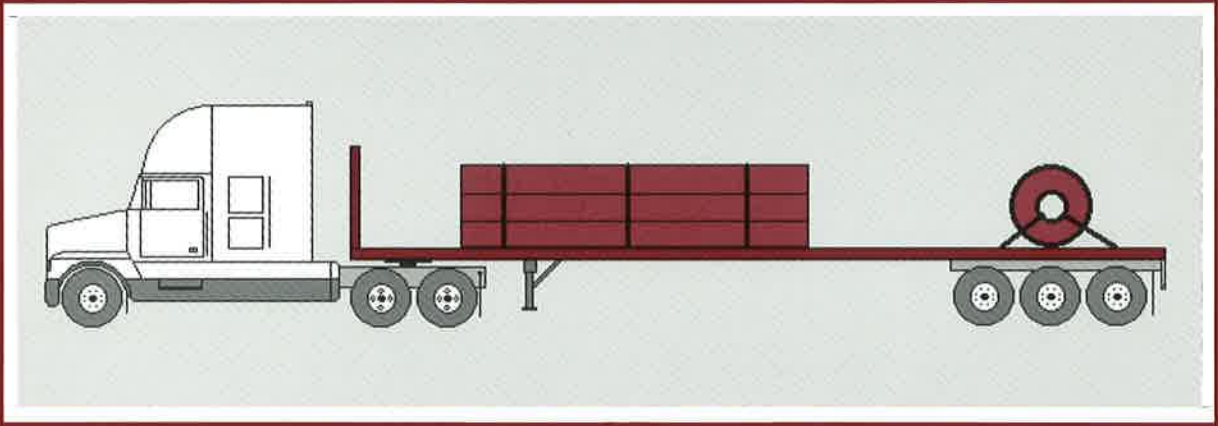
CCMTA Load Security Research Project

Report # 7

FRICTION COEFFICIENTS BETWEEN TYPICAL CARGO AND TRUCK DECKS



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

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FRICTION COEFFICIENTS BETWEEN TYPICAL CARGO AND TRUCK DECKS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

J.R. Billing, C.P. Lam P.Eng.
Strategic Vehicle Technology Office
Strategic Transportation Research Branch
Ontario Ministry of Transportation
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8

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Canadian Council of Motor Transport Administrators
2323 St. Laurent Blvd.
Ottawa, Ontario
K1G 4J8

Telephone: (613) 736-1003
Fax: (613) 736-1395

E-mail: ccmta-secretariat@ccmta.ca
Internet Web site: www.ccmta.ca

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 coefficients of friction between typical cargo and typical truck decks. The effect of sand, oil, water and a rubber mat in the interface between the cargo and the deck was also evaluated.

The results show some articles of cargo may have either consistently low or consistently high coefficients of friction on all truck decks, whereas the coefficients may vary quite widely for most cargo, depending on the deck material. A sandy or wet interface may either increase or decrease the coefficients of friction, depending on cargo and deck surface characteristics. An oily interface always reduces coefficients of friction, whereas rubber mats in the interface always result in coefficients of friction over 0.5.

Recommendations are made that friction should be considered as part of the cargo securement system, to the extent that it can be made reliable.

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 friction between cargo and truck decks, and between cargo and tiedowns, played a significant role in avoiding cargo movement or loss. It was also necessary to understand the role of friction in cargo securement systems to interpret the data from tests conducted for many other parts of the project. The work reported here addresses these issues through a series of full-scale tests to determine the coefficients of friction between typical cargo materials and typical truck deck materials, as outlined in Section 10.2 of the project proposal. The effect of sand, oil, water and a rubber mat in the interface between the cargo and the deck was also evaluated.

The tests found that the coefficient of static friction, the level that must be overcome to start the cargo sliding, ranged from 0.13 to 0.71 for the various types of cargo tested on the various dry decks. Some cargo had consistently high coefficients of friction on all decks, some had consistently low coefficients, and for others, the coefficients varied more or less widely, depending on the deck.

Coefficients of friction tended to increase if at least one of the surfaces was soft, so that sand could indent into it, or water could be absorbed by it. If both of these surfaces were hard, then sand or water in the cargo-deck interface tended to decrease coefficients of friction. Coefficients of friction tended to decrease if there was oil in the cargo-deck interface, and tended to increase significantly if a rubber mat was placed between the cargo and the deck.

It is recommended that a high coefficient of friction should be a consideration in specification of the deck for trailers and cargo handling equipment like skids that are also used during transportation, and that the use of rubber mats to increase the coefficient of friction should be encouraged. It is recommended further that the role that a high friction coefficients play in inhibiting cargo movement should be formally recognized in the proposed cargo securement standard, so that credit is given for friction where it clearly plays a substantial role in cargo securement. Finally, no matter how high the level of friction, it remains inherently unreliable, so should never be considered the sole means of cargo 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. This section recognizes the direct contributions of those who organized and conducted this part of the work. It also recognizes that there have been many indirect contributions by others.

The project was funded jointly by the following :

- Alberta Transportation and Utilities;
- Allegheny Industrial Associates;
- The Aluminum Association;
- American Trucking Associations;
- British Columbia Ministry of Transportation and Highways;
- Canadian Trucking Research Institute;
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- Transport Canada, Road and Motor Vehicle Safety Directorate;
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- 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.

The test rig was designed by Walter Mercer, and the work was conducted by Norm Carlton, Gary Giles, Walter Mercer, Bill Stephenson and Mike Wolkowicz of Strategic Vehicle Technology Office of MTO.

Steve Warian of Aragon Group, St. Paul, Minnesota donated Transdeck. Paul Martin of Waterloo Concrete Products and Bill Nipper of Lafarge Canada arranged for loan of concrete pipe on behalf of the producer members of the Ontario Concrete Pipe Association. Bob Caldwell of National Rubber in Toronto donated the rubber pad.

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 presence of friction can have a dominant role in the response of articles that may have sliding contact. This occurs in many of the tests being conducted as part of this project [1], so it was necessary to understand the role of friction in cargo securement systems to be able to interpret the results of many of these other tests. Friction has not been considered reliable [2], and is not recognized in existing North American cargo securement regulations. However, there are many reports where use of a high-friction interface has reduced the incidence of cargo movement, so it seemed useful to investigate whether friction could be made reliable at an adequate level to help prevent cargo movement.

This series of tests investigates friction between typical cargo surfaces and truck deck surfaces. It includes the effects of dirt, oil, water, sand and rubber interfaces between the cargo and deck. A test determines the coefficients of static and sliding friction for combinations of cargo, deck and interface. Static friction occurs at the instant the cargo begins to move. Sliding friction occurs while the cargo slides at constant speed on the deck. Friction is expressed as a dimensionless coefficient, where the force causing motion of the cargo is divided by the weight of the cargo. The coefficient of static friction is usually somewhat larger than the coefficient of sliding friction, which means that it takes a higher force to start an article of cargo sliding than it does to keep it sliding.

The work reported here is outlined in Section 10.2 of the project proposal [1]. A separate study extended this work to examine the effect of vibration on friction [3], for some of the conditions covered in this series of tests.

2/ Test Program

2.1/ Objective

The objective of this test was to determine the coefficients of static and sliding friction between combinations of typical cargo and truck deck material for various interface conditions.

2.2/ Scope

The friction test addressed the following typical truck deck materials :

1/ Coarse oak;
2/ Smooth oak;
3/ Smooth spruce;
4/ Smooth steel;
5/ Grooved aluminum, parallel to the grooves;
6/ Grooved aluminum, transverse to the grooves; and
7/ Transdeck, a proprietary fibre-board.

It addressed the following typical cargo materials :

1/ Smooth steel;
2/ Oak;
3/ Spruce;
4/ Machine feet;
5/ Steel pads;
6/ Plastic skid;
7/ Concrete;
8/ Rubber; and
9/ Paper.

It used the following deck surface conditions :

1/ Clean and dry;
2/ Sandy;
3/ Oily;
4/ Wet; and
5/ A rubber pad placed loosely on the deck beneath the cargo.

These give a total of 315 combinations, of which the 90 deemed most likely were selected, as shown in the test matrix given in section 3.5 below. In addition, a separate test was conducted using concrete pipe.

3/ Procedures

3.1/ Test Apparatus

The test was conducted on the test rig shown in Figure 1. The rig provided a flat bed, approximately 2.4 m (8 ft) square, to which the test deck was attached.

The load was represented by a sled, seen in Figure 1, which weighed about 198 kg (438 lb). The sled had a smooth steel bottom, which provided that skid material directly. Structures representing steel pads and machine feet, and a plastic skid, were bolted directly to the sled, as seen in Figures 2, 3, and 4. Other skid materials were attached to pieces of plywood that were bolted to the base of the sled, as seen in Figure 1. The concrete skid material was achieved with a concrete block about 0.61x1.22x0.53 m (24x48x21 in), shown in Figure 5. The sled could be loaded with one or two of these concrete blocks, as seen in Figures 1 and 2. Concrete block 1 weighed 905 kg (1,995 lb), and was always used for tests with a single block. Block 2 weighed 927 kg (2,043 lb). A hydraulic actuator with a stroke of about 0.46 m (18 in) and a load capacity of about 40 kN (9,000 lb) was attached to the rig, and was controlled to pull parallel to the deck at a constant speed of about 8.3 mm/s (0.33 in/s). A drawbar was attached between the sled and the actuator, to pull the sled, as seen in Figure 1.

A separate test was set up using three 1.2 m (48 in) concrete pipes, each weighing about 1,000 kg (2,200 lb).

3.2/ Instrumentation and Data Capture

A Strainsert model CPA-1.25 (SS)X0 clevis pin load sensor, rated at 80.096 kN (18,000 lb), and seen in Figure 1 joining the drawbar and actuator, was used to measure the tension in the drawbar. A Unimeasure model P510-20 pull cord transducer was attached to the bed, and its cord was attached to the sled to measure the forward motion of the sled, also seen in Figure 1. Data from these two instruments was captured into a PC-based data acquisition system at a sample rate of 200 Hz per channel. This sample rate provided adequate definition to identify the peak load at break-away.

3.3/ Test Procedure

For each test series, the deck material was placed on the bed of the test rig, butting against a transverse beam close to the hydraulic actuator, and either resting in place or screwed to the bed. The deck condition was then prepared for a particular run. The deck was swept to provide a clean deck condition. A large coffee can of fine mortar sand was broadcast by hand on the deck for a sandy deck condition. The deck was painted liberally with old rancid cooking oil for the oily deck condition. Water was spread by hand from a pail for the wet surface condition. Five rubber strips each 0.3 m (1 ft) wide were placed longitudinally on the deck for the rubber mat deck condition. In all cases, the oily condition was the last one done for a particular deck, to avoid contamination of other conditions. In all cases, the wet deck condition was the last

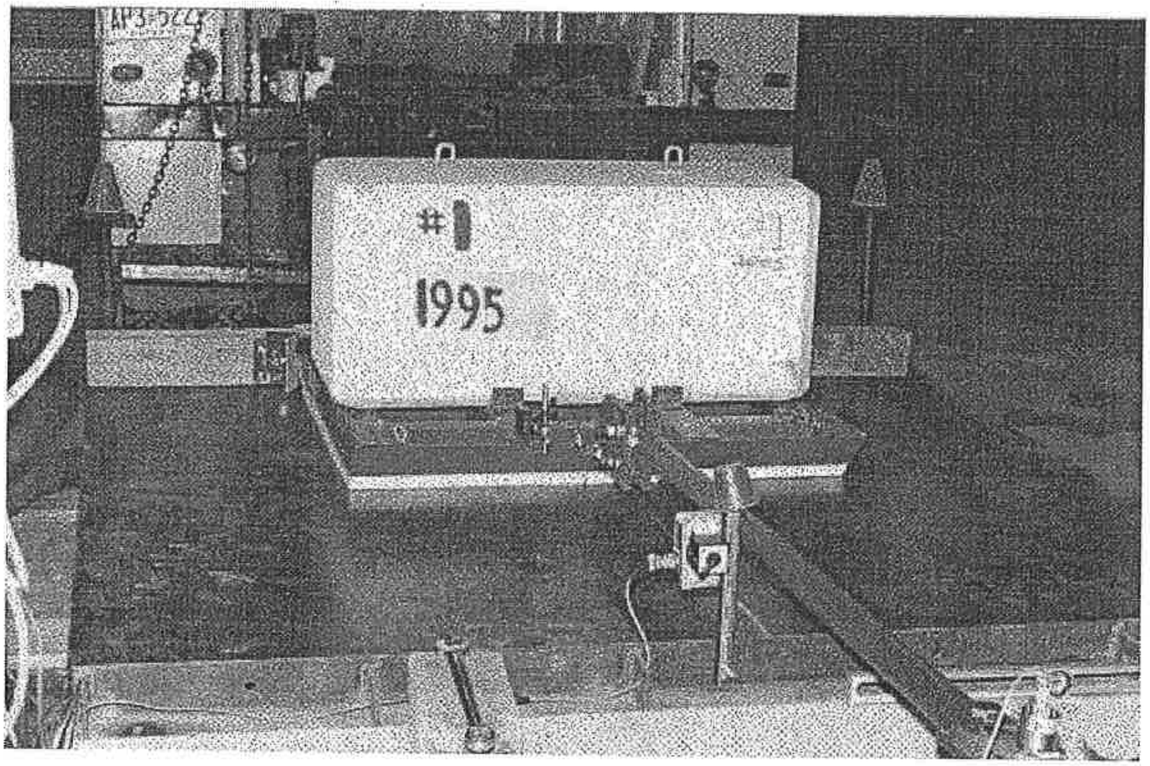

Figure 1/ View of Test Rig, with Spruce Skid on Steel Deck

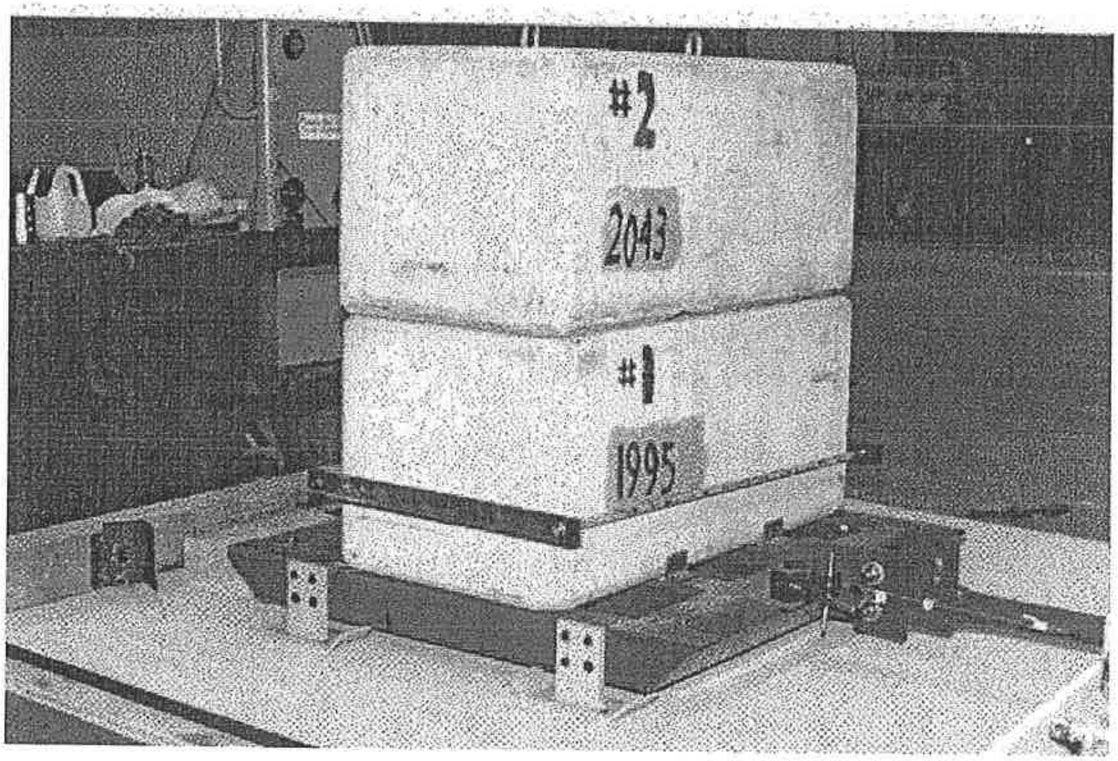

Figure 2/ Sled with Steel Pads on Smooth Oak Deck

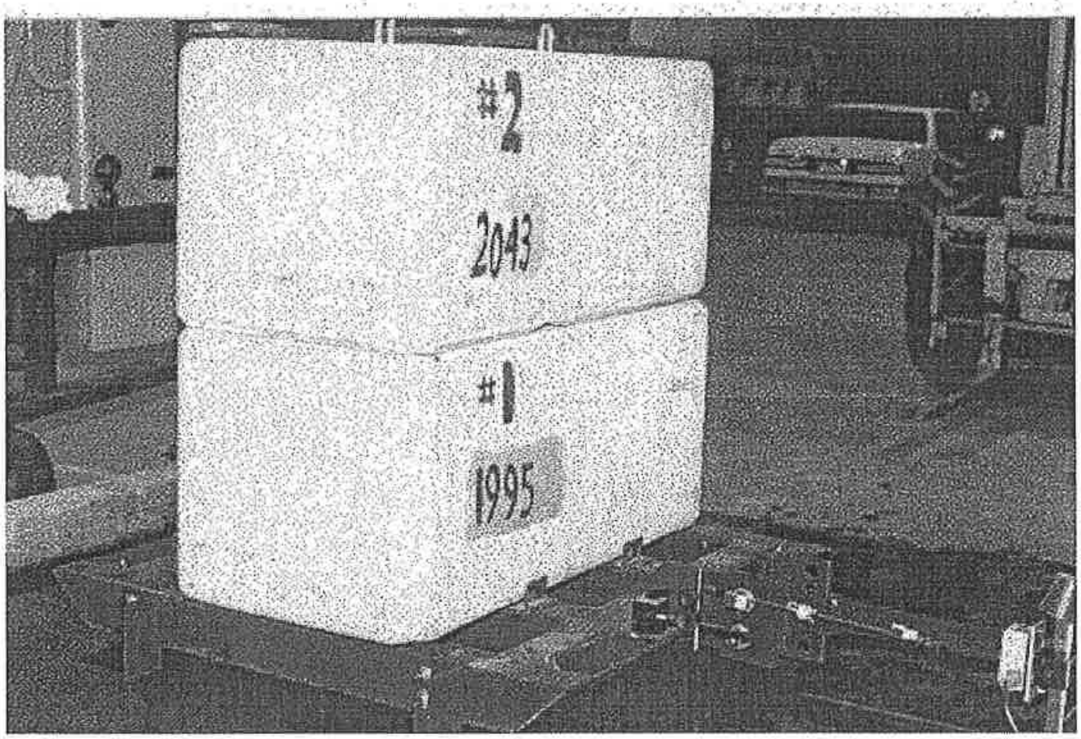

Figure 3/ Sled with Machine Feet on Steel Deck

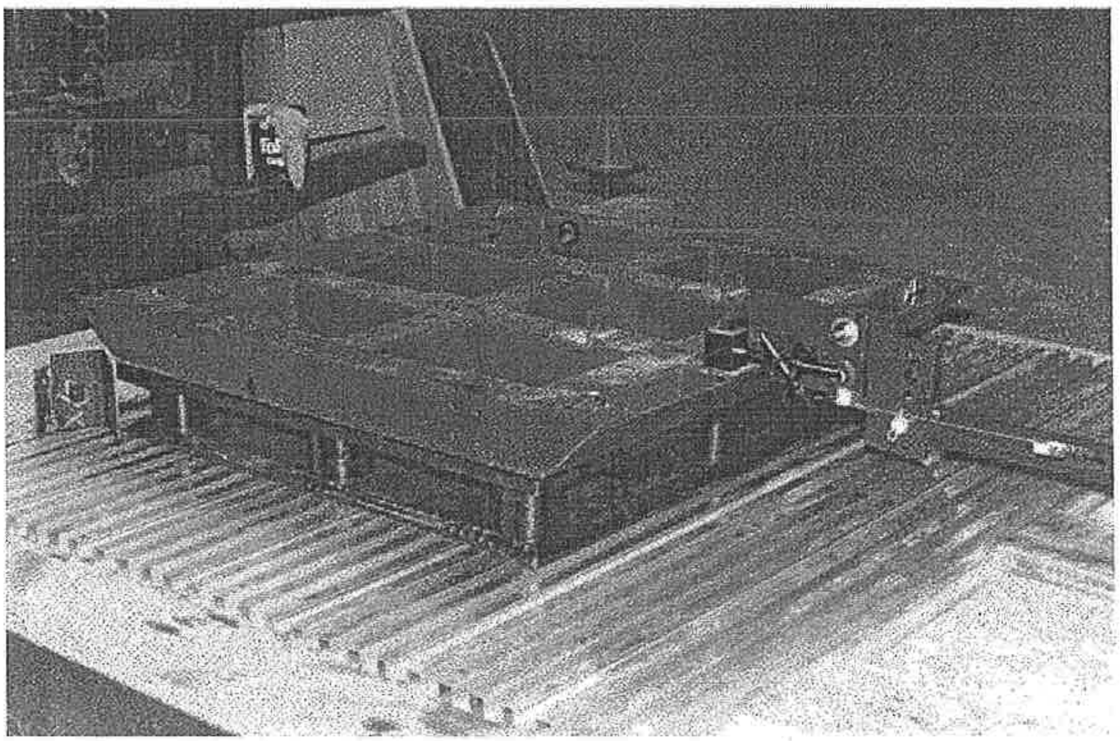

Figure 4/ Sled with Plastic Skid on Crosswise Grooved Aluminum Deck

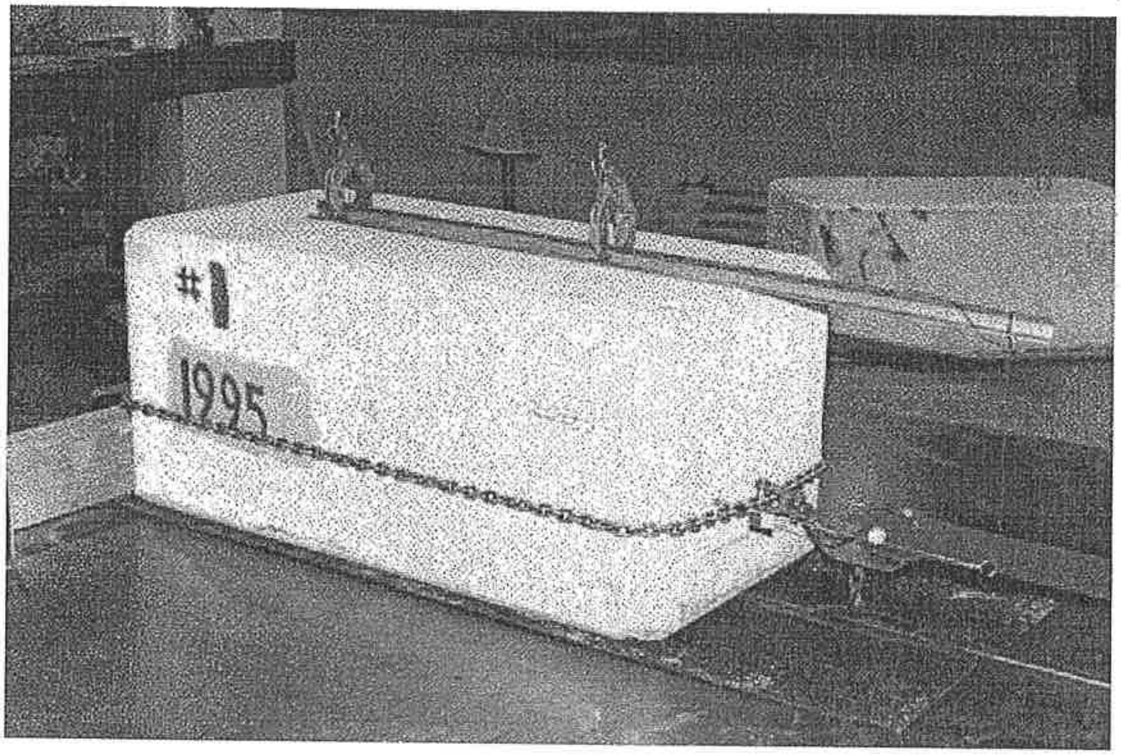

Figure 5/ Concrete Block on Steel Deck with Rubber Mat Interface

condition done in an evening, so that the deck had a chance to dry at least overnight.

The skid material was prepared, either by placing the concrete block on the deck, or by attaching the appropriate base to the sled and placing the sled on the deck. The drawbar was attached to the concrete block or sled, and was adjusted so that it was level. The sled was straightened as well as possible, and any load was placed on it. The pull cord was attached to the sled. The actuator was adjusted to relieve any tension in the drawbar.

The set up of the experiment with the concrete pipes was somewhat different than that described above. A total of three concrete pipes were used, with one sitting on top of the other two as seen in Figure 6. They were supported by two 10x10 cm (4x4 in) hardwood blocks placed transversely on the deck, and the pipes were restrained laterally by means of wedge blocks nailed to these blocks on both sides. Two series of tests were conducted. In the first series, the bottom two pipes were restrained while the top pipe was pulled longitudinally over the other two, as shown in Figure 6. The second series pulled all three pipes over the timbers, as shown in Figure 7.

Once the load was in place and the pull was set up, 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. When

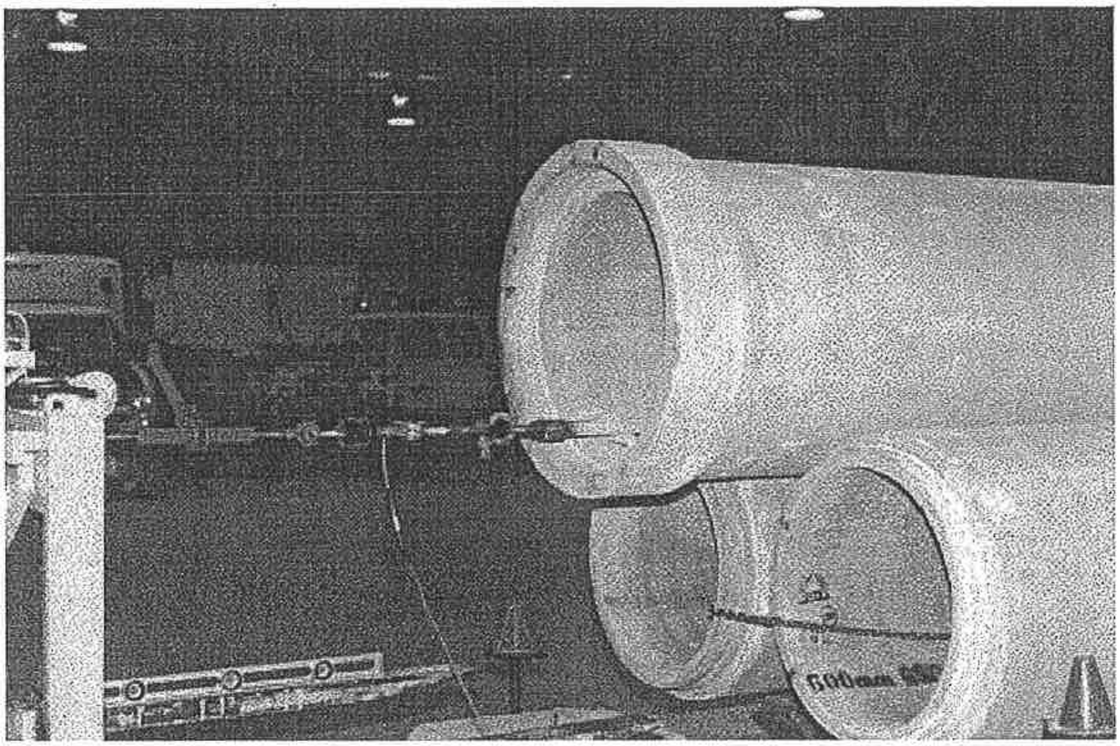

Figure 6/ Pulling Top Concrete Pipe

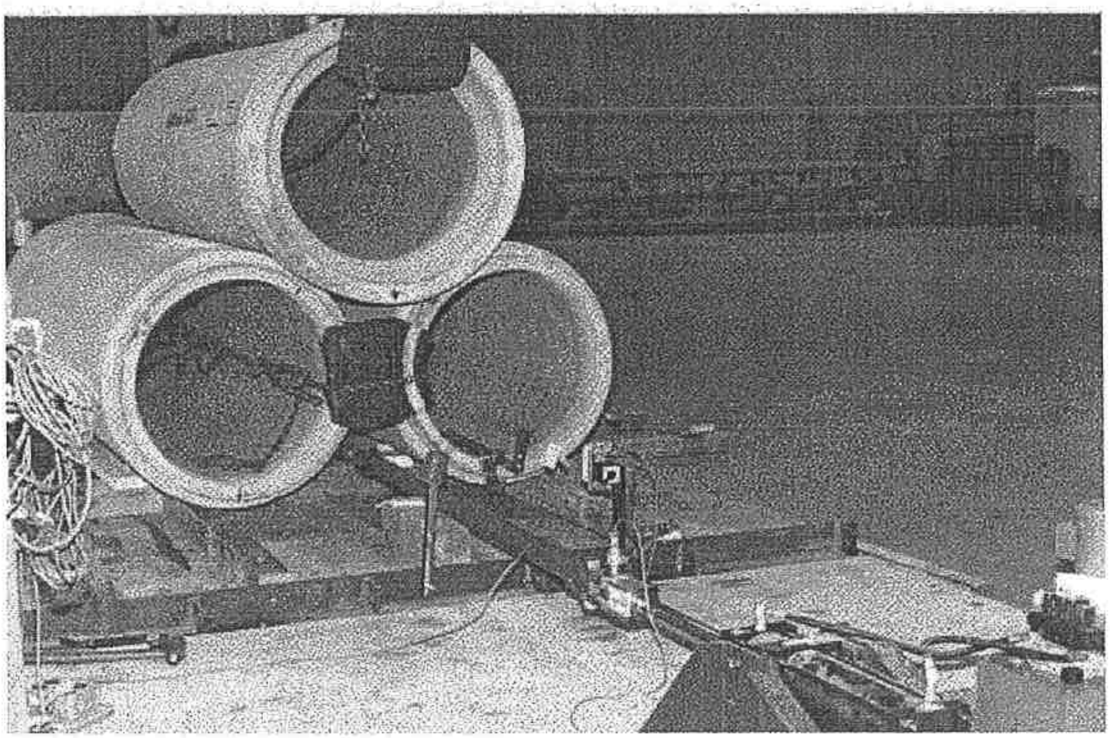

Figure 7/ Pulling All Three Concrete Pipes all was ready, data acquisition was re-started, and about three seconds later the hydraulic system was actuated to pull the sled forward for a distance of about 7.5 cm (3 in). At this point the hydraulic system was stopped, and data acquisition was also stopped. The hydraulic actuator was then momentarily reversed, to relieve the drawbar tension somewhat. It was not necessary to reduce the tension to zero, and this was avoided so that there was no risk of pushing the sled back. The above process was then repeated, for the full stroke of the actuator. There were usually a total of five similar pulls for a typical test condition.

The pull cord and drawbar were detached from the sled, the load was removed, and the sled was removed from the deck. The deck and skid materials were examined for surface damage. The entire process was repeated for the next test.

The data in the PC were saved to a file on the hard disk, under a file name that completely described the test conditions. The data were retrieved, the calibrations were examined, adjusted if necessary, and a quick look assessed whether the data looked 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 saved again, and a backup was saved immediately on a floppy disk.

Samples of equipment and test activity were recorded on video tape. Colour 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. Figure 8 shows the force and displacement response for a typical run. The procedure took such a run, consisting of several pulls of the sled, and for each pull it determined the static and sliding friction. The static friction was taken as the highest instantaneous friction coefficient reached before the sled starts to move, seen in Figure 9, which is an enlargement of the fourth pull in Figure 8. The sliding friction coefficient was evaluated by taking the average value over the two consecutive seconds of data that had the lowest mean square deviation, as also shown in Figure 9. It was found that the first pull for any test condition consistently produced different results than the succeeding pulls, as seen in Figure 8. The same result was found in the tests that examined the effect of vibration on friction [3]. It was supposed that the load was not quite straight, and the imperceptible process of straightening the load contaminated the data. For this reason, the first pull in every run was discarded, and results were only computed for the second and subsequent pulls. The results of each pull were tagged with the test conditions from the file name, and were added to an ASCII summary file. This procedure was able to deal with all runs, so every pull was processed in exactly the same manner.

When all runs had been processed, the summary file was read into a spreadsheet, average coefficients of friction were computed and graphical summaries of the results were prepared.

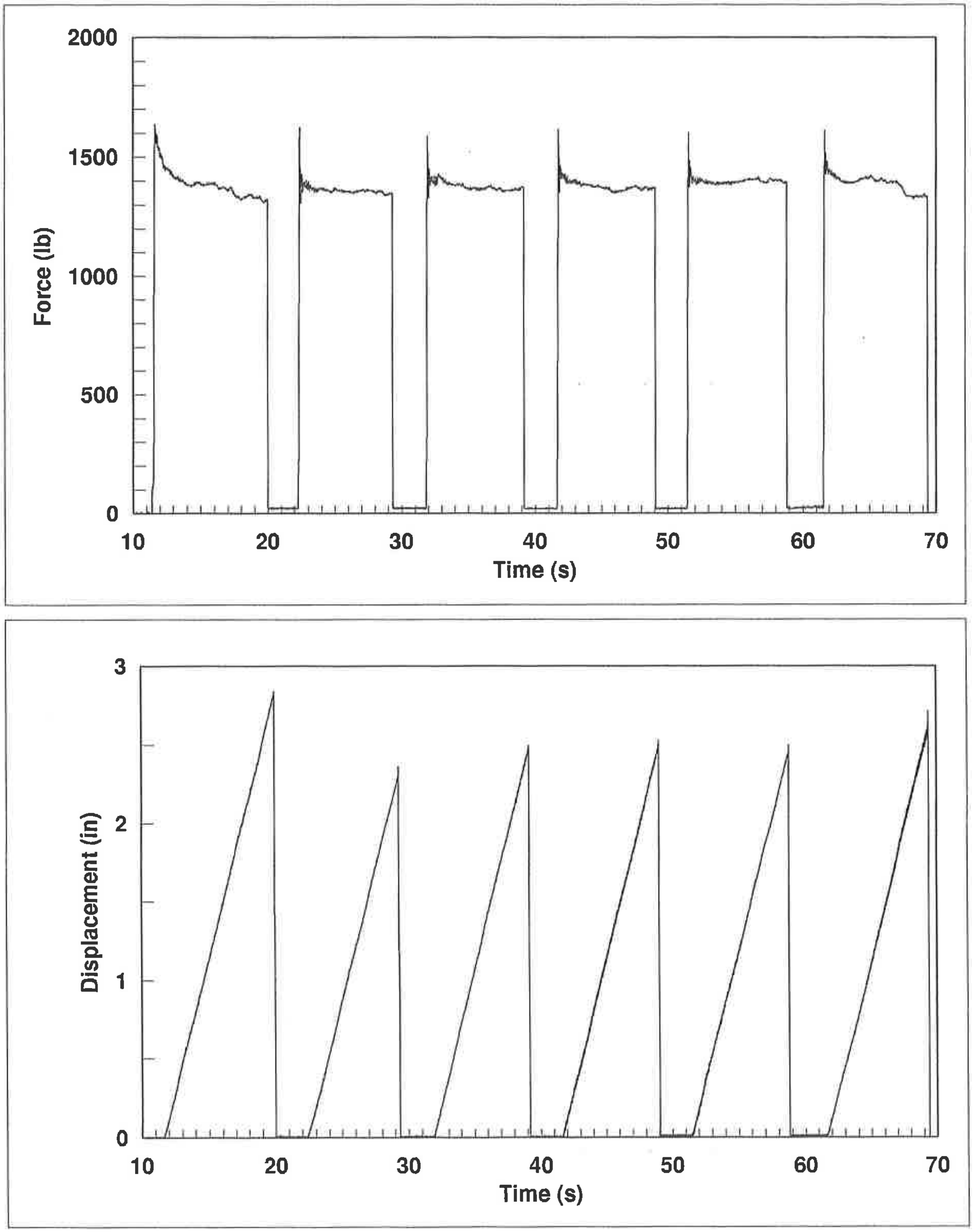

Figure 8/ Force and Displacement Responses for a Typical Pull

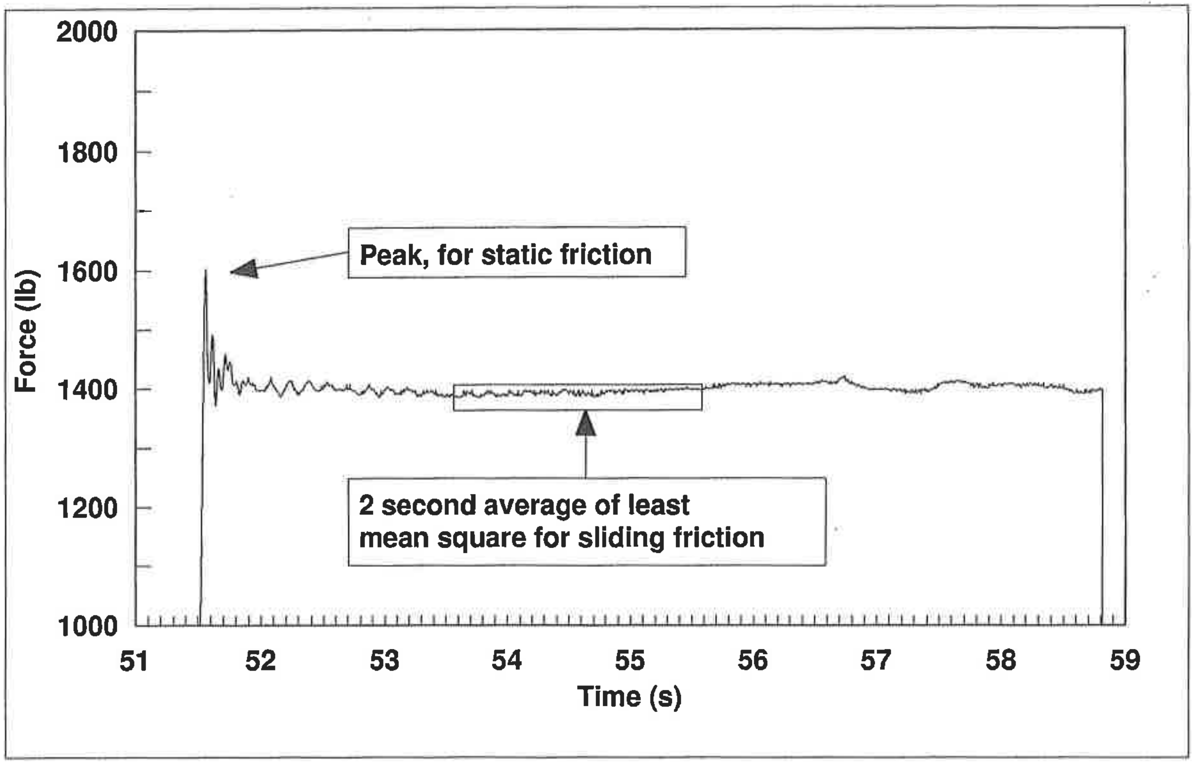

Figure 9/ Detail of Force Response for Typical Pull

3.5/ Test Matrix

The scope identified seven deck materials, nine skid materials and five surface conditions, for a total of 315 combinations. A subset of these combinations was selected that eliminated those conditions judged unlikely to occur in daily practice. This left the 90 conditions shown in Table 1, where surface condition C denotes a clean and dry deck, S a sandy deck, O an oily deck, W a wet deck, and R a clean and dry deck with a rubber mat placed loosely on it. Each of the conditions in Table 1 was tested with the sled loaded with one or two concrete blocks. In some case, it was also tested with the sled empty.

Table 1/ Test Matrix

		Surface Condition				
Deck Material	**Skid Material**	**C**	**S**	**O**	**W**	**R**
Coarse oak	Smooth steel	x				
	Smooth oak	x		x		
	Spruce	x				
	Machine feet	x			x	
	Steel pads	x			x	
	Plastic skid	x		x		x
	Concrete	x			x	
	Rubber	x		x		
Smooth oak	Smooth steel	x		x		x
	Smooth oak	x				
	Plastic skid	x		x		x
	Concrete	x			x	
	Rubber	x		x		
	Paper	x		x		x
Smooth spruce	Smooth steel	x				
	Spruce	x	x		x	x
Smooth steel	Smooth steel	x				
	Spruce	x	x			
	Machine feet	x		x		
	Plastic skid	x			x	x
	Concrete	x			x	x
	Rubber	x		x		
	Paper	x	x	x		x

		Surface condition				
Deck Material	**Skid Material**	**C**	**S**	**O**	**W**	**R**
Aluminum, along grooves	Smooth steel	x				
	Spruce	x			x	
	Machine feet	x		x		
	Plastic skid	x			x	x
	Concrete	x				
	Rubber	x		x		
Aluminum, across grooves	Smooth steel	x				
	Spruce	x			x	
	Machine feet	x		x		
	Plastic skid	x			x	x
	Concrete	x				
	Rubber	x		x		
Transdeck	Smooth steel	x				
	Oak	x	x			
	Machine feet	x		x		
	Steel pads	x		x		
	Plastic skid	x			x	x
	Concrete	x				
	Rubber	x			x	
	Paper	x	x			x
Concrete pipe	Concrete pipe	x			x	
	Spruce blocks	x			x	

4/ Results

4.1/ Effect of Vertical Load

The effect of vertical load on the frictional characteristics at the skid-deck interface was studied by adding concrete blocks on top of the skid material or the sled and repeating the same test sequence. The results showed that friction coefficients increased slightly as the vertical load was increased in the few instances where either the skid or the deck material was compressible. However, there was no observable pattern for other combinations, and sometimes friction coefficients increased with vertical load, and other times they decreased. The change in friction coefficient was less than 10% of the average in most cases when the vertical load was increased from about 180 kg (400 lb) to 2,040 kg (4,500 lb). It was therefore to concluded that the effect of vertical load on the frictional characteristics was not significant within the scope of this part of the work, where the objective is to identify combinations of deck and cargo that may have a particularly low or particularly high coefficient of friction. Indeed, when the gross variations in surface properties of the test samples are considered, it is expected that there would be at least as large variation in friction coefficients for different samples of the same deck and skid materials as there was for variation in vertical load. The test results for all valid pulls for all vertical loads were therefore averaged together to give coefficients for the static and sliding friction for each skid-deck combination.

4.2/ Coarse Oak Deck

The deck consisted of five nominal 2.5x25 cm (1x10 in) rough-sawn planks screwed down to the deck of the test rig parallel to the direction of pull. The planks included normal imperfections like warping that are typical in this grade of lumber. No attempt was made to create a smooth or planar surface, so contact between the sled and deck was not entirely even.

Table 2 shows the results of friction tests on the coarse oak deck. On the clean surface, the static friction coefficient ranged from 0.25 for the plastic skid to 0.70 for the rubber skid, and the sliding friction coefficient ranged from 0.19 for the steel pads to 0.65 for the rubber skid. On the wet surface, the static coefficient of friction increased for all skid materials tested, by 34-65%. However, when oil was introduced on the deck, both coefficients of friction were always reduced, by 16-50%. When the rubber mats were inserted between the plastic skid and the deck, the static and sliding friction coefficients were improved to 0.51 and 0.49 respectively.

4.3/ Smooth Oak Deck

The deck consisted of five nominal 2.5x25 cm (1x10 in) planed planks screwed down to the deck of the test rig parallel to the direction of pull. Again, the planks included the normal imperfections of this grade of lumber. No attempt was made to create a smooth or planar surface, so contact between the sled and deck was not entirely even.

	Surface Condition									
	Clean		**Sandy**		**Oily**		**Wet**		**Rubber**	
Skid	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**
Steel	0.51	0.47								
Oak	0.37	0.29			0.26	0.15				
Spruce	0.37	0.30								
Machine Feet	0.29	0.25					0.39	0.26		
Steel Pads	0.26	0.19					0.39	0.19		
Plastic Skid	0.25	0.20			0.20	0.12			0.51	0.49
Concrete	0.46	0.40					0.76	0.46		
Rubber	0.70	0.65			0.59	0.41				
Paper										

Table 2/ Friction Coefficients on Coarse Oak Deck

	Surface Condition									
	Clean		**Sandy**		**Oily**		**Wet**		**Rubber**	
Skid	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**
Steel	0.50	0.46			0.28	0.15			0.62	0.59
Oak	0.40	0.35								
Spruce										
Machine feet										
Steel Pads										
Plastic Skid	0.20	0.16			0.18	0.11			0.50	0.47
Concrete	0.36	0.41					0.77	0.50		
Rubber	0.70	0.64			0.49	0.30				
Paper	0.32	0.27			0.28	0.14			0.70	0.66

Table 3/ Friction Coefficients on Smooth Oak Deck

Table 3 shows the results of friction tests on the smooth oak deck. On the clean surface, the static friction coefficient ranged from 0.20 for the plastic skid to 0.70 for the rubber skid while the corresponding sliding friction coefficients ranged from 0.16 to 0.64 respectively. Oil on the smooth oak deck always degraded the friction between the deck and the skid materials. The effect was more significant for sliding friction, where the friction coefficient diminished by 67% for steel, 53% for rubber and 31% for the plastic skid. Concrete was the only skid material tested on the wet surface, and its static friction coefficient of 0.77 and a sliding friction coefficient of 0.50 were significant increases over the values on the clean and dry surface. When rubber mats were inserted between the skid and the deck, friction coefficients greatly improved for all three skid materials tested.

Comparison of Tables 2 and 3 shows that there is fairly good agreement between friction coefficients for the same skid material and surface condition between the coarse and smooth oak decks. Generally, coefficients are slightly lower for smooth oak, which would generally be expected.

4.4/ Spruce Deck

The deck consisted of five nominal 2.5x25 cm (1x10 in) planed planks screwed down to the deck of the test rig parallel to the direction of pull. Again, the planks included the normal imperfections of this grade of lumber. No attempt was made to create a smooth or planar surface. Again, contact between the sled and deck was not entirely even.

Table 4 shows the results of friction tests on the spruce deck. Only two skid materials were tested on this surface, because of its limited application. On the clean surface, the static friction coefficients of the spruce and steel plate skid were 0.49 and 0.45 and the corresponding sliding friction coefficients were 0.47 and 0.43 respectively. There was little effective change for spruce on a sandy deck, but there were substantial increases in both coefficients with the wet spruce deck and when the rubber mats were inserted between the spruce skid and the spruce deck.

4.5/ Smooth Steel Deck

The surface deck was a plate of 3 mm (0.125 in) sheet steel placed on the test rig deck.

Table 5 shows the friction coefficients for different skid materials under various surface conditions on the smooth steel deck. On the clean surface, the static friction coefficient ranged from 0.18 for machine feet skid to 0.56 for the rubber skid, with a corresponding sliding friction coefficient range of 0.15 to 0.54 respectively. There were significant reductions in friction for the skid materials tested on the sandy surface, possibly because the sand was unable to indent the steel deck. While the peak and sliding friction coefficients of the machine feet skid were only slightly reduced to 0.16 and 0.14 respectively when oil was present on the steel surface, the friction coefficients for rubber and paper skids were drastically reduced. On the wet steel surface, the plastic skid had a slight reduction in friction, whereas there was a substantial increase for concrete.

	Surface Condition									
	Clean		Sandy		Oily		Wet		Rubber	
Skid	Static	Slide	Static	Slide	Static	Slide	Static	Slide	Static	Slide
Steel	0.45	0.43								
Oak										
Spruce	0.49	0.47	0.50	0.43			0.78	0.61	0.70	0.67
Machine feet										
Steel Pads										
Plastic Skid										
Concrete										
Rubber										
Paper										

Table 4/ Friction Coefficients on Smooth Spruce Deck

	Surface Condition									
	Clean		Sandy		Oily		Wet		Rubber	
Skid	Static	Slide	Static	Slide	Static	Slide	Static	Slide	Static	Slide
Steel	0.27	0.25								
Oak										
Spruce	0.40	0.40	0.33	0.29						
Machine feet	0.18	0.15			0.16	0.14				
Steel Pads										
Plastic Skid	0.21	0.18					0.20	0.16	0.56	0.53
Concrete	0.26	0.26					0.35	0.33	0.57	0.55
Rubber	0.56	0.54			0.24	0.16				
Paper	0.43	0.40	0.27	0.23	0.24	0.19			0.60	0.57

Table 5/ Friction Coefficients on Smooth Steel Deck

When rubber mats were inserted between the skid and the deck, the friction at the skid-deck interface was dramatically increased.

4.6/ Aluminum Deck with Lengthwise Grooves

This deck consisted of extruded panels about 30 cm (12 in) wide with grooves with a width and depth of about 2.5 cm (1 in), and about the same distance apart, running the length of the panel. Panels were designed to interlock along the sides. Panels were cut to the length of the deck of the test rig, and were simply placed on the deck with the grooves parallel to the direction of pull.

Table 6 shows the friction coefficients of various skid materials on the aluminum deck with lengthwise grooves. On the clean deck surface, all the skid materials tested had a static friction coefficient well over 0.50, except the plastic skid. When the surface was oily, there was a significant reduction, especially for the rubber skid. The test results were mixed on the wet surface. The spruce skid had slightly higher friction coefficients while the plastic skid had slightly lower coefficients than on the clean surface. The friction coefficients of the plastic skid were improved to 0.5 and 0.47 respectively when the rubber mats were inserted between the skid and the deck, to levels consistent with those measured on other decks.

4.7/ Aluminum Deck with Crosswise Grooves

This deck consisted of the same extruded panels described above, but simply rotated 90 deg so that the grooves were perpendicular to the direction of the pull.

Table 7 shows the friction coefficients of various skid materials on the aluminum deck with crosswise grooves. The test matrix was exactly the same as that for pulls along the grooves, so that a direct comparison could be made of the effect of groove orientation on the friction characteristics of this deck. It is clear by comparing Tables 6 and 7 that the friction coefficients for pulls across the grooves are somewhat lower than that for pulls along the grooves for the clean and dry interface. The only skid that comes at all close is rubber, and the others are 25-42% lower. The friction coefficients for oily, wet and rubber interfaces are comparable to those for the corresponding conditions in Table 6. Indeed, it is of interest that the values for the plastic skid on rubber are almost exactly the same for the two orientations of this deck material.

4.8/ Transdeck Deck

Transdeck is a proprietary fibre board with a textured surface that was provided in 1.22x2.44 m (4x8 ft) sheets. The sheets were simply placed on the deck of the test rig, with the long side parallel to the direction of pull.

Table 8 shows the friction coefficients for the various skid materials on Transdeck. On the clean dry deck, they were relatively low, except for concrete, rubber and paper.

	Surface Condition									
	Clean		Sandy		Oily		Wet		Rubber	
Skid	Static	Slide	Static	Slide	Static	Slide	Static	Slide	Static	Slide
Steel	0.63	0.59								
Oak										
Spruce	0.65	0.65					0.69	0.64		
Machine feet	0.60	0.57			0.45	0.41				
Steel Pads										
Plastic Skid	0.24	0.21					0.19	0.15	0.50	0.47
Concrete	0.59	0.55								
Rubber	0.68	0.66			0.24	0.17				
Paper										

Table 6/ Friction Coefficients on Aluminum Deck with Lengthwise Grooves

	Surface Condition									
	Clean		Sandy		Oily		Wet		Rubber	
Skid	Static	Slide	Static	Slide	Static	Slide	Static	Slide	Static	Slide
Steel	0.42	0.40								
Oak										
Spruce	0.42	0.40					0.57	0.52		
Machine feet	0.44	0.43			0.41	0.38				
Steel Pads										
Plastic Skid	0.18	0.13					0.15	0.11	0.50	0.48
Concrete	0.34	0.33								
Rubber	0.59	0.56			0.27	0.20				
Paper										

Table 7/ Friction Coefficients on Aluminum Deck with Crosswise Grooves

	Surface Condition									
	Clean		Sandy		Oily		Wet		Rubber	
Skid	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**	**Static**	**Slide**
Steel	0.24	0.20								
Oak	0.33	0.26	0.48	0.40						
Spruce										
Machine feet	0.24	0.20			0.19	0.12				
Steel Pads	0.27	0.23			0.19	0.12				
Plastic Skid	0.25	0.18					0.20	0.13	0.53	0.50
Concrete	0.48	0.42								
Rubber	0.71	0.68					0.75	0.72		
Paper	0.46	0.40	0.43	0.35					0.72	0.66

Table 8/ Friction Coefficients on Transdeck

On the oily surface, the two skid materials tested both showed a significant decrease in friction coefficients. When the surface was wet, the friction coefficients of the plastic skid decreased slightly, while those of the rubber skid were increased slightly. When the rubber mats were inserted between the skid and the deck, friction coefficients for the plastic skid and paper increased sharply.

4.9/ Concrete Pipe

Table 9 summarizes the results for the concrete pipes.

The static friction coefficients between concrete pipes were 1.05 and 0.97 on the clean and wet surfaces, and the corresponding sliding friction coefficients were 0.90 and 0.82, when the upper pipe was pull across the lower two to give a concrete-to-concrete interface. The same two surface conditions were also evaluated when all three pipes were pulled, as a stack, across the 10x10 cm (4x4 in) hardwood supports. The static friction coefficients were 0.74 and 0.82 on the clean and wet surfaces respectively, and the corresponding sliding friction coefficients were 0.60 and 0.62. All tests exhibited significant stick-slip limit cycle-type responses.

The second result above, when all three pipes were pulled as a group, had the softwood wedge blocks nailed to the hardwood supports so that they would not move as the pipes were pulled. In fact, the surface of the pipe severely abraded both support and wedge

Surface condition	Friction coefficient			
	Concrete pipes		4x4 Hardwood	
	Static	Slide	Static	Slide
Clean	1.05	0.90	0.74	0.60
Wet	0.97	0.82	0.82	0.62

Table 9/ Friction Coefficients of Concrete Pipes

Skid	Deck Material						
	Coarse Oak	Smooth Oak	Spruce	Steel	Along Al Grooves	Across Al Grooves	Trans-deck
Steel	0.51	0.50	0.45	0.27	0.63	0.42	0.24
Oak	0.37	0.40					0.33
Spruce	0.37		0.49	0.40	0.65	0.42	
Machine feet	0.29			0.18	0.60	0.44	0.24
Steel Pads	0.26						0.27
Plastic Skid	0.25	0.20		0.21	0.24	0.18	0.25
Concrete	0.46	0.36		0.26	0.59	0.34	0.48
Rubber	0.70	0.70		0.56	0.68	0.59	0.71
Paper		0.32		0.43			0.46

Table 10/ Summary of Static Friction Coefficients blocks. When the same test was repeated with the wedge blocks simply hammered into place, the pipes quickly dragged the wedge blocks off the edge of the support blocks. The pipes were actually chained together for this test, to prevent them rolling away, but in normal use, if wedge blocks are dislodged then presumably pipes gain some freedom to roll that they did not have.

5/ Analysis and Discussion

5.1/ Overall Summary

Table 10 presents a summary of the static friction coefficients for the clean deck condition, bringing together the first columns of Tables 2 through 8.

This table shows, for the combinations tested, that there is a range of static friction from 0.18 to 0.71. There are undoubtedly other possible combinations of skid and deck that would be outside this range, at either end. It is clear that the plastic skid has a consistently low coefficient of friction, and rubber has a high coefficient of friction, no matter what deck either rests on. Others show some to significant variation, and it must be concluded that in general, the coefficient of friction of a particular article of cargo could be low, moderate or high depending on the deck on which it was placed.

5.2/ Effects of Skid-Deck Interface

Surface roughness was another parameter that had been examined in this test program using the smooth and coarse oak deck surfaces. Friction test measurements indicated that the friction coefficients for those skid materials tested on the clean surface of the smooth and coarse hardwood decks were almost identical except for the plastic skid. Thus, no significant effect of surface roughness on the frictional characteristics on these skid-deck combinations could be detected. This seems to contradict with the conventional technical publication [4] which stated that surface roughness could have a significant effect on the friction characteristics between two surfaces. However, the results quoted in the reference was probably obtained from a very carefully controlled surface and small test specimens as opposed to the decks and skids used in this test program. The hardwood decks employed were constructed from commercial 5x25 cm (2x10 in) oak planks in either the smooth or coarse grade as sold. Even though effort had been made to select the best pieces available from the shelf, no attempt had been made to machine the deck surface after it was put together. The objective was to simulate a typical commercial deck surface as close as possible. Thus, the effect of other surface conditions such as wood texture and deck irregularities could be higher than that of the individual lumber surface roughness. For all practical purposes, the surface roughness of the deck was deemed to have no significant effect on the overall friction coefficient of the skid-deck combination.

The presence of contaminants in the skid-deck interface is known to affect the friction characteristics of the skid-deck combination [4]. These tests also demonstrate that, and show some significant effects.

The presence of sand on the deck, representative of a generic dirt, tended to reduce friction when both surfaces were hard, when it probably acted like ball bearings between the two surface. However, when one surface was soft, friction tended to increase, probably because the sand granules would become embedded in the softer surface , making it like sandpaper.

The presence of oil on the deck always reduced the coefficients of friction.

The presence of water resulted in an effect similar to that of sand. When both surfaces were hard, it tended to reduce friction, as it was effectively lubricating the interface. However, when one surface could absorb water, then friction tended to increase. These tests used only a relatively small amount of water, and it might be expected that a large amount of water that exceeded the absorptive capacity of the surface would result in water standing on the surface and lubricating the interface, as when neither surface was absorptive.

The presence of rubber mats between the cargo and deck always increased the coefficients of friction. If the coefficient of friction between the cargo and the rubber mat was less than that between the mat and the deck, then the cargo would slide over the mat, and the mat would remain stationary on the deck. In the converse case, the cargo would adhere to the mat, and would drag it across the deck. There were also some cases where the coefficients of friction for the two surfaces were close, and the cargo both slid on the mat and dragged it across the deck.

5.3/ Experimental Factors

The design of the hydraulic actuator only allowed the drawbar to be pulled at a single speed. This resulted in essentially a step input in force, hence some dynamic transient response, at the beginning of each pull. However, in most cases, the responses appeared to be well damped and the pulling force settled rapidly to a fairly steady state after a few oscillations. As a result, the coefficients of static friction may therefore be somewhat different than if the load was pulled more slowly. However, this series of tests was really only trying to establish the range of coefficients of friction, with a view perhaps to categorizing them as "high", "medium" and "low". These effects are not considered likely to be large enough that they would affect the broad conclusions drawn from this work.

A non-linear slip-stick or limit cycle response occurred for some combinations of cargo and deck, most commonly with concrete on the wood decks. This phenomenon probably arose from coupling with a vibration mode due to flexibility of the test rig and the fluid column in the hydraulic actuator. Since it is believed that each cycle was equivalent to a single typical pull, the data were useful and could be processed using the standardized procedure described above.

Pulls were conducted repeatedly on the same areas of the test decks. This clearly resulted in some wear, at least of the wooden decks, and this may have resulted in some smoothing of the deck surface and some reduction in coefficient of friction. This would seem to raise questions about the validity of the work. However, if the deck were replaced after every pull, there would be sample variations in deck surface properties and deck smoothness between samples that would also affect the results. This could only be addressed by standardizing the deck materials, by planing or machining, and that would destroy the very properties that are so typical of much of truck cargo and decks. Again, within the objective simply to categorize friction levels, the variation seen in successive pulls was not considered large enough to have a significant effect on the overall conclusions to be drawn from this work.

5.4/ Comparison with Other Data

There is essentially no literature on friction measurements between typical truck cargo materials and the type of materials used for truck decks. Most friction measurements reported in the literature were made fifty or more years ago [4], and it appears that they were made with quite small carefully machined samples using measurement techniques much less sophisticated than current practice. These also provide some very large ranges, and appear of little practical use for cargo securement purposes.

Static measurements made during the examination of friction under vibration do provide some basis for comparison [3]. In general, there is quite good agreement for sliding friction. The static friction found here tends to be somewhat lower than there, presumably because the 200 Hz sample frequency used here would be less likely to be close to a peak than the 1000 Hz sample frequency used during the vibration tests. There are also differences, for example, where the oak deck was of quite different roughness in the two tests, so the results cannot be compared directly. It is of interest that this difference indicates a likely and realistic sample range.

In another part of this project, tests were also conducted on securement methods for dressed lumber [5], and on stability of large rolls of paper [6], and these can be interpreted to infer coefficients of static friction. These tests were conducted using a truck with a Transdeck deck. The dressed lumber tests produced equivalent static coefficients in the range 0.41-0.52 [5], which appear compatible with results presented here. Direct comparison is a little difficult, as the spruce bundles rested on 10x10 cm (4x4 in) spruce blocks placed on the deck. The paper roll tests produced equivalent static coefficients of friction of 0.47 and 0.50 [6], which compare relatively well with 0.46 here. Two different rubber mats increased the static coefficient of friction to 0.60 to 0.63 [6], but they were of a different type than used in these tests, where the coefficient increased to 0.72.

5.5/ Discussion

Other work conducted as part of this project has concluded, in part [5] :

> "Friction along the surfaces of contact between the load and its supports would appear to be the principal factor that affects load security."

There certainly have been a number of accidents where cargo movement is believed to have played a significant role in the accident. Large paper rolls seem to be one commodity repetitively involved in this class of accident. While there are many reports of movement of otherwise un-restrained rolls during the course of a normal and uneventful trip, there are also reports that a rubber mat placed beneath each roll substantially eliminates movement. The static coefficient of friction of paper on paper has been reported as low as 0.17, and this work finds values as low as 0.32 for paper on other materials, which increases to at least 0.60 when a rubber mat is used.

Consider an otherwise un-secured article of cargo just sitting on the deck of a truck, and assume for the moment ideal roads that are completely smooth and without cracks, potholes or joints, so that the truck can drive in a vibration-free environment. Over a long period of time, driving in traffic, following the roadways and obeying traffic control devices will produce distributions of longitudinal and lateral acceleration that will be approximately normal. That is, there will be large numbers of (say) low decelerations due to minor speed adjustments, small numbers of moderate decelerations, and few emergency decelerations. The probability of the cargo shifting on this truck is clearly dependent on the relationship between the coefficient of static friction between the cargo and deck, and the distribution of longitudinal and lateral acceleration. If the coefficient of friction is low, the cargo has a much higher probability of shifting than if it is high, because the frequency of exceeding any level of acceleration diminishes sharply as that level increases.

It is clear, from this idealized example, that if the coefficient of friction between cargo and deck, and maybe also between cargo and tiedowns, could be increased for all truck trips, it should result in a significant reduction in cargo movement. These tests also show that use of rubber mats can produce consistently high coefficients of friction. There are presumably other materials with equivalent properties. However, there are serious questions about how reliable friction can be considered. The truck deck is subject to severe vibration, the friction properties of friction-enhancing materials may diminish with wear, and the surfaces may become contaminated. These considerations presumably all contribute to the current regulations, where no credit is given for any level of friction in the securement system. All carriers must provide sufficient tiedowns to secure cargo. Those who voluntarily use means to increase the friction coefficients on their trucks clearly are reducing the risk of cargo movement and loss. Carriers who do not do this are equally in compliance with the securement regulations, but may have a much higher real likelihood of cargo movement or loss. It is this that is the area of concern. Quite simply, if friction is the principal real factor preventing cargo shift and loss, it should be recognized and credit should be given to those who use it, to encourage or require others to do the same. Following are three approaches, which address this issue in different ways:

- Recognizing that friction may not be completely reliable, there could be a recommended practice to use friction-enhancing materials.
- Alternatively, the proposed cargo securement standard could give some credit for any additional friction used by the carrier, which recognizes and encourages use of friction-enhancing materials.
- Finally, the proposed standard could require some minimum level of friction.

There may be other approaches, too, including combinations of these. In considering these, it is imperative to guard against factors that make cargo-deck friction unreliable. For example, the dynamic characteristics of cargo, deck, and interface all played a significant role in friction in the presence of vibration, and rubber mats could contribute to cargo hop at typical high levels of vertical acceleration [3]. Tests of cargo securement methods for dressed lumber showed that 10x10 cm (4x4 in) spacers beneath packages of lumber effectively became rollers when rubber mats were placed above and below them while trying to increase the coefficient of friction [6]. Factors like these must be carefully considered in setting prudent levels for friction that will generally be reliable, and that unexpected outcomes of good intentions do not, in fact, have adverse consequences.

This discussion has addressed friction as it contributes to an overall cargo securement system that may also include tiedowns, blocking and other means of securement. No matter how high the level of friction, it cannot be considered totally reliable so should never be considered the sole means of securement.

6/ Conclusions

A series of tests were conducted to determine static and sliding coefficients of friction for typical cargo on typical truck decks. These tests were conducted at full scale, to represent the typical imperfections in materials seen at this scale. Friction coefficients were determined with the deck clean, and with the cargo-deck interface contaminated with sand, oil or water, or with a rubber mat placed on the deck beneath the cargo.

The tests found that the coefficient of static friction, the level that must be overcome to start the cargo sliding, ranged from 0.18 to 0.71 for the various types of cargo tested on the various dry decks. The coefficient of sliding friction, the level that must be overcome to maintain the cargo sliding at constant velocity once it has started sliding, ranged from 0.13 to 0.68 for the same case, and was 8 to 28% less than the coefficient of static friction, for dry decks. Some cargo had consistently high coefficients of friction on all decks, some had consistently low coefficients, and for others, the coefficients varied more or less widely, depending on the deck.

The tests also found that coefficients of friction tended to increase if at least one of the surfaces was soft, so that sand could indent into it, or water could be absorbed by it. If both of these surfaces were hard, then sand or water in the cargo-deck interface tended to decrease coefficients of friction.

Finally, the tests found that coefficients of friction tended to decrease if there was oil in the cargo-deck interface, and tended to increase significantly if a rubber mat was placed between the cargo and the deck.

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 [7].

7/ Recommendations

The following recommendations emerge from this work:

1/ A high coefficient of friction should be a consideration in specification of the deck for trailers. This should also extend to consider the reliability of this friction over the life of the trailer, due to the effects of wear and contamination of either the cargo or the deck by substances that may affect its friction properties.

2/ The plastic skid used in these tests exhibited rather low coefficients of friction. Cargo handling equipment that is also used during transportation, of which this skid is probably just one example, should also be designed with high coefficients of friction, on both surfaces.

3/ Rubber mats, and any other materials with equivalent friction properties, appear to increase the coefficient of static friction over 0.5 (considered high) for all combinations of cargo and deck tested, and their use should be encouraged.

4/ The role that a high friction coefficient plays in inhibiting cargo movement should be formally recognized in the proposed standard.

5/ Credit should be given for friction where it clearly plays a substantial role in cargo securement.

6/ Friction, even high initial friction, must continue to be considered inherently unreliable. However, probabilistic approaches can be used to determine friction levels that will provide any required minimum level of risk.

7/ If friction requirements are set, then appropriate test methods should also be specified.

8/ No matter how high the level of friction, it remains inherently unreliable, and should never be considered the sole means of cargo securement.

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