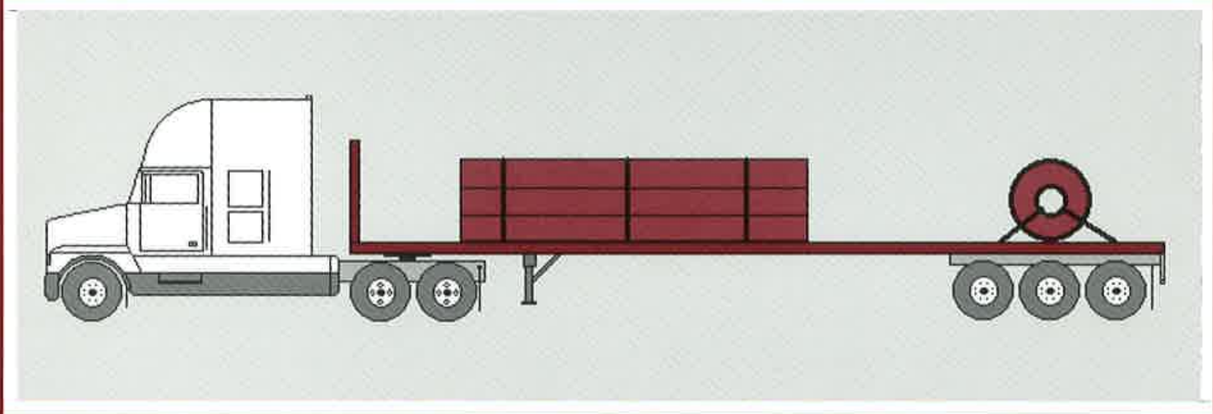
CCMTA Load Security Research Project

Report # 11

TESTS ON METHODS OF SECUREMENT FOR THICK METAL PLATE



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

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Report # 11

TESTS ON METHODS OF SECUREMENT FOR THICK METAL PLATE

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 tests were conducted to determine the forces required to cause movement of thick metal plate when secured flat on a truck deck by transverse tiedowns. The tests also examined the effect of movement of the plate on tension in the tiedowns. They were conducted for steel plates of various width, pulled in directions parallel and perpendicular to the vehicle longitudinal centre-line.

The tests, and subsequent analysis, showed that the transverse tiedown contained the plate under lateral loading, and tiedown tensions would not be excessive. Under longitudinal loading, the plate tended to slip out from under the tiedown. Chain tiedowns dimpled the edge of the plate, and did not slip in these tests, but webbing tiedowns always slipped and in some cases the rough edge of the plate severed the webbing.

Recommendations are made regarding securement of thick metal plate.

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 a number of commodities that are known to be difficult to secure on trucks, and thick metal plate was one of these. This was addressed by a series of tests to determine the resistance to movement of heavy steel plate of different dimensions, secured in different ways, and the effect of movement of the plate on the tiedowns. The work reported here is outlined in Section 13.3 of the project proposal.

A test rig was built, and a 0.61 m (2 ft) long steel plate was secured to it with a single instrumented chain or synthetic webbing tiedown, tensioned initially to 20 % of the working load limit of the particular tiedown. The plate was then pulled parallel to the truck deck, perpendicular to the longitudinal centre-line of the vehicle (representing a lateral acceleration due to turning), and parallel to the longitudinal centre-line of the vehicle (representing a longitudinal acceleration due to braking). The applied force, plate movement and the tiedown tension at mid-span and where the tiedown was secured to the test rig were measured.

The tests, and subsequent analysis, showed that the transverse tiedown contained the plate under lateral loading, and tiedown tensions would not be excessive. Under longitudinal loading, the plate tended to slip out from under the tiedown. Chain tiedowns dimpled the edge of the plate, and did not slip in these tests. Thus, as the plate moved, elongation of the tiedown provided both resistance to motion, and caused a significant increase in friction between the plate and the deck. Webbing tiedowns always slipped, and in some cases the rough edge of the plate severed the webbing.

Securing thick metal plate with transverse tiedowns appears to be adequate. Preferably, however, the plate should be placed against a bulkhead or other cargo so that it cannot slide forward. Webbing tiedowns should only be considered if the plate is so immobilized, and additionally the tiedown is protected from contact with the plate by some means that cannot be cut or abraded, and will not slip out from the tiedown.

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;
- Commercial Vehicle Safety Alliance;
- Forest Engineering Research Institute of Canada;
- Manitoba Highways and Transportation;
- Ministère des Transports du Québec;
- New Brunswick Ministry of Transportation;
- Newfoundland Ministry of Transportation and Public Works;
- New York State Department of Transportation;
- Nova Scotia Ministry of Transportation;
- Prince Edward Island Department of Transportation;
- Saskatchewan Government Insurance;
- Saskatchewan Highways and Transportation;
- Société des Assurances Automobile du Québec;
- Transport Canada, Road and Motor Vehicle Safety Directorate;
- 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 and composed of 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 work was conducted in part by Norm Carlton, Bill Stephenson, Gary Giles and Mike Wolkowicz of Strategic Vehicle Technology Office.

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.

There are a number of types of cargo that are not a typical cuboid shape, so are difficult to secure on flatdeck trailers. A number such were identified during the development of the project, and sheets of thick metal plate were one of these. These plates may be narrower or wider than the trailer deck, and may also be oiled. The purpose of this test was to determine the resistance to movement of plates of various width, and to determine the effect of the plate movement on the tiedowns. The work was outlined in Section 13.3 of the project proposal [1].

2/ Test Program

2.1/ Objectives

The objectives of this test were to determine :

1/ The acceleration required to cause motion of a secured thick metal plate;
2/ The effect of movement of the plate on tension in the tiedowns;
3/ The effect of plate width; and
4/ The mechanics of plate dislodgement and arrest.

2.2/ Scope

The test was conducted using three thick metal plates, one narrower, one about the same width, and one wider than a typical truck deck.

Each plate was set on two hardwood blocks, and tests were conducted with the plate :

1/ Unsecured;
2/ Secured with a single chain tiedown; and
3/ Secured with a single synthetic webbing tiedown without corner protection.

The tiedown spanned the full width of the plate.

Force was applied to the plate to represent a longitudinal (braking) or lateral (turning) acceleration of the truck.

3/ Procedures

3.1/ Test Apparatus

The test was conducted on the rig shown in Figure 1. It provided a flat wooden deck, about 2.4 m (8 ft) square, supported by side rails fitted with anchor brackets so that tiedowns could be attached on all sides. 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 to the actuator to pull the plate, as seen in Figure 1. Two 10x10 cm (4x4 in) hardwood blocks, 2.44 m (8 ft) long, were placed on the deck, either transversely or longitudinally, and the steel plate was placed on these. When secured, a tiedown was placed over the length of the plate, then attached by shackles through instrumented chain links to the anchor brackets on the side rails. The tiedown included a load cell to measure tension above the plate, and was tensioned with a ratchet binder. The tiedown and instrumentation are illustrated in Figure 2.

The test used three hot rolled, flame cut, mild steel plates, all 2.5 cm (1 in) thick and 0.61 m (2 ft) long, as follows :

1/ A narrow plate, 1.83 m (6 ft) wide, narrower than a typical truck deck;
2/ An intermediate plate, 2.44 m (8 ft) wide, about the same width as a typical truck deck; and
3/ A wide plate 3.05 m wide (10 ft), wider than a typical truck deck.

The tiedowns used were:

2/ 5/16 in grade 7 chain with a working load limit of 2,132 kg (4,700 lb), and
2/ 7.5 cm (3 in) synthetic webbing with a working load limit of 1,814 kg (4,000 lb).

Figure 1/ Test rig, with 2.44 m (8 ft) wide plate, set for a lateral pull

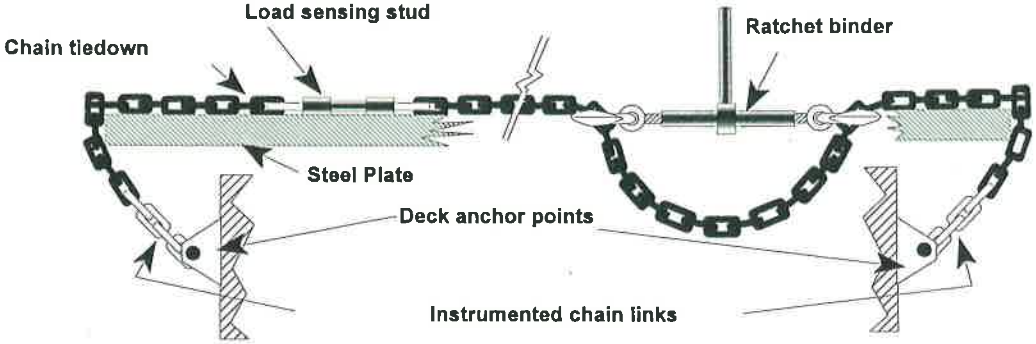
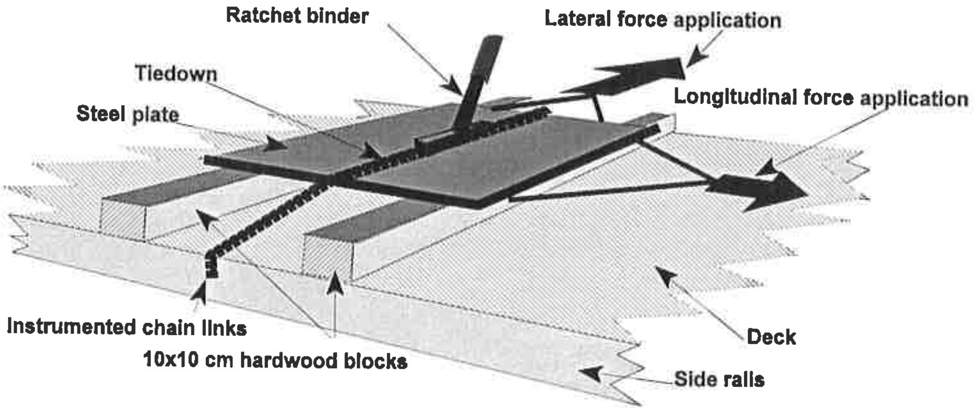
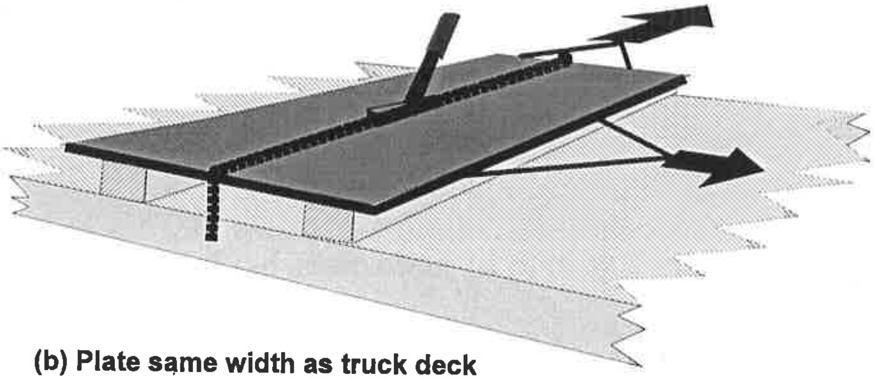


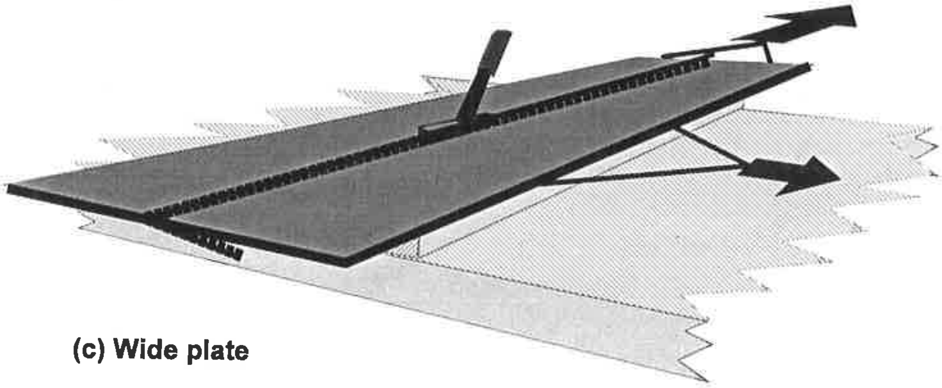
Figure 2/ Arrangement of Tiedown and Instrumentation



(a) Narrow plate



(b) Plate same width as truck deck



(c) Wide plate

Figure 3/ Orientations of Plate, Tiedown and Applied Force

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), seen in Figure 4 joining the actuator to the links used to pull the steel plate, was used to measure the tension in the drawbar. A Unimeasure model P510-20 pull cord transducer was attached to the deck, and its cord was attached to the steel plate to measure its forward motion. The tiedown was attached to each anchor point through a three-link section of chain, where the middle link was strain gauged with a four-arm bridge. These were calibrated, and each formed a convenient and compact load cell to measure tiedown attachment tension in the limited space available, as shown in Figure 5. A Strainsert Model SJ-F8 Type H load sensing stud, rated at 66.75 kN (15,000 lb), was attached to the tiedown on top of the plate to measure the tension applied to the tiedown. It was attached through spherical joints, to eliminate transfer of moments and torsion, as shown in Figure 7.

Data from these instruments was captured into a PC-based data acquisition system using a sample rate of 50 Hz, which was adequate to define the applied force, the tensions in the tiedowns and the displacement of the plate. A video camera was used to record characteristics of the test that were not discernable through instrumentation.

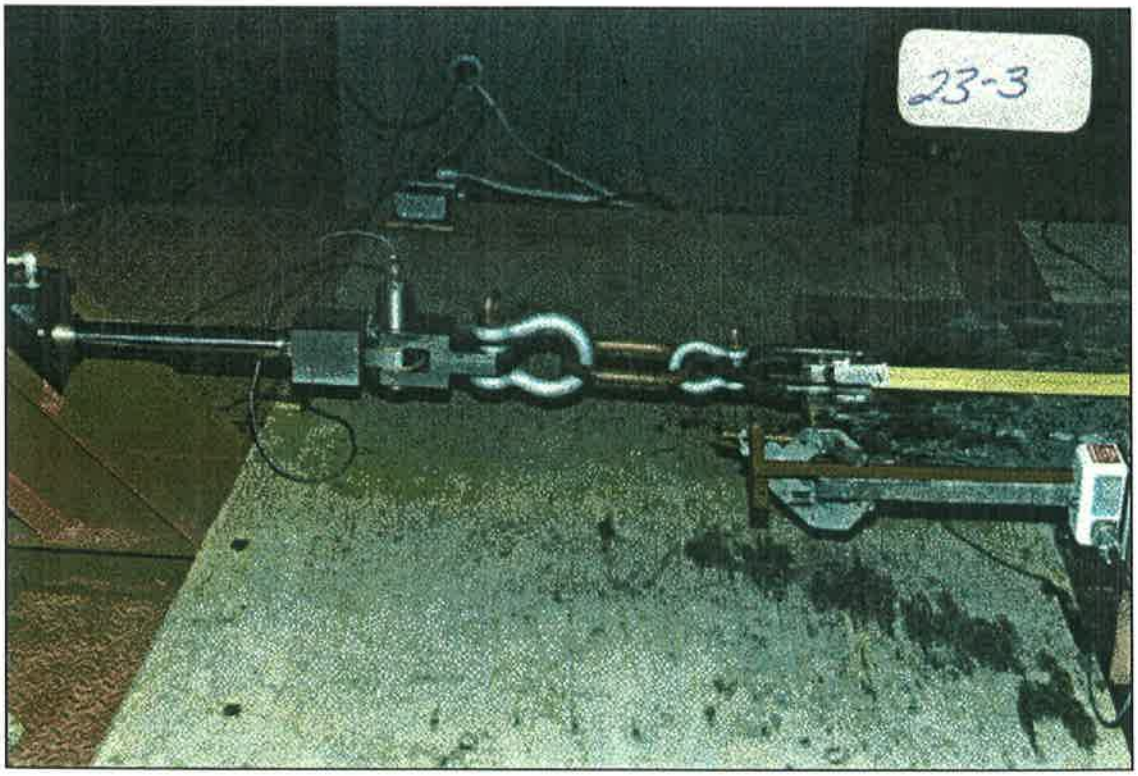


Figure 4/ Clevis Pin for Measuring Application Force

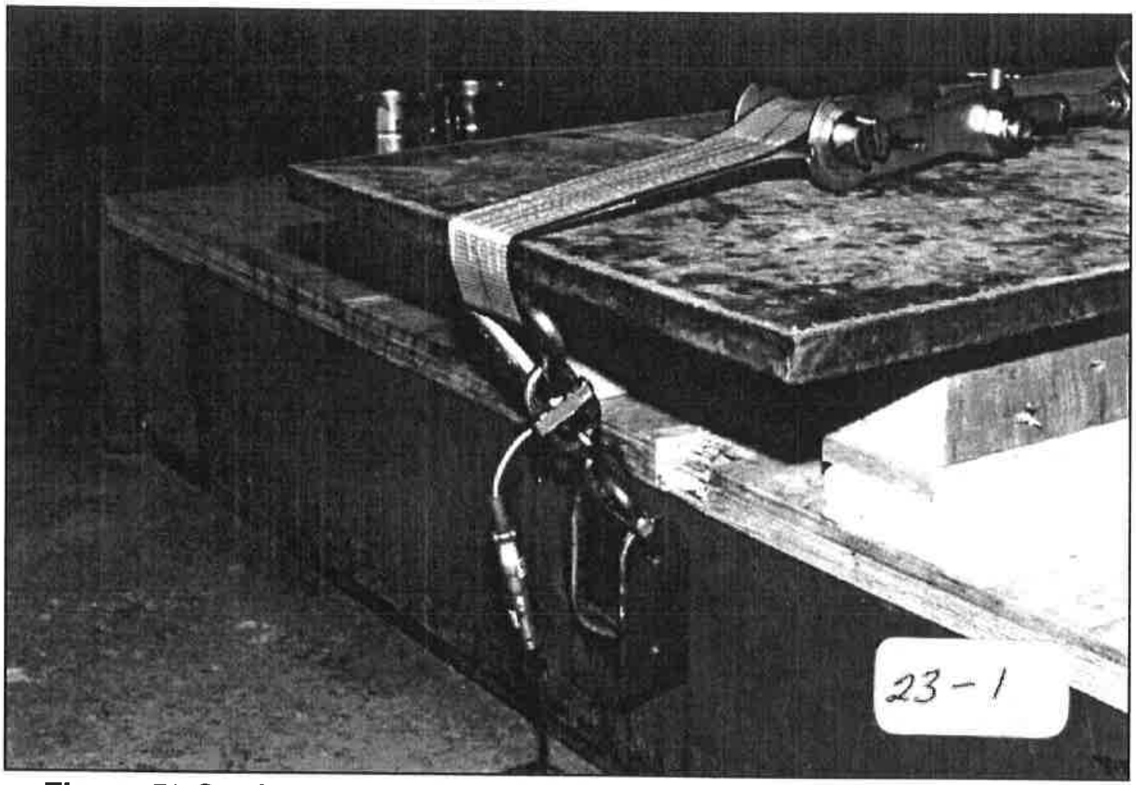


Figure 5/ Strain gauged chain link for measuring tension at tiedown

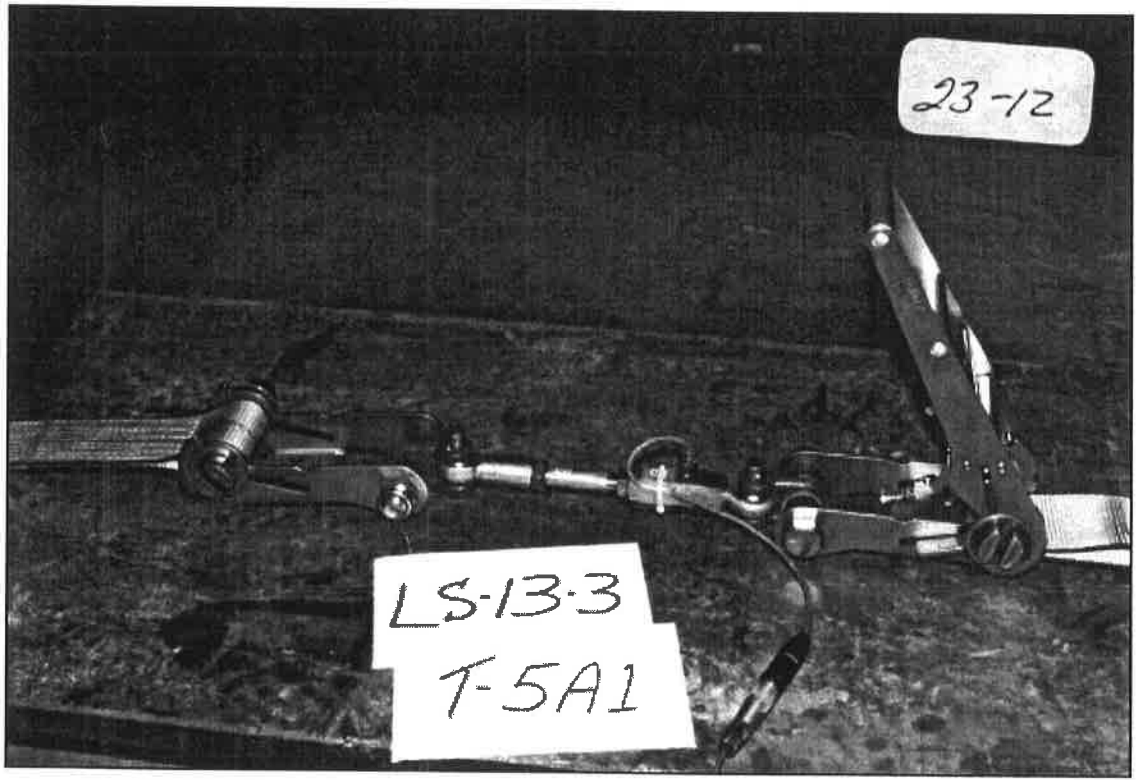


Figure 6/ Transducer to measure Tension in tiedown main span

3.3/ Test Procedures

Prior to testing, each plate was prepared by welding a connector bracket for lateral pulls, and by drilling for shackle connections for longitudinal pulls. Each plate was then weighed.

The 10x10 cm (4x4 in) hardwood blocks were placed on the deck about 0.3 m (1 ft) apart, and the steel plate was centred on the deck in the appropriate orientation for the pull being conducted, as shown in Figures 7 and 8. The tiedown was placed loosely over the plate, and attached to the strain gauged chains with shackles. The load sensing stud was inserted in the tiedown, and the pull cord transducer was attached. The data acquisition system was turned on, and the transducer outputs were zeroed. Data acquisition 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. The tiedown was tensioned to 20% of its working load limit, instrument checks were done, data acquisition was re-started, and about three seconds later the hydraulic system was actuated to pull the plate. The pull was applied until either any tiedown tension reached twice the tiedown working limit, the hydraulic actuator reached maximum force, or damage to test equipment was becoming evident. 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. The pull cord and drawbar were detached from the plate. The plate and tiedowns were examined for 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

The data from each run was simply calibrated and de-trended in a specialized test data processing program written at MTO. Traces of pull force and tiedown tensions were examined to determine the characteristics of responses, and peak values were extracted manually, entered in a spreadsheet program, and were summarized in tables and graphical form for this report.

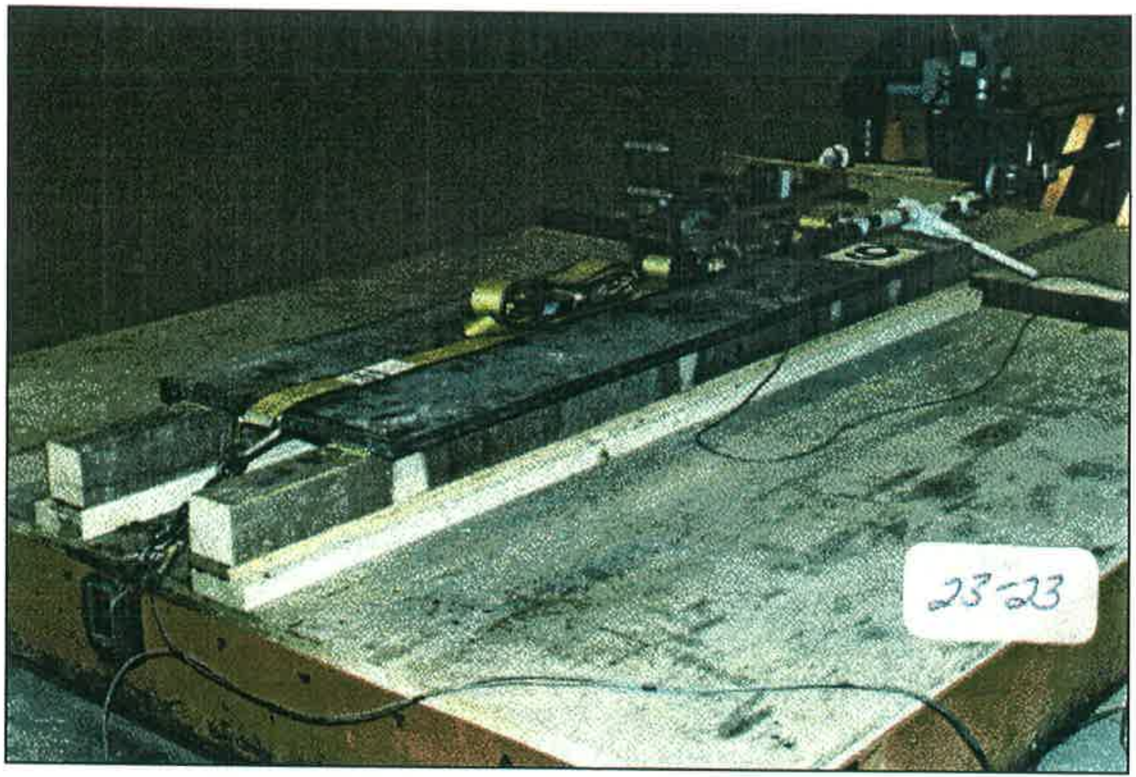


Figure 7/ Pull representing lateral acceleration

Figure 8/ Pull representing longitudinal acceleration

3.5/ Test Matrix

The scope identified three plate widths, three securement conditions and two pull directions, for a total of 18 combinations. These are presented in Table 1.

Table 1/ Test Matrix

Test	Pull Direction		Plate Width			Tiedown	
	Lateral	Longitudinal	1.83 m	2.44 m	3.05 m	Chain	Webbing
1(a)	X		X			X	
1(b)		X	X			X	
2(a)	X			X		X	
2(b)		X		X		X	
3(a)	X				X	X	
3(b)		X			X	X	
4(a)	X		X				X
4(b)		X	X				X
5(a)	X			X			X
5(b)		X		X			X
6(a)	X				X		X
6(b)		X			X		X
7(a)	X		X			Baseline test with 61 cm (24 in) Plate	
7(b)	X			X		Baseline test with 61 cm (24 in)Plate	
7(c)	X				X	Baseline test with 61 cm (24 in)Plate	
7(d)		X			X	Baseline test with 91 cm (36 in)Plate	
7(e)		X		X		Baseline test with 91 cm (36 in)Plate	
7(f)		X	X			Baseline test with 91 cm (36 in)Plate	

4/ Results and Observations

4.1/ Lateral Loading

Lateral loading represents an external acceleration of a truck driving in a curve, where the steel plate is secured to the truck by transverse tiedowns. The plate is set up so that the pull is in the same direction as the tiedown, and the plate tends to slide under the tiedown. When the plate moved, the tiedown spanning the plate was strained and it imparted increased friction and containment forces on the plate. The tensions were different in each of the three segments due to the friction and snagging effect of the tiedown at the corners. Figure 9 shows a typical pull, on the narrow 1.83 m (6 ft) wide plate, secured with a chain tiedown. It plots the applied force and the three tiedown tensions measured against displacement of the plate. The undulations in the curves are due to chain links moving over the corner of the plate. As each link moved over the corner, it altered the effective centre-line length of the chain, which increased and decreased the tension in the chain.

The applied force and maximum tensions attained in lateral loading are shown in Figure 10. In all cases the largest tiedown tension was less than the applied force. The tiedown tensions for the narrowest plate, 1.83 m (6 ft) wide, tended to fall in a narrower

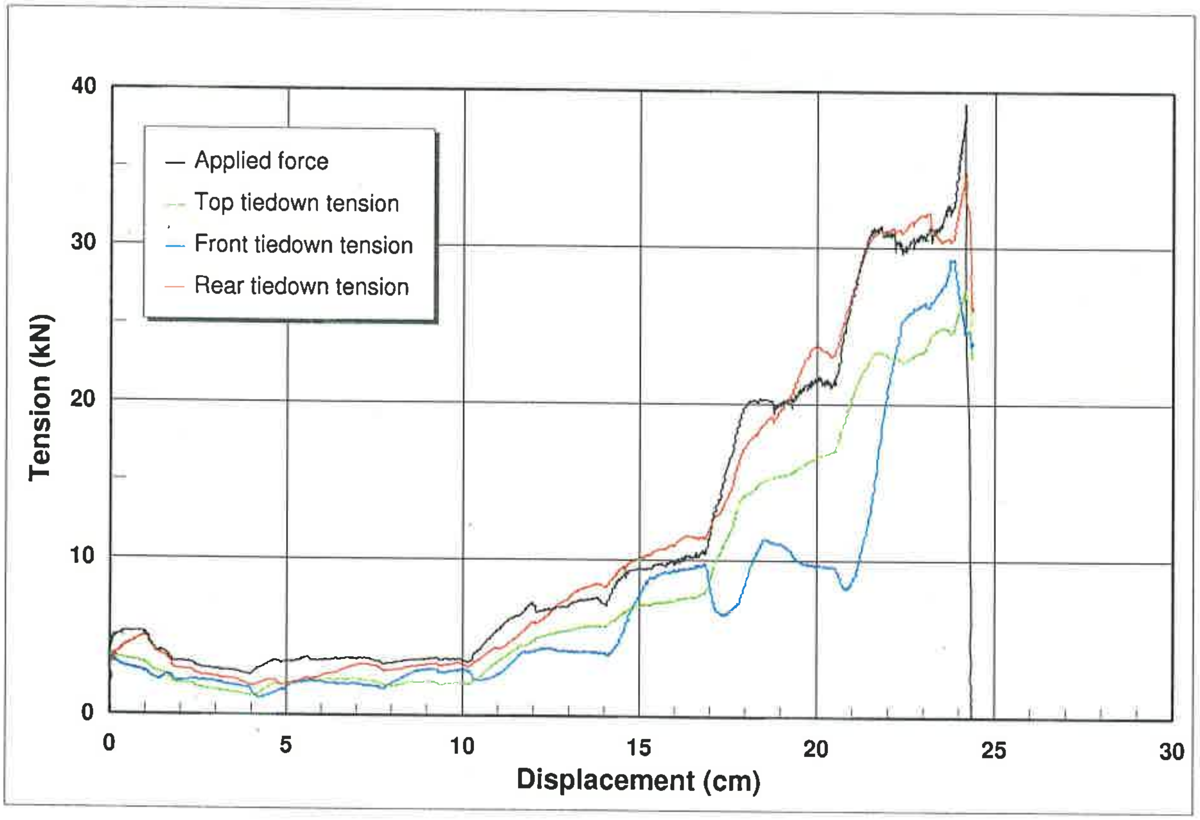


Figure 9/ Applied force and tiedown tensions against displacement Lateral pull with chain tiedown on 1.83 m (6 ft) wide plate

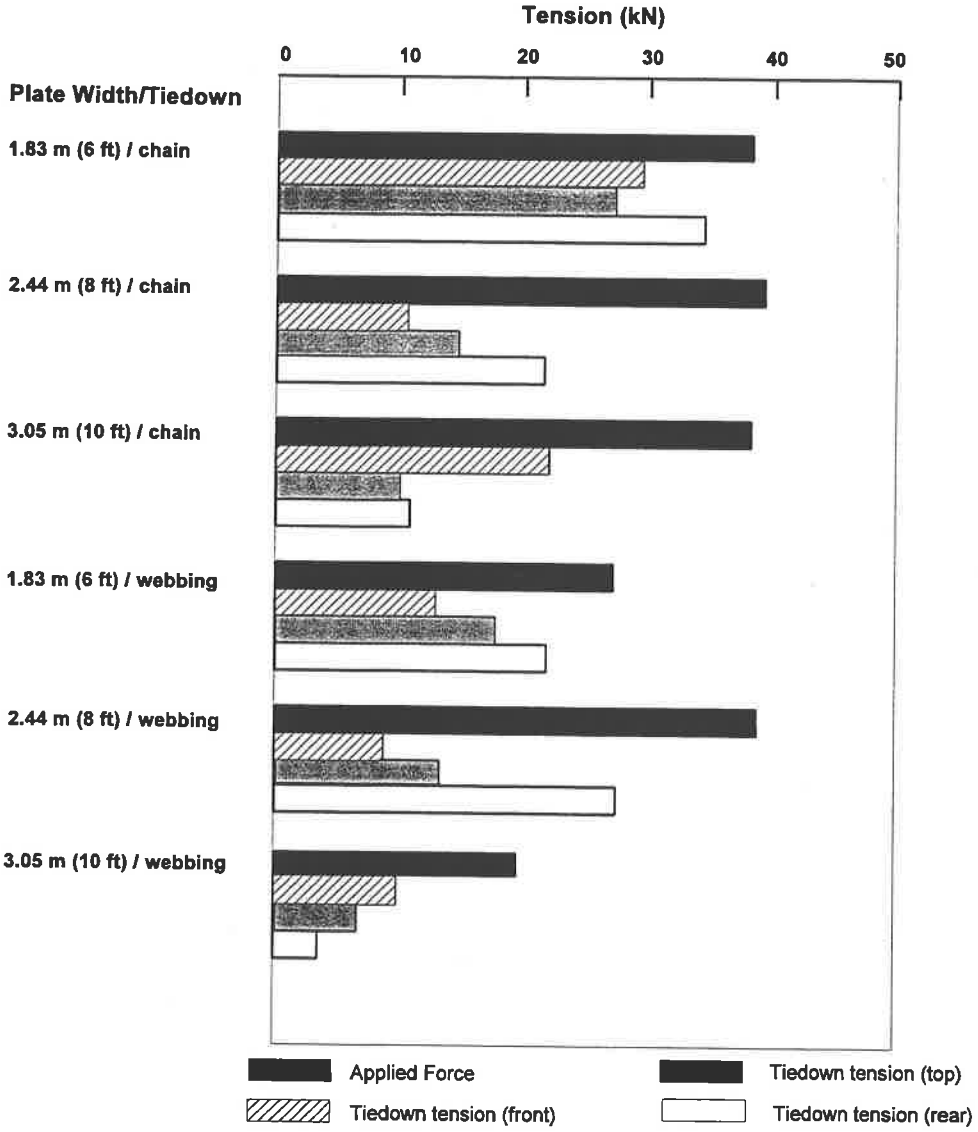


Figure 10/ Maximum applied force and tiedown tensions under lateral loading

range, and were slightly higher, than for the wider plates. The same data are expressed as a percentage of applied load in each segment of the tiedown in Figure 11. The wider plates, 2.44 and 3.05 m (8 and 10 ft), each had tiedown tensions in the range of 20 to 70 % of the applied force. In the worst case the maximum tension was 90 % of the applied force. There did not appear to be any consistent pattern of individual tiedown segment load sharing.

Figure 12 presents the applied force against lateral displacement for all three plate widths, for a chain tiedown in the upper graph, and a webbing tiedown below. The "bumps" on the curves for the narrow and wide plates are due to chain links hanging on the plate corners, causing irregular loading. The curves for webbing are relatively smoother, though the notched shape suggests continuous small slip-stick action.

When the chain links interacted with the plate at the corners, the plate was clearly the loser, as the harder chain links dimpled and gouged the softer plate corners. This could reduce the wrap perimeter of the tiedown by a small amount. With the webbing, abrasion was evident at the contact surface at the plate corner, and the webbing was scuffed, but there was no clear evidence that there was significant fibre damage in the relatively short duration of these tests with new webbing.

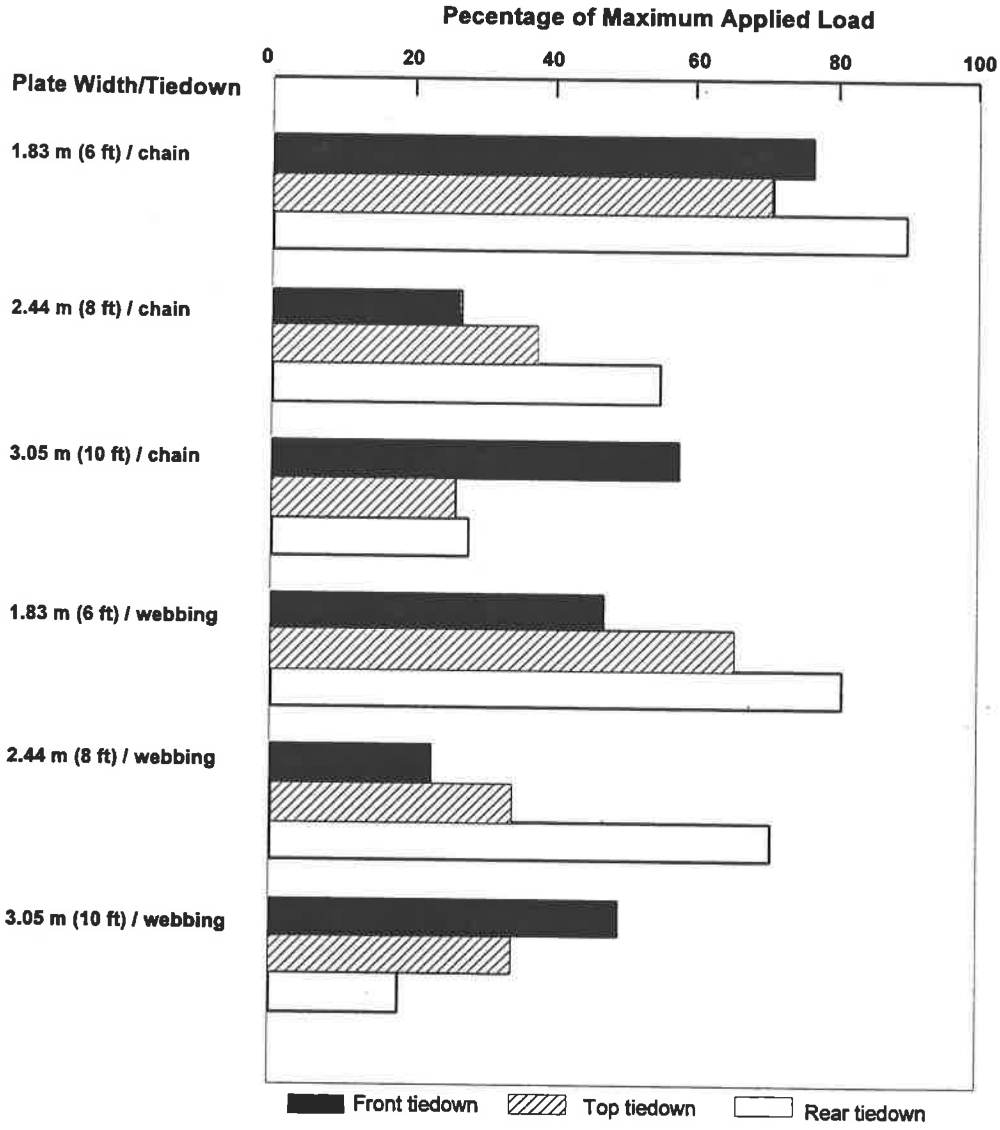


Figure 11/ Maximum tensions as a percentage of maximum lateral force

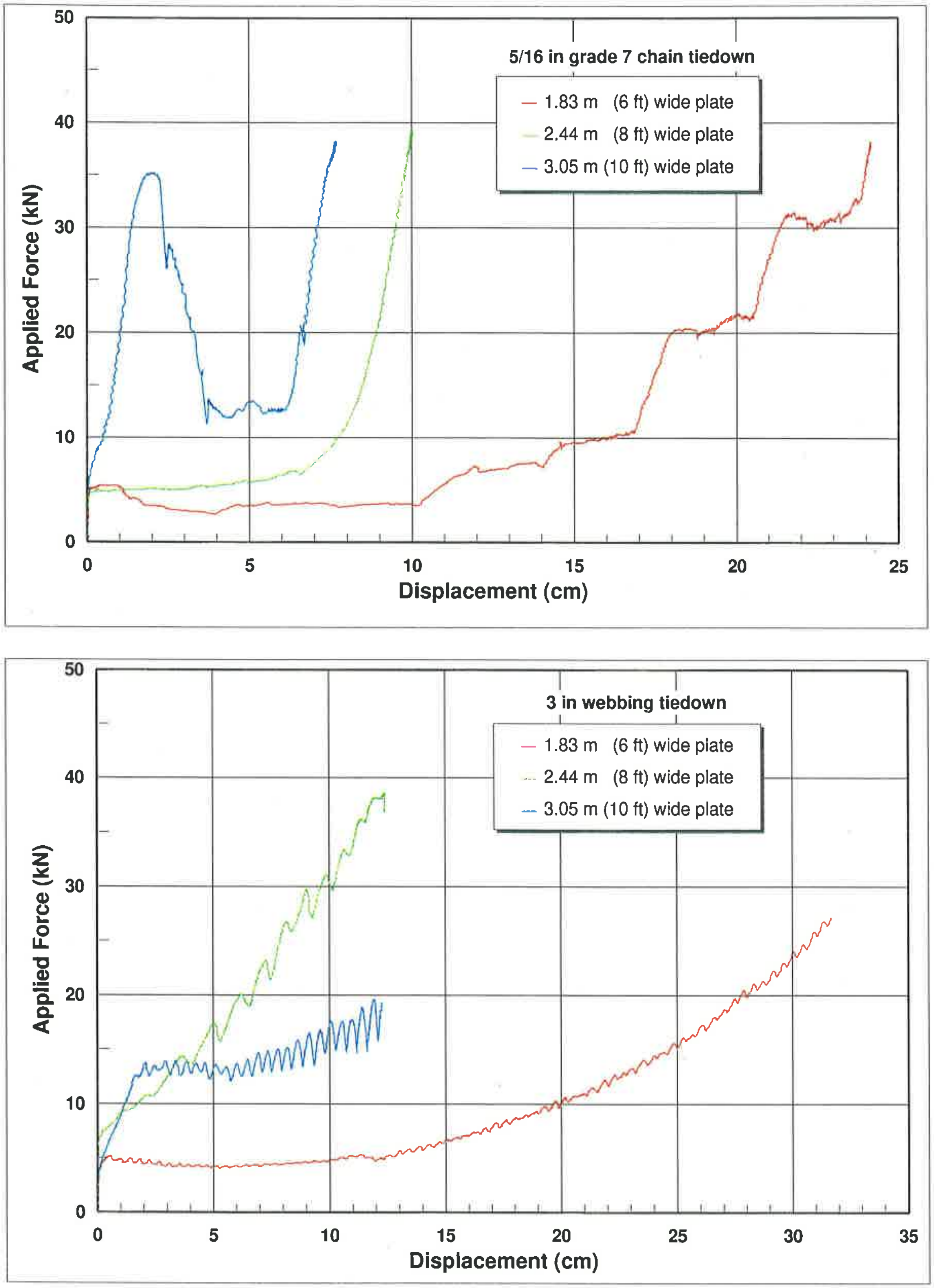


Figure 12/ Applied Force vs Lateral Displacement for Three Plate Widths

4.3/ Longitudinal Loading

Longitudinal loading represents braking of a truck, where the plate is secured to the truck by transverse tiedowns. The plate was set up with the pull transverse to the tiedown, and it tended to slide out from under the tiedown. Figure 13 shows a typical pull, on the narrow 1.83 m (6 ft) wide plate, secured with a webbing tiedown. It plots the applied force and the three tiedown tensions against displacement of the plate. The tiedown rode along with the pull, with the two end spans elongating as the plate moved, and the tensions increased. After about 10 cm (4 in) of movement, several small slips occurred, and about 2 cm (1 in) later, a major slippage occurred, which reduced all the tensions by about 50%. Subsequent smaller slips occurred as the pull continued, which tended to hold the tensions within a relatively narrow range. In all cases, slippage occurred simultaneously on both edges of the plate. The rough edge of the plate was sufficiently sharp in some cases to cut the webbing. In most cases, when chain was used, the links tended to dimple the steel plate at the corners. This contributed significantly to the resistance of the plate to motion since the chain tended to "nest" in the indentations and allowed much of the applied force to be resisted by the chain.

The applied force and maximum tiedown tensions attained in longitudinal loading are shown in Figure 14. In all cases, the tension in the top section of the tiedown was less

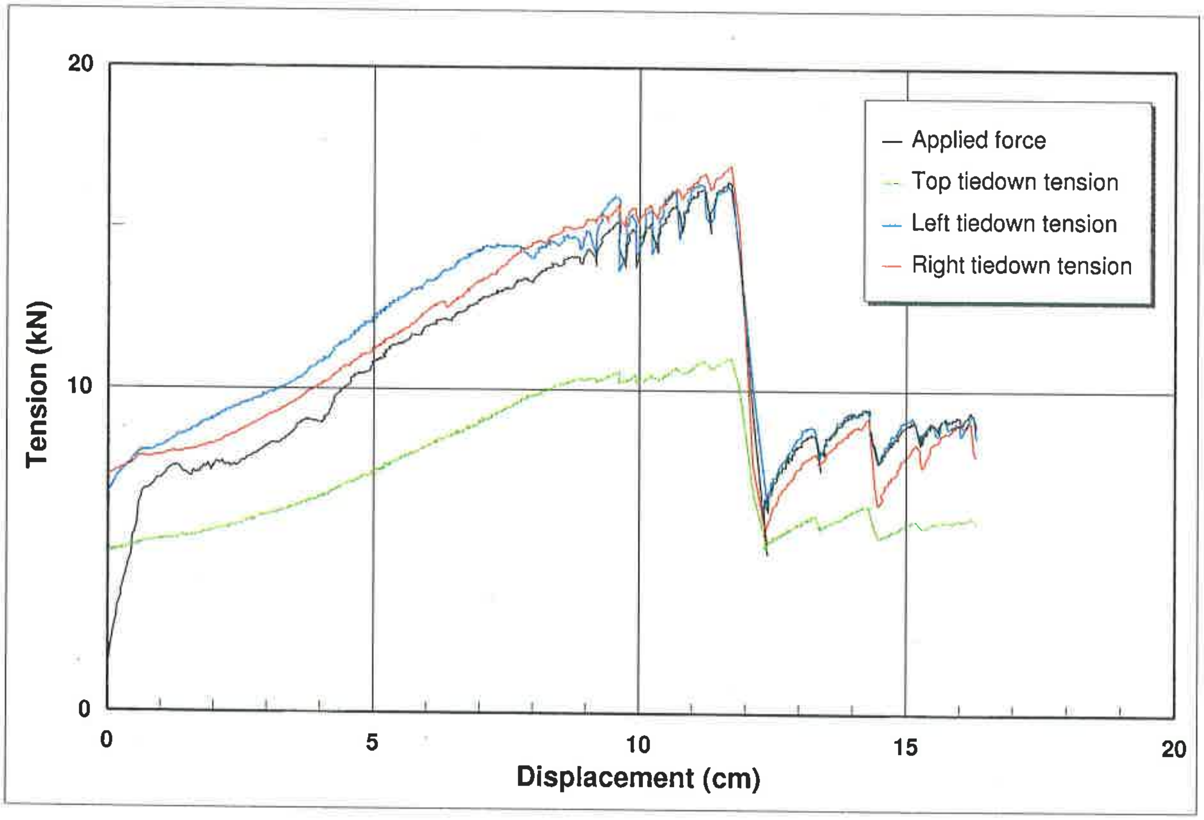


Figure 13/ Applied force and tiedown tensions against displacement
Longitudinal pull with webbing tiedown on 1.83 m (6 ft) wide plate

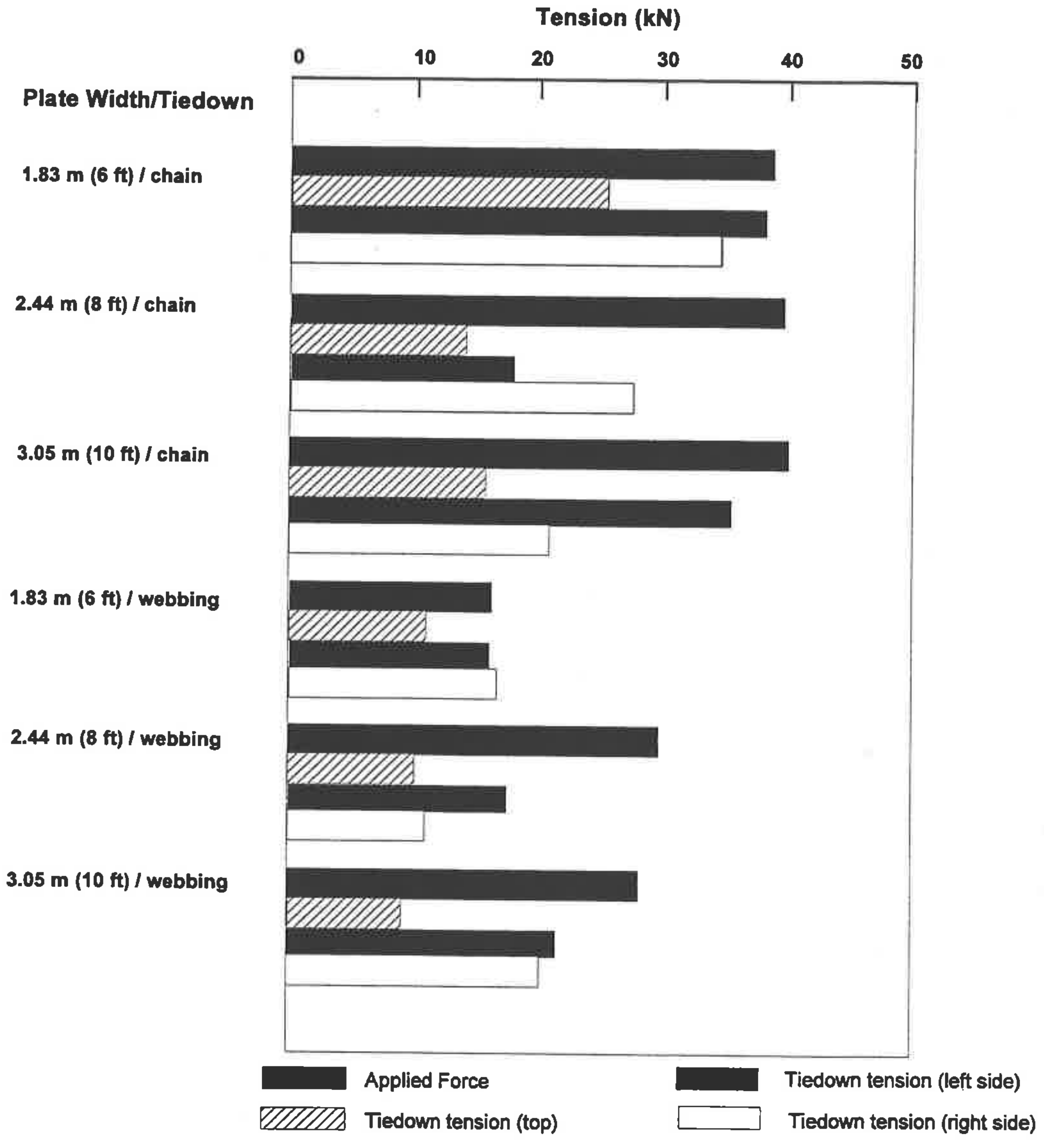


Figure 14/ Maximum applied force and tiedown tensions for longitudinal pull

than the sides. This is because friction between the tiedown and the corners of the plate does not allow the full extent of tension due to the extension of the side spans to migrate to the centre span. The side sections of the tiedown suffer the greatest extension because of the geometry of the longitudinal pull situation. Since the friction of the corners tends to inhibit any pulley effect, the side spans of the tiedown accept a larger share of the load. This larger share tends to cause a larger vertical force on the plate and hence contributes to a greater friction load between the plate and deck. The same data are expressed as a percentage of maximum applied load in Figure 15.

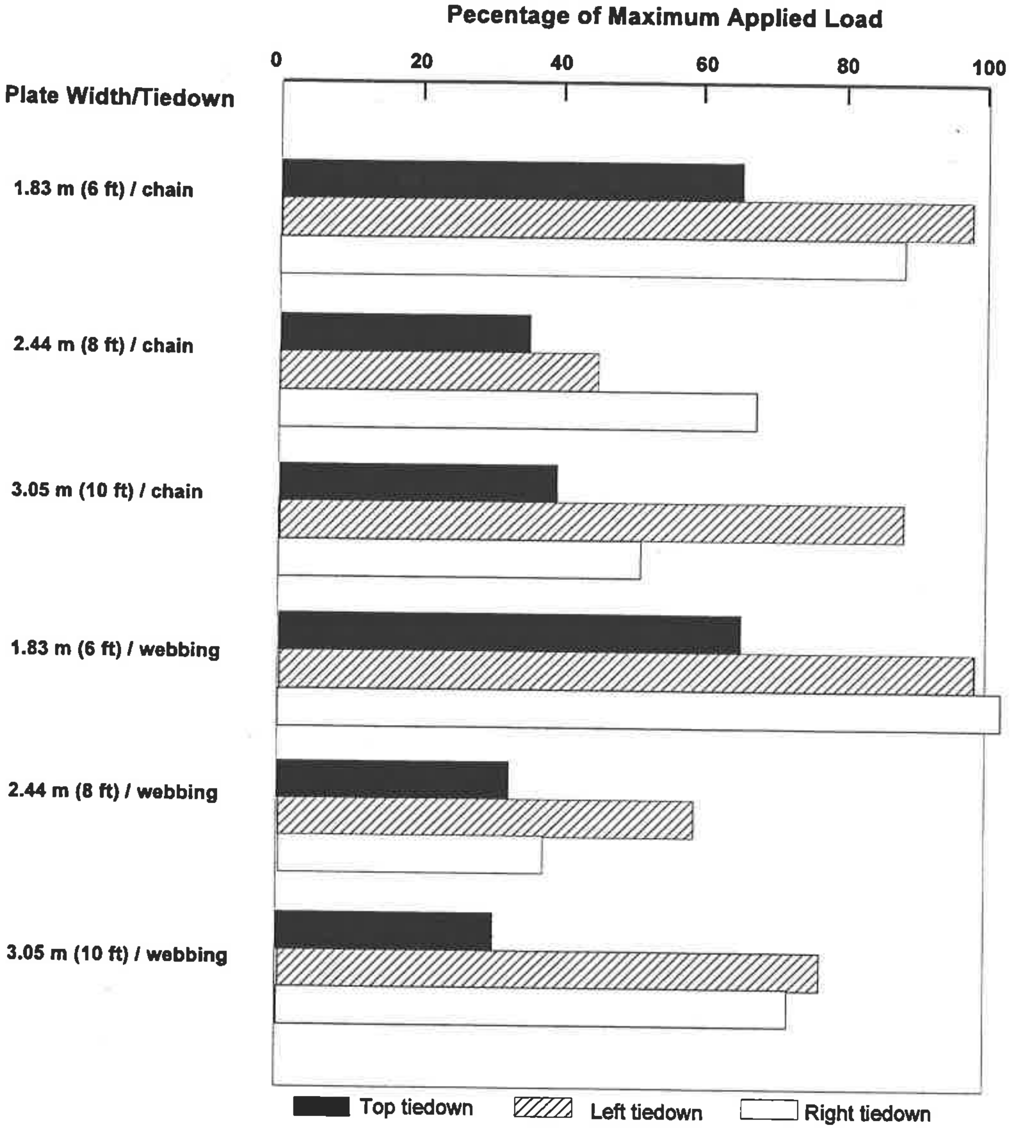


Figure 15/ Maximum tensions as a percentage of maximum longitudinal force

Figure 16 shows the applied force against longitudinal displacement for all three plate widths, for a chain tiedown in the upper graph, and a webbing tiedown below. The chain tiedowns did not slip, so the increase in resistance was strictly a matter of the increase in tension due to elongation of the tiedown effectively increasing the friction between the plate and its supports, and resisting the pull. The traces for webbing show that the webbing slipped, as discussed above. The steep drop in force for the 2.44 m (8 ft) wide plate was because the webbing was almost totally severed, and the plate jerked forward as the tiedown tension disappeared.

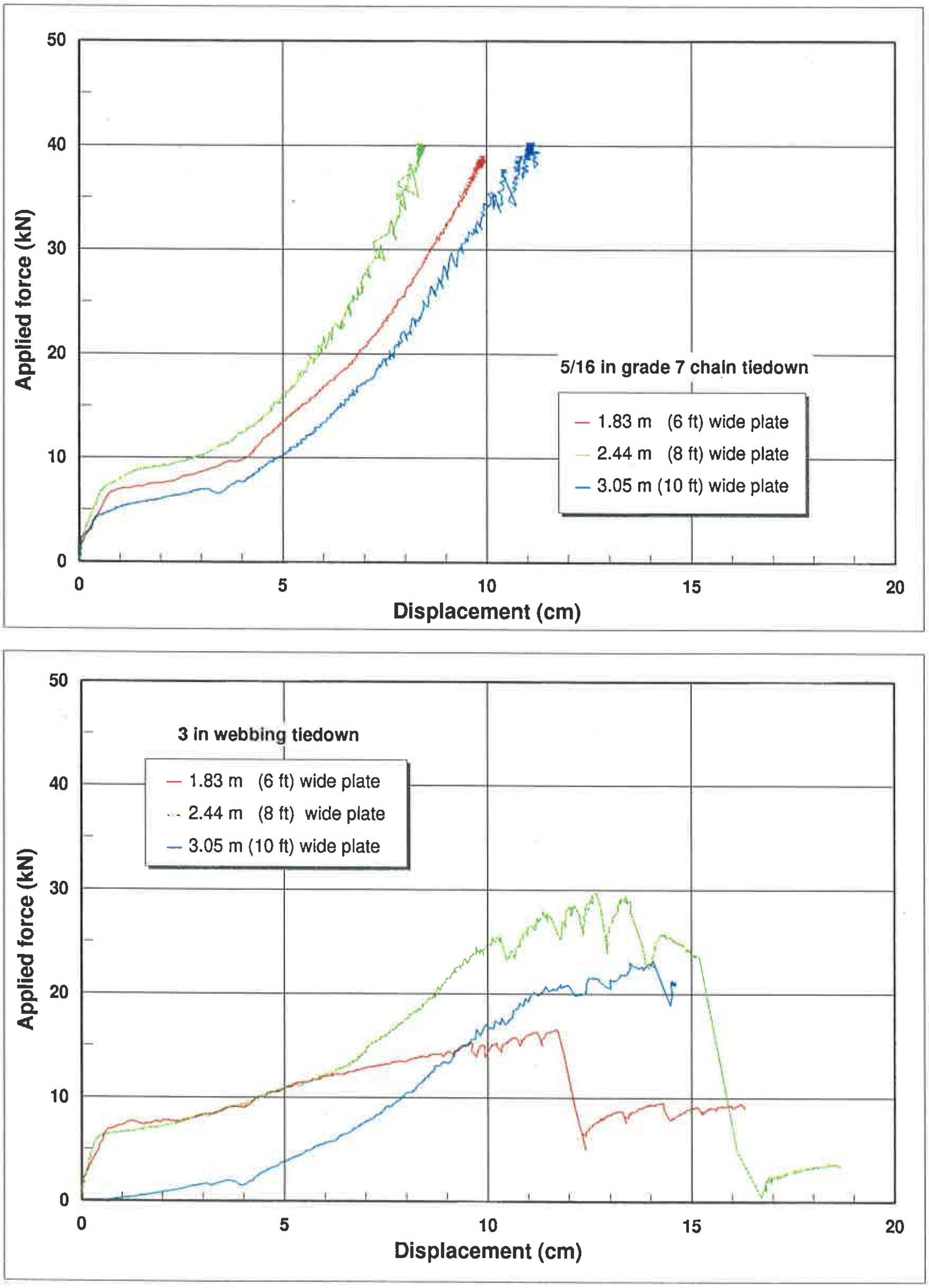


Figure 16/ Applied Force vs Longitudinal Displacement for Three Plate Widths

5/ Analysis and Discussion

5.1/ Resistance to Lateral Motion

Forces in the plane of a flat plate restrained by a tiedown will cause the plate to move if the force is sufficiently large. When a force acts on a flat plate the force is resisted by friction between the plate and deck, the resultant force in the direction of motion of the tiedowns, and the increase in friction brought on by the contribution of tiedown tension to vertical force. As a plate commences to move, the perimeter bounded by the tiedown (length of tiedown) increases with displacement. The increase in tiedown length causes, through elongation, a tension in the tiedown. The tiedown tension reacts on the plate by the creation of a resultant force that acts both against the sliding motion of the plate, and vertically.

Figure 17 shows the increase in tiedown length for various displacements and plate/ truck deck width ratios. It is seen that the percentage increase in tiedown length for a given displacement is a maximum when the truck deck width equals the plate width. As the plate width ratio either increases or decreases, there is a symmetrical lesser increase in tiedown length, so narrow or wide plates would cause less tension increase as they displaced, allowing freer plate movement to a disturbing force.

As a plate is displaced, the tension in the tiedown increases. The tension in the tiedown, when acting across the plate edge, produces forces at that point that can be

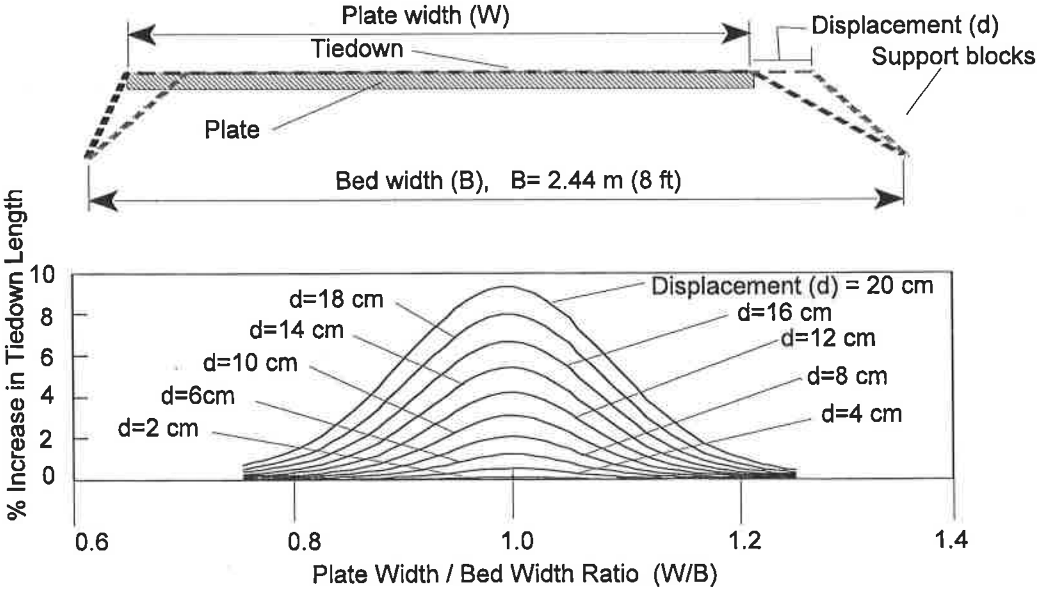
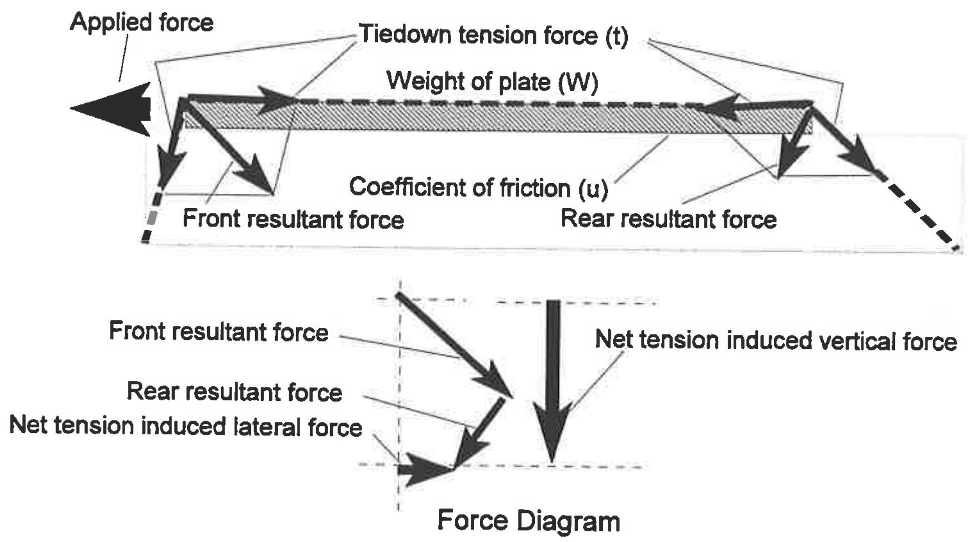


Figure 17/ Tiedown Length Increase for Various Plate Widths and Displacements



$$\textbf{Force resisting applied force} = \text{Net tension induced lateral force} + (\text{Net tension induced vertical force} + W) \times u$$

Figure 18/ Analysis of Tension and Friction Forces

resolved in a lateral (horizontal) direction in direct alignment with the applied force, and, a vertical force that contributes to the friction component of the applied force, as shown in Figure 18.

By using analysis to isolate the components that make up the applied force it becomes possible to model any size steel plate and predict the forces present in the tiedowns. Consider a plate secured by two 5/16 in grade 7 chain tiedowns, each with a working load limit of 2,132 kg (4,700 lb) connected to the truck at four anchor points. Under current practice, this allows a steel plate weighing 8,545 kg (18,800 lb). The situation was calculated for three plate widths, 1.83 m (6 ft), 2.44 m (8 ft) and 3.05 m (10 ft). The tiedown tension results are shown in Figure 19. A similar model was used for webbing with a working load limit of 1,814 kg (4,000 lb) and a corresponding decrease in plate weight to 7,273 kg (16,000 lb), and those results are shown in Figure 20. It can be seen that the tiedown tensions in both cases do not reach 100% of their working load limit, the tensions being between 40 and 90% depending on plate width, up to an external acceleration of 1.0 g, an acceleration well beyond the capability of all trucks.

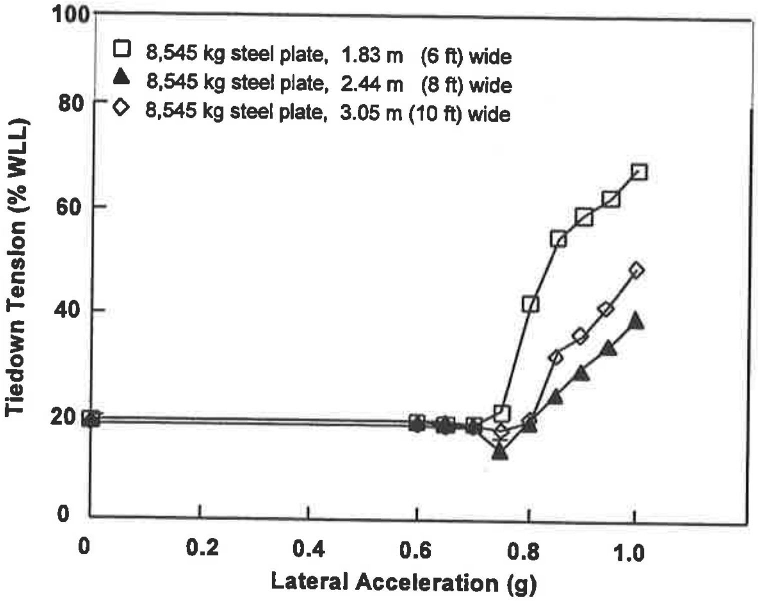


Figure 19/ Projection for 5 cm (2 in) steel plate weighing 8,545 kg (18,800 lb) with two 5/16 in grade 7 chain tiedowns during a lateral pull

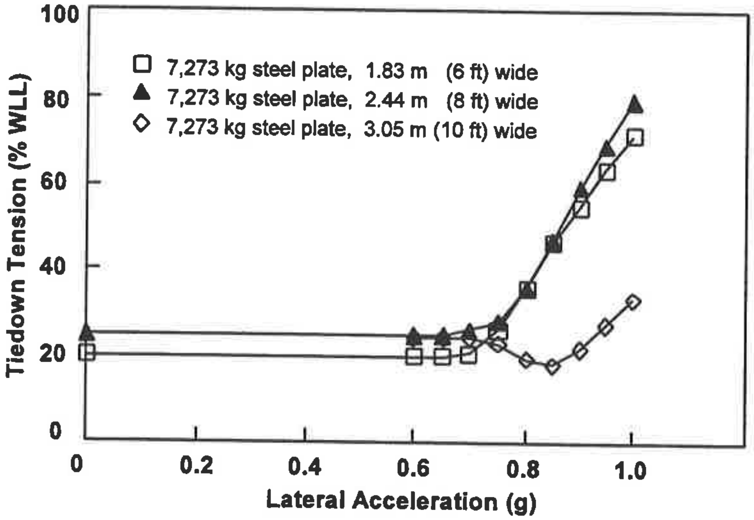


Figure 20/ Projection for 5 cm (2 in) steel plate weighing 7,273 kg (16,000 lb) with two 3 in webbing tiedowns during a lateral pull

5.2/ Resistance to Longitudinal Motion

When the plate was pulled longitudinally, friction between the plate and the tiedown caused the tiedown to adhere to the plate and move with it. The movement continued until the displacement produced sufficient tension in the tiedown to cause the webbing tiedown to slip back on the surface of the plate, or to indent the edge of the plate and cause binding, in the case of the chain. The increase in tension caused by the displaced plate produces a reactive force in the same plane as the applied force and an increase in the vertical force that contributes to the friction force.

The cross section design of the webbing tiedown allows little shear distortion and when the webbing was displaced laterally under tension, the trailing edge tended to lift and the leading edge tended to dig in. Because of the relative hardness of the webbing and steel, the leading edge slipped back on the plate, rather than digging in. In many cases, the plate edge cut the webbing tiedown as slipping occurred.

The chain links, because of point contact of the links at the plate edge, and the relative hardness of the plate and chain steel, dimpled the steel plate and caused indents that held the chain links from slipping. The captive effect of the links generated a high resistance force in the chain that countered the applied force and contributed to the friction component of the reaction.

Analysis of the forces for a longitudinal pull also allowed a projection to other sizes and thicknesses of plate to determine the effectiveness of chain and webbing tiedowns. Figure 21 shows similar results for chain tiedowns on three widths of steel plate weighing 8,545 kg (18,800 lb), and Figure 22 for webbing tiedowns on a 7,273 kg (16,000 lb) steel plate. Both results predict tiedown tensions well below the working load limit at external accelerations up to 1.0 g, an acceleration somewhat beyond the maximum braking capability of a loaded truck.

5.3/ General

The mechanism holding the plate on the truck in the lateral loading situation is different than that of the longitudinal loading situation. In the lateral situation, the tiedown forms a captive restraint that contains the movement even if friction is not present, as the tiedown is physically wrapped around the plate and bears directly on it. In the longitudinal situation, the plate is held by friction, both between the tiedown and plate and plate and deck. Motion of the plate causes the tiedown to elongate because friction between the plate and tiedown carries the tiedown along with the plate, which increases the vertical force, increasing the friction force between the plate and deck. If the tiedown does not indent and "snag" the plate, then friction is the only mechanism holding the plate in place. Should the coefficient of friction between the tiedown and plate decrease for any reason, such as a dirty or oily surface, then the restraining ability of the tiedown may be compromised.

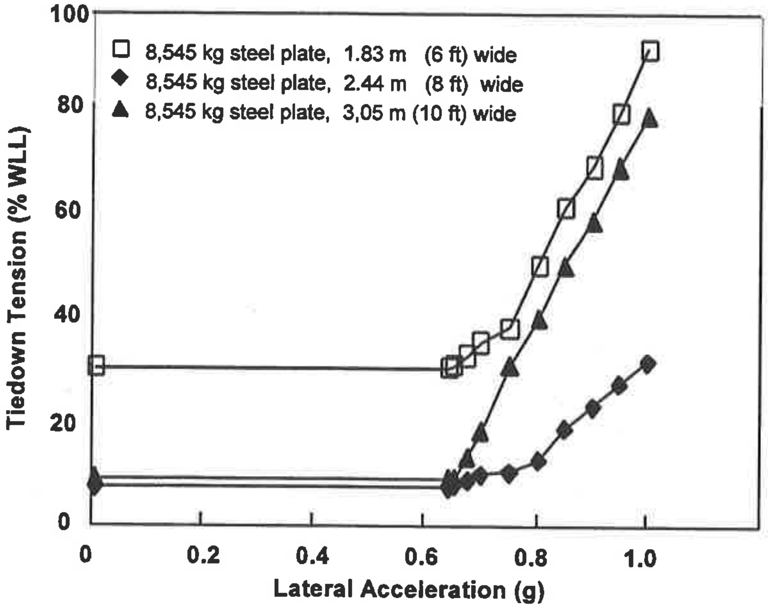


Figure 21/ Projection for 5 cm (2 in) steel plate weighing 8,545 kg (18,800 lb) with two 5/16 in grade 7 chain tiedowns during a longitudinal pull

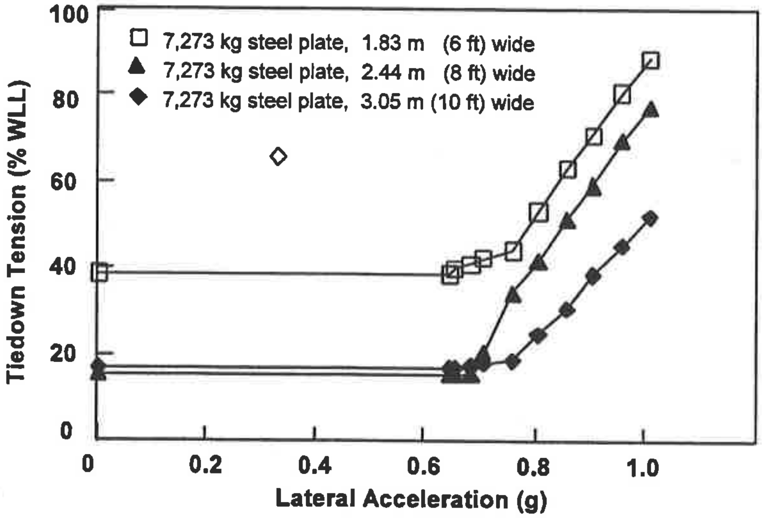


Figure 22/ Projection for 5 cm (2 in) steel plate weighing 7,273 kg (16,000 lb) with two 3 in webbing tiedowns during a longitudinal pull

6/ Conclusions

A series of tests has been conducted to examine securement of thick metal plate of different widths using transverse chain or webbing tiedowns, tensioned initially to 20% of their respective working load limit, to secure steel plates. These tiedowns were able to contain the test plate in lateral loading situations. In the longitudinal direction, the tiedown held the plate through a friction mechanism that allowed slipping movement of the plate. The chain tended to dimple the edge of the plate, increasing the effective friction by interlocking the chain and the plate. Webbing tended to distort slightly and since it could not dimple the steel surface, it slipped and allowed the plate to slide out. The forces to cause slippage, although high with the specific materials tested could be reduced substantially by the presence of oil or dirt on the plate surface. Once relative motion was initiated between the tiedown and the plate in the longitudinal direction, the applied forces tended to level or drop. The motion caused the softer webbing to be cut and abraded by the plate edge, sometimes culminating in complete severance.

Analysis suggests that tensions should stay below the tiedown working load limit for both lateral and longitudinal accelerations up to 1.0 g.

Using a transverse tiedown to span the plate contained the cargo and maintained manageable tensions within the tiedown during lateral loading. However, under longitudinal loading, the webbing tiedown allowed the plate to slip and this relative motion sometimes cut the webbing.

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 [2].

7/ Recommendations

1/ Thick metal plates may be secured with transverse tiedowns tensioned initially to about 20% of the working load limit of the tiedown.

2/ The tiedowns should be tensioned from above the plate, so that the tension is shared across the tiedown as well as possible.

3/ Preferably, the plate should be placed against a bulkhead or other cargo so that it cannot slide forward. If this is not feasible, use of additional longitudinal tiedowns could be considered to ensure the plate does not slide.

4/ Where the plate surface is dirty or oily around the tiedown, it should be cleaned to maximize friction between the plate and the tiedown.

5/ Webbing tiedowns should only be used to secure thick metal plate if the cargo is placed against a bulkhead or other cargo so that it cannot slide forward, and the tiedown is protected from contact with the plate by some means that cannot be cut or abraded, and will not slip out from between the tiedown and plate.

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