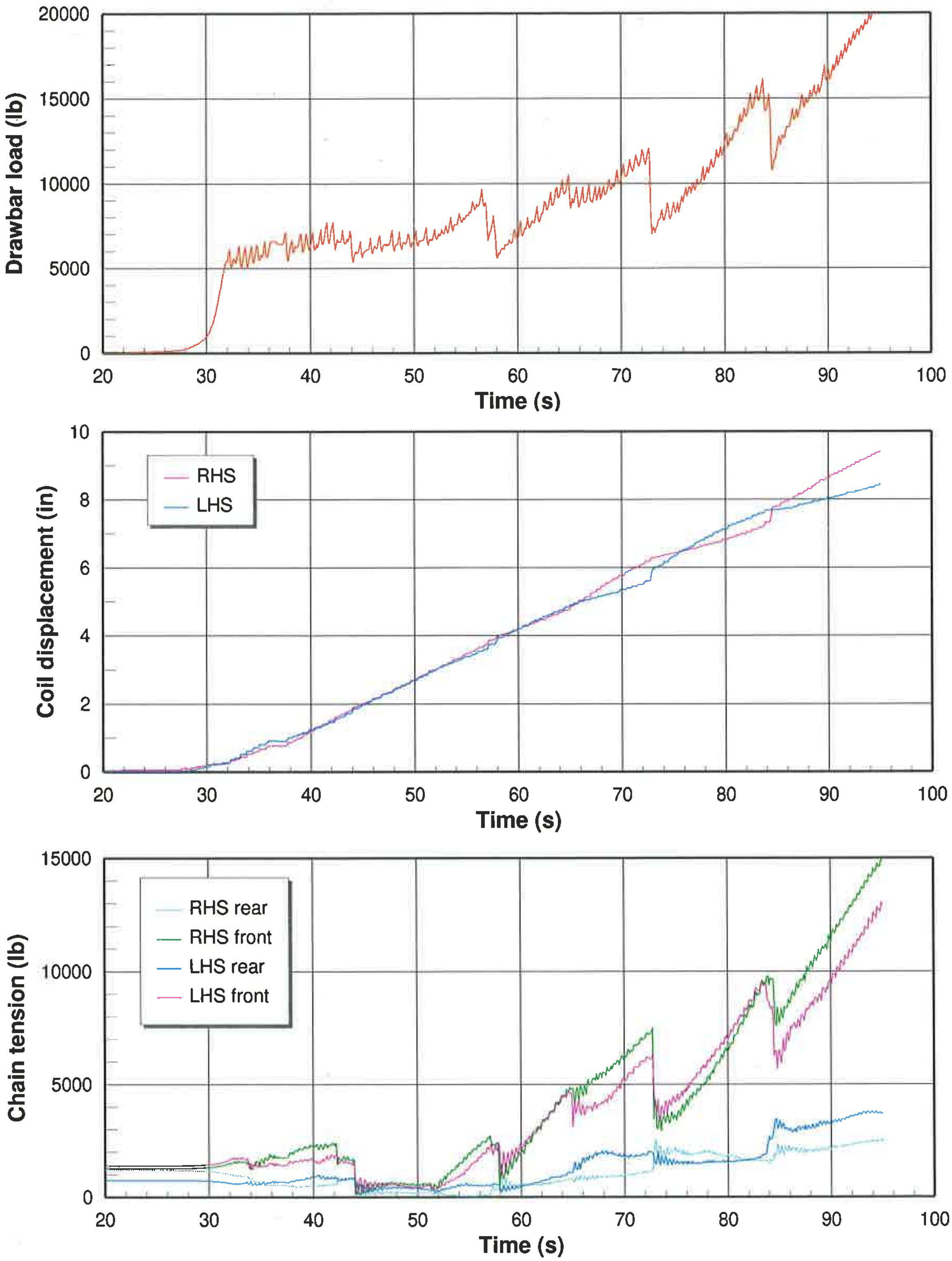


Figure 28/ Longitudinal pull of 10,523 kg (23,200 lb) coil on deck
Two 3/8 in grade 7 chains straight through eye at 65 deg, initial tension of 20% of WLL

chain tensions, for straight-through chains at a tiedown angle of 65 deg. Initially, the drawbar load increased rapidly to overcome friction between the coil and the deck. When the coil started to move, there was little increase in chain tension, and the coil slid for about 10 cm (4 in) at a net resistance in the range 26.7-31.1 kN (6-7,000 lb). At this point, chain tensions started increasing, providing more resistance, but each time a link passed over the edge of the eye, the tension was relieved. The test was terminated when the coil started to yaw after it had moved over 20 cm (8 in).

Table 10 summarizes the resistance of the chains from this series of tests, obtained from the drawbar load less the average sliding friction, reported as 23.58 kN (5,300 lb) in Table 2 for this coil. Equivalent accelerations were computed directly from the weight of the coil, as the jib boom supported the cross-member, not the coil.

Table 10/ Resistance of chain securement to longitudinal pull 10,523 kg (23,200 lb) coil, no blocking, 20% initial tension

Tiedown angle (deg)	Chain Orientation	Resistance					
		at WLL			at 2xWLL		
		kN	lb	g	kN	lb	g
45/45 deg	Straight	31.48	7,075	0.305	58.41	13,126	0.566
	Crossed	28.27	6,351	0.274	63.07	16,173	0.697
65/65 deg	Straight	22.78	5,120	0.221	58.10*	13,056*	0.563
	Crossed	37.53	8,433	0.363	61.76	15,878	0.684
85/85 deg	Straight	16.83	3,781	0.163	44.19	9,930	0.428
	Crossed	14.46	3,249	0.140	40.40	9,078	0.391
-45/-45 deg	Straight	25.66*	5,764*	0.248	21.67*	4,871*	0.296
	Crossed	35.18	7,905	0.341	71.70	16,114	0.781

* Coil started to yaw

4.4.4/ Conclusions

While it is not clear whether straight or crossed chains are preferred, the tiedown angle should not exceed 65 deg.

4.5/ Friction of Cradle for a Lateral Pull

4.5.1/ Scope

This test series investigates the resistance of cradle formed of steel bunks and hardwood blocks, carrying a coil, to a lateral pull, as outlined in section 12.7 of the proposal [1]. The tests examined the friction between the cradle and the deck, dry and wet, as well as with rubber mats between the cradle and the dry deck. The second half of the series examined the effect of different types of rubber material between the coil and the block with the cradle secured to prevent movement. The complete test matrix is shown in Table 11.

Table 11/ Test matrix for resistance of coil on cradle to a lateral pull

	Deck Surface Condition (Cradle unsecured)			Interface between Coil and Block (Cradle secured)		
Interface Orientation	**Dry**	**Wet**	**Rubber Mat**	**Conveyor Belt**	**Tire tread**	**Rubber Mat**
None	X	X	X			
Parallel				X	X	X
Perpendicular				X	X	

4.5.2/ Specialized Test Setup and Procedures

This test series used a cradle constructed from three steel bunks and two 10x10 cm (4x4 in) bevelled blocks, and the 10,523 kg (23,200 lb) coil, all set up for a lateral pull, as shown in Figure 29. The surface condition of the test deck or the blocks was prepared with the coil lifted by the overhead crane, which allowed the appropriate interface material to be introduced. The cradle was secured using two spacers placed between the block and the transverse tiedown rail at the rear of the test rig, as seen in Figure 30. Drawbar load, and coil and bunk displacements were measured.

4.5.3/ Results

Table 12 summarizes the resistance of the various surface conditions. With the cradle unsecured, the coil and cradle assembly started sliding when static friction between the bunks and the dry deck was overcome, equivalent to a static friction coefficient of 0.31. This value is consistent with the result obtained for steel pads on coarse oak [3], and the value obtained for the coil in Section 4.1. When rubber mats were inserted between each bunk and the deck, the static friction coefficient increased to 0.35. However, when the deck was wet, friction was high enough to prevent the cradle sliding, and the

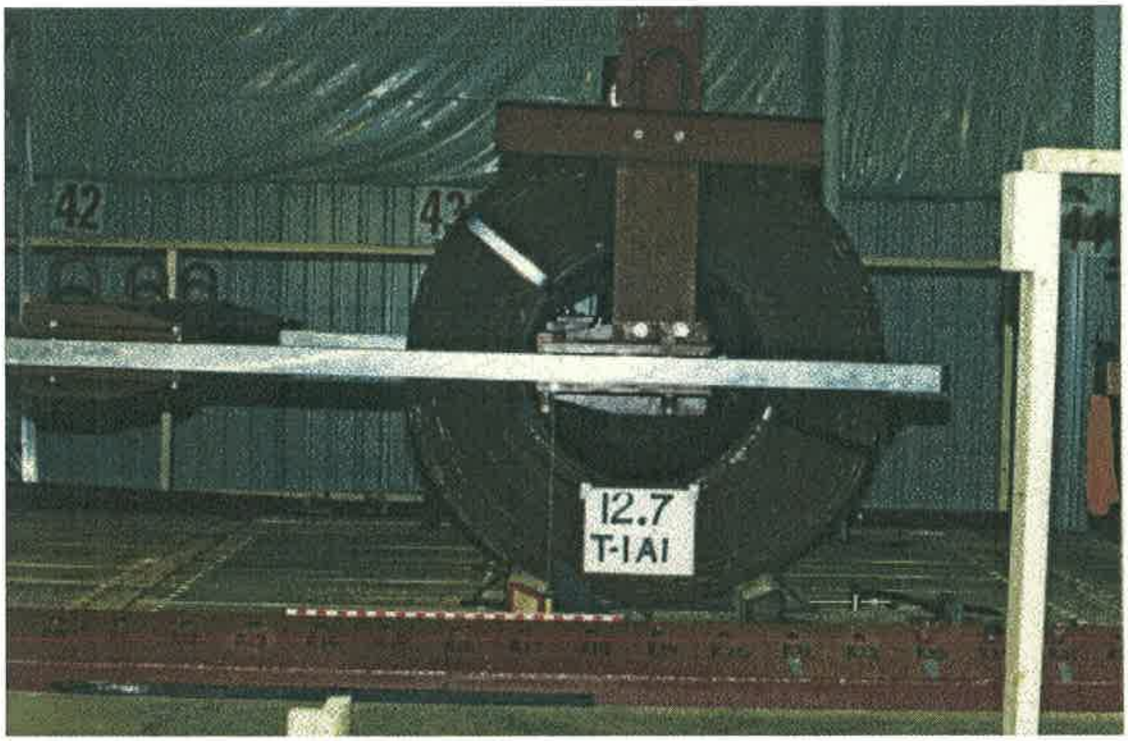


Figure 29/ Setup for friction of cradle
Lateral pull for 10,523 kg (23,200 lb) coil

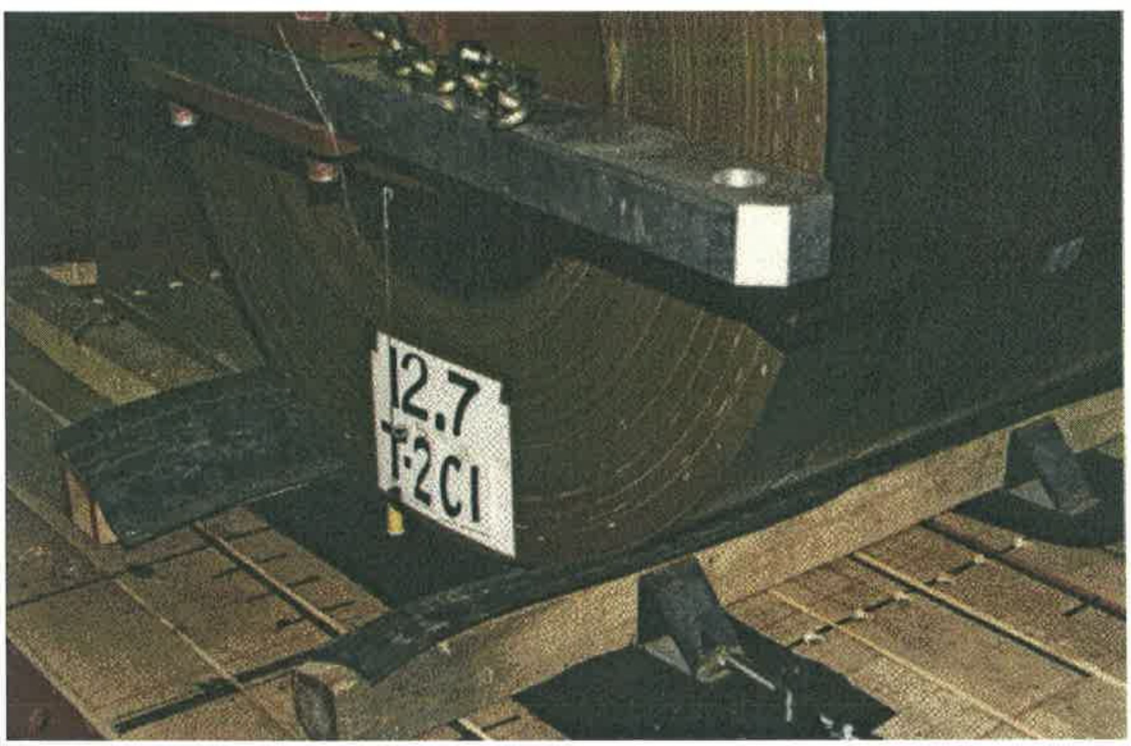


Figure 30/ Setup for friction of cradle with cradle secured
Lateral pull for 10,523 kg (23,200 lb) coil with used tire treads on blocks

Table 12/ Effect of interface condition on friction for coil in cradle
Lateral pull of 10,523 kg (23,200 lb) coil

		Resistance		
Cradle	**Interface**	**kN**	**lb**	**g**
Unsecured	Dry	33.68*	7,568*	0.306
	Wet	44.44	9,988	0.404
	Rubber mat	38.11*	8,564*	0.347
Secured	Conveyor belt along blocks	45.02	10,116	0.409
	Tire tread along blocks	44.77	10,063	0.407
	Rubber mat along blocks	43.20	9,710	0.393
	Conveyor belt across blocks	45.08	10,131	0.410
	Tire tread across blocks	44.69	10,045	0.407

* Coil and cradle slid as a unit along the deck surface.

coil climbed up the bevelled block in a manner similar to that with secured blocking, reported in Table 4, at a drawbar load equivalent to 0.40 g. When the cradle was secured, the resistance was largely unaffected by the friction material inserted between the coil and the block, and was comparable to the results for secured blocking, presented in Table 4.

4.5.4/ Conclusions

When an unsecured cradle is subjected to an external acceleration, the cradle will slide if the coefficient of friction between the cradle and deck is less than the resistance of the block, otherwise the coil will roll out of the cradle.

None of the friction materials placed between the coil and the block affected the resistance of the block

4.6/ Resistance of Coil in Cradle with Chains to Lateral Pull

4.6.1/ Scope

This test series investigated the resistance of a coil secured with chains in an unsecured cradle to a lateral pull, as outlined in section 12.8 of the proposal [1]. The cradle was constructed from two 10x10 cm (4x4 in) bevelled blocks placed within three equally spaced steel bunks. Tiedowns were provided either by a single 3/8 in grade 7 chain, or two such chains at equal and opposite angles. The effect of initial tension was also examined. Each configuration was repeated by adding conveyor belts parallel to the blocks, between the coil and the blocks. Table 13 shows the test matrix.

Table 13/ Test matrix for resistance of coil in an unsecured cradle with chains

Interface	Chains	Initial tension (%WLL)	Tiedown angle (deg) 45	90
None	1x3/8 in	0	X	
		20		X
		50		X
	2x3/8 in	20	X	
		50	X	
Conveyor belt along blocks	1x3/8 in	0	X	
		20		X
		50		X
	2x3/8 in	20	X	
		50	X	

4.6.2/ Specialized Test Setup and Procedures

The 20,139 kg (44,400 lb) coil was used in a lateral pull as described in Section 4.5. The conveyor belt was inserted between the coil and the blocks by using the overhead crane to raise the coil from the cradle. The tiedowns were tightened from the right-hand side. Figure 31 shows a typical test setup.

4.6.3/ Results

Figure 32 shows a typical pull, using two 3/8 in chains at 45 deg with an initial tension of 20% of WLL, and with a conveyor belt interface between the coil and blocks. The drawbar load initially moved the coil forward about 1.25 cm (0.5 in), probably closing up

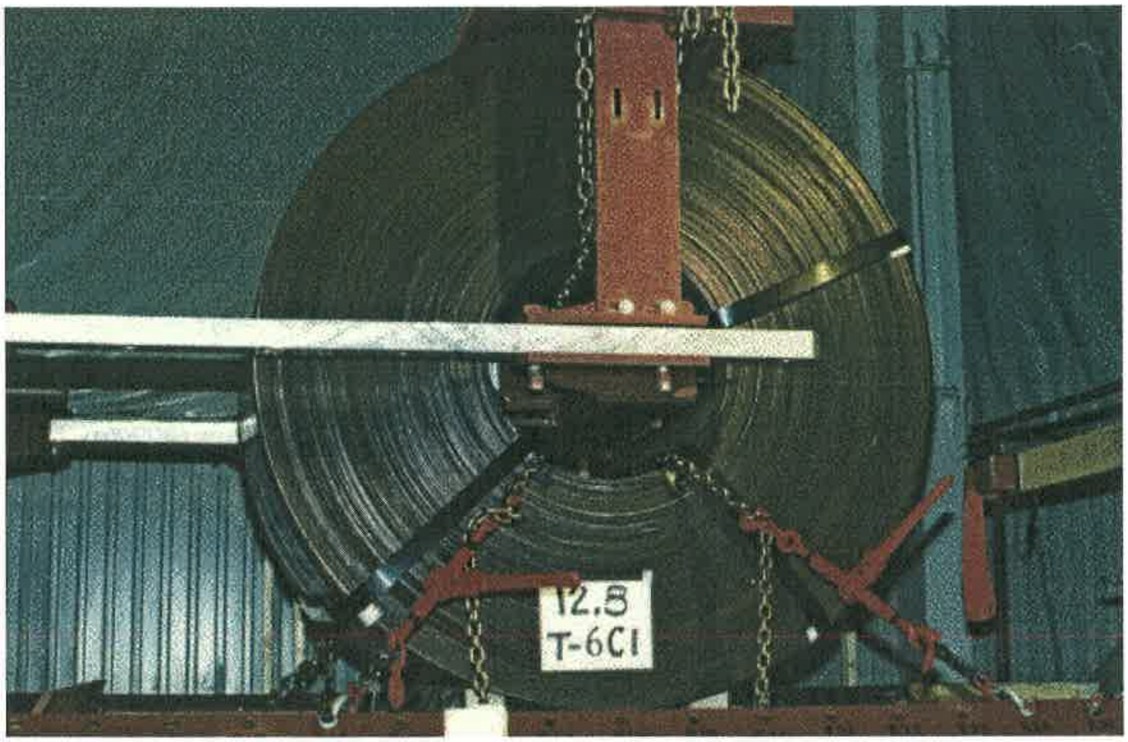


Figure 31/ Setup for lateral pull with unsecured cradle and tiedowns 20,139 kg (44,400 lb) coil with two 3/8 in chains

the interface and any free play in the cradle components, and without any significant change in chain tensions. From here, the drawbar load increased rapidly to about 62.3 kN (14,000 lb), with the 45 deg chain providing resistance, and the other chain slackening off. At this point, the left-hand side of the cradle slipped about 0.02 cm (0.007 in), which slightly relieved the tension in the chain. The pull continued, with two more minor slips on the left-hand side of the cradle, until the chain reached twice its working load limit. The coil at this point had moved rearward about 5 cm (2 in), but had not visibly lifted off the cradle.

Table 14 summarizes the results of the combined resistance of a coil in a cradle with chain tiedowns for various configurations, with the equivalent acceleration based simply on the mass of the coil. In some cases, mostly with a tiedown angle of 90 deg, the coil lifted off the block opposite the pull direction. However, the cradle never slipped more than about 0.08 cm (0.03 in) in any of these pulls, or any other pull. It is may or may not be coincidental that the slip always occurred on the left-hand side, which is the opposite side from which the tiedowns were tensioned, and would be the side with the lower initial tension. However, the slip never equalized tensions on both sides of the coil. These results show again that a tiedown angle of 45 deg is much more effective than a tiedown angle of 90 deg. While the initial tension in the chain had less effect on the overall resistance than found in Section 4.3, there was almost always less capacity with an initial tension of 50% of WLL compared with 20%. Adding friction material between the coil and blocks had no effect on the resistance of cradle and tiedown.

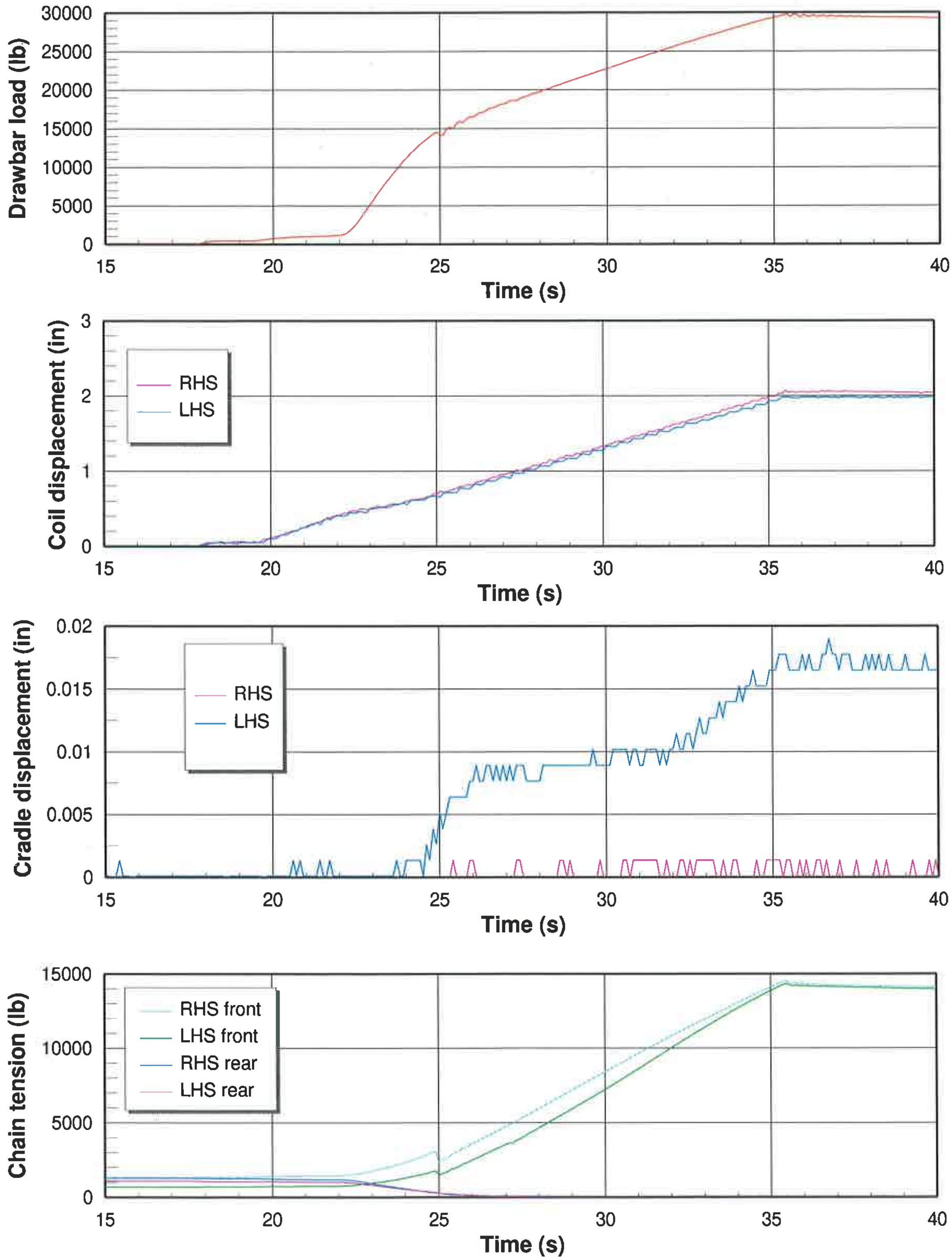


Figure 32/ Lateral pull of 20,139 kg (44,400 lb) coil on conveyor belts, unsecured cradle
Two 3/8 in grade 7 chains at 45 deg, initial tension 20% of WLL

Table 14/ Resistance of coil in an unsecured cradle with chains
Lateral pull of 20,139 kg (44,400 lb) coil

Chains, interface	Tiedown angle (deg)	Initial tension (% WLL)	Resistance at WLL			Resistance at 2xWLL		
			kN	lb	g	kN	lb	g
1x3/8 in	45	0	89.78	20,176	0.454	123.54	27,764	0.625
	90	20	67.72	15,219	0.343	73.05	16,415	0.370
	90	50	67.34	15,133	0.341	74.86	16,823	0.379
2x3/8 in	45/-45	20	90.88	20,423	0.460	126.66	28,465	0.641
	45/-45	50	86.82	19,511	0.439	127.32	28,614	0.644
1x3/8 in, conveyor belt along blocks	45	0	92.42	20,769	0.468	121.35	27,271	0.614
	90	20	67.66	15,205	0.342	70.35	15,810	0.356
	90	50	69.04	15,517	0.349	75.11	16,879	0.380
2x3/8 in conveyor belt along blocks	45/-45	20	91.13	20,481	0.461	125.21	28,138	0.633
	45/-45	50	81.64	18,346	0.413	120.54	27,089	0.610

As found in Section 4.5, a static friction coefficient of about 0.3 for the cradle provides resistance of about 61.3 kN (13,800 lb). From Section 4.2, the blocking resistance is probably at a little less than this, and indeed in these tests, the coil was always tending to lift off, the cradle never slipped seriously. From Section 4.3, two 3/8 in chains at 45 deg with an initial tension of 20% of WLL provide resistance of about 35.6 kN (8,000 lb). Combining the blocking resistance and chain resistance produces a reasonable correlation with the results in Table 14.

4.6.4/ Conclusions

In this case, the resistance of friction between the cradle and deck exceeded the resistance of blocking, so the coil tended to lift off rather than the cradle slide. However, in the inverse case, if the cradle started sliding, the chains would need to arrest the coil and cradle. Presence of a rubber mat between the coil and blocks had no effect on the resistance for a lateral pull.

The separate resistance of friction, blocking and tiedowns appear to combine to the total resistance found in this test.

4.7/ Friction of Coil in Secured Cradle for a Longitudinal Pull

4.7.1/ Scope

This test series measured the friction between the coil and blocks for a longitudinal pull with the 20,139 kg (44,400 lb) coil in a secured cradle, under various surface conditions, as outlined in Section 12.9 of the proposal [1]. It examined the effect of block length in comparison to the width of the coil, with lengths of 75, 100 and 125% of the coil width, the effect of dry, wet and oily block surfaces, and the effect of friction materials, such as rubber mat, old tire tread and conveyor belt strips. Table 15 shows the test matrix.

Table 15/ Test matrix for friction of coil in secured cradle for longitudinal pull

		Interface between coil and block					
Interface condition	Block (% coil width)	None	Rubber mat	Used tire tread		Conveyor belt	
				Parallel	Perp	Parallel	Perp
Dry	75	X					
	100	X					
	125	X	X	X	X	X	X
Wet	75	X					
	100	X					
	125	X	X	X	X	X	X
Oily	100	X					
	125					X	

4.7.2/ Specialized Test Setup and Procedures

This test series used the 20,139 kg (44,400 lb) coil on 10x10 cm (4x4 in) bevelled blocks in a cradle, set up for a longitudinal pull. The cradle was secured longitudinally by nailing a pair of 5x10 cm (2x4 in) cleats to the deck at each end of the first bunk, with similar spacers between consecutive bunks, as seen in Figure 33. Each interface or condition was applied with the coil lifted by the overhead crane. The drawbar load and displacement of the coil were measured.

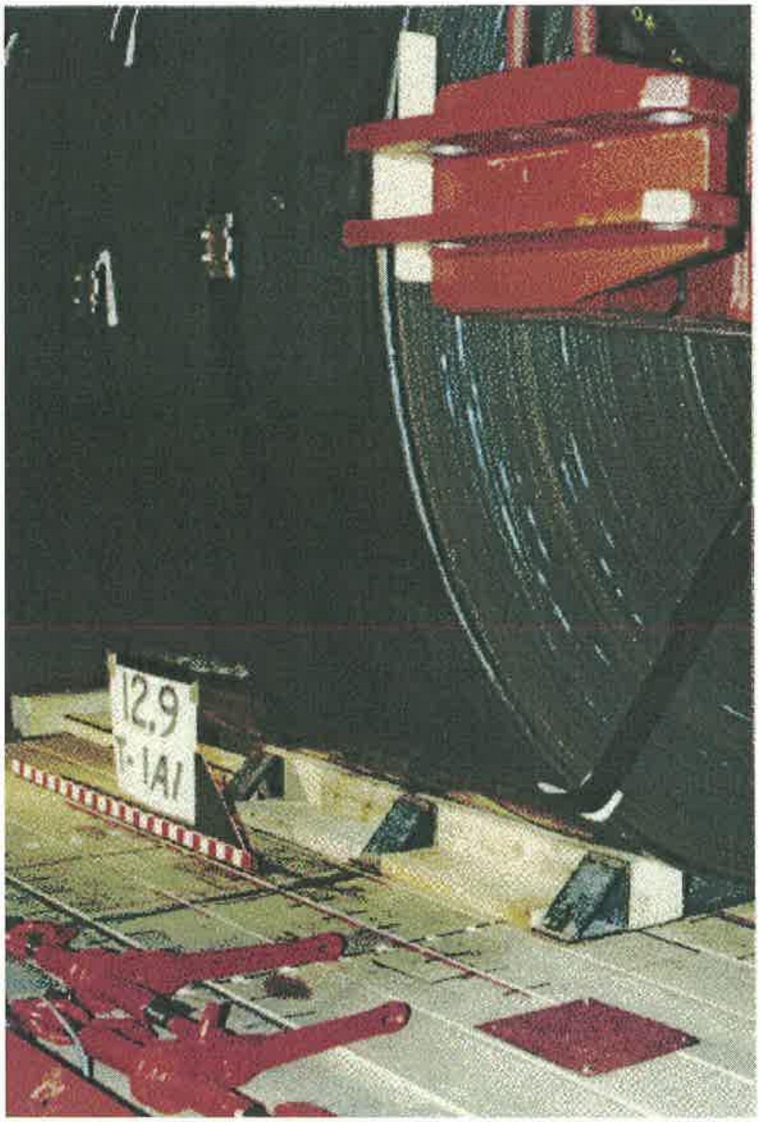


Figure 33/ Setup for friction of coil in secured cradle
Longitudinal pull of 20,139 kg (44,400 lb) coil

4.7.3/ Results

Table 16 summarizes the resistance for three lengths of blocking and three block surface conditions. Coefficients of friction were computed using adding 680 kg (1,500 lb) to the weight of the coil to recognize the weight of added test equipment. On the dry block surface, there appeared to be a small decrease in static friction between the coil and the block when the block length was increased. No regular pattern was evident when the block surface was wet. The reason that the slide friction was higher than the static friction for the wet surface was due to significant slip-stick vibration during the pull process after the initial peak with the shorter block lengths, as shown in the typical response in Figure 34. The coil also yawed slightly as it was pulled, as seen by the difference in the displacement measurements.

Table 16/ Effect of block length and surface conditions on friction
Longitudinal pull of 20,139 kg (44,400 lb) coil on secured cradle

Block Surface	Type	Resistance for block length (% of coil width)								
		75 %			100 %			125 %		
		kN	lb	μ	kN	lb	μ	kN	lb	μ
Dry	Static	45.44	10,211	0.222	41.79	9,392	0.205	38.59	8,674	0.189
	Slide	36.04	8,099	0.176	35.55	7,989	0.174	36.93	8,300	0.181
Wet	Static	36.92	8,298	0.181	45.82	10,298	0.224	37.27	8,376	0.182
	Slide	39.99	8,985	0.196	46.23	10,390	0.226	34.44	7,740	0.167
Oily	Static				42.95	9,652	0.210			
	Slide				32.94	7,403	0.161			

Table 17/ Effect of interface material and surface conditions on friction
Longitudinal pull of 20,139 kg (44,400 lb) coil on secured cradle

Interface	Condition	Resistance					
		Static			Slide		
		kN	lb	μ	kN	lb	μ
Rubber mat	Dry	60.98	13,705	0.299	58.6	13,168	0.287
	Wet	42.09	9,460	0.206	42.09	9,460	0.206
Used tire tread along blocks	Dry	76.13	17,108	0.373	72.46	16,284	0.355
	Wet	54.15	12,170	0.265	65.84	14,798	0.322
Used tire tread across blocks	Dry	59.31	13,330	0.290	52.87	11,880	0.259
	Wet	36.93	8,300	0.181	40.79	9,166	0.200
Conveyor belt along blocks	Dry	42.78	9,615	0.209	52.17	11,725	0.255
	Wet	32.29	7,257	0.158	40.06	9,004	0.196
	Oily	11.72	2,635	0.057	16.37	3,680	0.080
Conveyor belt across blocks	Dry	51.74	11,627	0.253	45.67	10,262	0.224
	Wet	28.14	6,324	0.138	28.66	6,440	0.140

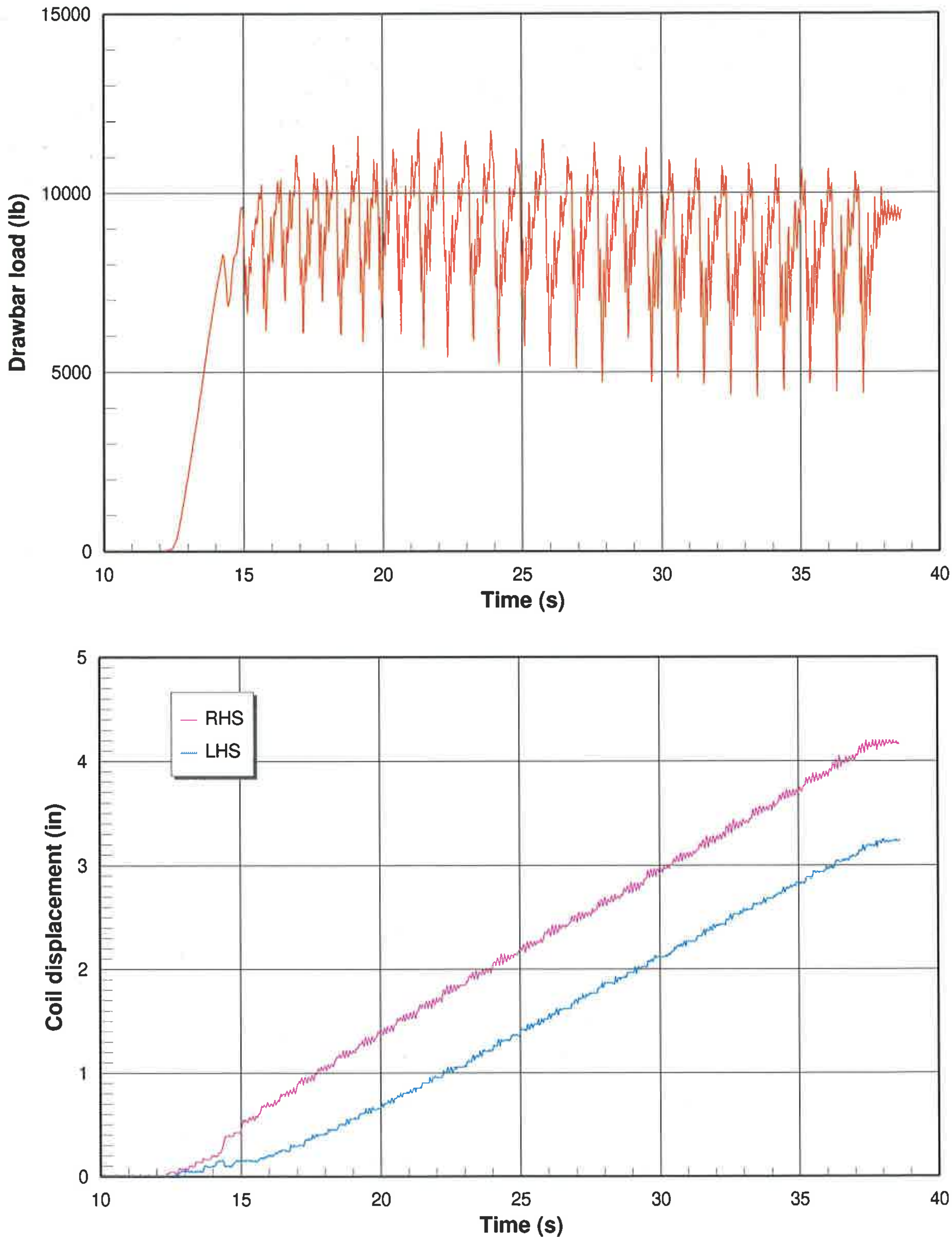


Figure 34/ Longitudinal pull of 20,139 kg (44,400 lb) coil on secured cradle
Wet 4x4 in bevelled blocks, 75% length of coil

Table 17 summarizes the friction forces between the coil and the cradle with various materials in the interface to increase the coefficient of friction. With a dry interface, the highest resistance was obtained using the old tire tread placed along the block. When the interface was wet, the resistance was significantly reduced for all friction materials examined. When the conveyor belt surface was contaminated with oil, the resistance was drastically reduced. In some cases, the slide friction was apparently higher than the static friction, because the bands on the coil cut into the friction material as the coil slid, and dragged the friction material with it along the block. This distorted the bands, though none in fact broke. In one instance, a coil was sliding on the hardwood blocks and a band caught in the wood and broke. If a coil was less securely banded than this coil, it could telescope. The presence of the soft friction material could help in this regard, as the band would be more likely to gouge the rubber and allow the coil to continue sliding, rather than hanging up and breaking.

4.7.4/ Conclusions

Coefficients of friction of metal coils on hardwood blocks for a longitudinal pull are quite low, around 0.20. They are slightly improved if the block is shorter than the coil, possibly due to the higher pressure, as found in other tests [3]. They are significantly improved by use of a high-friction interface between the coil and block. The friction material is more effective along the entire length of the blocks, rather than in narrow strips across the blocks. The effectiveness of friction material is somewhat reduced when it is wet, and significantly reduced when the coil or interface is oily.

4.8/ Friction of Unsecured Cradle for a Longitudinal Pull

4.8.1/ Scope

The purpose of this series of tests was to measure the friction between the cradle and deck for a longitudinal pull, as outlined in section 12.10 of the proposal [1], with a dry and wet oak deck, as well as a rubber mat with either a dry, wet or oily surface inserted between the cradle and the deck. Table 17 shows the test matrix.

Table 17/ Test matrix on cradle-deck friction
10,523 kg (23,200 lb) coil secured to cradle

	Interface between Bunk and Deck		
Interface	**Dry**	**Wet**	**Oily**
Wood deck	X	X	
Rubber mat	X	X	X

4.8.2/ Specialized Test Setup and Procedures

This test series applied a longitudinal pull to the 10,523 kg (23,200 lb) coil, using a setup similar to that of the previous test series. However, the cradle was unrestrained, and the coil was secured to the cradle by 5x10 cm (2x4 in) cleats nailed to the blocks at the rear of the coil on both sides, and chains, as shown in Figure 35. The interface condition was applied with the coil raised using the overhead crane. The drawbar load and coil and cradle displacements were measured.

4.8.3/ Results

Figure 36 shows the drawbar load and displacements with rubber mats between the cradle and the deck. As the drawbar load was applied, the coil started slipping along the cradle, but the cradle only started to move when the free play in its securement tightened up. The cradle initially slipped over the mat, then dragged it along the deck.

Table 19 summarizes the friction between the cradle and deck for the various interface conditions. Coefficients of friction were again computed with 680 kg (1,500 lb) added to the weight of the coil to recognize the weight of test equipment. Again, the wet deck provided higher friction than the dry deck, and a rubber mat also provided a significant increase in friction, dry or wet. With the dry or wet rubber mat, the cradle initially slid on the mat, but then dragged it along the deck, possibly because the bunks were indented into the mat. However, when the upper surface of the mat was oily, the cradle slid on the mat, which remained stationary on the deck, and friction was reduced about by half.

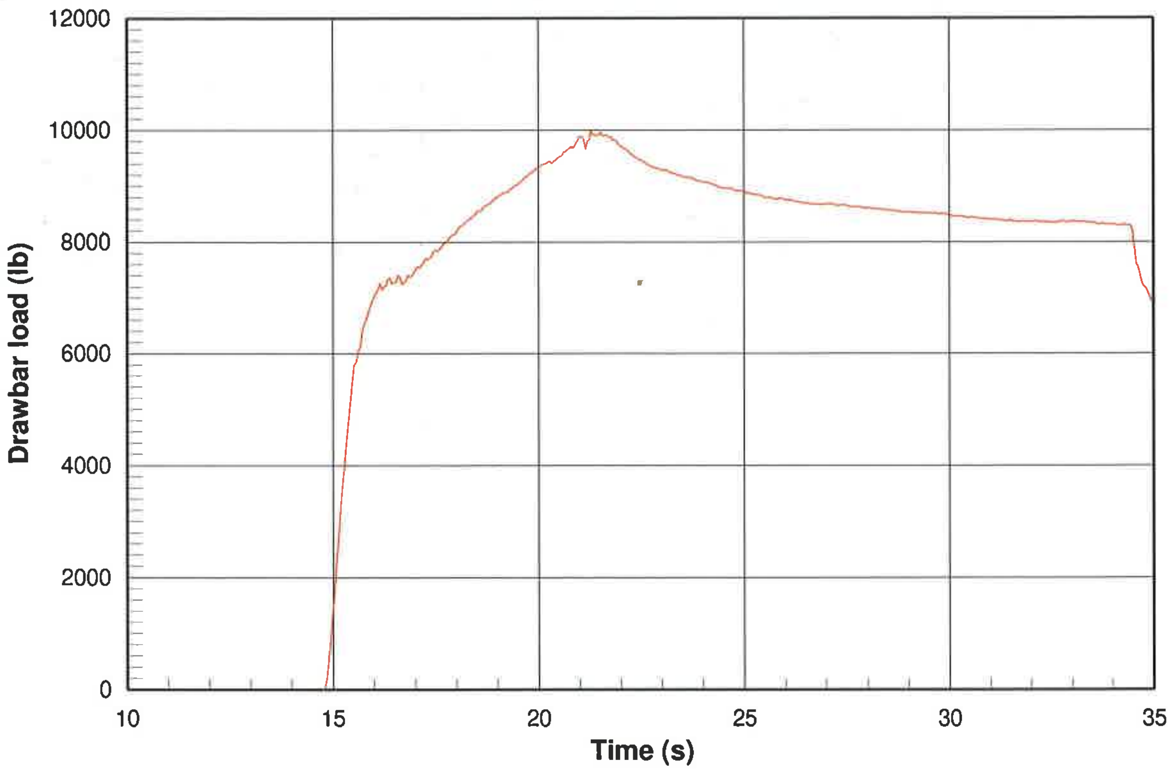
**Figure 35/ Setup for friction of coil secured to unsecured cradle
Longitudinal pull of 20,139 kg (44,400 lb) cradle on rubber mats**

**Table 19/ Effect of interface material and surface conditions on friction
Longitudinal pull of 10,523 kg (23,200 lb) coil secured to unsecured cradle**

Interface	Condition	Resistance					
		Static			Slide		
		kN	lb	μ	kN	lb	μ
None	Dry	35.92	8,073	0.327	27.09	6,088	0.246
	Wet	56.09	12,606	0.510	34.71	7,799	0.316
Rubber mat	Dry	44.60	10,023	0.406	37.33	8,388	0.340
	Wet	44.50	10,000	0.405	38.79	8,717	0.353
	Oily	22.41	5,036	0.204	14.81	3,330	0.135

4.8.4/ Conclusions

Placing the cradle on rubber mats significantly increases friction between the cradle and the deck. However, friction is significantly reduced if the mats are oily.



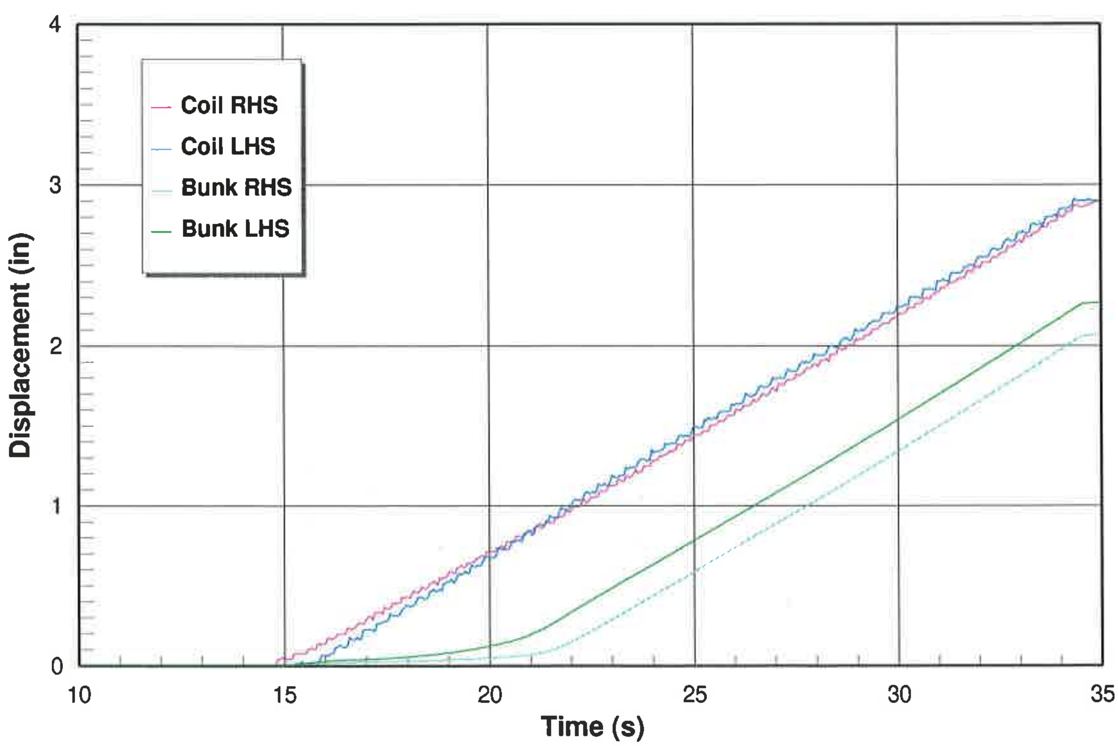


Figure 36/ Longitudinal pull of 10,523 kg (23,200 lb) coil in unsecured cradle
Coil secured to cradle, cradle on rubber mats

4.9/ Resistance of Coil in Cradle with Steep Angle Chains to Longitudinal Pull

4.9.1/ Scope

The objective of this test series was to measure the combined effect of friction and tiedowns at an angle of about 85 deg on the resistance of a coil in a cradle to a longitudinal pull, as outlined in section 12.11 of the proposal [1]. Tiedown was provided either by four 1/4 in or two 3/8 in grade 7 chains arranged in pairs with equal and opposite angles, either straight through the eye, or crossed. Three initial tensions were examined for each securement configuration. Table 20 shows the test matrix.

Table 20/ Test matrix for resistance of coil in cradle with steep angle chains 10,523 kg (23,200 lb) coil for longitudinal pull

Chains	Chain Orientation	Initial tension (% WLL)		
		5 %	20 %	50 %
4 x1/4 in	Straight	X	X	X
	Crossed	X	X	X
2 x 3/8 in	Straight	X	X	X
	Crossed	X	X	X

4.9.2/ Specialized Test Setup and Procedures

This test used a longitudinal pull with the 10,523 kg (23,200 lb) coil in a cradle assembly using 10x10 cm (4x4 in) bevelled blocks, and 1/4 in or 3/8 in grade 7 chains at a tiedown angle of about 85 deg, as shown in Figure 37. Because of the length of the ratchet binder, shackles and strain gauged chain links, it was necessary to install these in the front of the coil and pull away from the side at which the tension was applied. The drawbar load, coil and cradle displacement, and tensions at each end of each chain were measured.

4.9.3/ Results

Figure 38 shows a typical time history of drawbar load, chain tensions and coil and cradle movement, for two 3/8 in grade 7 straight-through chains. After overcoming the initial friction, the coil started sliding along the blocks, and the drawbar load fluctuated with the chain tensions as chain links rolled over into the eye of the coil. The cradle stayed essentially stationary, but the coil moved over 25.4 cm (10 in) during the test.

Table 21 summarizes the results from this series of tests. The equivalent accelerations

Figure 37/ Setup for longitudinal pull of coil in unsecured cradle 10,523 kg (23,200 lb) coil with 3/8 in chain tiedowns at steep angle

are based directly on the mass of the coil. Again, the tiedowns just exceed the current requirement for aggregate capacity [2]. In all cases, the coil moved 25.4 cm (10 in) or more during a test, but the cradle stayed essentially still. This was expected, as coil-bunk friction was found to be less than cradle-deck friction in Sections 4.7 and 4.8. There was no clear pattern between initial tension and resistance. Crossed chains gave higher resistance at the two lower initial tensions than for straight through chains.

These results appear reasonably consistent with those obtained by combining a coefficient of friction of about 0.2, from Table 16, with the chain resistance from Table 10.

4.9.4/ Conclusions

While crossed chains may be slightly superior to straight through chains for this case, higher resistance is available with lower tiedown angles.

Combining the separate resistances of friction and tiedowns from earlier tests matches reasonably the resistance of this test.

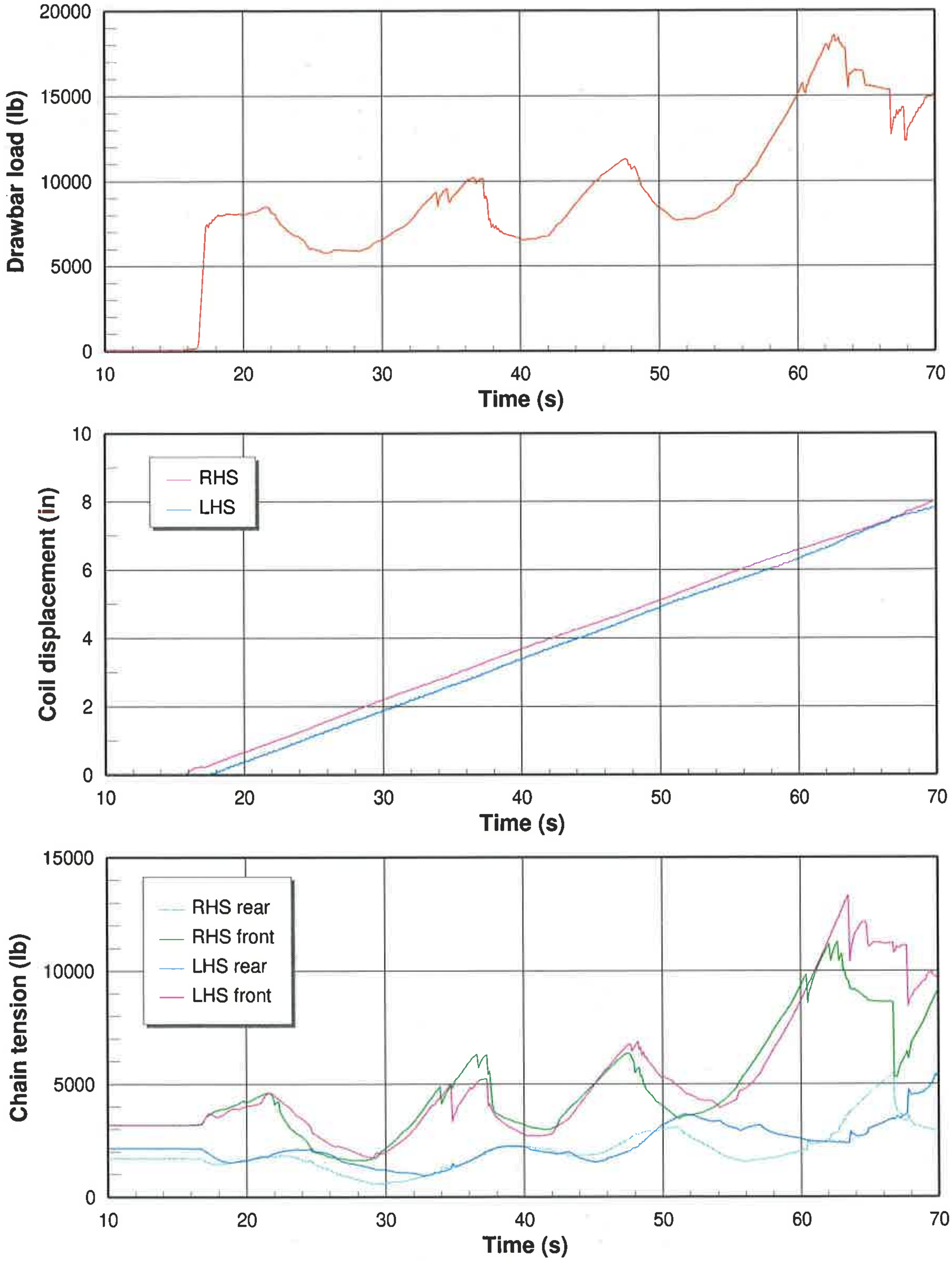


Figure 38/ Longitudinal pull of 10,523 kg (23,200 lb) coil in cradle
Two 3/8 in grade 7 chains straight through eye at initial tension of 50% of WLL

Table 21/ Resistance of coil in cradle with steep angle chains 10,523 kg (23,200 lb) coil for longitudinal pull

Chains	Initial tension (% WLL)	Chain Orientation	Resistance					
			at WLL			at 2xWLL		
			kN	lb	g	kN	lb	g
4x1/4 in	5	Straight	43.44	9,763	0.421	74.61	16,768	0.723
		Crossed	51.13	11,491	0.495	76.71	17,118	0.738
	20	Straight	36.33	8,163	0.352	72.11	16,206	0.698
		Crossed	49.47	11,118	0.479	82.28	18,491	0.797
	50	Straight	42.34	9,515	0.410	74.16	16,667	0.718
		Crossed	40.86	9,182	0.396	72.29	16,245	0.700
2x3/8 in	5	Straight	41.10	9,237	0.398	78.48	17,637	0.760
		Crossed	46.26	10,398	0.448	78.02	17,533	0.755
	20	Straight	46.67	10,488	0.452	81.87	18,400	0.793
		Crossed	46.76	10,509	0.453	78.94	17,741	0.765
	50	Straight	49.32	11,080	0.477	82.30	18,495	0.797
		Crossed	49.32	11,084	0.478	75.63	16,996	0.732

4.10/ Resistance of Coil in Cradle with Shallow Angle Chains to Longitudinal Pull

4.10.1/ Scope

The objective of this test series was to measure the combined effect of friction and shallow angle tiedowns on the resistance of a coil, secured by two 3/8 in grade 7 chains in an unsecured cradle, for a longitudinal pull, as outlined in section 12.12 of the proposal [1]. Table 22 shows the test matrix .

Table 22/ Test matrix for resistance of coil in cradle with shallow angle chain 8,264 kg (18,220 lb) coil for longitudinal pull

Tiedown angles front/rear (deg)	Chain Orientation	Interface	Initial tension (% WLL)		
			5 %	20 %	50 %
45/45 deg	Straight	Wood	X	X	X
	Crossed	Wood	X	X	X
		Rubber		X	
60/60 deg	Straight	Wood		X	
	Crossed	Wood		X	
45/85 deg	Straight	Wood		X	

4.10.2/ Specialized Test Setup and Procedures

This test used a longitudinal pull with the 8,264 kg (18,220 lb) coil in a cradle assembly using 10x10 cm (4x4 in) bevelled blocks, and two 3/8 in grade 7 chains, similar to that of the previous section, but at a shallow tiedown angle. The setup is shown in Figure 39. The drawbar load, coil and cradle displacement, and tensions at each end of each chain were measured.

4.10.3/ Results

Table 23 summarizes the resistance from this test series, again with equivalent accelerations based on the mass of the coil. Some tests stopped when the drawbar load reached the weight of the coil, before the tension in the chain reached twice its working load limit. There seemed no clear pattern between chain orientation and longitudinal resistance of the tiedown assembly. The chain initial tension also seemed to have no significant effect on resistance. When used tire treads were placed along the blocks, this raised to coil-block friction above the cradle-deck friction, and the coil dragged the cradle along the deck. In all other cases, the coil slid along the blocks.

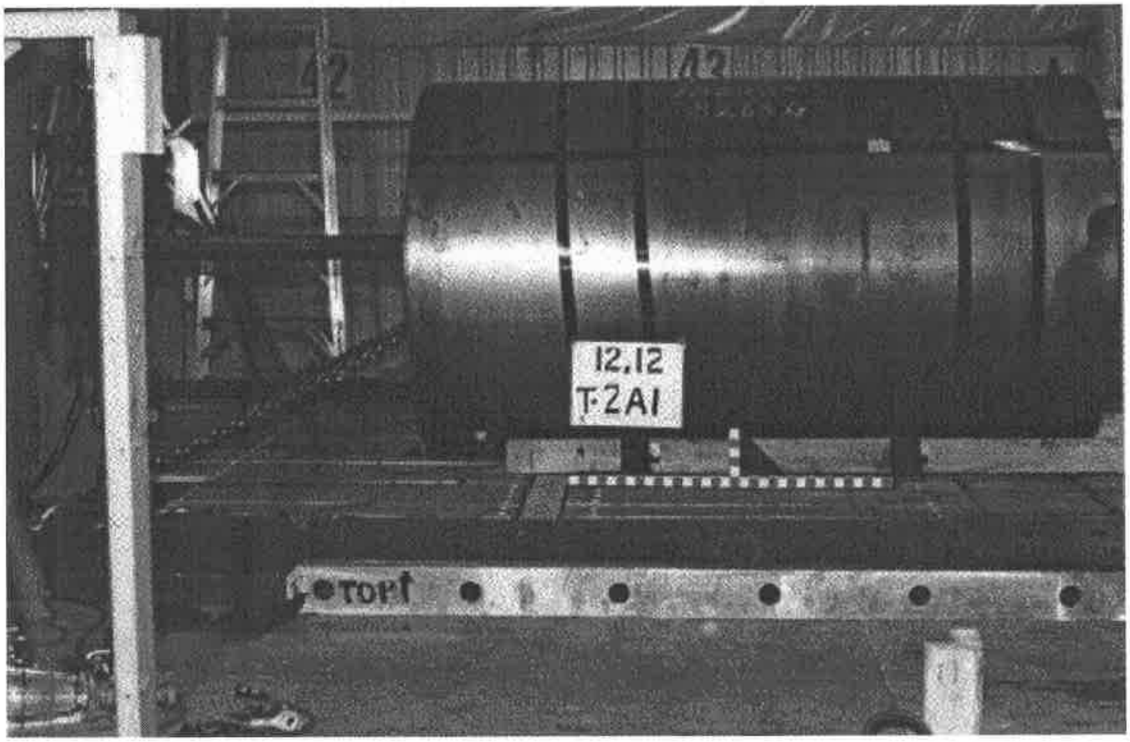


Figure 39/ Setup for longitudinal pull of coil in unsecured cradle
8,264 kg (18,220 lb) coil with 3/8 in chain tiedowns at shallow angle

4.10.4/ Conclusions

Crossed chains may provide slightly higher resistance than straight through chains for these tiedown arrangements.

Combining the separate resistances of friction and tiedowns from earlier tests matches reasonably the resistance of this test.

Table 23/ Resistance of coil in cradle with shallow angle chains 8,264 kg (18,220 lb)) coil for longitudinal pull

Tiedown angles front/rear	Initial tension (% WLL)	Chain Orientation	Resistance					
			at WLL			at 2xWLL		
			kN	lb	g	kN	lb	g
45/45 deg	5	Straight	53.98	12,133	0.666	76.56	17,205	0.944
		Crossed	57.51	12,924	0.709			
	20	Straight	58.52	13,150	0.722			
		Crossed	58.55	13,158	0.722			
		Crossed*	60.74	13,650	0.749			
	50	Straight	50.20	11,280	0.619			
		Crossed	64.47	14,489	0.795			
45/45 deg	20	Straight	54.59	12,268	0.673			
		Crossed	54.07	12,152	0.670			
45/85 deg	50	Straight	65.23	14,658	0.805			

* This case had rubber mats between the coil and blocks, and the cradle started to move at 69.54 kN (15,628 lb) or 0.858 g.

4.11/ Resistance of Coil in Cradle with Tiedowns over the Coil

4.11.1/ Scope

The objective of this test series was to examine the resistance of a coil in a cradle, secured with chain or webbing tiedowns over the coil, to longitudinal and lateral pulls, as outlined in section 12.13 of the proposal [1]. The tiedowns used were two 3/8 in grade 7 chains with a working load limit of 2,948 kg (6,500 lb), and two 7.5 cm (3 in) synthetic webbing tiedowns, with a working load limit of 2,268 kg (5,000 lb). Up to three initial tensions were examined for each type of tiedown. In the case of the lateral pull, tests were also conducted with the cradle secured. Table 23 shows the test matrix.

Table 23/ Test matrix for longitudinal and lateral pulls of a coil in a cradle with tiedowns over the coil for 10,523 kg (23,200 lb) coil

Tie-downs	Cradle	Pull Orientation	Initial tension (% WLL)		
			5 %	20 %	50 %
2x3/8 in chains	Unsecured	Longitudinal	X	X	X
		Lateral	X		X
	Secured	Lateral	X	X	
2x3 in webbing	Unsecured	Longitudinal	X	X	X
		Lateral	X		X
	Secured	Lateral		X	X

4.11.2/ Specialized Test Setup and Procedures

This test series used both longitudinal and lateral pulls with the 10,523 kg (23,200 lb) coil placed in a cradle that used 10x10 cm (4x4 in) bevelled blocks. The setup for a longitudinal pull is shown in Figure 40. The tiedowns were tensioned from the left-hand side. The setup for the lateral pull is shown in Figure 41. The tiedowns were tensioned from the front. When the cradle was secured, two spacers were placed between the cradle and the steel rail bolted across the rear of the deck in front of the hydraulic actuator. The tiedowns were then secured over the coil, symmetrically about its centre-line, and were tightened to the appropriate initial tension. Drawbar load, coil displacement, block displacement and tensions in the tiedowns were measured.

Figure 40/ Longitudinal pull with webbing tiedown over coil in a cradle

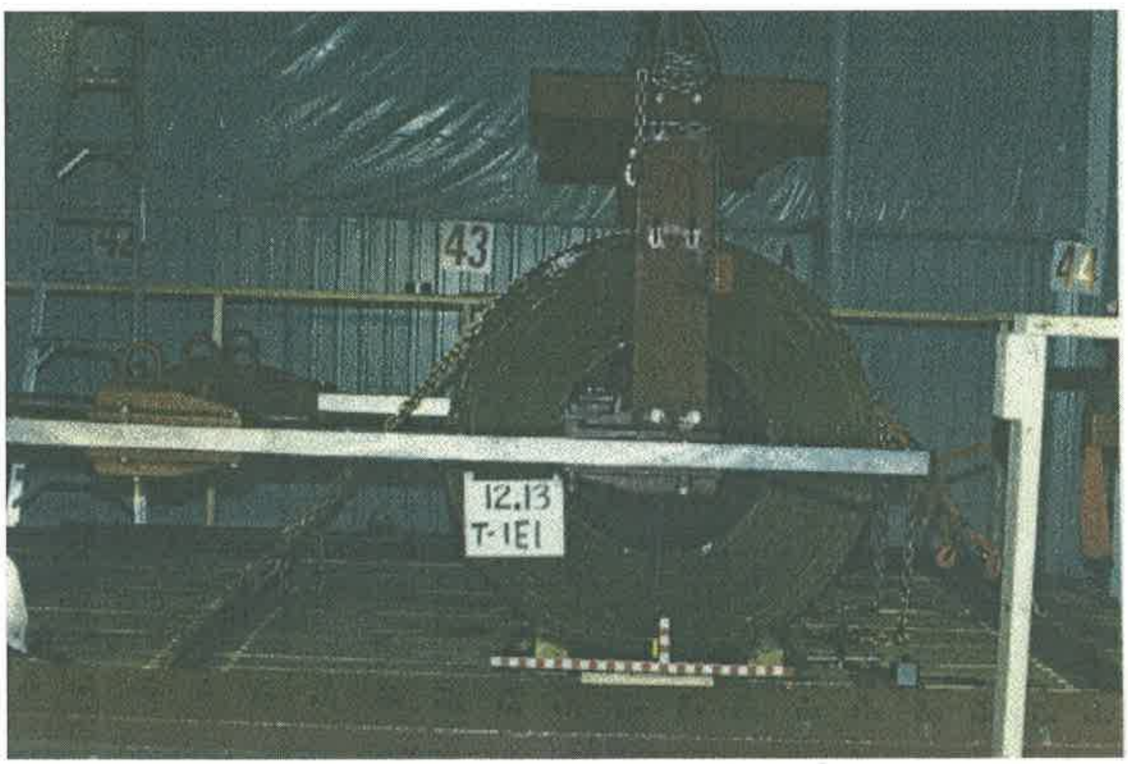


Figure 41/ Lateral pull with chain tiedown over coil in a cradle

4.11.3/ Results

Figure 42 shows responses from a longitudinal pull with two 3/8 in chain tiedowns at an initial tension of 20% of WLL. It is noted that the initial tensions equalized relatively well, with the chains stretched over the smooth arc of the coil. After overcoming the frictional resistance, the coil moved in a continuous slip-stick mode for about 28 cm (11 in), and the chain tensions increased as the drawbar load increased. The chains did not slip on the coil. The cradle did not move, as cradle-deck friction had been found to exceed coil-bunk friction in Sections 4.7 and 4.8.

Figure 43 shows the responses from a similar pull, using two 3 in webbing tiedowns with an initial tension of 50% of WLL. Initially, the tensions in the tiedowns increased as the drawbar load was increased. However, when the drawbar load reached its peak around 38.5 kN (8,646 lb) at a time of about 80 s, the right tiedown crept slowly back along the coil, followed soon after by the left tiedown. The tiedown tensions dropped, and so did the drawbar load. The coil was pulled a total of 35.5 cm (14 in), but the cradle did not move. Again, there was substantial vibration due to slip-stick action between the coil and the blocks. It appears that a sustained external acceleration could cause the coil to slide a significant distance. If the acceleration lasted long enough, and the blocks were short enough, the coil could slide sufficiently far that it would tip out of the cradle.

Figure 44 shows the same responses for a lateral pull, with two 3 in webbing tiedowns at an initial tension of 50% of WLL. After overcoming the initial friction of about 35.6 kN (8,000 lb), the cradle started sliding towards the actuator. It slid about 11.4 cm (4.5 in), then stopped. The subsequent apparent reversal of movement arises because of the way the LVDT's were set up measure on the bunks, and may be associated with transfer of the weight of the coil onto the rear block. The actuator continued and pulled the coil a further 47 cm (18.5 in) up onto the rear block.

Table 24 summarizes the results for this series of tests, with equivalent accelerations based on the mass of the coil. For the 3/8 in chain and 3 in webbing tiedowns, the longitudinal resistance appears to increase slightly as the initial tension increased, except for the 20% WLL initial tension. Similar trends were found for the lateral pulls with the chain tiedowns. The cradle never moved for longitudinal pulls, but always moved some distance for lateral pulls. In all cases, chain tiedowns provided significantly greater resistance than webbing tiedowns. In particular, for a longitudinal pull, the webbing simply slipped back along the coil as it moved, relieving the tension. While there would be no danger ever of breaking these tiedowns, they could allow the coil simply to slide out of the cradle if a sufficiently large external acceleration could be sustained.

With the cradle was secured against movement for a lateral pull, resistance for both chain and webbing tiedowns was significantly improved.

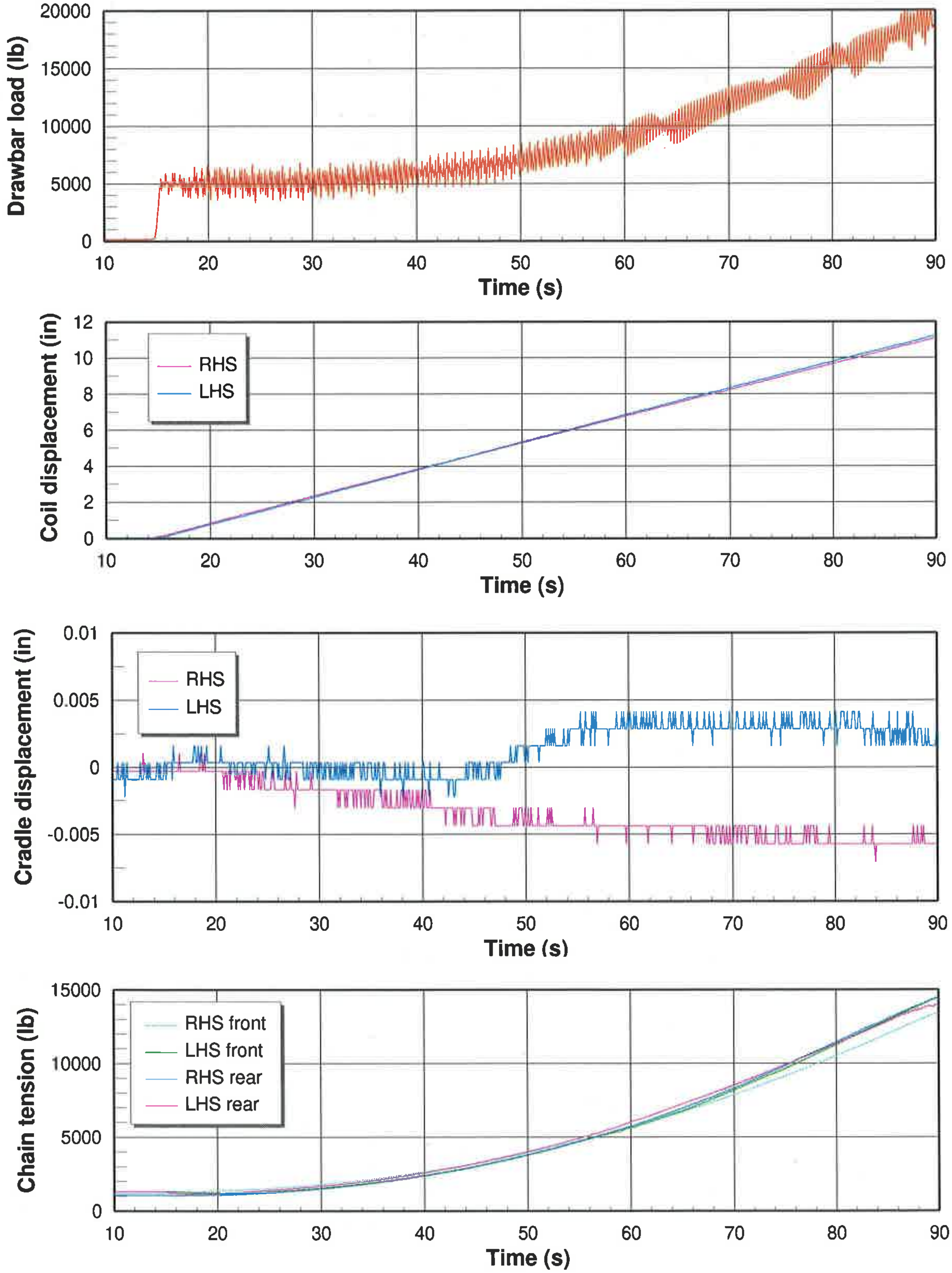


Figure 42/ Longitudinal pull of 10,523 kg (23,200 lb) coil in unsecured cradle
Two 3/8 in grade 7 chains transversely over coil , initial tension 20% of WLL

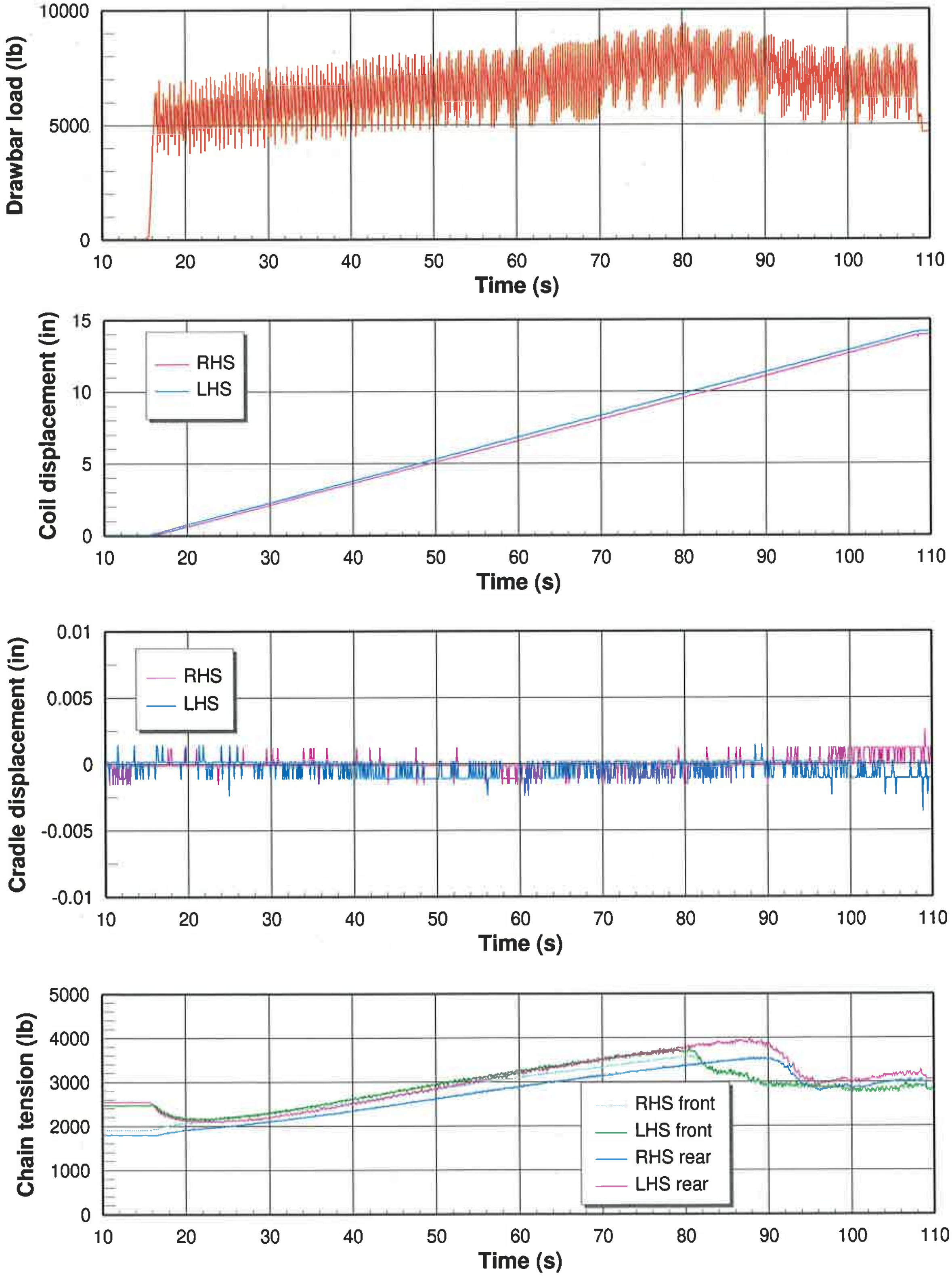


Figure 43/ Longitudinal pull of 10,523 kg (23,200 lb) coil in unsecured cradle
Two 3 in webbing tiedowns transversely over coil , initial tension 50% of WLL

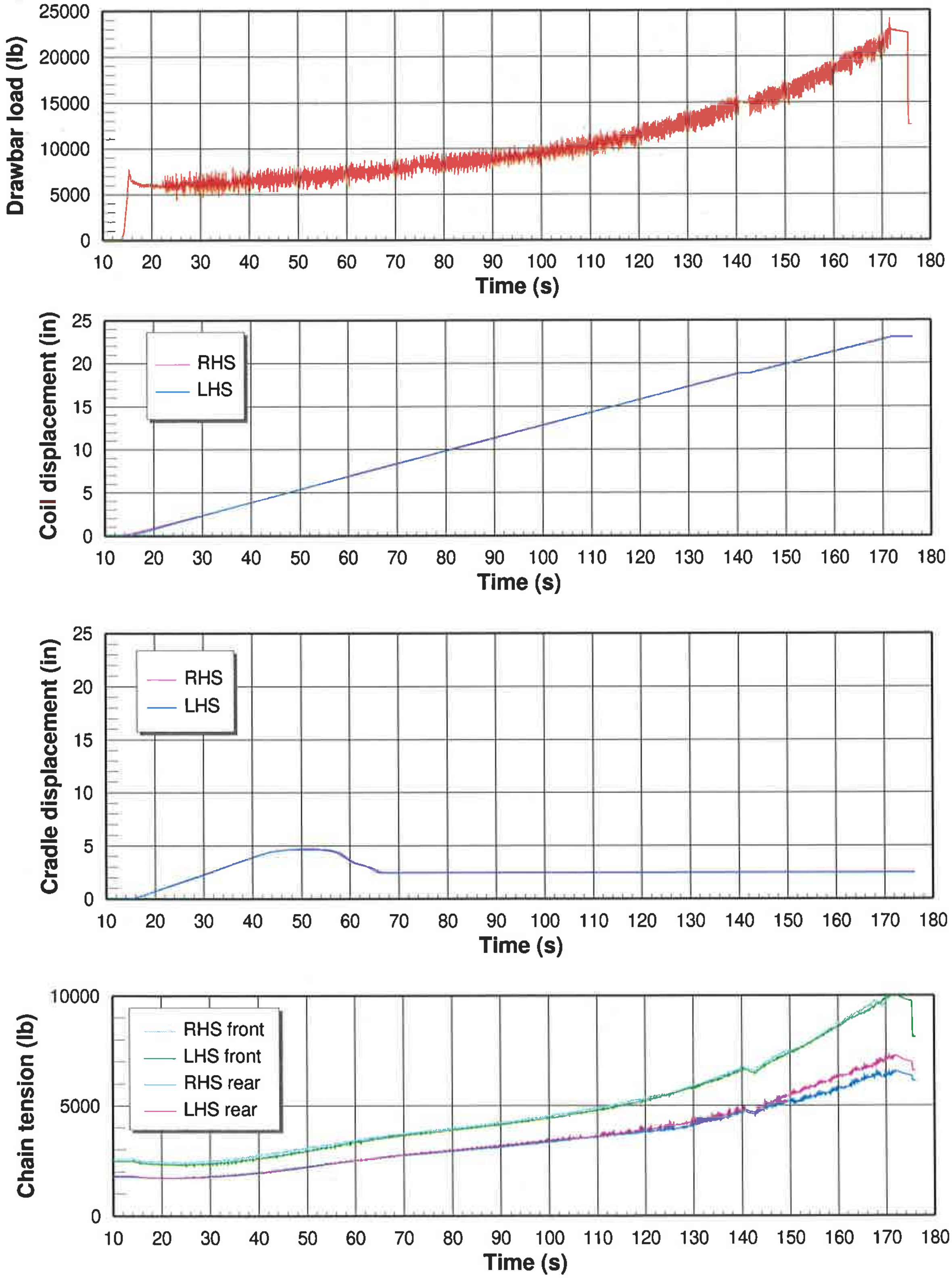


Figure 44/ Longitudinal pull of 10,523 kg (23,200 lb) coil in unsecured cradle Two 3/8 in grade 7 chains transversely over coil , initial tension 20% of WLL

Table 24/ Resistance of tiedowns over coil in cradle
10,523 kg (23,200 lb) coil for longitudinal and lateral pulls

Tiedowns, cradle	Initial tension (% WLL)	Pull	Resistance at WLL kN	at WLL lb	at WLL g	at 2xWLL kN	at 2xWLL lb	at 2xWLL g
Chains, cradle unsecured	5	Longitudinal	45.56	10,239	0.441	73.32	16,478	0.710
		Lateral	57.44	12,908	0.556	97.17	21,836	0.941
	20	Longitudinal	42.50	9,551	0.411	79.25	17,811	0.768
	50	Longitudinal	53.96	12,125	0.522	94.84	21,314	0.919
		Lateral	61.66	13,856	0.597	99.33	22,322	0.962
Chains, cradle secured	5	Lateral	94.79	21,303	0.918	110.50	24,834	1.070
	20	Lateral	94.10	21,146	0.911	115.12	25,872	1.115
Webbing, cradle unsecured	5	Longitudinal	33.87*	7,612	0.328			
		Lateral	48.14	10,819	0.466	85.37	19,185	0.827
	20	Longitudinal	31.56*	7,093	0.306			
	50	Longitudinal	41.75*	9,382	0.404			
		Lateral	45.77	10,287	0.443	101.95	22,911	0.987
Webbing, cradle secured	20	Lateral	65.83	14,793	0.637			
	50	Lateral	74.01	16,632	0.717	80.49	18,089	0.780

* Highest value. Tiedowns did not reach their working load limit.

4.11.4/ Conclusions

Chain tiedowns provided significantly more resistance than the more flexible webbing tiedowns, particularly for a longitudinal pull. Very high resistance was achieved for a lateral pull when the cradle was secured. Transverse tiedowns, especially webbing, over a coil with its eye longitudinal would clearly be more effective if the coil and cradle were both immobilized.

4.12/ Resistance of Nailed Wood Blocking Cradle

4.12.1/ Scope

This series of tests examined the resistance of a cradle made from nailed wood blocking to longitudinal and lateral pulls, as outlined in section 12.14 of the proposal [1]. The cradle was constructed with a 10x10 cm (4x4 in) hardwood block pressed against the length of the coil on each side, with a 5x10 cm (2x4 in) crossmember nailed across the top of each block at each end of the coil. The test matrix was as follows :

1/ Longitudinal pull of the coil with the cradle unsecured.
2/ Longitudinal pull of the coil with the cradle secured.
3/ Lateral pull with the cradle unsecured.
4/ Lateral pull with the cradle secured by three 5x10 cm (2x4 in) cleats.
5/ Lateral pull with the cradle across three equally spaced 5x10 cm (2x4 in) studs nailed to the deck, and secured by cleats nailed to on each side of each stud.

4.12.2/ Specialized Test Setup and Procedures

Longitudinal and lateral pull setups were used for these tests, with the 10,523 kg (23,200 lb) coil resting directly on the deck. The cradle was constructed from two 10x10 cm (4x4 in) square hardwood blocks pushed firmly against the sides of the coil, with a 5x10 cm (2x4 in) spruce crossmember nailed across them at each end of the coil, as seen in Figure 45. When the cradle was secured, fillers were placed between the block and the lateral steel rail at the rear of the deck. The blocks were kept in place against the coil by three 5x10 cm (2x4 in) cleats. Each test monitored drawbar load, and coil and cradle displacements.

4.12.3/ Results

Table 25 gives a summary of the test results, with equivalent accelerations again based just on the mass of the coil. The crossmember was strong enough to keep the coil on the unsecured cradle for a longitudinal pull, and the cradle slid along the deck for at a static friction coefficient of 0.206. With a lateral pull of the unsecured cradle, the coil started to roll up on the rear block, which lifted the front block off the deck, then the cradle slipped forward, relieving the drawbar load. This sequence occurred repeatedly in the same run. The resistance was comparable to that in Section 4.5 for a cradle composed of blocks and bunks, but that cradle simply slid smoothly along the deck.

The 5x10 cm (2x4 in) crossmember was held with three 7.62 cm (3 in) spiral nails at each end, and the wood quickly failed at the nail locations with a longitudinal pull of the secured cradle. A lateral pull of the cradle secured by three 5x10 cm (2x4 in) cleats nailed to the deck easily extracted the nails. Placing the cradle across three 5x10 cm (2x4 in) studs nailed to the deck significantly improved its resistance to a lateral pull, but would have made no difference for a longitudinal pull.

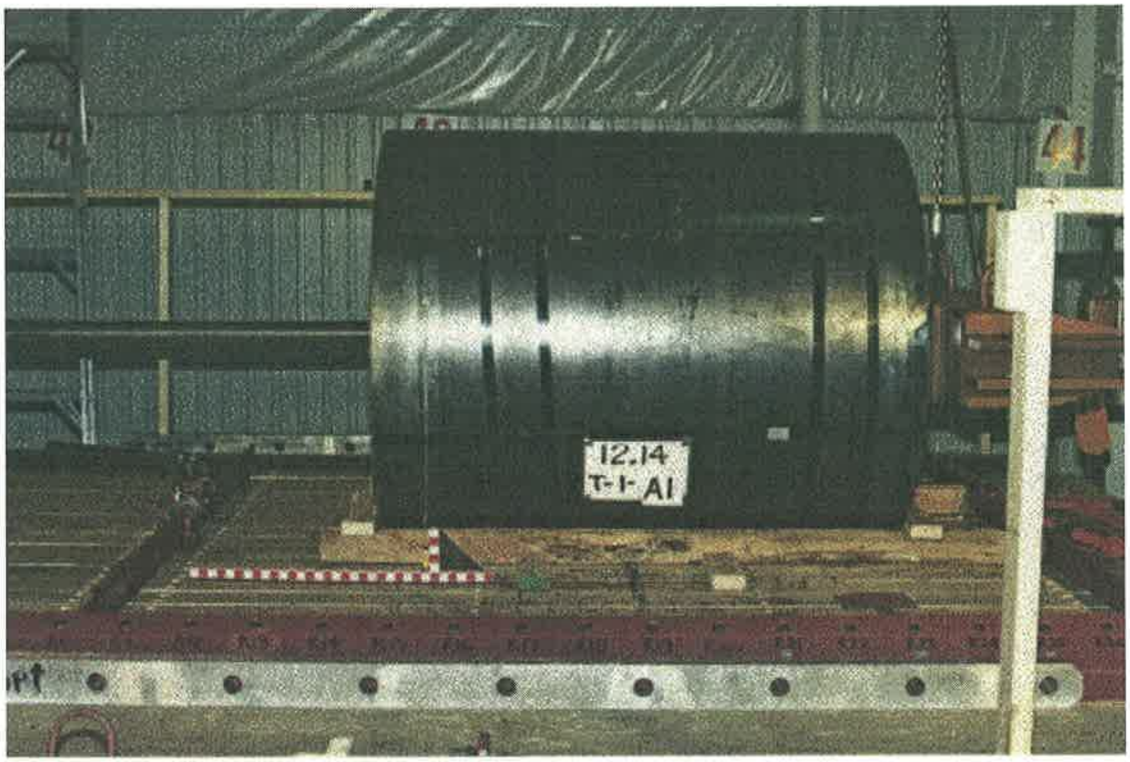


Figure 45/ Longitudinal pull with nailed wood blocking cradle
10,523 kg (23,200 lb) coil with cradle unsecured

Table 25/ Longitudinal and lateral resistance of nailed wood cradles
10,523 kg (23,200 lb) coil for longitudinal and lateral pulls

Cradle	Pull	Resistance		
		kN	lb	g
Unsecured	Longitudinal	21.26	4,778	0.206
	Lateral	34.23	7,693	0.331
Secured with spacers against rail	Longitudinal	38.86	8,732	0.376
Secured with three cleats nailed to deck	Lateral	41.18	9,255	0.399
Secured on three 2x4 in stubs with cleats	Lateral	57.56	12,935	0.558

4.12.4/ Conclusions

A cradle made from nailed wood blocking is not suitable for securing a heavy metal coil.

5/ Analysis and Discussion

5.1/ Effects of Friction

The deck was constructed from commercially available 5x15 cm (2x6 in) rough oak planks that are typical of those used by trailer manufacturers. The initial surface condition should therefore be typical of a new deck. As the tests progressed, the surface changed somewhat due to wear and tear. All tests were conducted pulling along the planks of the deck. If a pull was made across the planks, interference at raised edges between planks would appear as a higher effective coefficient of friction. By using a number of typical coil sizes and tiedown and blocking equipment that are typically used by the coil transportation industry, it is believed that the results provide a representative lower bound for static friction conditions.

The static friction coefficients were about half of those found for a flat steel plate on a coarse oak deck in a set of friction measurements conducted as part of the project [3]. The coil, of course, exerts almost a line load on the deck, at a high local pressure, compared to the distributed load on the 1.2x1.2 m (4x4 ft) steel plate. The friction coefficients were more comparable to those found for steel pads or machine feet in the previous tests, which have a somewhat higher pressure than the steel plate [3].

In some runs with friction materials between the coil and the blocks, resistance increased after the coil started sliding. Inspection of the test specimen showed abrasion of the surface of the friction material. It is likely that as the coil slid, the metal bands on the coil cut into the rubber, which increased the resistance, appearing to create a sliding friction coefficient higher than the static coefficient. No band broke while sliding on rubber, while one did break while the coil was being pulled along a wood surface. Thus, use of interfaces to increase friction may also reduce the likelihood of broken bands, which can allow the coil to telescope.

The presence of oil significantly reduced friction, as found in other recent work [3,5]. Apparently, many coils are oiled for shipment, and it would appear difficult to avoid equipment getting contaminated by oil if an oiled coil is ever moved on a vehicle. Friction inhibits cargo from moving, so is really the first line of defence in any cargo securement system that does not immobilize the cargo. If friction is reduced, such as by the presence of oil, it increases the burden that must be assumed by other parts of the securement system [5].

5.2/ Effect of Blocks and Blocking

An unsecured block always either popped out under load, or was pushed along by the coil when it moved. Blocks that are simply pushed against a large metal coil are therefore insecure [5]. Once they become loose, they leave the tiedowns to provide all the resistance to a coil that is now in motion. This entails too much risk. Blocks are not likely to be significantly improved by nailing cleats to the deck to provide support, as the typical 7.62 cm (3 in) nail through a 5x10 cm (2x4 in) piece of softwood lumber only contributes a working load limit of about 1.3 kN (300 lb) [4]. It requires over 80 such nails to provide 0.5 g resistance for a 22,680 kg (50,000 lb) coil, and it is unlikely anyone would be prepared to put in so many nails, or would want to remove the block afterwards. The only appropriate use of hardwood blocks is with bunks to form a cradle [5]. A cradle formed from nailed wood blocking has significantly less structural integrity than one formed with steel bunks. Typically, block size, shape and spacing (derived from bunk size) are fixed, and coil diameter varies, so resistance may vary with coil diameter. It may be less than that obtained from some of these tests, which were conducted by adjusting the spacing of the blocks, to generate the optimum resistance.

During the tests with a lateral pull with secured blocking, the maximum resistance occurred just as the coil was lifting off the deck or the second block, when it had moved less than 1.9 cm (0.75 in). Block resistance decreased as the coil rolled around its point of contact with the block, and then remained almost constant as it rolled up or across the block. Thus, if a coil secured only by blocking is subjected to a sufficiently high steady external acceleration, it will roll right over the block, accelerating as it goes.

The most effective cradle has the deepest well. For these tests, the blocking was bevelled by cutting the entire top surface at an angle of 22 deg. The well can be made deeper by chamfering only perhaps 2.5 cm (1 in) of the inner edge of the block, and separating the blocks by increasing the width of the bunk to reduce the clearance between the coil and the deck to a minimum. However, the coil should never touch the deck, to ensure that its weight holds the blocks firmly in the bunks. A deeper cradle with a steeper bevel would provide greater resistance, but this would only be effective if the cradle was secured against sliding. Such a cradle would probably need to be a manufactured article permanently installed on the vehicle, as it is difficult to achieve a deeper well using the current system of blocks and bunks.

5.3/ Effect of Tiedowns

The resistance provided by a chain tiedown is limited by the tension induced in the chain. The resistance depends on the orientation of the tiedown to the force it must resist. The larger the deviation of the tiedown from the direction of the force, the lower the resistance, or the greater the movement of the coil to generate that resistance [5]. It is therefore important to keep the tiedown angle as small as possible.

For a multi-chain tiedown with different tiedown angles, those at the shallowest angle reach their working load limit sooner than those at steeper angles, and the tiedown at the steepest angle provides little resistance. It is therefore preferable to have all chains secured at as low an angle as possible. There is no doubt that the actual level of securement will increase for no change of securement effort if tiedowns are applied at angles that make them most effective.

With a lateral pull, a chain resisted the pull simply by stretching as the coil moved.

However, with a longitudinal pull, the coil moved along the chain, and links rolled over the edge into the eye. Because of the finite and inflexible shape of each link in the chain, tension increased slowly as a link approached the eye, then decreased rapidly as it entered the eye, causing the chain to twist and re-align. If a sustained external acceleration caused the coil to move, it would probably proceed in a series of jerks. With multiple chain tiedowns, the probability of having a link of each chain simultaneously roll over the edge of the eye was fairly low. This may explain partially why there was no consistent pattern between the resistance generated from crossed chain and straight through chain arrangements.

5.4/ Corner Protection

Use of chains through the eye of a coil imposes high local stresses on the corner of the eye that can deform several laps of a thin gauge coil, even under the forces simply of tensioning the tiedown. The coil might get severely damaged in a severe deceleration resisted primarily by the tiedowns. Shippers may require, and carriers may use, corner protectors to prevent damage to the edge of the eye, to ensure the coil is delivered as it was manufactured.

There was some concern when these tests began that the test coils should be treated with care. For the first lateral pull against chain tiedowns, the chain was placed on apparently substantial formed steel corner protectors. As the drawbar load increased, the chain simply crushed the corner protector. When the drawbar load was released, chain tension diminished to zero well before the coil was back in its original position, because of the crush. After a real emergency stop, a crushed corner protector would result in the tiedown becoming loose. This would be a potential hazard if the driver did not stop immediately and do a walk-around to check the vehicle and cargo securement, then tighten the tiedowns.

When the tests continued, small tabs were cut from thin sheet metal, but these usually fell out as the pull proceeded, before they could get crushed, and the chains were slightly less tight when the pull force was removed. The tests therefore generally proceeded without corner protection, and the edge of the coils did indeed get quite thoroughly mashed. Finally, a new design of protector was offered. This was a 90 deg curve, manufactured from about 3 mm (1/8 in) mild steel plate and welded on the outside, so that the inside was square and fitted the eye and face of the coil exactly. This successfully withstood a pull to twice the chain working load limit with only minor dimpling. It was not possible to assess the effect on the coil, whose edge was by now very well chewed, but it was clear that if the chain had minimal impact on this style of corner protector, then it would have minimal impact on the coil, too.

There appears to be wide range of means used to protect the edge of the eye of metal coils. If the coil is not totally immobilized, a high external acceleration will cause it to move against chains through the eye. If a corner protector is softer than either the coil or the chain, or there is free space between the chain channel and the coil surface, the corner protector will simply be crushed. As noted above, this could leave tiedowns loose, which clearly is a potential safety hazard. So, a corner protection device should :

1/ have a channel for the tiedown, or be so large that it cannot fall out from under the tiedown;
2/ have no space under the chain path that can crush when the chain tightens; and
3/ be of comparable hardness to the tiedown.

5.5/ Putting it all Together

Trucks could experience longitudinal deceleration in the range 0.60-0.80 g while braking, whereas the lateral acceleration while turning is rather unlikely to exceed 0.50 g. Where the choice of coil orientation (eye lateral or longitudinal) is available to the motor carrier, the coil should be oriented so that the securement system provides its greatest resistance to the forces arising from braking. However, there are many situations where the orientation is constrained by the means of loading at the origin, or of unloading at the destination. It is therefore necessary to ensure adequate means of securement for coils in either orientation.

While a number of securement systems were able to generate quite high resistance, that resistance was often not achieved until the coil had moved a significant distance. Blocking formed by a cradle, and friction between the cradle and deck, can together provide a lateral resistance of the order of 0.40 g. The cradle should form as deep a well as possible, to minimize demand on the tiedowns, which are inherently less reliable than the well. It is clearly preferred that the cradle should be immobilized to inhibit forward movement by some means, rather than allowing it to slide under extreme loading. This also minimizes the demand on the tiedowns. It is also desirable to immobilize the coil so that it cannot slide along the blocks. It is believed that these objectives are feasible, either by fabricating a specialized coil well for flatbed trailers, or by simple means involving a kit of parts than can easily be handled by one person. If the securement objectives are clearly stated and understood, and means are developed to address them, it should be readily apparent to carrier, shipper or inspection personnel that the proper equipment is being used to secure large metal coils.

If there is any contamination by oil, the coefficients of friction drop substantially. The coil may slide on the blocks, or the cradle may slide on the deck. However, oil does not affect the resistance provided by blocking for a lateral pull. Consequently, in this case, it is preferred to orient the cradle so that the coil has its eye transverse to the vehicle, the so-called "suicide" arrangement. The cradle should also be immobilized against forward movement, to compensate for the reduction in friction. Properly oriented tiedowns then provide direct resistance to the forces arising from braking in the most effective manner, and minimize the likelihood that the coil will start to move. The coil should also be immobilized against sliding along the cradle. Blocks wider than the coil would allow cleats to be nailed to the blocks, which may be adequate in this regard.

6/ Conclusions

The tendency of a large metal coil with its eye horizontal to roll on a flat surface is inherently incompatible with transportation on flatbed trailers. It takes considerable effort to provide proper securement for an article that is so difficult to handle.

The metal coil and coarse oak deck combined for a static coefficient of friction for the coil in a longitudinal pull of about 0.27. With the coil on dry bevelled maple blocks, the static friction coefficient for a longitudinal pull was 0.23, and the presence of water or oil on the block surface did not have a significant effect on this value. Friction was significantly increased by inserting friction materials such as rubber mat, old tire treads or conveyor belts between the coil and the blocks. However, water or oil on the surface of this friction material drastically reduced the friction between the coil and material. The friction coefficient decreased from 0.23 to 0.20 as the length of blocking was increased from 75% to 125% of the coil width. The static friction coefficient for a longitudinal pull on a cradle formed from blocks placed in steel bunks on a dry deck was 0.34, increasing to 0.53 when the deck was wet. A rubber mat under the bunks increased this to 0.42. Wetting the rubber mat had no effect, but the presence of oil significantly reduced the static friction coefficient, to 0.21.

The rolling resistance of the coil was about 0.01. For a lateral pull, the static friction coefficient between the cradle and the dry deck was 0.31, and a rubber mat under the bunks increased this to 0.35.

Blocking provides resistance to a lateral pull, as the coil must rise over the block. The resistance depends on the block size, shape and spacing. The resistance provided by blocking increases as the coil sits deeper in the well created by the blocking. The blocks should be as large as possible, with the minimum chamfer, and placed as far apart as possible as long as the coil does not contact the deck. The relationships are strictly those of statics. Unsecured blocking always popped out, allowing the coil to crash on the deck. Secured blocking always remained in place, and provided a resistance equivalent to an external acceleration in the range 0.40 to 0.75 g.

The resistance of chain tiedowns to a lateral pull deteriorates as the tiedown angle to the horizontal is increased. Considering the physical size of the coil and the limited width of the trailer deck for tiedown, the lowest tiedown angle used of roughly 45 deg generated the highest lateral resistance. Larger tiedown angles resulted in less resistance with the same chain tension level. A 90 deg (vertical) tiedown allows large coil motions before it develops significant resistance when used alone, or adds very little resistance when used in combination with chains at more effective angles. For a symmetric tiedown arrangement, with chains at equal and opposite tiedown angles, an initial tension higher than 20% of the chain working load limit resulted in significantly lower resistance available before the chain reached its working load limit. As an example, the resistance generated by symmetric 3/8 in chain tiedowns at 45 deg at the chain working load limit was equivalent to an external acceleration of about 0.33 g.

Similarly, the effectiveness of chain tiedowns in providing resistance to a longitudinal pull decreased as the angle relative to the coil centre line was increased, and angles higher than 65 deg resulted in lower resistance. Generally speaking, the crossed chain arrangement was equivalent to the straight through chain arrangement.

The resistance generated by combining a cradle and chain tiedowns could be computed fairly accurately as the sum of the resistances from each of these components separately. For an unsecured cradle with chain tiedown, the total lateral resistance is the sum of the chain resistance and the lesser of the blocking resistance and friction resistance between the cradle and deck interface, whereas the total longitudinal resistance is the sum of the chain resistance and the lesser of the friction resistance at the coil/block interface and the cradle/deck interface.

There is considerable increase in resistance by inserting friction materials between the coil and the blocks for a longitudinal pull, but no improvement in for a lateral pull .

When tiedowns are placed over the top of the coil, webbing provides significantly less resistance to longitudinal and lateral pulls than chain.

Nailed wood blocking was not an effective way to restrain either blocking or the coil, and cleats were not effective in restraining blocking.

This report presents technical results from just one task in this project. The results may be limited by the scope of this task, but are placed in context in the summary report [6].

7/ Recommendations

1/ Large metal coils are inherently incompatible with flatbed trailers, so they should preferably be transported on custom-designed trailers or in custom-designed compartments that provide sufficient longitudinal and lateral securement.

2/ Hardwood blocks should always be used in combination with bunks, to form a cradle that keeps the blocks in place under the coil in extreme loading conditions.

3/ Blocks should be as high as possible, with the minimum chamfer necessary, and should be placed as far apart as possible so that the clearance between the deck and the coil is minimized.

4/ The cradle should preferably be immobilized so that it cannot slide on the deck

5/ The coil should preferably be immobilized so that it cannot slide along the blocks.

6/ If the cradle or coil are not immobilized, then means should be used to increase the coefficient of friction at the cradle/deck and coil/block interfaces.

7/ When symmetric chain tiedowns are placed through the eye of a coil with its eye lateral on the vehicle, the chain angle should not exceed 45 deg to the horizontal,

8/ The initial tension in a chain tiedown should not exceed 20% of the tiedown working load limit.

9/ Where an odd number of tiedowns is used, the last (odd) tiedown should be placed to resist the force of deceleration of the vehicle.

10/ While the crossed chain arrangement appears equal to the straight through arrangement for the longitudinal pull, it is significantly poorer for the lateral pull, so the straight through arrangement is preferred.

11/ For a coil with its eye longitudinal on the vehicle, chain tiedown angles should be kept as low as possible and should never be higher than 65 deg with respect to the side of the vehicle.

12/ Any desired level of lateral and longitudinal resistance can be delivered by making appropriate use of cradle dimensions, friction and chain tiedowns.

13/ Placing the cradle so that the coil has its eye laterally on the vehicle should, in general, provide the most reliable securement.

14/ Webbing tiedowns are generally too elastic for use, even over the top of a coil.

15/ Special measures should be taken to avoid surfaces becoming contaminated with oil, and if this arises, or an oil-soaked coil is being transported, a likely reduced level of friction resistance should be compensated by an increase in resistance provided by other sources.

16/ Coil corner protectors should be at least of equivalent hardness to the tiedown, should conform to the shape of the eye, with no space beneath, and should be large enough or channelized so that the tiedown does not slip off the corner protector under extreme loading.

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