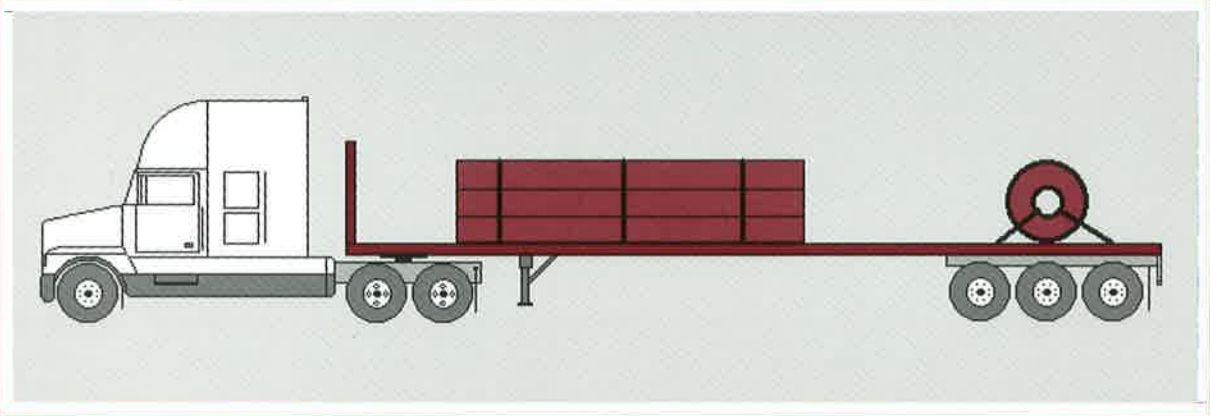
CCMTA Load Security Research Project

Report # 5

EFFECT OF CARGO AND TIEDOWN CHARACTERISTICS ON EQUALIZATION OF TENSION IN THE SPANS OF TIEDOWNS



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

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EFFECT OF CARGO AND TIEDOWN CHARACTERISTICS ON EQUALIZATION OF TENSION IN THE SPANS OF TIEDOWNS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

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Disclaimer

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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.

Table of Contents

Abstract

A series of tests examined the effect of cargo and tiedown characteristics on tension in the spans of transverse tiedowns over an article of cargo. The test covered rigid and compliant cargo, chain and webbing tiedowns, square steel, round steel and square wood corners on the cargo, and various initial tiedown tensions. The truck was driven over a road course, and tensions in the tiedowns were monitored.

The initial tensions on each side of a tiedown over rigid cargo tensioned from one side of a vehicle were always different, and never equalized when the vehicle was driven, regardless of tiedown, corner characteristics or initial tension. A high initial tension tended to compress compliant cargo, but a low initial tension was insufficient to do this and vehicle motions caused the cargo to compress and the tiedowns quickly became loose. A tiedown tensioned from the centre resulted in better tension equalization and less tension loss in driving. The corners were damaged by high point loads, especially for chain tiedowns over square corners, sometimes so severely that the tiedown became loose.

Recommendations are made regarding cargo loading and use of transverse tiedowns.

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.

Current cargo securement regulations assume that a transverse tiedown that passes over or through an article of cargo, without being attached to it, achieves equal tension in each span of the tiedown, like a rope passing over friction-less pulleys. Clearly, however, a chain link can engage a square corner or bite into cargo or dunnage. It was necessary to understand how the initial tension develops in tiedowns, and how tension is affected by road vibration during driving, for various cargo and tiedown characteristics. This work was outlined in Section 8.4 of the project proposal.

A series of tests examined the effect of cargo and tiedown characteristics on tension in the spans of transverse tiedowns over an article of cargo. The test covered rigid and compliant cargo, chain and webbing tiedowns, square steel, round steel and square wood corners on the cargo, and various initial tiedown tensions. The truck was driven over a road course, and tiedown tensions were monitored.

The initial tensions on each side of a chain or webbing tiedown over a rigid cargo, tensioned from one side of a vehicle, were markedly different due to friction around the corners of the cargo, regardless of the geometry or hardness of the corner. When the vehicle was driven on the highway, some tension was lost from both sides. The tensions never equalized, regardless of tiedown, corner characteristics or initial tension.

For a compliant cargo, a high initial tension tended to compress the cargo and make it rigid, leading to results similar to the rigid cargo. A low initial tension was insufficient to compress the cargo, and vehicle motions caused the cargo to compress so the tiedowns quickly became loose.

When a tiedown was tensioned from the centre, tension was much better equalized, and less tension was lost in driving than when the tiedown was tensioned from one side.

The corners were damaged by high point loads, especially for chain tiedowns over square corners. Such damage, while not detrimental to steel corners or the chain tiedown, did reduce tiedown tension. High tension in both chain and webbing tiedowns caused severe local indentation and cracking of wood corners. In some cases, chain tiedowns damaged the corner so severely that the tiedown became loose.

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;
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- Canadian Trucking Research Institute;
- Commercial Vehicle Safety Alliance;
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- Manitoba Highways and Transportation;
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- New York State Department of Transportation;
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- Société de l'Assurance 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 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 work was conducted additionally by Norm Carlton, Gary Giles, Bill Stephenson and Mike Wolkowicz of Strategic Vehicle Technology Office of MTO.

Some of the tiedown equipment used in these tests was donated for the project by Kinedyne Canada Ltd.

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.

Cargo on many trucks is secured by means of tiedowns that are attached to one side of the truck, pass over or through the cargo, and are attached and tightened on the other side of the truck. This process would be expected to result in a higher tiedown tension on the side which was tightened, as friction where the tiedown contacts the cargo provides some restraint to development of tension in the tiedown. Most current regulations are believed to assume that such tiedowns, which are not attached to the cargo, achieve equal tension in each span of the tiedown due to vibration as the truck travels along the road. This could be as a consequence of small movements of the tiedown, the cargo, or both. The assumption that tiedown tensions equalize is equivalent to assuming that the tiedown acts as if it is rope passing over friction-less pulleys which are free to rotate, so is colloquially known as the pulley effect. It is clear, however, that a chain tiedown might hang up if a link engages a square corner, or bites into the cargo or dunnage, and this could prevent the small adjustments necessary for tensions to equalize. It was therefore necessary to determine the extent to which tension equalizes in the spans of tiedowns, for various cargo and tiedown characteristics. The work reported here is a series of tests which examine the tension in the spans of cargo tiedowns while a truck is engaged in normal travel on a highway, as outlined in Section 8.4 of the project proposal [1].

2/ Test Program

2.1/ Objective

The objective of this test is to examine the effect of cargo and tiedown characteristics on tension in the spans of a transverse tiedown that passes over an article of cargo.

2.2/ Scope

A test vehicle was driven on a typical road trip, and tiedown tensions were monitored continuously to determine the extent to which they equalized during the trip.

Chain and webbing tiedowns were used, with four different initial tensions :

1/ low, 5% of the tiedown working load limit (WLL);
2/ moderate, 20% of WLL;
3/ high, 50% of WLL; and
4/ extreme, between 85 and 100% of WLL.

Two types of cargo were used :

1/ a rigid article that cannot deform internally or move on the bed of the truck; and
2/ a compliant article, that may deform internally and move on the bed of the truck.

The tiedowns passed over a corner attached to the cargo of one of three different configurations :

1/ a rigid circular steel corner that would be expected to provide minimal frictional interaction with a tiedown;
2/ a rigid square steel corner that would be expected to engage links of a chain tiedown; and
3/ a square wooden corner that would be expected to provide high frictional interaction with a tiedown.

3/ Procedures

3.1/ Test Apparatus

The test was conducted using concrete blocks to represent the required articles of cargo, placed on the rear of a flatbed semitrailer drawn by a tractor, as illustrated in Figure 1. Two types of cargo were represented, one rigid and the other compliant.

The rigid cargo is illustrated in Figure 2, and is shown diagrammatically in Figure 3.

Figure 1/ Test Vehicle, seen with Rigid Cargo

This was assembled from four tiers, each consisting of three concrete blocks approximately 1.22x0.61x0.53 m (48x24x21 in) in size and weighing about 907 kg (2,000 lb). The orientation of the blocks was rotated for each tier, so that the lifting lugs on the top of each block interlocked with a hole in the base of the block above. Blocking of nominal 10x10 cm (4x4 in) timber was nailed to the deck of the semitrailer to immobilize the base tier. Steel angles were placed on each vertical corner, and were held in place by two chains bound tightly with load binders. A square steel top cap was placed on the upper tier of blocks, and was held in place by tightening two jam screws on each face of the cap into contact with the blocks. Two chain tiedown assemblies were used on each side to provide independent attachment of the top cap to the semitrailer.

The compliant cargo is illustrated in Figure 4, and shown diagrammatically in Figure 5. This was assembled from three tiers of the same concrete blocks used for the rigid cargo, with each tier oriented along the length of the semitrailer. Each block was separated about 9 mm (3/8 in) from its neighbour, and each tier was separated from the tier below by a nominal 10x10 cm (4x4 in) timber so that the lifting lugs on the top of a block would not interlock with the superior block. A steel channel was placed on top of the timber to reduce friction so that the superior tier could slide if it wanted to. The steel top cap used for the rigid load was cut longitudinally in two and was simply placed on the upper tier of blocks. Two chain and binder tiedowns were attached to the top cap

Figure 2/ Rigid Cargo

loosely on each side to provide independent attachment of the load to the semitrailer, without restricting its ability to move slightly during transit. Chains were also attached loosely through the lifting lugs of each tier of blocks to prevent large sliding movements.

Two types of tiedown were used :

1/ 3 in synthetic webbing, with a working load limit (WLL) of 1,814 kg (4,000 lb), and
2/ 5/16 in grade 70 chain, with a working load limit of 2,041 kg (4,500 lb).

Three identical tiedown assemblies were installed over the cargo for each run. Each consisted of a ratchet binder attached to a lug on the right-hand side of the trailer, then

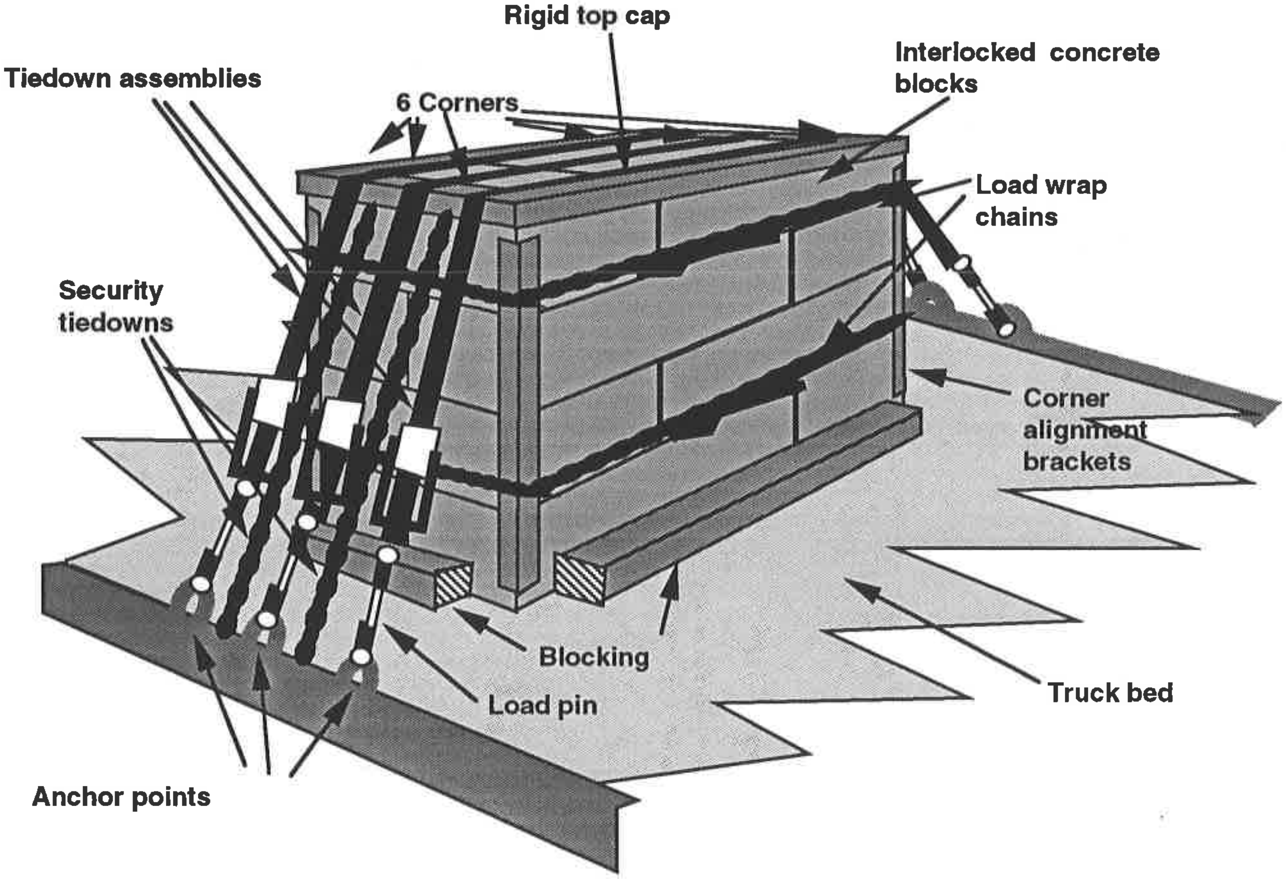


Figure 3/ Rigid Cargo

Figure 4/ Compliant Cargo

through a load sensing pin to the tiedown, which passed over a test corner on each side of the top cap and was attached through another load sensing pin and a chain stub to a lug on the left-hand side of the semitrailer. This is all shown diagrammatically in Figure 6. The test required evaluation of tiedowns passing over square steel, round steel and square wood corners on the cargo, illustrated in Figures 6, 7, 8 and 9.

3.2/ Instrumentation and Data Capture

Six identical Strainsert Model SJ-F8 Type H load sensing pins, rated at 66.75 kN (15,000 lb), were used to measure the tension on each side of three tiedowns. These were designed to respond only to tension loads, so were attached to the tiedown through spherical joints that eliminated transfer of moments and torsion.

Vehicle speed was measured using the electrical pulse output from an Anti-Lock Brake System wheel speed sensor and exciter ring mounted on the rear axle of the trailer. This system produced 100 pulses per revolution and was calibrated over a known measuring distance, therefore the frequency of the pulse train was directly related to vehicle speed. It was conditioned by a Metraplex tachometric signal conditioning card for inclusion in the data acquisition system.

Longitudinal and lateral accelerometers were mounted on the centre-line of the front of the top cap. Vertical acceleration of the deck of the semitrailer and the lead axle of the tandem axle group were measured using IC Sensors model 3140-010 semi-conductor

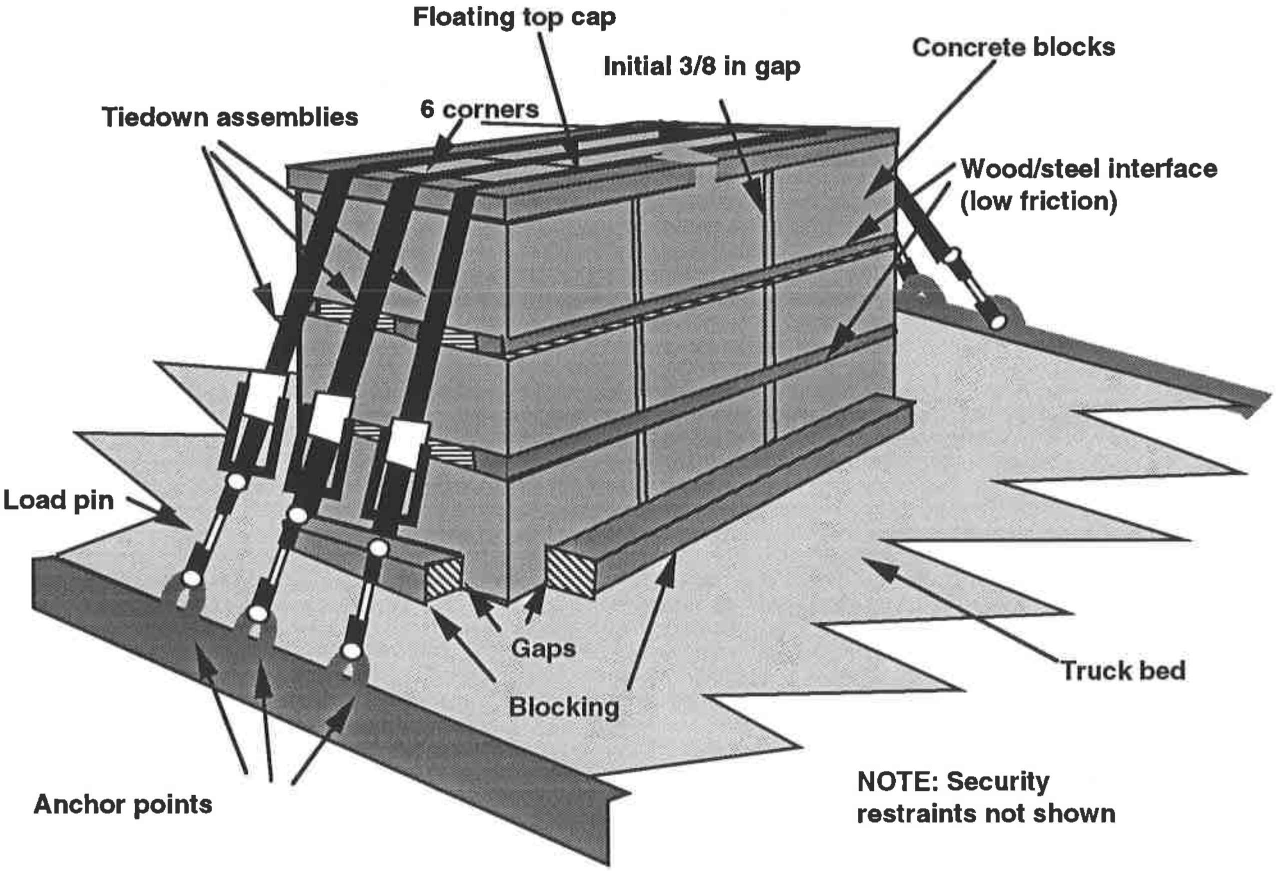
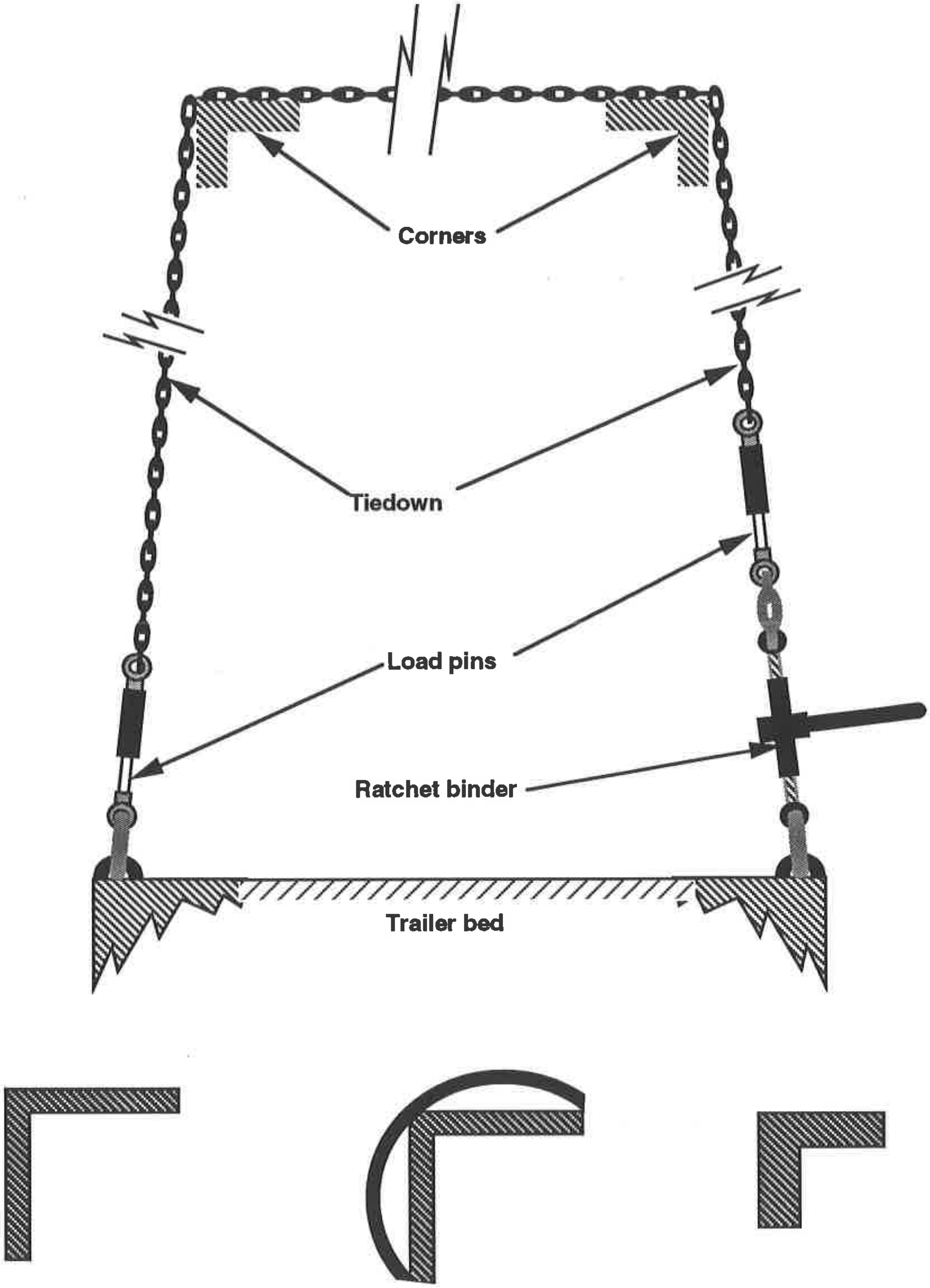


Figure 5/ Compliant Cargo



Square Steel Corner
(1 in plate)

Round Steel Corner
(4-1/2 in radius)

Wood Corner
(1-3/4 in spruce)

Figure 6/ Tiedown Assemblies

Figure 7/ Round Steel Corner with Chain Tiedown

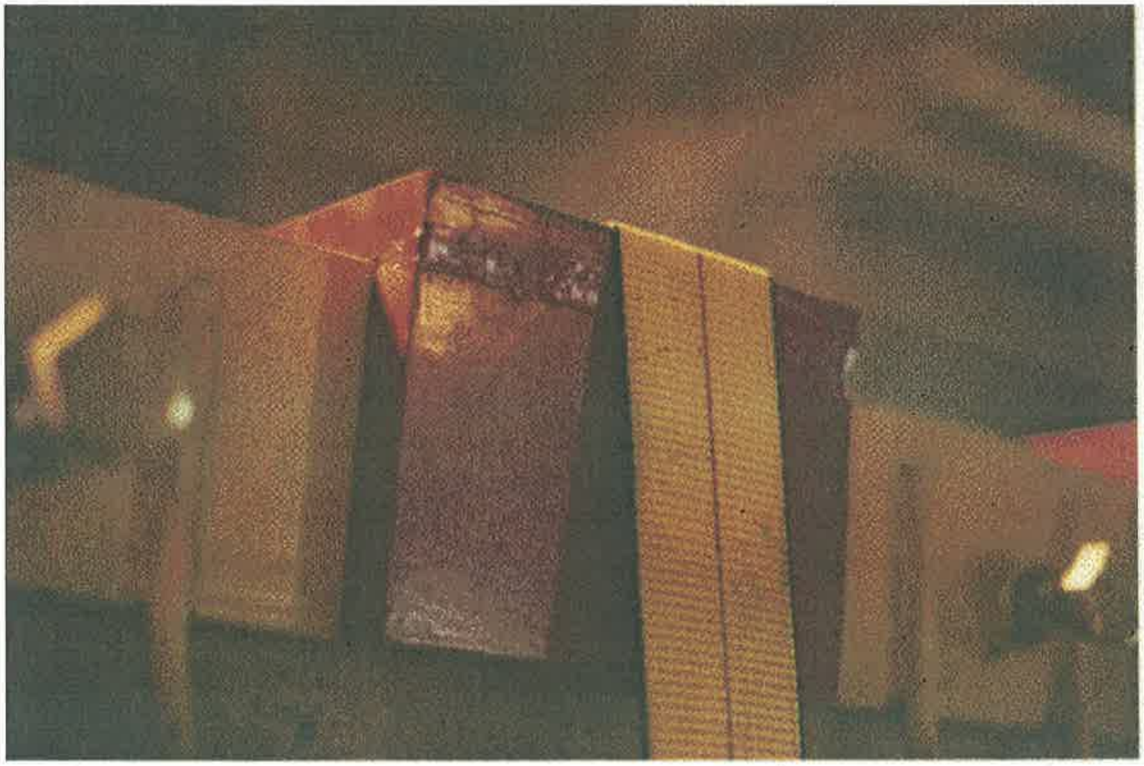


Figure 8/ Square Steel Corner with Webbing Tiedown

Figure 9/ Square Wood Corner with Chain Tiedown

accelerometers producing 200 mV/g, and connected to Metraplex piezoresistive signal conditioners. The data acquisition system consisted of a signal conditioning and pulse-amplitude modulated (PAM) multiplex system mounted on the semitrailer. Each instrumentation input was conditioned to provide a standard 2.0 V output for the selected full-scale value by selecting appropriate parameters on individual plug-in adapter cards within the multiplex unit. The conditioned output signals were transmitted as a PAM data stream from each of several multiplex units to a control unit, which synchronized and merged the PAM data streams. A twelve-bit analog-to-digital converter in the control unit digitized the data channels at a rate of 100 samples per second for each channel, and produced a composite pulse-code modulated (PCM) data stream in standard IRIG format. The control unit added two synchronization and two digital data words to produce a data frame of 40 twelve-bit words. An interface to the control unit allowed an electronic calibration to be applied to the entire data acquisition system. The PCM data stream was broadcast by radio telemetry from a transmitter on the semitrailer, and was received by a chase vehicle following closely behind the test vehicle. The PCM data stream was recorded on one track of a Honeywell 5600C instrumentation tape recorder. IRIG B time code generated by a Datum 9300 time clock was recorded on a second track, and voice comments were recorded on a third track. The standard test circuit was a round trip of approximately 45 minutes duration, which would produce data files that would overwhelm computer capacity. An interval timer was therefore built to control the tape recorder. It cycled through a wait of 60 s, turned on the tape recorder for 6 s, turned off the tape recorder, and began another 60 s wait.

3.3/ Test Procedure

The test vehicle was parked beside the chase vehicle in the test building with its engine off and the particular corners and tiedowns installed. The data acquisition system on the test vehicle, and the data capture system on the chase vehicle, were both powered up. The load binder for each test tiedown was slackened so that the tiedown was visibly loose, with at least 15 cm (6 in) of slack per side. This produced tension in the load pins equal to the weight of suspended tiedown, which was considered the zero tension situation. The output of each load pin was checked, and adjusted to zero as necessary through the data acquisition system. The tape recorder in the chase vehicle was started, and the data acquisition system was cycled manually through a system calibration, followed by a few seconds of zero data. After this was complete, the recorder was stopped.

The four independent tiedowns for the top cap, or the additional loose tiedowns of the compliant load, were checked for security and adjusted if necessary. The test tiedowns were then adjusted to the particular test condition. Each tiedown was first tightened by hand, by intermittent pulling and rippling, ensuring particularly that the chain tiedown was not twisted. The ratchet binder of the centre tiedown was then tightened so that the tension on the right-hand side load pin was within about 45 N (10 lb) of the prescribed value for the test condition, without regard to the tension on the other side of the same tiedown. The front tiedown was then tightened in the same way, followed by the rear tiedown. The three test tiedowns were then checked for security. Since tightening a subsequent tiedown tended to release the tension slightly on those tiedowns previously tightened, the tensions in all three test tiedowns were adjusted sequentially until all were within the given tolerance of the prescribed value. Because the distribution of tension in a chain tiedown may depend on how its links engage the corners, as discussed below, the manner in which the chain engaged the corners was noted at this point.

The tape recorder in the chase vehicle was started, and initially ran continuously. It first recorded the initial tensions, then the test vehicle was started and was driven from the test building to Ontario Highway 4, followed by the chase vehicle. It took about eight minutes to reach Highway 4, and involved accelerating from and braking to a stop, low-speed turns, a short passage where a speed of about 70 km/h (45 mph) was reached, which included a distinct bump at a railway grade crossing. The test vehicle turned south on Highway 4, and accelerated to cruise at 80 km/h (50 mph). The chase vehicle followed, and the interval timer on the tape recorder was started. The test vehicle slowed to 50 km/h (30 mph) as it passed through the town of Lucan, then resumed highway speed, made a loop turn at Highway 7 and returned by the same route to the start, for a trip length of about 40 km (25 mi) and a duration of 45 min. When the test vehicle was stationary, with its engine off, the tape recorder was stopped and the tape was removed and taken into the data laboratory.

The test staff had some concerns to drive the compliant load on the highway, so a similar procedure was followed for an equivalent distance, but simply driving on the runways within the confines of the test facility. While the highest speed possible on the runway was about 60 km/h (35 mi/h), and this speed could not be maintained for long, the runway is rougher than the highway and the procedure involves more turns, so the two tests could be regarded as reasonably equivalent.

Samples of equipment and test activity were recorded on video tape for future use. Colour still photographs and slides were taken of the vehicle, cargo, instrumentation and test activity. A detailed log of test activities and observations was maintained.

3.4/ Data Processing

The data tape from each run was played back from a second tape recorder into a Metraplex PCM work station. The data were saved to a file on the hard disk of the workstation, and a backup file was made on a floppy disk. The data file was pre-processed using a specialized test data processing developed at MTO, and key data were extracted and entered into a spreadsheet for analysis and presentation.

3.5/ Test Matrix

The test program consisted of runs as described above for all combinations of two types of tiedown, three initial tensions, two types of cargo and three types of corner. They are summarized in Table 1 below, as the schedule of conditions for each type of tiedown.

Table 1/ Test Matrix

Test	Tension (% WLL)				Cargo		Type of corner		
	5	20	50	100	Rigid	Compliant	Round steel	Square steel	Square wood
1a	X				X		X		
1b	X				X			X	
1c	X				X				X
2a	X					X	X		
2b	X					X		X	
2c	X					X			X
3a		X			X		X		
3b		X			X			X	
3c		X			X				X
4a		X				X	X		
4b		X				X		X	
4c		X				X			X
5a			X		X		X		
5b			X		X			X	
5c			X		X				X
6a			x			X	X		
6b			X			X		X	
6c			X			X			X
7a				X	X		X		
7b				X	X			X	
7c				X	X				X
8a				X		X	X		
8b				X		X		X	
8c				X		X			X

4/ Results

4.1/ Characteristics of Responses

Figure 10 shows the responses from both sides of the three webbing tiedowns set at an initial tension of 20% of working load limit (WLL) over round steel corners, together with vehicle speed, during a 45 minute trip with rigid cargo. The horizontal axis marked time is a little unusual. About the first 300 s, from the start to the main highway, is in real time, and thereafter the data shown are the 6 s samples from the interval timer. This is why the speed curve looks so rough, it just represents 6 s samples 60 s apart over a total time of about 35 min, and the steps are the instantaneous variations in vehicle speed, minute by minute. The trip used the round steel corners, which would be expected to give the greatest likelihood that tensions will equalize on both sides of the vehicle. Figure 11 shows the same trip with a chain tiedown, in the same conditions. It is clear from both these figures that the right-hand side tensions are initially higher than the left-hand side tensions, due to friction losses at the corners. Further, while there was some loss of tension on both sides, and the tighter side lost more tension, the tensions stabilized and there was no tendency for them to equalize during this trip. A second repetition of this trip, immediately after the conclusion of the first, without touching or adjusting of the tiedowns, resulted in no change in tension whatever, in any tiedown.

Figure 12 shows a similar trip, but the chain tiedown was tensioned from the centre of the cargo, rather than the right-hand side. Clearly, the two sides equalized much better initially at about 50% of WLL, and there was virtually no loss of tension as the trip progressed.

Finally, Figure 13 shows a trip for a compliant cargo secured with chain tiedowns with the initial tiedown tension at 20% of WLL, which was not sufficient to cause the concrete blocks to bunch together. This trip was slightly shorter than the previous three. The tiedown tensions started to equalize as soon as the vehicle started moving, and within 5-6 min of continuous driving the concrete blocks had bunched together and the tiedown tensions equalized at zero as they became slack.

4.2/ Loss of Total Tiedown Tension

The total tiedown tension is defined as the sum of the tensions of the right- and left-hand sides of the tiedown near the anchor points. It may be regarded in some way as a measure of the securement provided by the tiedowns.

Figures 14 and 15 show the total tiedown tension lost, as a percentage of tiedown WLL, during the trips with rigid cargo, for all corners, for chain and webbing tiedowns respectively at the four initial tensions. At the lower initial tensions, the square steel corners tend to have less effect on tension loss than the softer wood corners, although at 5% of WLL, about 0.9 kN (200 lb), the tension was so low that the corner shape and

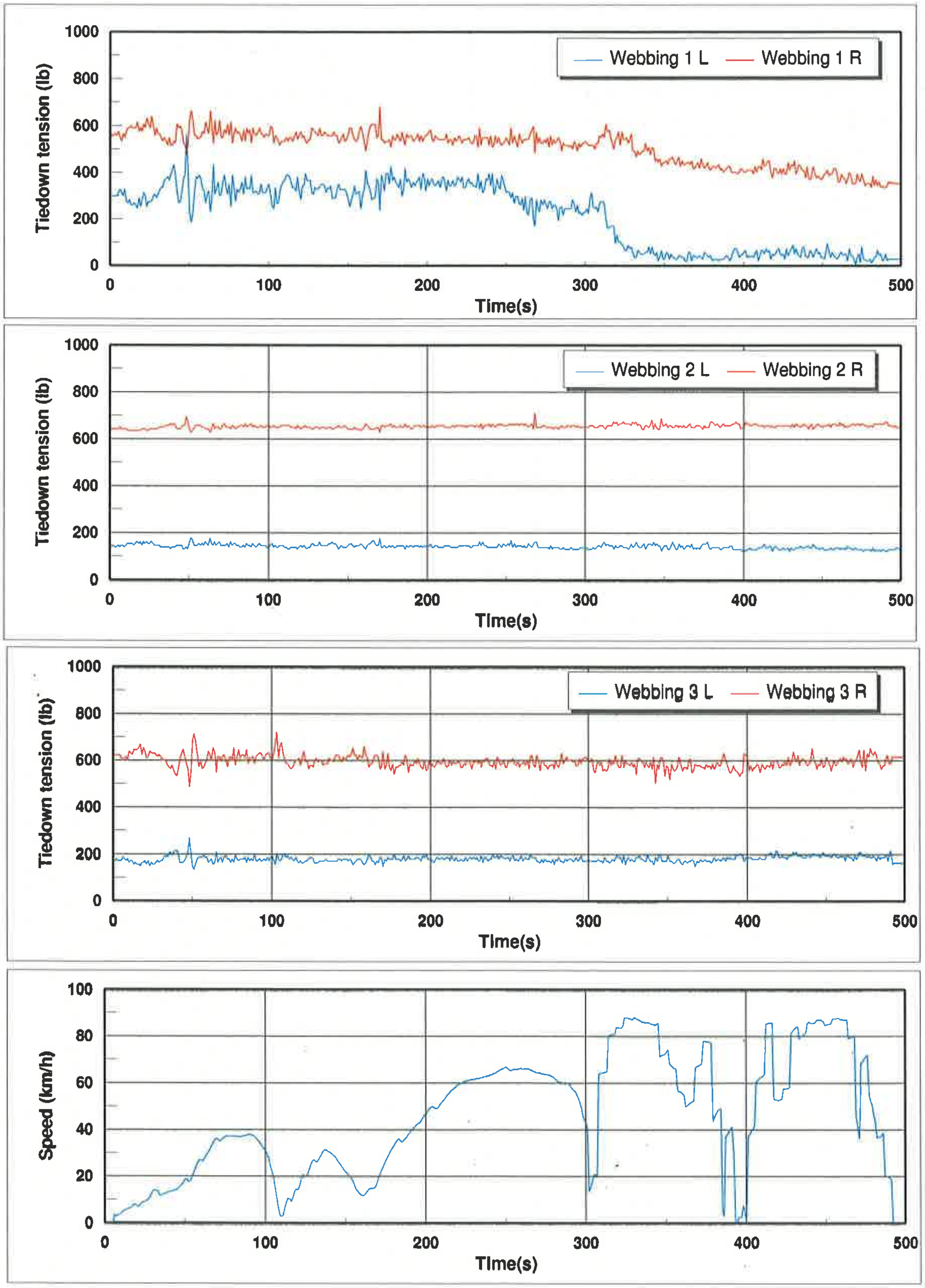


Figure 10/ Webbing Tiedown Responses, Round Steel Corners, Rigid Cargo, 20% WLL

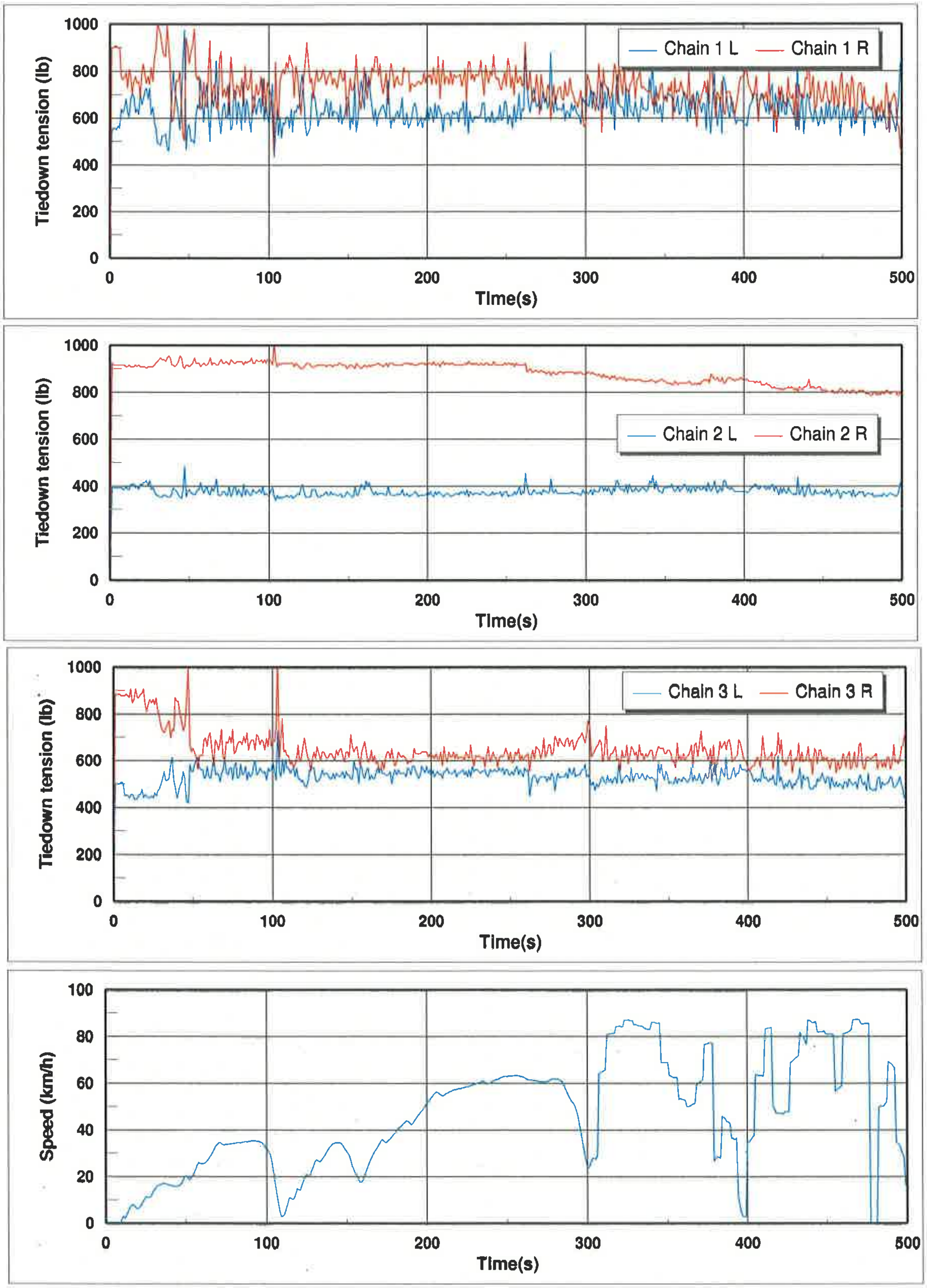


Figure 11/ Chain Tiedown Responses, Round Steel Corners, Rigid Cargo, 20% WLL

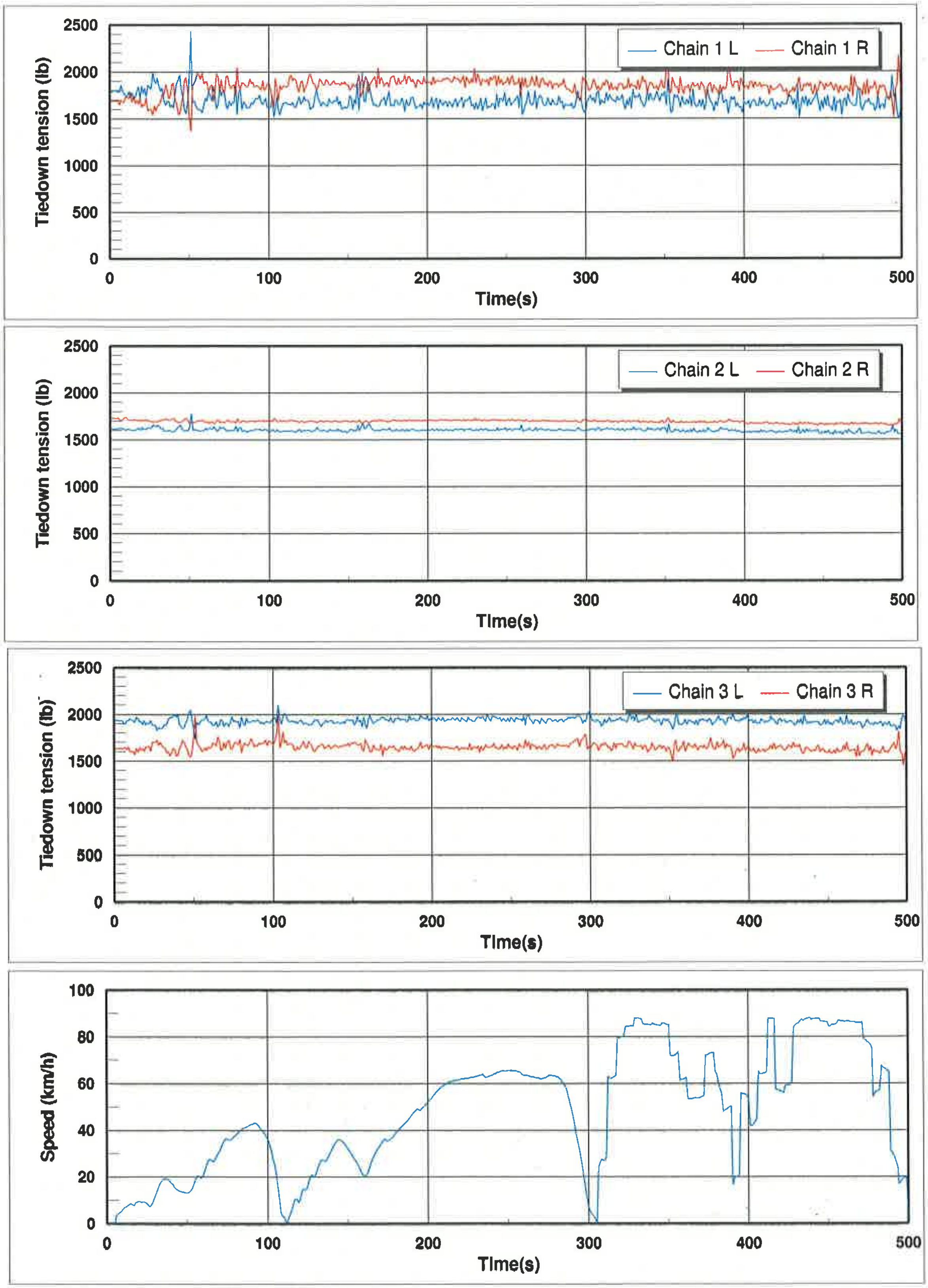


Figure 12/ Chain Tiedown Responses, Round Steel Corners, Rigid Cargo, 50% WLL Chain Tensioned from Centre of Cargo

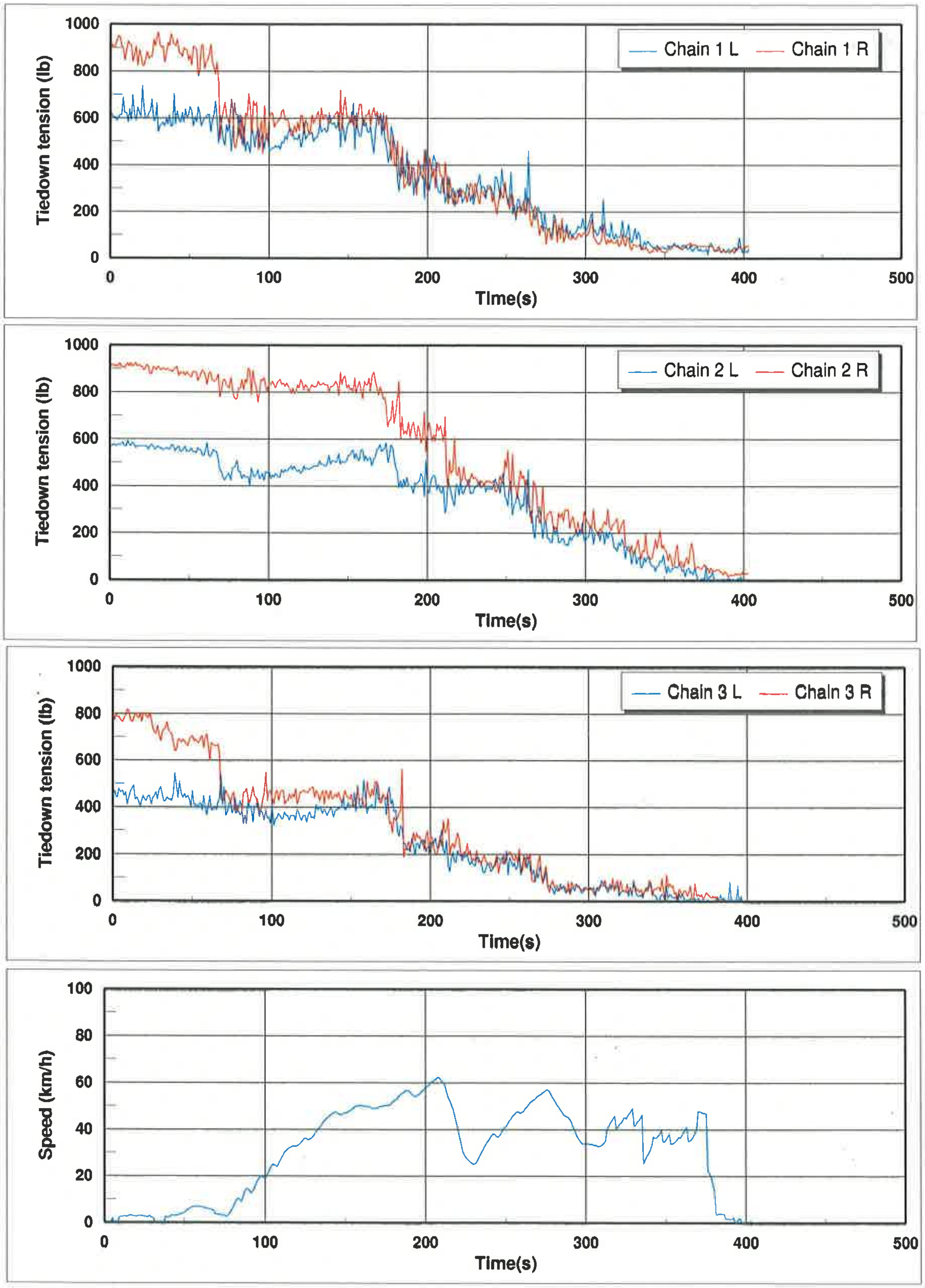


Figure 13/ Chain Tiedown Responses, Round Steel Corners, Compliant Cargo, 20% WLL

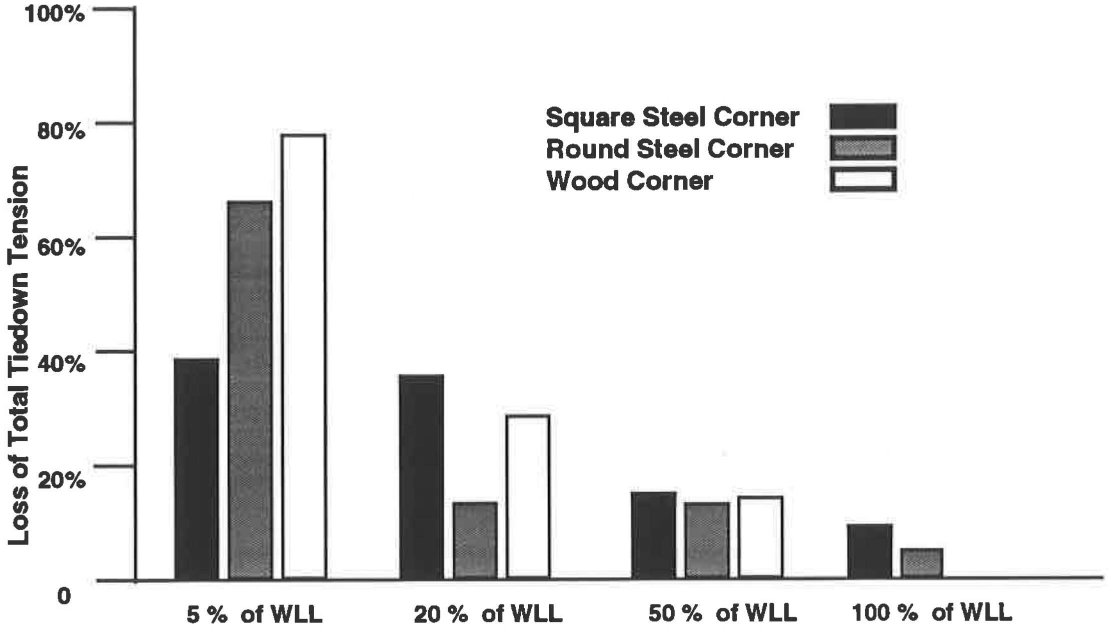


Figure 14/ Loss of Total Tiedown Tension for 5/16 in Chain Tiedowns for Rigid Cargo

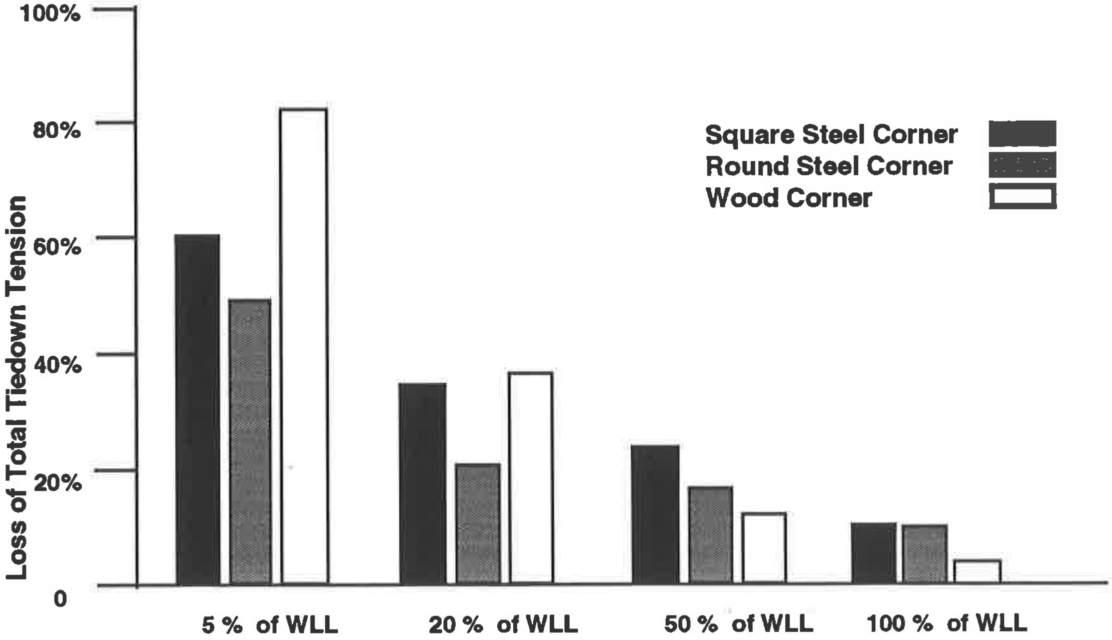


Figure 15/ Loss of Total Tiedown Tension for 3 in Webbing Tiedowns for Rigid Cargo hardness would hardly have a significant influence on the tension. At initial tensions over 20% of WLL, the chain lost marginally less tension than the webbing, possibly because the webbing tends to relax a little after it is initially stretched. With both types of tiedown, a lesser percentage of initial tension was lost as the initial tension increased.

Figures 16 and 17 show the same results for the compliant cargo. The chain tiedown lost 95% of the total tension, compared to 70% for the webbing, at an initial tension of 20% of WLL, which was not sufficient to compress the cargo. However, when the vehicle began moving, the tiedowns quickly became slack and the tension disappeared. When the tiedowns were tensioned initially to 50% of WLL or more, this was enough to compress the cargo, and it effectively became rigid, when the results are more comparable to those shown in Figures 14 and 15. The type of corner did not seem to influence the loss of total tiedown tension significantly for compliant cargo. Figure 18 summarizes the results from the compliant cargo, illustrating that when the cargo is compressed to become rigid, there is significantly less loss of tension.

4.3/ Equalization of Tiedown Tension

The ratio of left-hand side tiedown tension to right-hand side tiedown tension is an indicator of tiedown tension equalization. Initially, it is small, as the tiedown is tensioned from the right-hand side. It increases as the right-hand side tends to lose more tension than the left. If it reaches unity, 1.0, the tensions on both sides of the tiedown have equalized.

Figures 19 and 20, for the rigid load, show the range of tiedown tension ratio for the various initial tensions, for chain and webbing tiedowns respectively. It can be seen that a lower initial tension gives a greater tendency toward equalization, principally because significant tension is lost on both sides. Webbing seemed to have less tendency to adjust or equalize, especially over the sharp steel corner.

Figures 21 and 22 show the same results for the compliant cargo. At an initial tension of 20% of WLL, the tension ratio tended to unity, indicating equalization. However, this was because the cargo compressed during the trip, and the total tiedown force was significantly diminished. Although there was near equalization of tiedown tension, most of the tension was lost and the tiedowns were ineffective.

In all cases where the initial tiedown tension exceeded 20% of WLL, 3.36-4.00 kN (8-900 lb), the tiedown tension ratio did not approach unity. Initially, during earlier parts of the test run, there was some downward movement of the higher tension side, but it then stabilized and remained effectively uniform at a tension much higher than the lower tension left-hand side. Generally, as the percentage loss in total tiedown force decreased then so too did the tendency of the tiedown tension to equalize.

Figure 23 combines the data from Figures 19 through 22, to show the overall envelope of trends. It also includes two trips where the tiedowns were tensioned initially to 50% of WLL from the centre of the cargo. This resulted in an initial tension ratio near unity that persisted throughout the trip.

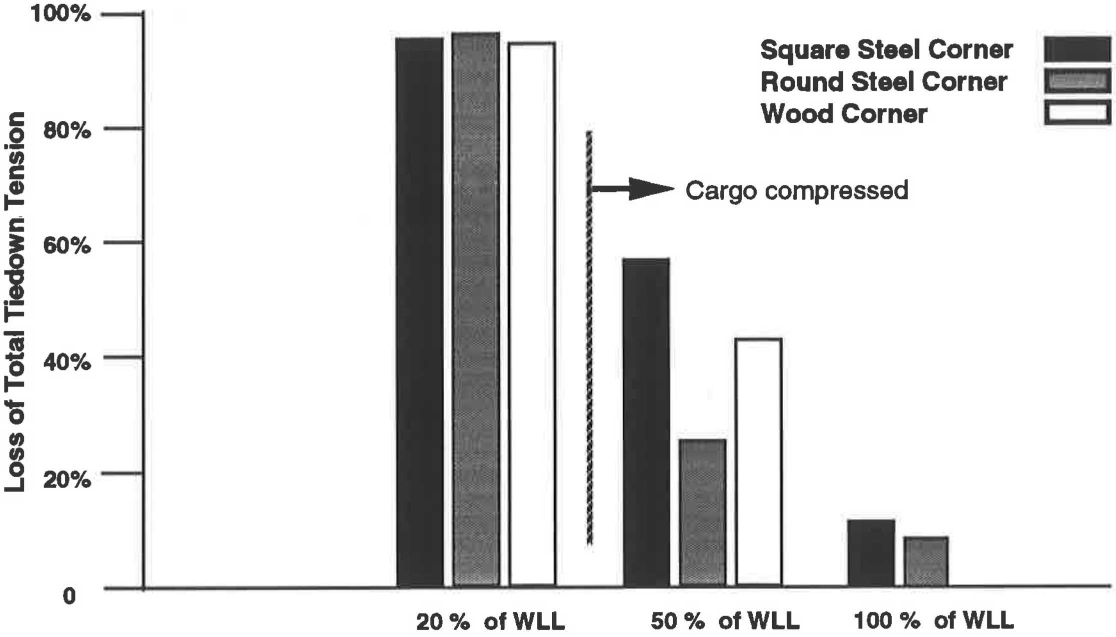


Figure 16/ Loss of Total Tiedown Tension for 5/16 in Chain Tiedowns for Compliant Cargo

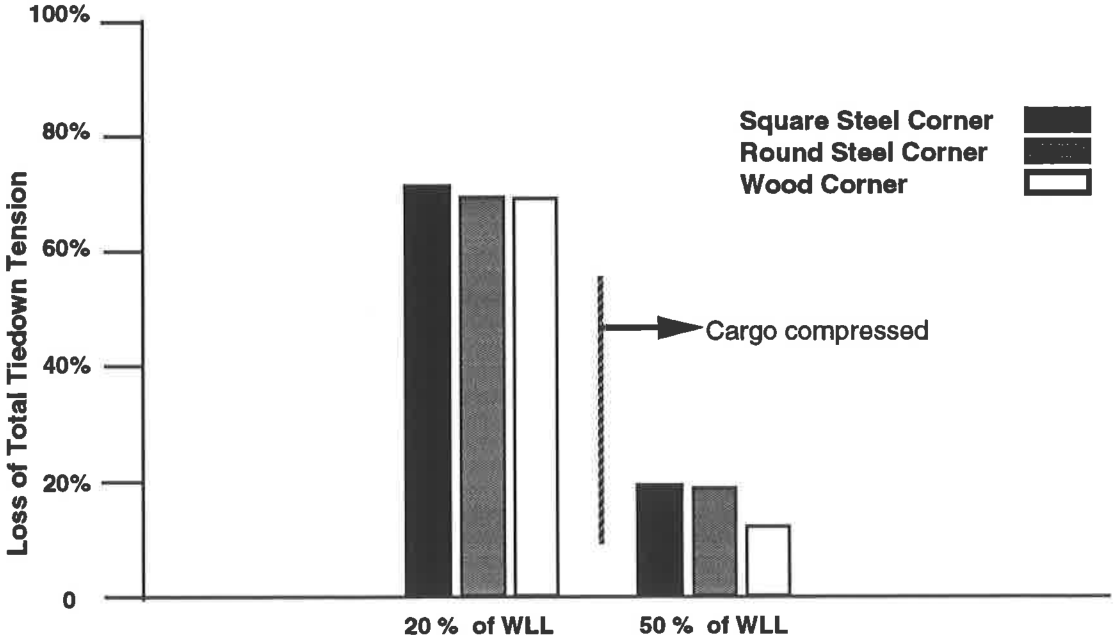


Figure 17/ Loss of Total Tiedown Tension for 3 in Webbing Tiedowns for Compliant Cargo

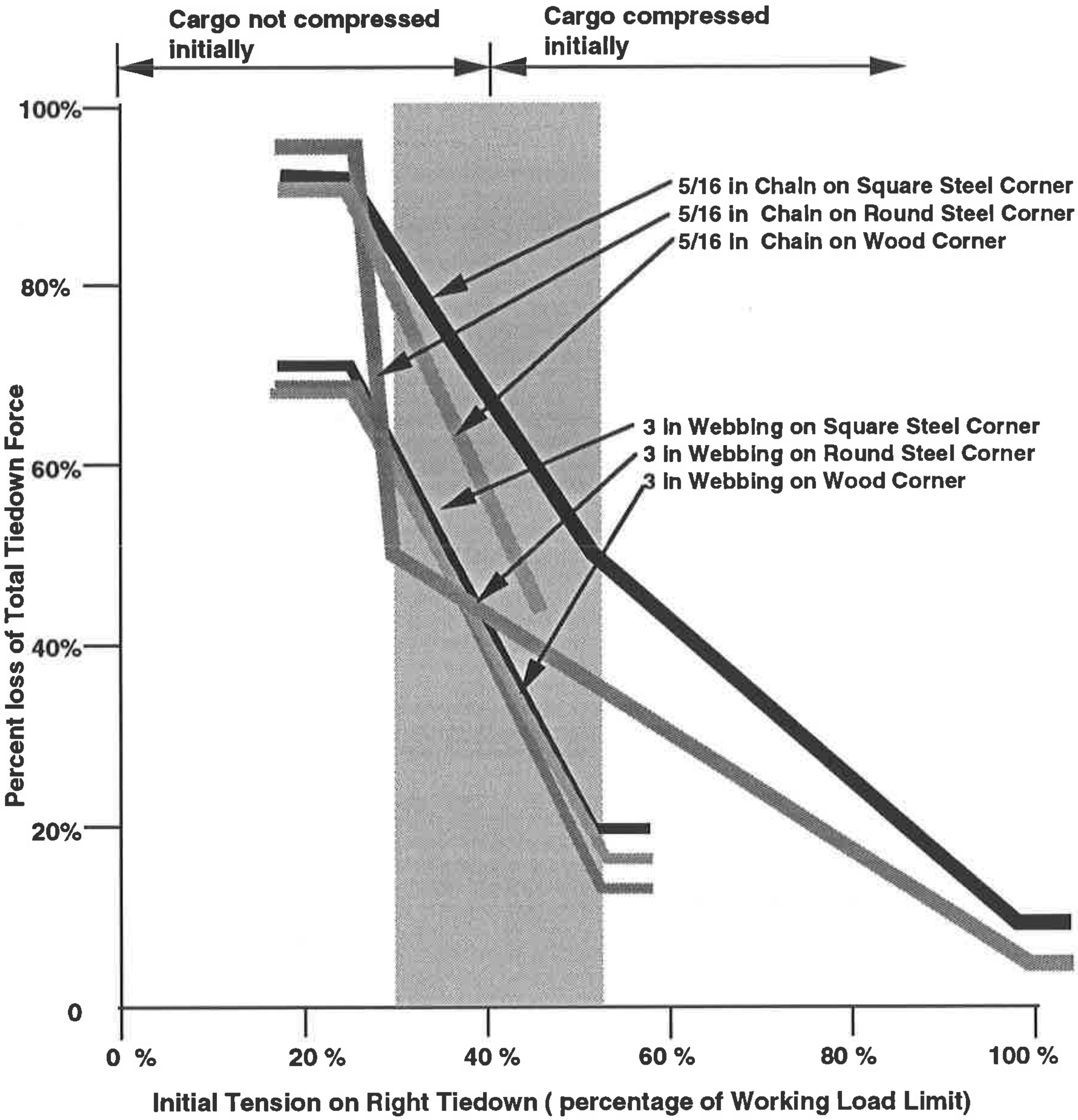


Figure 18/ Loss in Total Tiedown Tension for Compliant Cargo Due to Compression and Travel Vibration

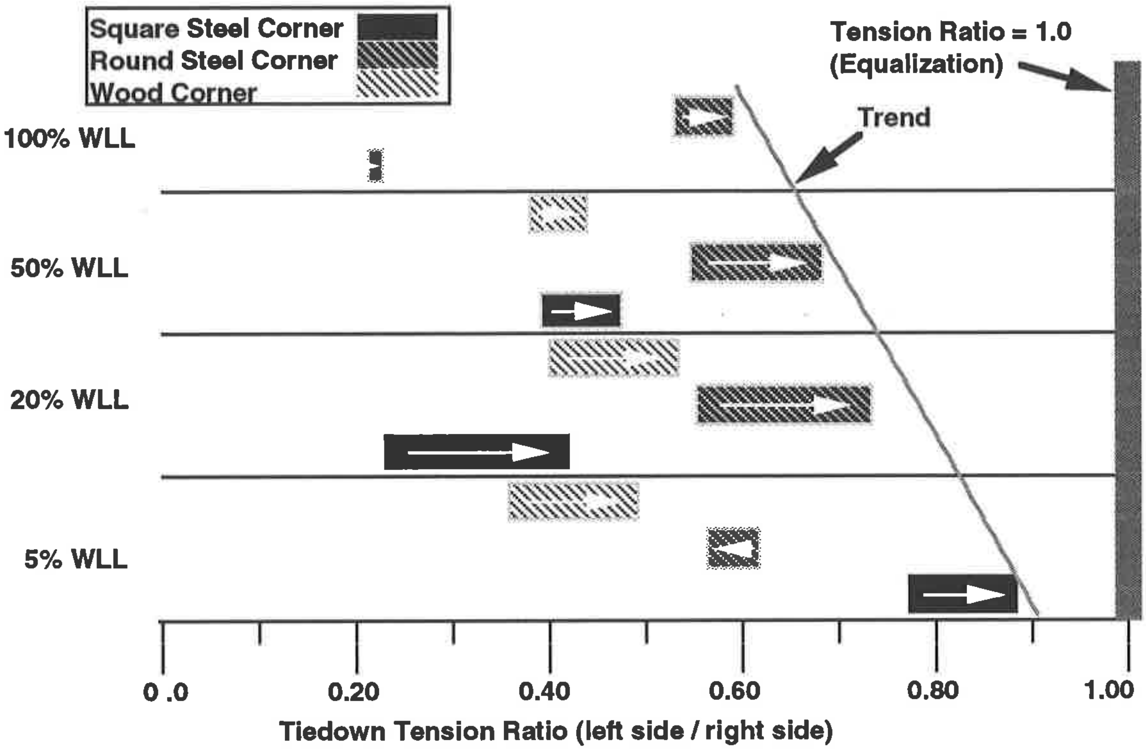


Figure 19/ Initial and Final Tension Ratios of 5/16 in Chain over Rigid Cargo

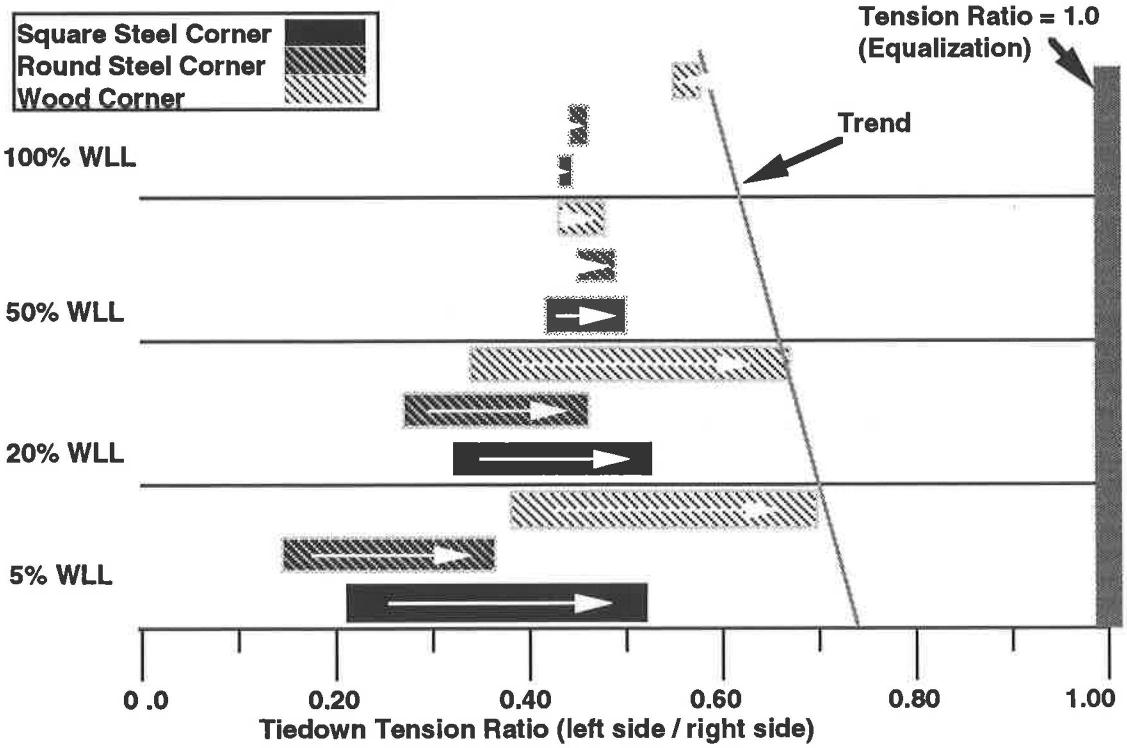


Figure 20/ Initial and Final Tension Ratios of 3 in Webbing over Rigid Cargo

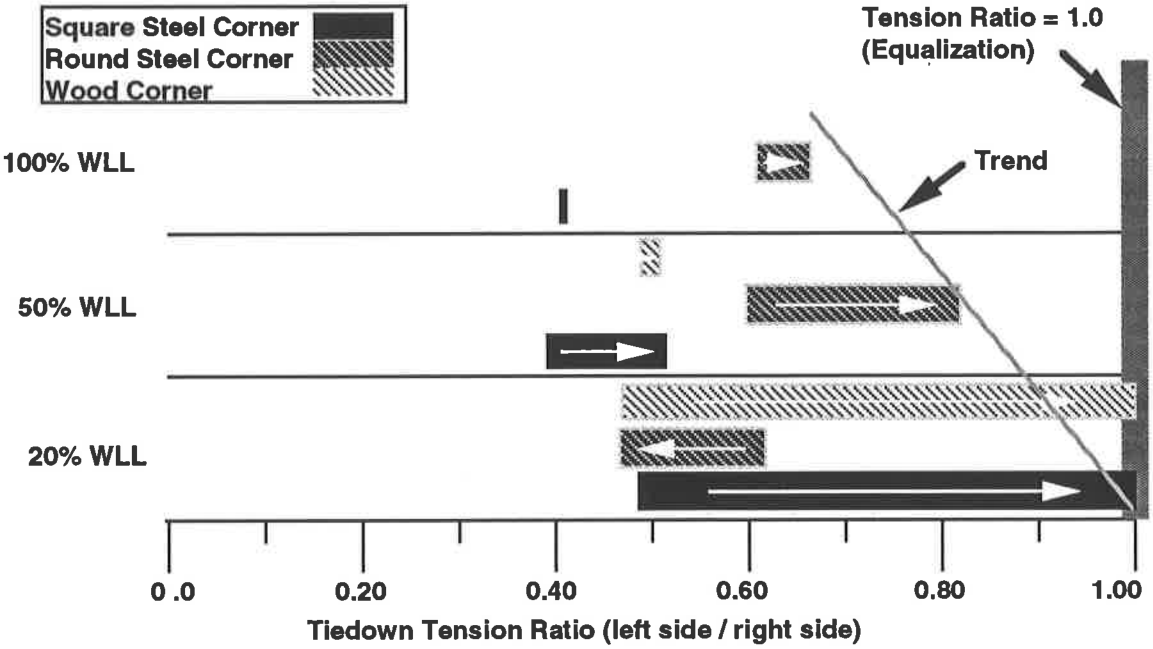


Figure 21/ Initial and Final Tension Ratios of 5/16 in Chain over Compliant Cargo

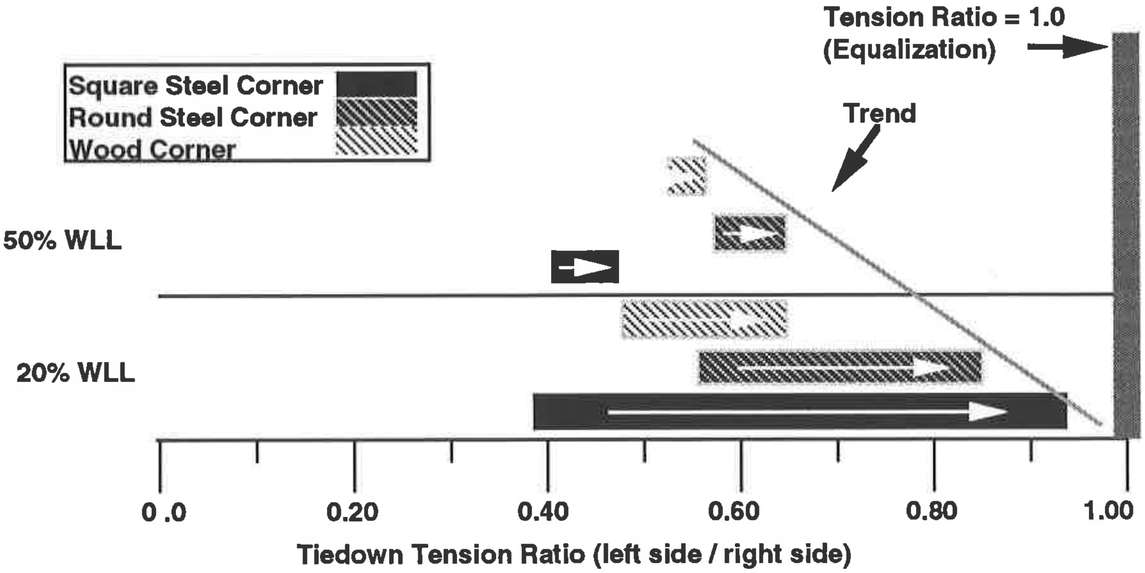


Figure 22/ Initial and Final Tension Ratios of 3 in Webbing over Compliant Cargo

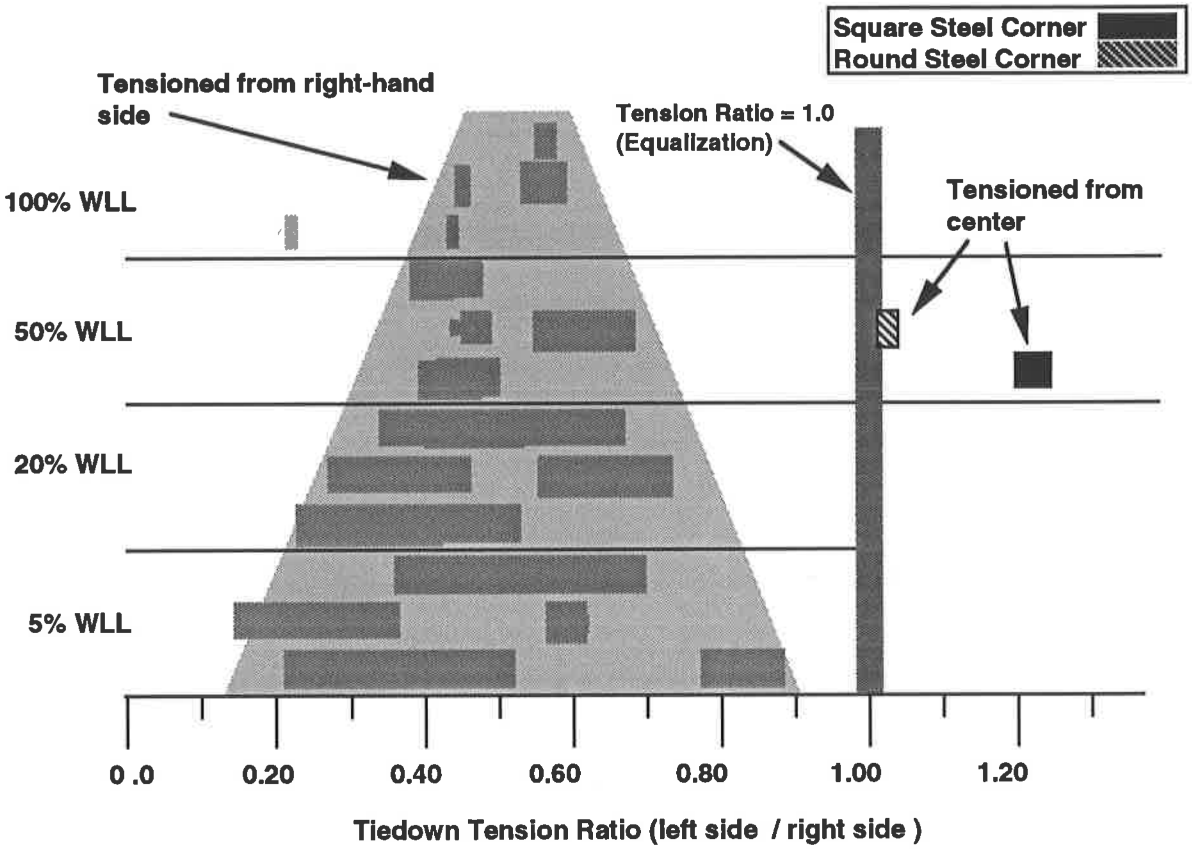


Figure 23/ Effect of Binder Location on Tiedown Tension Ratio and Tension Equalization

4.4/ Tiedown Damage to Corners

Webbing tiedowns did no damage to the steel corners. They indented and rounded the edge of the wood corner slightly at an initial tension of 20% of WLL, indented more at 50% of WLL, and at initial tensions of 85 to 100% of WLL, the webbing tended to cause local damage and splitting, unless great care was taken in tension application and corner placement. These cases are illustrated in Figure 24.

Chain tiedowns did not cause local damage to the round steel corner. They dimpled the square steel corners, as shown in Figure 25, at initial tensions over 20% of WLL, and the depth of the dimple and degree of abrasion increased as the initial tension increased. Chain tiedowns indented both sides of the wood corners as shown in Figure 26 for four initial tensions, for both right-hand side, the tensioned or binder side, and the left-hand side of the cargo. The damage was much more severe on the right-hand side.

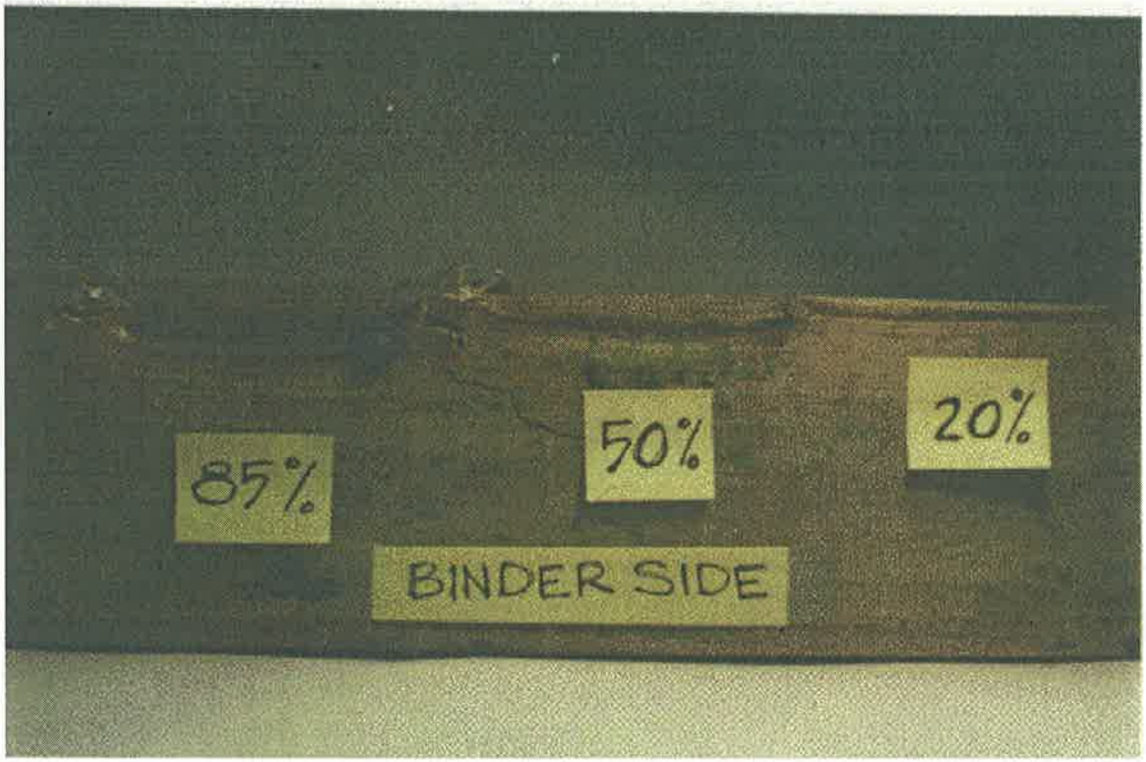


Figure 24/ Webbing Damage to Wood Corner

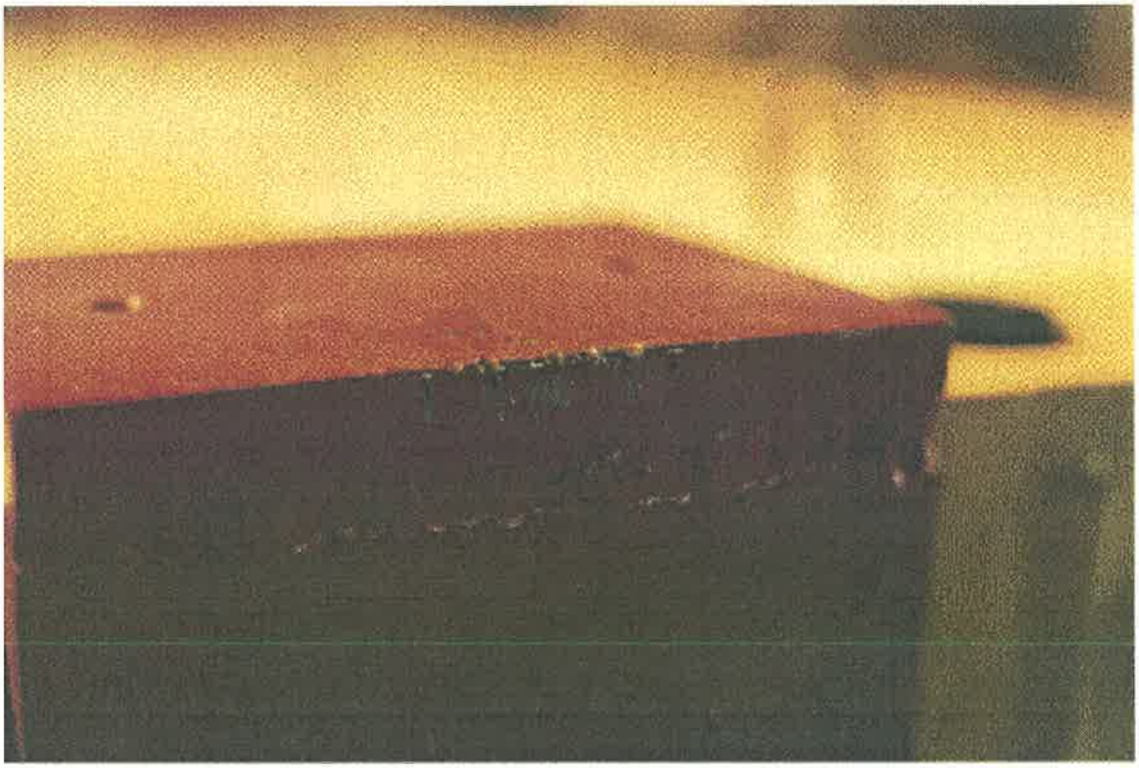


Figure 25/ Chain Damage to Square Steel Corner

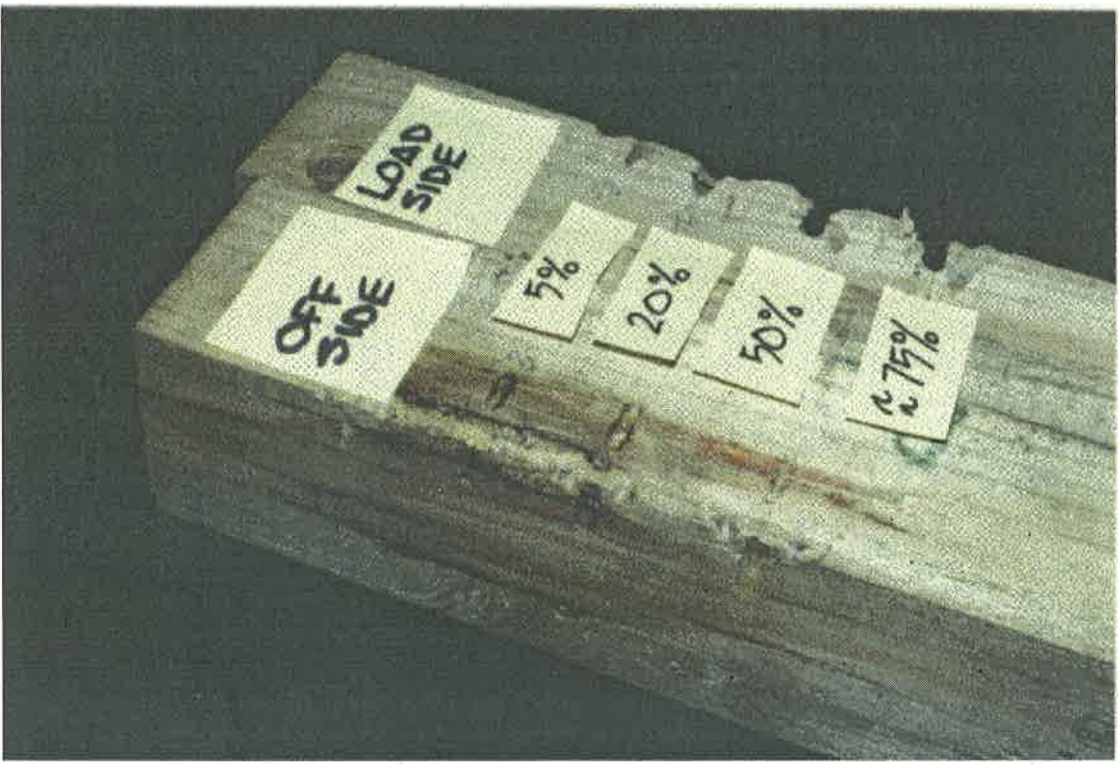


Figure 26/ Chain Damage to Wood Corners

5/ Analysis and Discussion

5.1/ Loss of Total Tiedown Tension for Rigid Cargo

Care was taken to try and create as rigid a cargo as possible, but there was still some residual compliance due to truck bed and frame flexure. The cargo was, however, quite rigid in comparison to many mixes of cargo. Three tiedowns were used in all tests, and invariably each behaved in a different manner. Data were collected from all three and then scrutinized for peculiarities and unusual behaviour patterns before being accepted as valid data.

The actual tiedown tension loss, per tiedown, measured in force units is shown in Figures 27 and 28. Both cargo types, and all corner types and initial tensions resulted in a loss of total tiedown tension, with the greatest loss at the higher initial tensions. Chain tiedowns consistently lost about 1.78 kN (400 lb) tension per tiedown, while webbing tiedowns lost 1.78-2.67 kN (4-600 lb). The chain tiedown on round corners tended to lose the least total tension, and the square steel and wood corners lost somewhat more, with the difference 0.44-0.67 kN (100-150 lb). For webbing, the least loss occurred with the wood corner, the greatest with the square steel corner. Webbing at high initial tension tended to form the wood corners in a manner that equalized contact pressure and promoted local slippage or scuffing at the contact point.

With the chain tiedown, high point loading of the chain on the steel corner caused indentation, as shown in Figure 25. This local deformation, possibly aided by abrasion due to vibration induced by driving, served to reduce the overall tension by effectively reducing the dimensional envelope of the cargo, thus allowing a degree of slackness in the tiedown. The loss in tension of the chain over the wooden corner was substantial during initial tensioning. The initial tensioning required an extended effort due to the plastic deformation of the wood as the chain applied pressure. Once the target tension was achieved, the chain continued to lose tension, at a slower rate, as a result of further indentation of the wood. Since the round steel corner allowed several chain links to contact the corner simultaneously, there was less pressure and hence no local plastic deformation of the corner. This resulted in a lower tension loss.

Webbing was unable to deform steel corners. The wood corners showed some compression and minor splintering. The webbing caused the wood to deform to a configuration reflecting the reactive pressure and hence produced a more uniform local pressure and lower contact friction. Larger losses were experienced with the webbing (as compared to chain) on the steel corners. Since webbing passing over steel did not deform the steel, there was a higher local contact friction as a result of the sharp edge. This was due to the higher resistivity of the steel to conform and thereby abrade and stretch the webbing to the point that the individual weave openings became smaller and the webbing mesh became more tightly compressed. A similar phenomenon was not as evident with the more ductile wood.

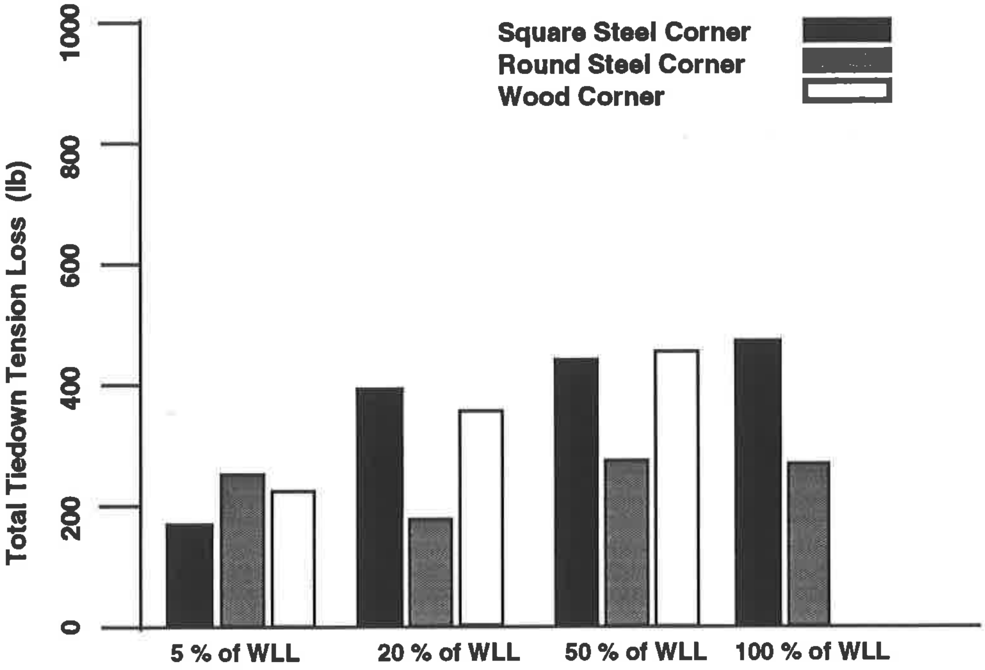


Figure 27/ Loss of Total Tiedown Tension of 5/16 in Chain Tiedowns for Rigid Cargo

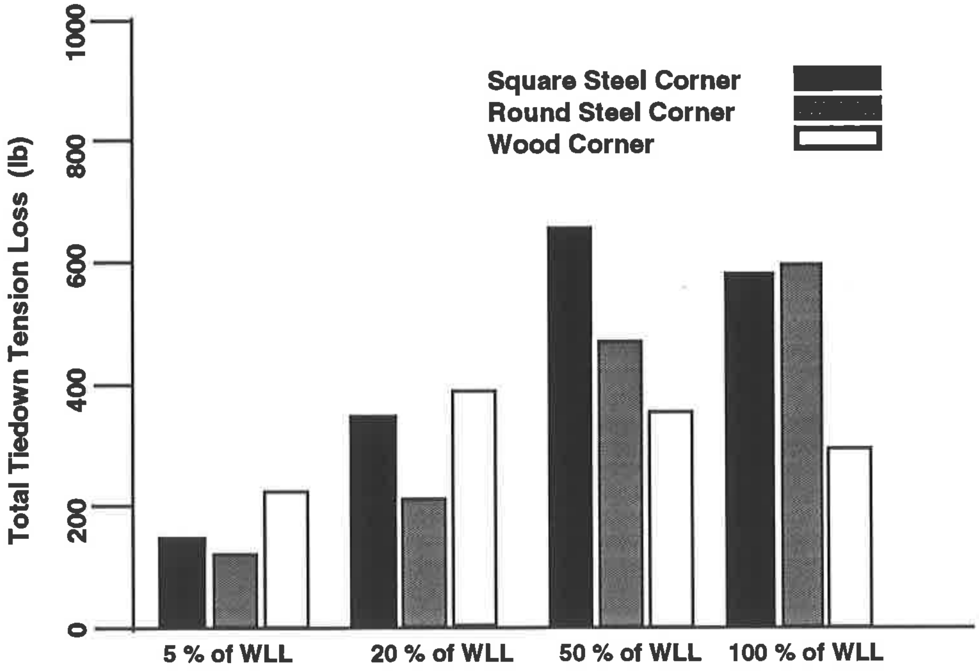


Figure 28/ Loss of Total Tiedown Tension of 3 in Webbing Tiedowns for Rigid Cargo

5.2/ Loss of Total Tiedown Tension for Compliant Cargo

With an initial tension of 20 to 50% of WLL, chain tiedowns on compliant cargo lost up to 7.55 kN (1,700 lb) in total tension, as shown in Figure 29. This was primarily due to the lack of equalization in the tiedown coupled with initial tension and inertial forces of the deck causing the cargo to shift and realign and hence cause the tiedown to lose some of its initial tension. When higher initial tensions were applied, the act of tensioning the tiedown forced the cargo to compress, when it effectively became rigid. There still remained some compliance, and road vibration and the residual forces in the tiedowns caused the blocks to nest further, hence reducing further the tiedown tensions.

Once the nesting of the compliant load had been completed, subsequent loss in total tiedown tension was similar for both chain and webbing tiedowns, in the range 1.77-2.65 kN (400-600 lb). The composition and make-up of the corner did not appear to influence the change in tiedown force significantly for compliant cargo.

5.3/ Loss of Tiedown Tension Around a Corner

When tiedowns were tensioned around a corner, a loss or differential in tension was observed, due to friction at the corner. The average loss across two identical corners was estimated assuming a proportional loss across each. The chain lost an average of 36% from the high side on a square steel corner, but the data are scattered because there are three ways that the contacting link can orient itself with the square corner :

1/ horizontal, Figure 30;
2/ vertical, Figure 31; and
3/ at an angle (usually a combination of the other two), as seen in Figure 8.

Any of these may arise when the chain tiedown is initially set up. Which arises depends exactly on the length of the chain, and how it is tensioned. In each of the first two cases, the contact link is acting as a lever, and all the tension bears directly on the edge, and the contact pressure was sufficient to indent a steel corner and cause a "catch point". The resulting damage to the corner was shown in Figure 25. Both these cases, and especially the second, are unstable, in the sense that any change of tension or tiedown length will tend to result in the third arrangement. The chain tiedown on a round steel corner consistently lost 23% of tension. The data for this was less scattered, possibly because the chain was not damaging the corner, and the chain set up consistently with all links at an angle of 45 deg to the steel surface. The chain lost an average of 35% of tension around a wood corner, with data becoming more scattered on the compliant load presumably due to load movement. As with the square steel corner, the chain orientation at the corner apex was a factor in the transmission of the load. The chain indented the wood and links locked into the corner, regardless of the link orientation, creating an interlocking catch point as seen in Figure 31.

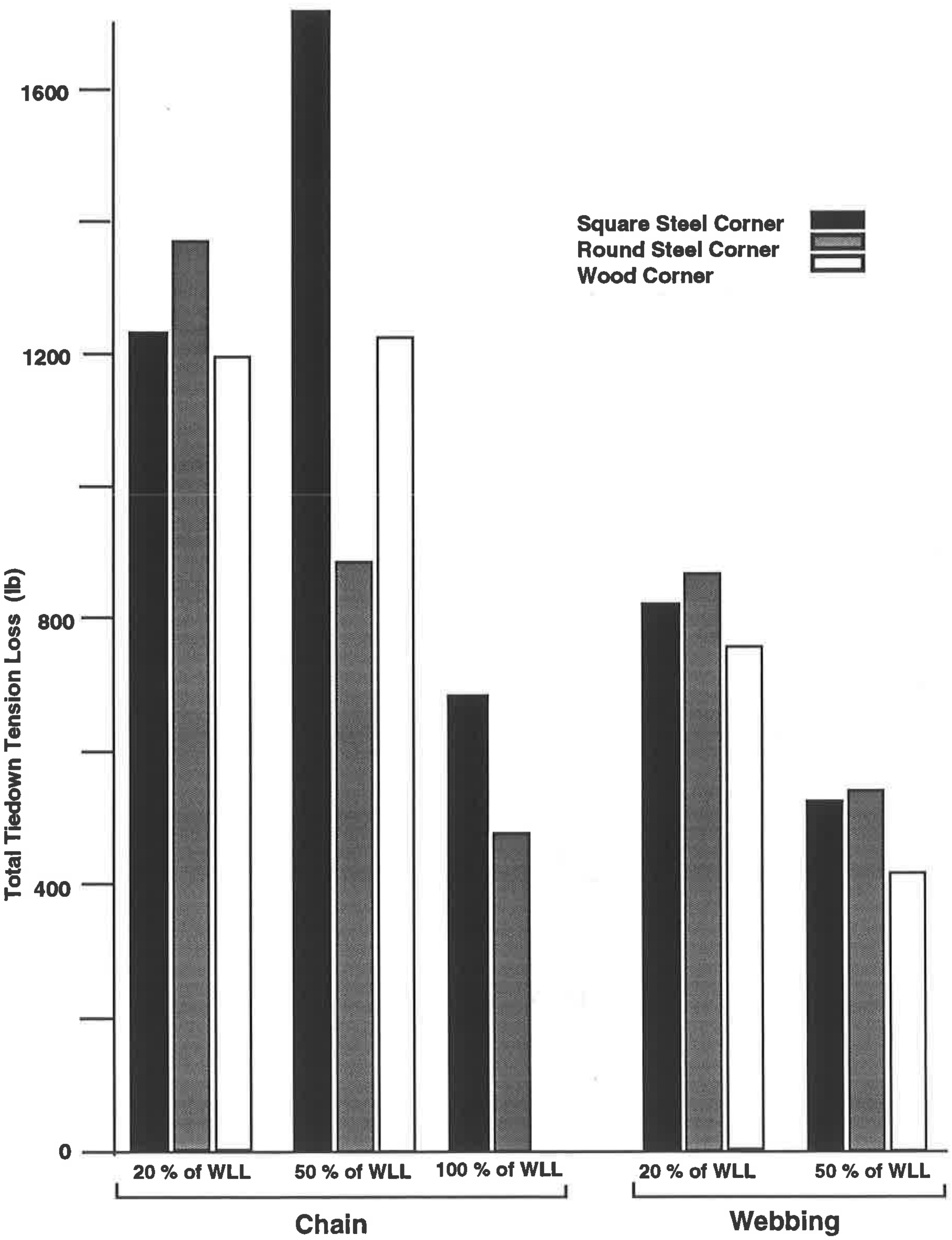


Figure 29/ Loss of Total Tiedown Tension for 5/16 in Chain and 3 in Webbing for a Compliant Cargo

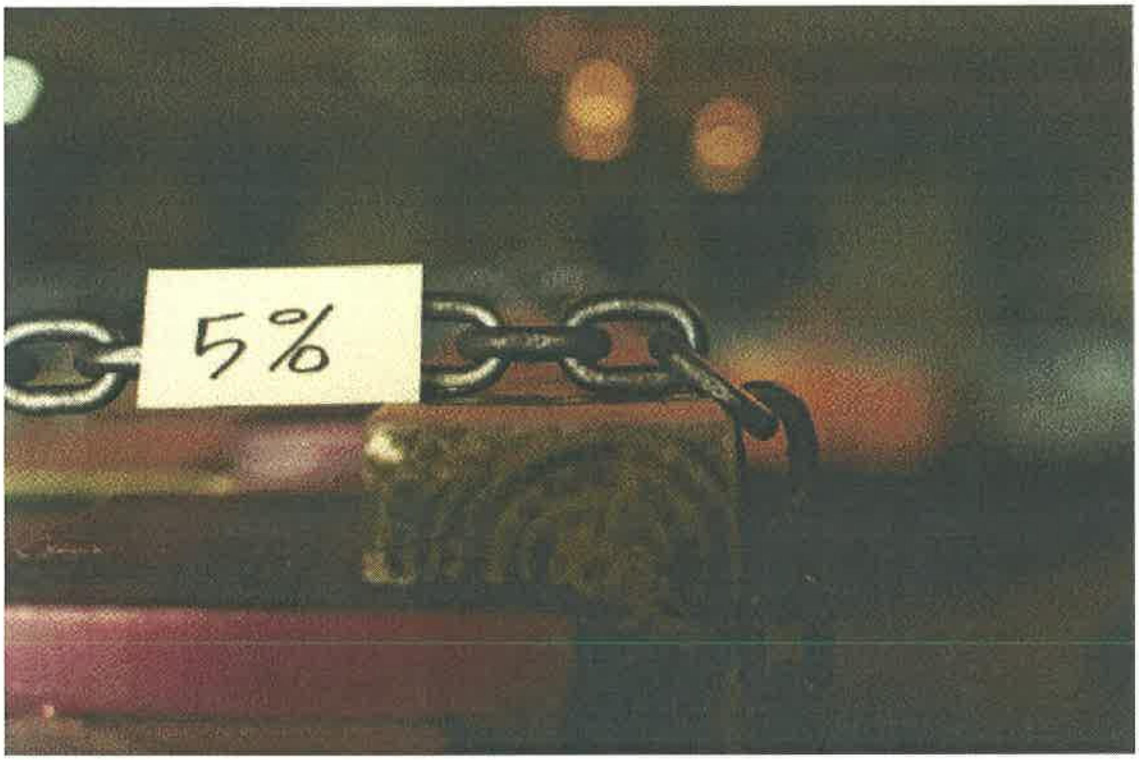


Figure 30/ Chain with Link Horizontal across Wood Corner

Figure 31/ Chain With Link Vertical, Indenting Wood Corner

When the contact link was horizontal or at the link connection over a square corner, the chain encountered a mechanical catch point and the tension was reacted by the corner edge. When the contact link was vertical, it reacted as a lever to transmit the tension, though the lever would be sensitive to the angle of the link at the corner. The contact link caused local deformation of the edge, widening the fulcrum to increase friction and modify the lever action. A link did not remain vertical for any length of time, either during tensioning or once the truck got under way. It appeared to be a relatively unstable position for a link during manual tensioning, and any vibration would cause the link to rotate to a horizontal position.

Webbing lost 36% of its tension across a sharp steel corner, for both the rigid and compliant cargo. It lost 40% across a round steel corner for rigid cargo and 20% for compliant cargo, as cargo movement caused webbing tensions towards equalization. It lost 26-29% across the wood corner for both rigid and compliant cargo.

5.4/ Initial Equalization of Tiedowns

Applying tension to the tiedown on one side only did not allow equalization to occur. Friction, or interference in the case of chain, caused losses in tension within the tiedown, so only a fraction of the initial right-hand side tension was transmitted to the other side. Several tests were conducted with the binder placed at the centre of the top of the cargo, in an attempt to apply as close to equal tensions on the two sides as possible. Figure 23 showed that the tension ratios remained close to unity when the tiedowns were tensioned from the centre, and there was significantly better retention of tiedown tension. This indicates that if initial tension is applied symmetrically, there is significantly less loss in total tiedown tension. It would appear that loss of total tiedown tension is related to an initial inequality of tiedown tension, and that some of the tension on the high side may be lost to the top span of the tiedown. Since the top span tension does not contribute to the total tiedown tension, it results in a loss vertically. The top tension does however contribute to compression of the cargo. This is advantageous for compliant cargo, but not necessarily for rigid cargo. It would appear that the more rigid the cargo, then the greater the need for equalization within the tiedowns, to best utilize the additional tiedown force to increase the effective deck/cargo friction. The more compliant load would not require the same degree of equalization since the tiedown would serve more as a capture medium than a friction enhancer. If equalization is available it would ensure both a high tiedown force as well as high compressive abilities.

6/ Conclusions

A test was conducted to determine if the tension in the vertical spans of transverse tiedowns tensioned from one side would equalize when subjected to road vibration. Two tiedowns were used, 5/16 in chain with a working load limit (WLL) of 2,041 kg (4,500 lb) and 3 in webbing with a WLL of 1,814 kg (4,000 lb). Two types of cargo were used, compliant cargo that had some allowance to compress, and rigid cargo that did not. Three types of corner were tested, square steel, round steel and square wood. Each tiedown was tensioned initially on one side to 5%, 20%, 50% or 85-100% of WLL, and tension was also applied from the centre of the tiedown for a few tests. After tensioning, the vehicle was driven and tiedown tensions were monitored.

When a chain or webbing tiedown was tensioned from one side of the vehicle over a rigid cargo, the initial tensions on each side of the tiedown were markedly different, due to friction around the corners of the cargo, and irrespective of the geometry or hardness of the corner. When the vehicle was driven on the highway, there was some loss of tension from both sides, but the tensions never equalized, regardless of tiedown type, corner characteristics or initial tension.

For the same test with a compliant cargo, a high initial tension tended to compress the cargo and make it more rigid, leading to similar results as the rigid cargo A low initial tension was insufficient to compress the cargo, and space remained between articles. Vehicle motions caused the cargo to compress, and the tiedowns quickly became loose.

When a tiedown was tensioned from the centre, tension was much better equalized, and less tension was lost in driving than when the tiedown was tensioned from one side.

The corners were damaged by high point loads, especially for chain tiedowns over square corners. Such damage, while not detrimental to steel corners or a chain tiedown, did result in deformation that reduced tiedown tension. High tension in both chain and webbing tiedowns caused severe local indentation and cracking of wood corners. In some cases, chain tiedowns damaged the corner so severely that the tiedown became loose.

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

Regarding loading of cargo :

1/ Cargo should loaded without space between articles, so that it is more closely rigid than compliant. If other considerations require lateral space between articles of cargo, then a filler or other means should be used to prevent the articles from moving together, and the filler should be placed so that it cannot come loose.

Regarding application and use of tiedowns :

2/ A tiedown tensioned from the centre provides more equalized tension at anchor points, but this should only be done if it does not incur undue risk of falling from atop the cargo.

3/ A tiedown should not be used in direct contact with cargo or dunnage that is much softer than the tiedown, where the corner will suffer permanent crush damage as the tiedown is tensioned. Robust corner protectors should be used that are hard enough to resist the local pressures of the tiedown.

4/ If there is reason to believe that cargo may be compliant, and there is no danger that its edges will be damaged by tiedowns, the tiedowns may be tensioned close to their working load limit to compress the cargo, then released and re-tensioned in a normal manner.

5/ A chain tiedown should be installed carefully so that it is free of twists, and so that the links set up in a stable manner at 45 deg at the corner.

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