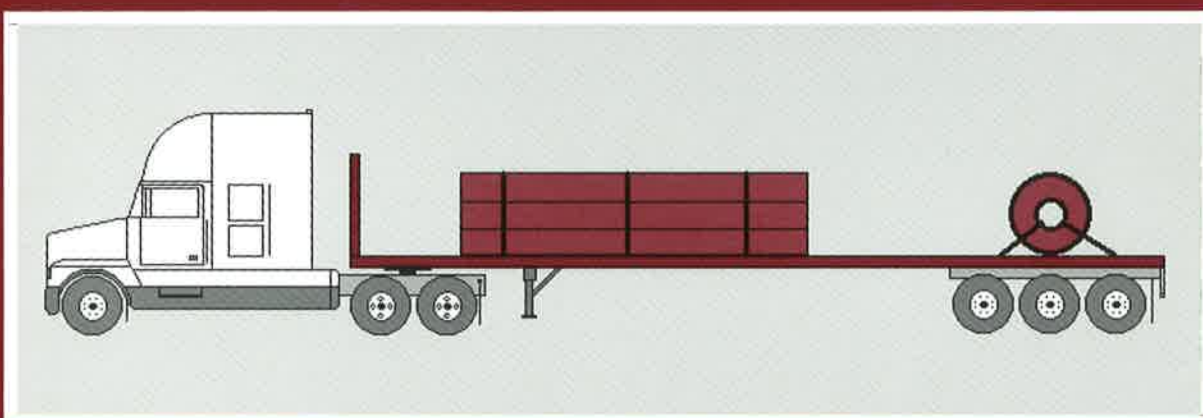
CCMTA Load Security Research Project

Report # 14

EFFECT OF TIEDOWNS ON WOOD BLOCKS USED AS DUNNAGE



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

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Report # 14

EFFECT OF TIEDOWNS ON WOOD BLOCKS USED AS DUNNAGE

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 1998 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 effect of chain, cable and webbing tiedown forces on the corners of spruce and maple dunnage blocks while under tension. The tests examined the effect of the degree of tension and shape of the tiedown on corner deformation and measured hysteresis effects of the dunnage and its ability to retain tension in the tiedown. The tests were conducted using tiedowns tensioned across the dunnage at three different angles.

The tests, and subsequent analysis, showed that maple hardwood displayed less deformation and splitting than the softer spruce. Both wood samples contributed to an abrupt loss of tension during unloading thereby displaying the mechanism of tiedown slackening during load shifting. At shallow tiedown wrap angles the tiedown tended to abrade the corner rather than indent it. Chain tended to splinter and crack the dunnage corners, wire rope tended to slice into the dunnage and webbing material tended to compress the surface without splintering or cracking.

Recommendations are made regarding the use of dunnage with various 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.

Dunnage is used to distribute the forces of a tiedown over a larger area of cargo than the area of the tiedown, or to protect the tiedown from abrasion by cargo with a sharp or rough edge. Preliminary work identified that little was known about the interaction of cargo, tiedowns and dunnage, so a series of tests were developed to determine the effect of tiedowns on dunnage, as outlined in Section 9.5 of the project proposal.

A reaction frame was built for these tests. A block of dunnage was installed and a tiedown was placed over it and connected to a screwjack assembly that applied tension to the tiedown in a series of increments up to 13.3 kN (3,000 lb), and then reduced in a similar manner. The test was repeated with a steel tubular section in place of the dunnage to measure the characteristic of the tiedown. This was subtracted from the dunnage result to eliminate the elastic effect of the tiedown and produce a characteristic for dunnage with that particular tiedown and wrap angle. Hardwood and softwood dunnage were tested with chain, wire rope and webbing tiedowns wrapped over the dunnage at angles of 45, 60 and 90 deg .

The dunnage deformed plastically under the tiedown and was permanently damaged. Tiedowns with a smaller cross-section indented further into the dunnage than those with larger cross-section, and wire rope indented more than chain of identical diameter. Webbing deformed the dunnage to produce the largest displacement. Chain tended to cause the corners to split, with gross surface damage, while wire rope tended to slice into the wood with only local damage. Webbing compressed the wood beneath it, without causing splitting. Tiedowns at shallower angles caused less damage to corners than tiedowns at larger angles.

Hardwood resisted indentation, splitting and surface abrasion better than softwood, and allowed lower displacement of the tiedown at identical tensions and wrap angles. Corner deformation was linearly related to the tiedown tension during an increase in tension. When the tension was decreased, it fell abruptly as there was no retained elasticity within the dunnage.

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;
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- New Brunswick Ministry of Transportation;
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- 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, Mike Wolkowicz, and Walter Mercer 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.

Dunnage is used to protect cargo by distributing the forces of a tiedown over a larger area of cargo than the area of the tiedown, or to protect the tiedown from abrasion by cargo with sharp or rough edges. The most common dunnage is wood blocking, due to its price, availability and adaptability to irregular surfaces. The dunnage is fabricated either to be sandwiched between cargo and the tiedown, or to conform to an irregular surface so that the tiedown can pass over it. Examples of use of dunnage are shown in Figure 1 for both an irregular shaped cargo that would normally have fragile protuberances such as electric panels, machine ways and irregular shaped, nested items such as pipes, steel bars, and pliable or malleable products. The issue that arises is how the dunnage, cargo and tiedown interact when there is high tension in the tiedown. The work was outlined in Section 9.5 of the project proposal [1].

2/ Test Program

2.1/ Objectives

The objectives of this test program were to examine the deformation and damage caused to dunnage by various tiedowns, and the effect of this on tiedown tension, for different tiedowns.

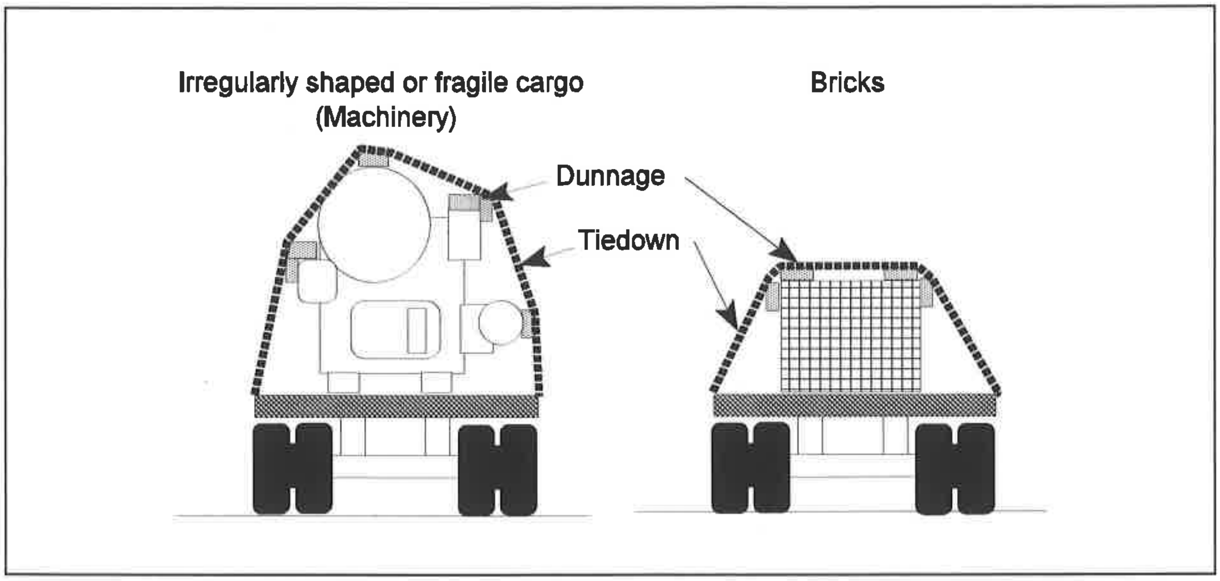

Figure 1/ Use of dunnage to secure cargo and protect cargo or tiedowns

2.2/ Scope

The test was conducted using two nominal 15x15 cm (6x6 in) square samples of dunnage, maple and pressure treated spruce, with a similar sized steel tubular section as a reference.

Each dunnage sample was tested with five tiedowns :

1/ 0.64 cm (1/4 in) steel chain;
2/ 0.95 cm (3/8 in) steel chain;
3/ 0.64 cm (1/4 in) wire rope;
4/ 1.27 cm (1/2 in) wire rope; and
5/ 5 cm (2 in) wide synthetic webbing.

The tiedown spanned the dunnage at three wrap angles, as shown in Figure 2 :

1/ 45 deg;
2/ 60 deg; and
3/ 90 deg.

Tension was applied to the tiedown to represent an increase in tiedown tension as might arise during tensioning a tiedown, or from shifting of the cargo. Any damage to the dunnage caused by the tiedown would cause a change in the shape of the dunnage that could affect the tension in the tiedown if the cargo returned to its original position, as shown in Figure 3.

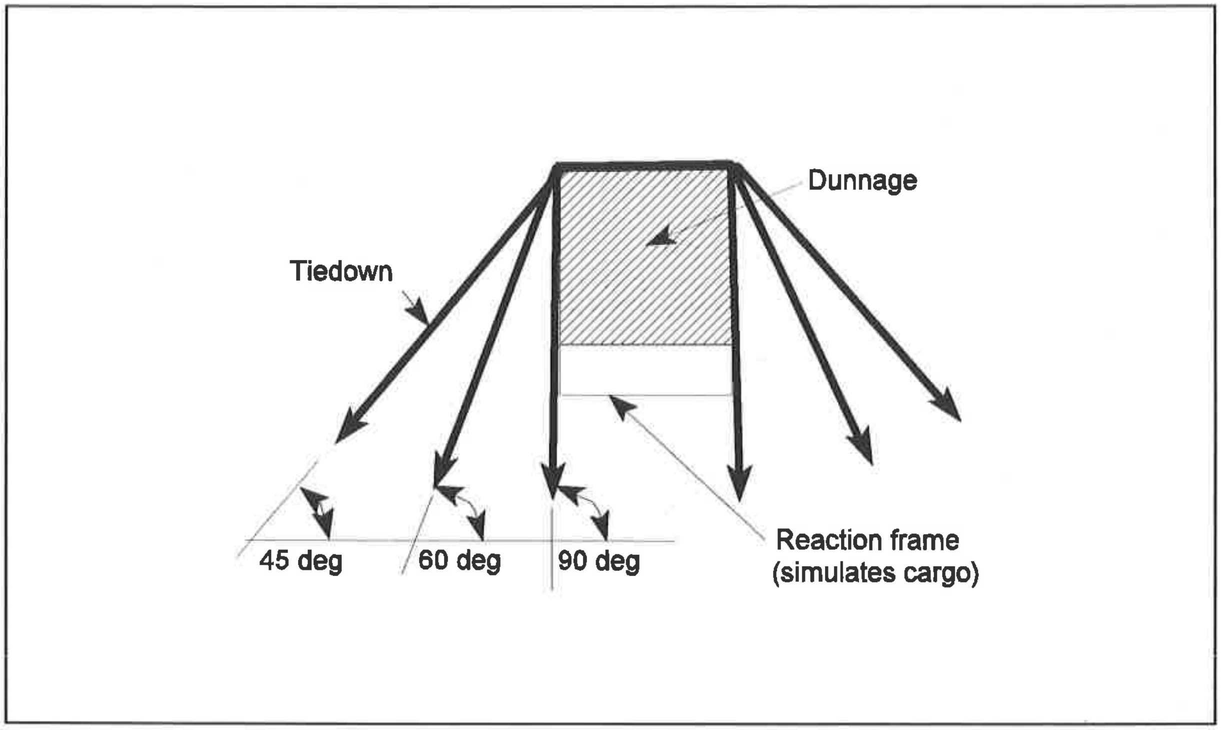

Figure 2/ Tiedown Wrap Angles

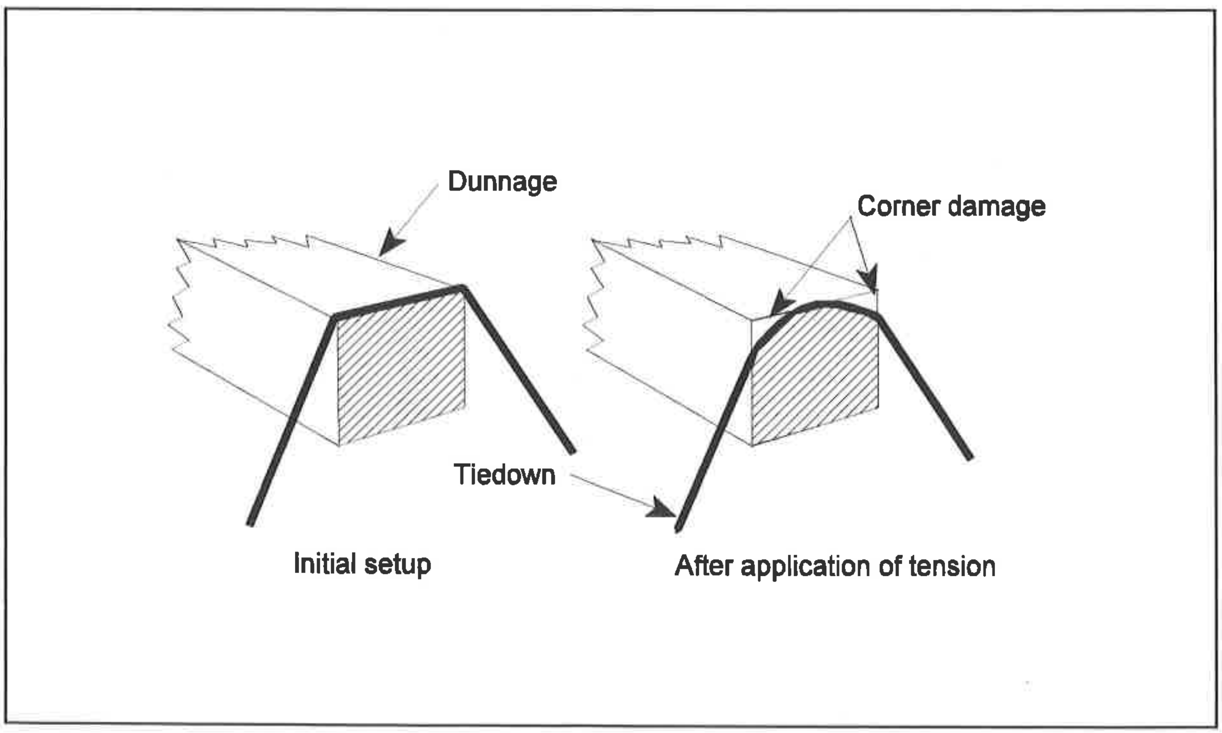

Figure 3/ Deformation of Dunnage Block by Tiedown

3/ Procedures

3.1/ Test Apparatus

The test was conducted using the reaction frame shown in Figures 4 and 5. The dunnage was mounted on the top of the frame so that a tiedown could pass over it. The base of the frame provided three mounting points which allow the tiedown to pass over the dunnage at different angles. A heavy duty manual industrial screwjack connected to an anchor point on the dunnage reaction frame was used to tension the tiedown. The screwjack applied displacement through a ratchet to a leadscrew, which, when reacted, produced a controlled tension in the tiedown. The screwjack was modified with a force transducer and displacement transducer, shown in Figure 6. The force transducer measured the tension applied to the tiedown by the screwjack, and the displacement transducer measured displacement of the jack clevis along the longitudinal centre-line axis of the screwjack. The screwjack was calibrated with force and displacement references. An second force transducer was connected between the other end of the tiedown and its anchor point.

The tiedowns used were :

1/ 0.64 cm (1/4 in) grade 8 steel chain with a working load limit (WLL) of 15.6 kN (3,500 lb);
2/ 0.95 cm (3/8 in) grade 8 steel chain with a WLL of 31.6 kN (7,100 lb);
3/ 0.64 cm (1/4 in) wire rope with a WLL of 4.5 kN (1,000 lb);
4/ 1.27 cm (1/2 in) wire rope with a WLL of 22.2 kN (5,000 lb), and
5/ 5 cm (2 in) wide synthetic webbing with a WLL of 14.8 kN (3,335 lb).

The dunnage samples tested, all nominally 15x15 cm (6x6 in) square, were :

1/ pressure treated construction grade spruce;
2/ mill sawn maple, cut to order; and
3/ structural steel composite section with affixed corner shrouds.

The test program measured the local deformation characteristics of dunnage by securing a rigid simulated cargo with a tiedown and dunnage, then progressively increasing tiedown tension. This simulated the cargo shifting, which would increase tiedown tension and tiedown pressure on the dunnage, and the tiedown would cut into the dunnage. The reduction in the length of the tiedown is a measure of how much it has cut into the dunnage. Characteristics of the dunnage could therefore be determined by measuring the displacement of the tiedown as the applied tension was increased.

Figure 4/ Dunnage Test Reaction Frame and Data Acquisition Equipment

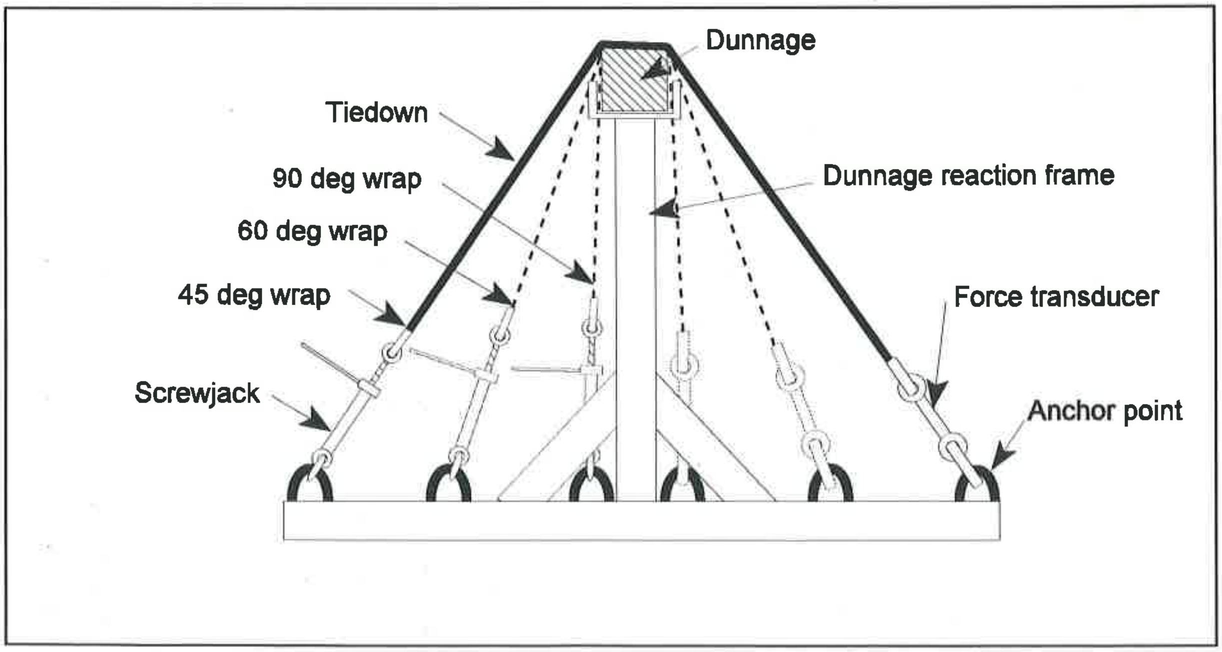

Figure 5/ Dunnage Reaction Frame Assembly

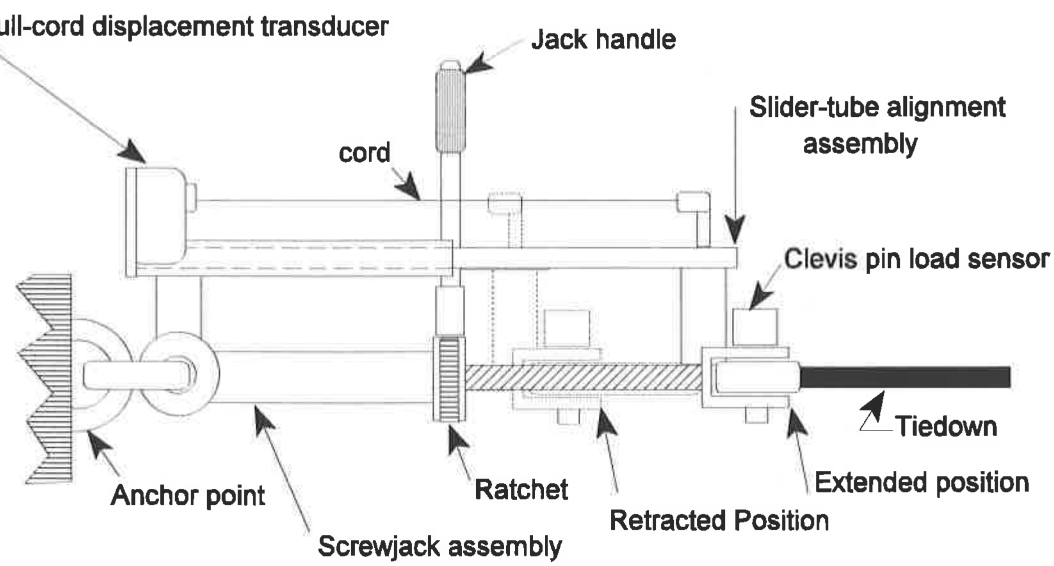

Figure 6/ Screwjack with Load and Displacement Transducers

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), joined the screwjack to the tiedown to measure tension in the tiedown. A Unimeasure model P510-2 pull cord transducer was attached to the fixed end of the screwjack, and its cord was attached to the moveable end and measured its translation. The tiedown passed over the dunnage in the frame and was attached to an anchor point on the other side through a Strainsert Model SJ-F8 Type H load sensing stud, rated at 66.75 kN (15,000 lb). The screwjack, tiedown and load sensing stud were connected with commercially available heavy duty connector hardware rated at least four times the working load limit of the tiedown.

Data from these instruments was captured into a PC-based data acquisition system using a sample rate which was adequate to define the applied force and displacements of the tiedown. Video and 35 mm cameras were used to record characteristics of the test.

3.3/ Test Procedures

The baseline steel dunnage sample was placed in the upper cradle of the dunnage reaction frame and shimmed and wedged to support it against the containment surfaces of the cradle. The screwjack was connected to the appropriate anchor point on the reaction frame base, and the tension transducer was connected to the corresponding anchor point other side of the frame. The tiedown was connected to the screwjack clevis connection, threaded over the dunnage sample and connected to the force transducer on the other side of the dunnage reaction frame.

The screwjack and force transducers were adjusted to zero force, the screwjack was cranked to apply a tension of about 13.4 kN (3,000 lb) in the tiedown, and the system was allowed to settle over several minutes, during which time the tension diminished. The tension was then increased to 13.4 kN (3,000 lb), allowed to stabilize, then gradually decreased to zero. The connectors and hardware were examined for damage and adjusted where necessary.

With the tension reduced so the tiedown was slack, the two force transducers were adjusted to zero output. The screwjack was then cranked to apply a load of 0.89 kN (200 lb). This load was chosen as being the test start point since it was low enough not to damage the dunnage sample under test, but was high enough to seat the mechanical hardware used with the tiedown and produce an initial tautness in the tiedown. At this point, the displacement transducer on the screwjack was set to zero.

The test loading commenced by cranking of the screwjack to increase the tension to about 2.22 kN (500 lb). As load was applied, minor deformation occurred in the dunnage sample, and the tiedown slipped over the dunnage which caused the tension to bleed off. The tension was gradually applied in stages until it stabilized at the target value. Displacement and tension data were collected at that point, any visual damage or significant occurrences were noted, photographed, and recorded. The screwjack was then cranked upwards in further increments of 2.22 kN (500 lb), and the procedure was repeated to bring the tension to the required stabilized value, up to 13.34 kN (3,000 lb). The tension was then decreased in an identical manner and data was collected back to 0.89 kN (200 lb) tension.

When the tension was completely reduced to zero, indicated by tiedown slackness, the force transducer readings were checked to determine if any drift or offsets were present. If there were signs of drift or offset, the magnitudes were evaluated, and if unacceptable, the test was repeated with a different dunnage surface under the tiedown. The data were examined and the test was repeated if irregular, inconsistent or questionable results were encountered.

The baseline steel dunnage sample was tested first, then followed by each of the wood dunnage samples. Care was taken in approach to each target tension, as wood damage became evident that greatly slowed the process of tension stabilization.

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 tension force and displacement were examined to determine the characteristics of responses. The baseline test data for identical wrap angle and tiedown were subtracted from the wood dunnage test data, and entered in a spreadsheet program, and were summarized in tables and graphical form for this report.

3.5/ Test Matrix

The scope identified three dunnage samples, five tiedown materials and three wrap angles. Table 1 presents the test matrix for each of the three dunnage samples.

Table 1/ Test matrix

Test Number	Tiedown device	Wrap angle (deg)		
		45	60	90
1(a)	0.64 cm (1/4 in) grade 8 chain	X		
1(b)	0.64 cm (1/4 in) grade 8 chain		X	
1(c)	0.64 cm (1/4 in) grade 8 chain			X
2(a)	0.95 cm (3/8 in) grade 8 chain	X		
2(b)	0.95 cm (3/8 in) grade 8 chain		X	
2(c)	0.95 cm (3/8 in) grade 8 chain			X
3(a)	0.64 cm (1/4 in) steel cable	X		
3(b)	0.64 cm (1/4 in) steel cable		X	
3(c)	0.64 cm (1/4 in) steel cable			X
4(a)	1.27 cm (1/2 in) steel cable	X		
4(b)	1.27 cm (1/2 in) steel cable		X	
4(c)	1.27 cm (1/2 in) steel cable			X
5(a)	5 cm (2 in) webbing	X		
5(b)	5 cm (2 in) webbing		X	
5(c)	5 cm (2 in) webbing			X

4/ Results and Observations

In all cases with chain and wire rope tiedowns, the wood dunnage was seen and heard to splinter at the corners under the tiedown with tensions between 2.22 kN (500 lb) and 4.45 kN (1,000 lb). With webbing, splintering was heard between 4.45 kN (1,000 lb) and 6.67 kN (1,500 lb). Evidence of indentation, splintering and compression of spruce dunnage can be seen in Figures 7, 8, and 9, for chain, wire rope and webbing tiedowns respectively. The damage was similar, but less severe, for the harder maple block.

When a tiedown is tensioned, it stretches so its length increases. However, when a tiedown is tensioned over dunnage, material directly under the tiedown is stressed and compresses, which reduces the length of the tiedown. Once tensioned, the tiedown often lost tension over a period of time, partly due to the properties of the tiedown, but also because the dunnage continued to deform plastically under the action of the applied load. The tension vs displacement characteristics of a tiedown during baseline and wood dunnage testing are as shown in Figure 10, as curves A and B respectively. The baseline test offered a steeper gradient with less hysteresis loss than the combined curve of wood dunnage and tiedown.

The total displacement of the end of the tiedown in the test on wood dunnage, curve B, represents the total elastic deformation of the tiedown plus the plastic and elastic deformation of the dunnage material. The characteristic of the tiedown over the rigid steel dunnage is represented by the baseline data, curve A. At any given reference load, the displacement due to dunnage is the total displacement from the dunnage less

Figure 7/ Chain Tiedown Indenting and Splintering Spruce

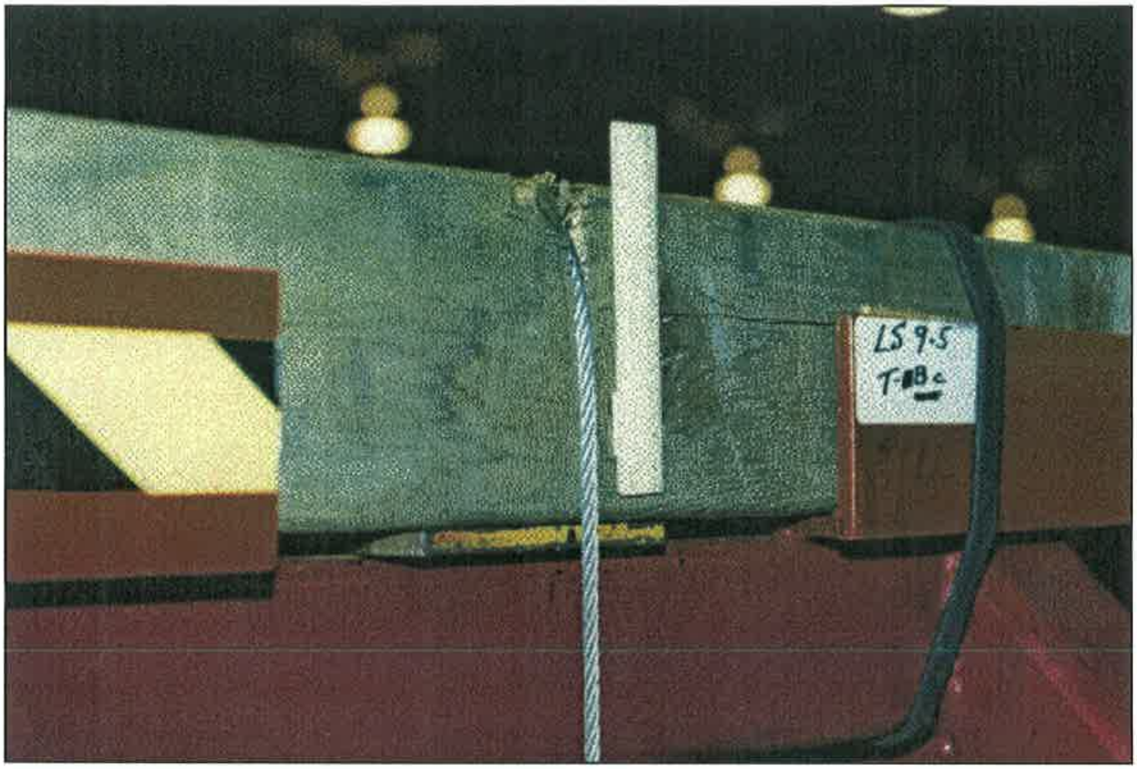

Figure 8/ Wire Rope Indenting and Splintering Spruce

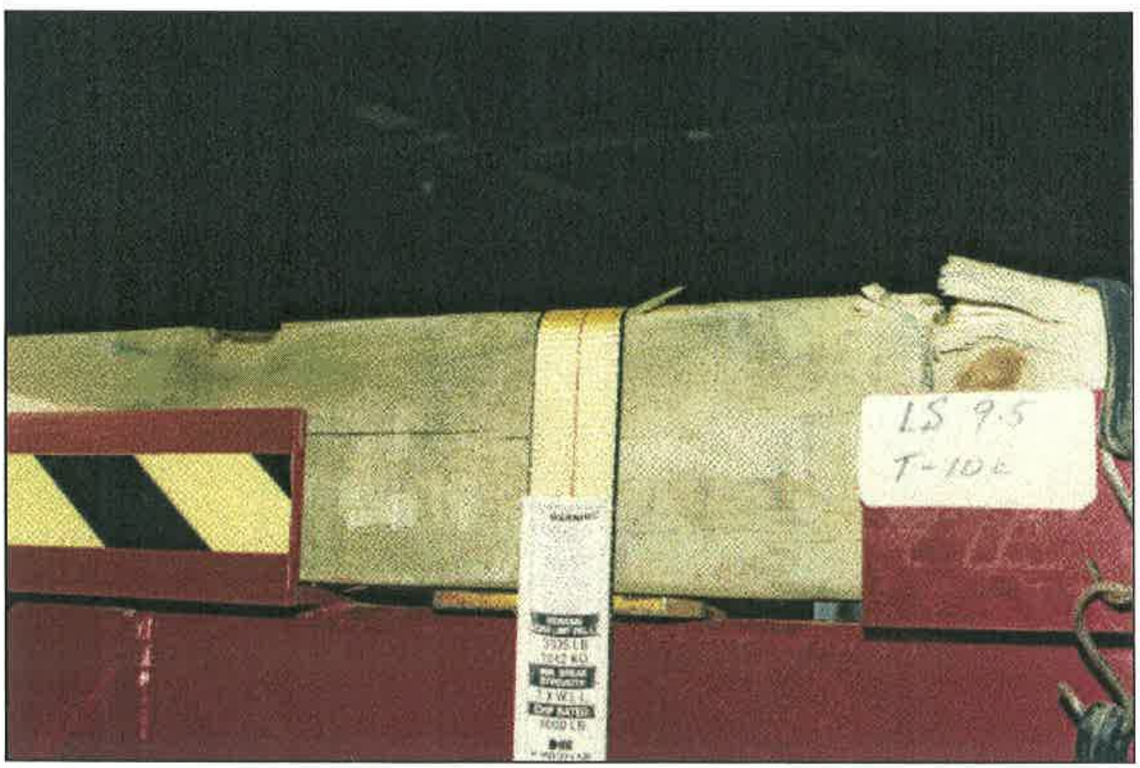

Figure 9/ Webbing Indenting Spruce

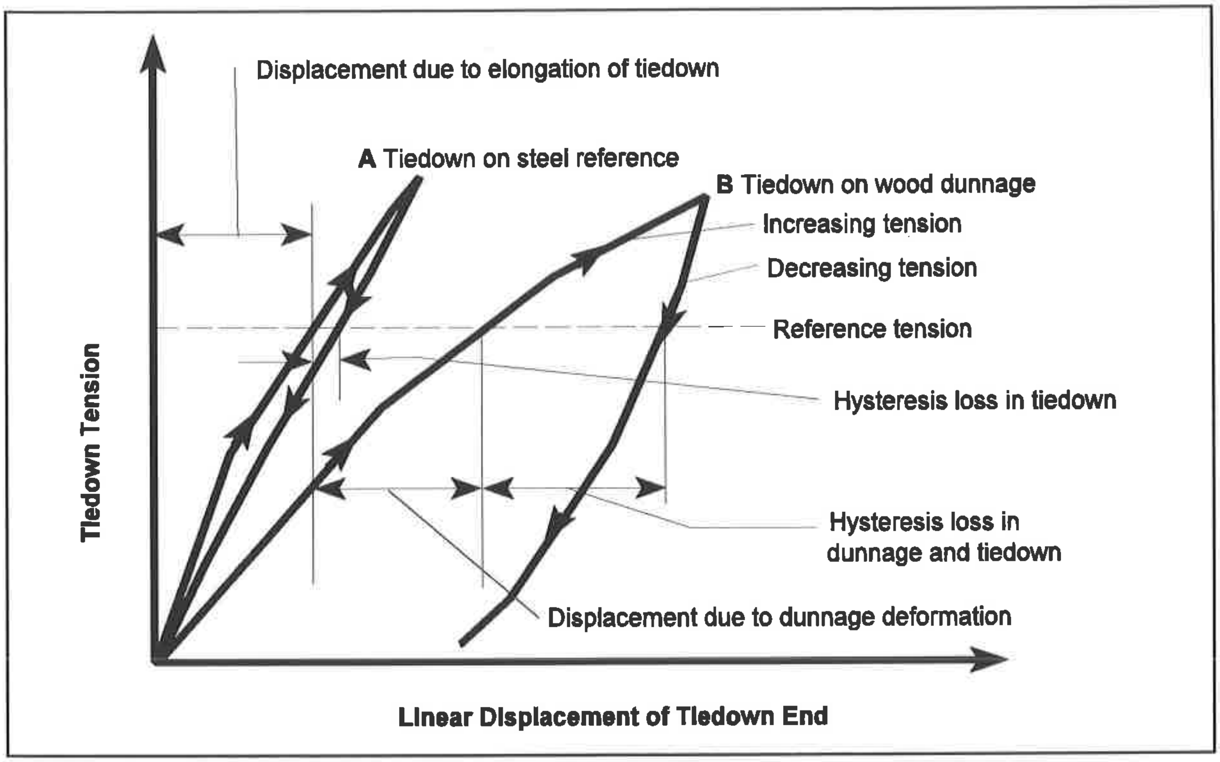

Figure 10/ Characteristic Tension vs Displacement of Screwjack for Baseline and Wood Dunnage Tests

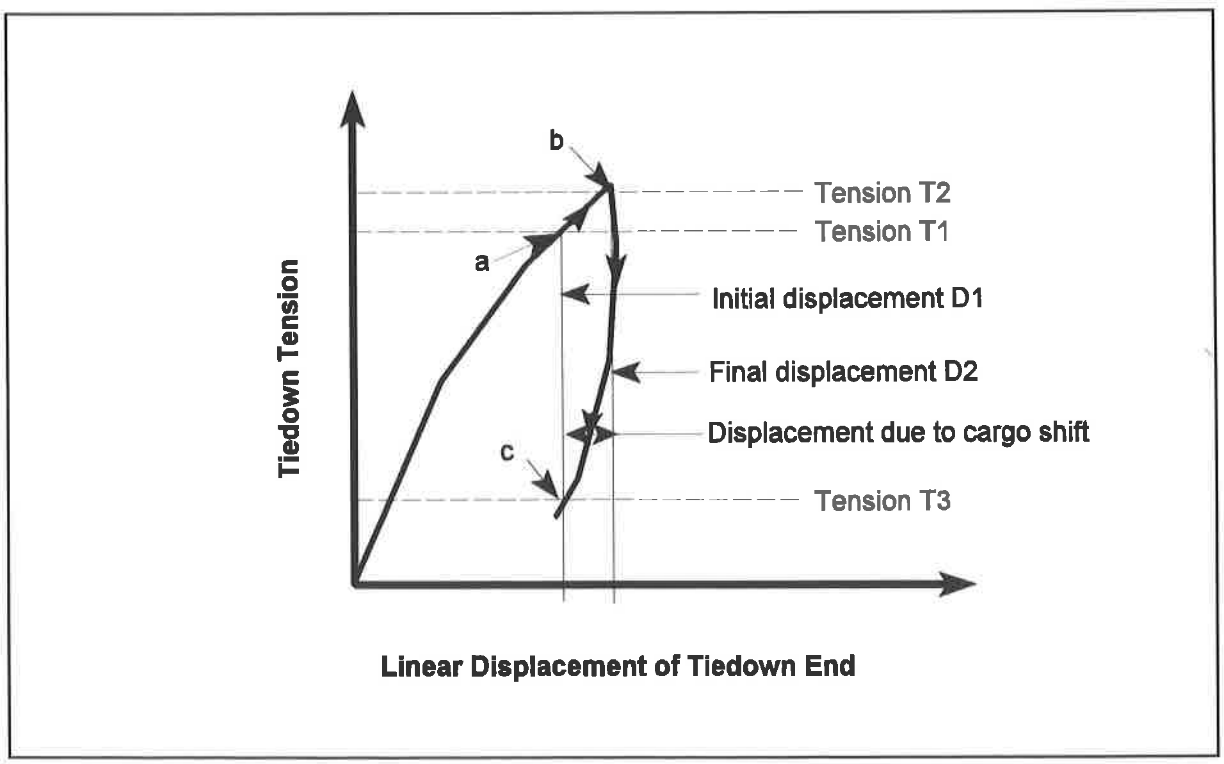

Figure 11/ Mechanism for Loss of Tiedown tension after Cargo Shift

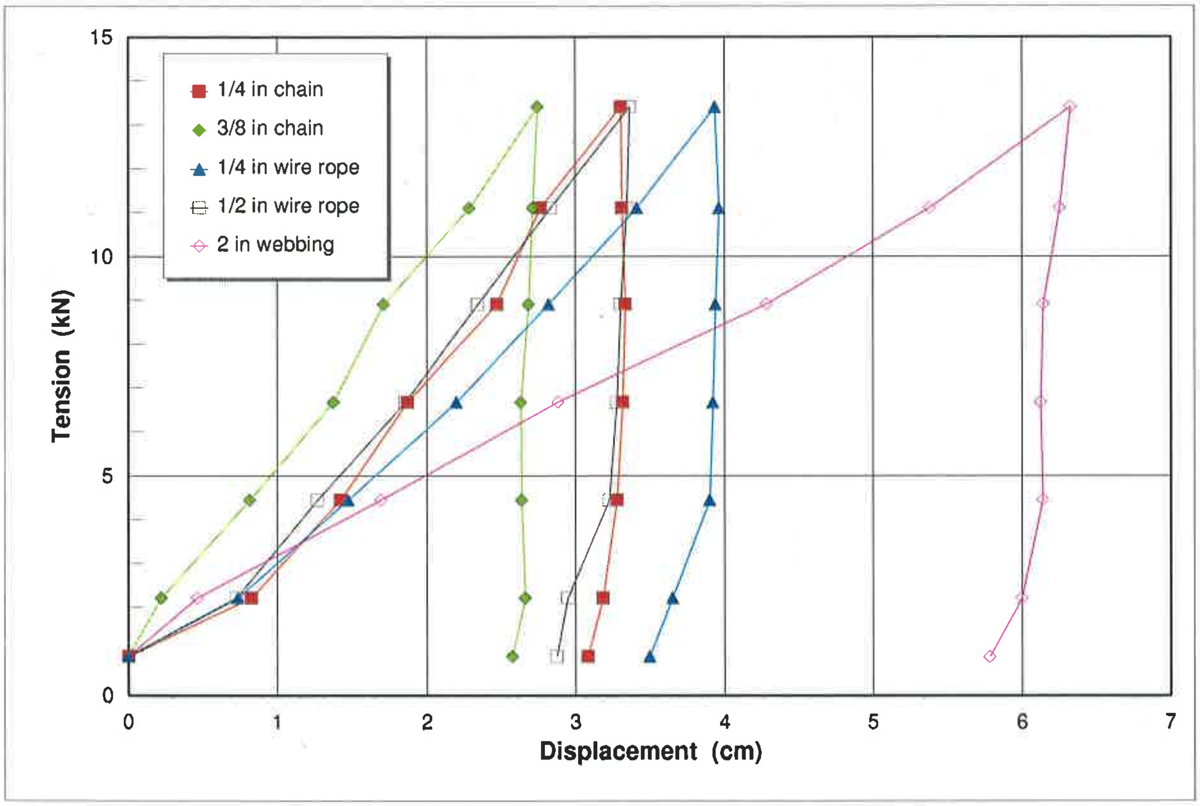

Figure 12/ Tension vs Displacement for Spruce Dunnage Wrapped at 90 deg

the displacement from the baseline test. When the baseline data for a given tiedown, wrap angle and tensions are subtracted from the wood dunnage data, the result is a curve which is the characteristic of the dunnage alone, as shown in Figure 11. This illustrates the magnitude and loss of tension as a result of permanent deformation of the dunnage. This curve also illustrates the effect of cargo movement on tiedown tension. If it is assumed that the cargo and dunnage are displaced on the truck deck so that the tiedown end displacement goes from D1 to D2, then the tension in the tiedown will go from T1 at point a to T2 at point b. If the cargo then shifts back to its original position, the tension comes down the curve to point c, resulting in a much lower tension, T3. This is the mechanism that causes loss of tension in a tiedown wrapped around wood dunnage. Such a characteristic may be expected to a lesser extent with cargo subject to vibration, where the tension may diminish more slowly over time. The tension loss is caused almost exclusively by the plastic deformations of splintering, indenting and notching of the dunnage, with little, if any, elastic recovery.

The force and displacement data corrected by subtraction of the baseline data are shown in Tables 2, 3, and 4 for 45 degree, 60 degree and 90 degree tiedown wrap angles respectively.

Tension vs displacement data, corrected to remove the baseline data, are shown for all tests on spruce in Figure 12.

Table 2/ Tiedown Displacement for 45 Degree Wrap (mm)
(Corrected for Tiedown Elasticity)

Tension		Maple					Spruce				
kN	lb	Chain		Wire Rope		Web	Chain		Wire Rope		Web
		1/4 in	3/8 in	1/2 in	1 in	2 in	1/4 in	3/8 in	1/2 in	1 in	2 in
0.89	200	0.01	-0.01	-0.00	-0.02	0.00	0.01	-0.00	0.01	-0.01	-0.00
2.22	500	1.32	2.35	0.01	-2.42	-1.38	4.08	0.23	-0.32	-1.82	4.24
4.45	1000	2.01	2.17	1.82	-1.38	6.43	4.08	1.32	2.04	2.19	16.81
6.67	1500	3.18	2.06	3.30	-0.98	12.44	5.96	3.09	5.52	4.44	27.65
8.90	2000	3.64	2.38	6.04	0.53	14.12	9.14	4.60	8.20	6.73	33.11
11.10	2500	4.75	3.65	7.22	0.38	19.72	10.57	5.82	12.51	7.63	44.10
13.40	3000	4.75	4.61	7.59	1.29	21.32	11.81	7.50	13.59	10.59	44.45
11.10	2500	5.00	4.50	7.70	0.87	20.51	11.77	7.20	13.64	10.00	44.04
8.90	2000	4.66	4.27	7.88	0.45	19.63	11.83	7.15	13.87	9.30	43.06
6.67	1500	4.37	3.88	7.26	0.26	15.08	11.60	7.20	13.59	8.59	41.83
4.45	1000	3.96	3.92	5.35	-0.21	15.50	11.15	7.71	11.67	8.26	42.64
2.22	500	3.27	5.15	3.83	-0.16	20.16	9.36	7.38	9.57	9.68	39.74
0.89	200	3.41	0.00	6.07	-0.52	19.28	8.66	6.31	10.23	8.34	39.04

Table 3/ Tiedown Displacement for 60 Degree Wrap (mm)
(Corrected for Tiedown Elasticity)

Tension		Maple					Spruce				
kN	lb	Chain		Wire Rope		Web	Chain		Wire Rope		Web
		1/4 in	3/8 in	1/2 in	1 in	2 in	1/4 in	3/8 in	1/2 in	1 in	2 in
0.89	200	-0.01	-0.02	0.00	-0.00	-0.01	-0.01	-0.01	-0.00	-0.01	-0.01
2.22	500	1.42	0.22	1.18	5.69	-0.85	3.52	3.61	3.18	2.19	5.67
4.45	1000	3.00	1.76	3.69	8.22	-1.72	6.32	9.39	6.88	5.49	16.23
6.67	1500	4.77	3.82	6.85	11.17	7.28	8.55	12.15	10.93	9.46	20.23
8.90	2000	7.59	5.09	8.65	12.80	14.19	12.73	14.65	16.86	12.80	26.90
11.10	2500	9.85	5.59	11.61	15.05	20.14	14.69	17.97	19.11	16.78	30.12
13.40	3000	12.21	5.50	11.90	16.25	26.24	17.55	19.36	23.96	20.19	34.18
11.10	2500	11.97	5.49	12.18	15.94	26.37	17.14	19.24	24.04	19.89	34.39
8.90	2000	11.90	5.40	12.37	15.81	25.62	16.79	19.08	24.03	19.89	33.85
6.67	1500	11.88	5.57	11.59	15.61	22.62	16.31	18.89	23.26	19.83	31.45
4.45	1000	11.79	5.40	10.56	15.22	22.93	15.95	18.32	21.57	19.05	33.25
2.22	500	11.44	5.22	8.89	13.75	19.27	15.55	17.49	20.11	17.45	31.37
0.89	200	9.52	4.53	8.77	14.07	20.29	13.59	16.12	18.70	17.87	31.24

Table 4/ Tiedown Displacement for 90 Degree Wrap (mm) (Corrected for Tiedown Elasticity)

Tension		Maple					Spruce				
kN	lb	Chain		Wire Rope		Web	Chain		Wire Rope		Web
		1/4 in	3/8 in	1/2 in	1 in	2 in	1/4 in	3/8 in	1/2 in	1 in	2 in
0.89	200	0.01	-0.01	-0.00	-0.02	-0.01	0.02	-0.00	0.00	-0.00	-0.00
2.22	500	1.43	2.43	6.41	5.63	5.69	8.25	2.21	7.34	7.26	4.65
4.45	1000	5.67	3.37	8.85	8.18	17.07	14.23	8.15	14.72	12.70	16.95
6.67	1500	8.06	3.49	12.50	10.77	23.96	18.72	13.76	21.99	18.56	28.83
8.90	2000	10.55	4.69	14.35	12.91	32.15	24.73	17.13	28.20	23.42	42.81
11.10	2500	13.13	7.36	17.34	14.95	31.61	27.65	22.86	34.13	28.33	53.79
13.40	3000	15.04	8.79	20.02	17.72	37.59	33.08	27.46	39.35	33.68	63.25
11.10	2500	14.83	8.77	19.97	17.41	37.55	33.13	27.15	39.63	33.46	62.54
8.90	2000	14.77	8.86	19.70	16.88	36.90	33.34	26.87	39.39	33.05	61.43
6.67	1500	14.70	8.66	19.64	16.23	36.32	33.18	26.34	39.22	32.78	61.24
4.45	1000	14.83	9.41	19.22	15.69	35.14	32.78	26.39	39.02	32.27	61.41
2.22	500	15.13	9.47	17.67	15.04	34.70	31.85	26.62	36.54	29.49	59.98
0.89	200	14.21	8.78	16.85	12.75	33.29	30.81	25.76	34.97	28.75	57.79

5/ Analysis and Discussion

5.1/ General

When dunnage is stressed by a tiedown, the contact is rarely pure compression. In practice, the tiedown slips over the dunnage as it is tightened, either wen the cargo is being secured, or if the cargo shifts. This abrades the dunnage and increases the pressure applied by the tiedown. This test represented these conditions, as one end of the tiedown was secured and the other end was displaced. This caused the tiedown to slide over the dunnage, causing abrasion, as pressure was simultaneously applied. The mechanism of the test pull is shown in Figure 13.

This method has the disadvantage that to produce abrasion, relative motion must exist between the tiedown and dunnage. This motion, accompanied by corner friction, tends to introduce differences in tension between the displaced side and the opposite side. The difference in tension across the dunnage, though recorded, is not presented here. Loss of tiedown tension across a corner, and the effect corner protection may have on cargo securement, are covered in other reports in this series [2, 3, 4]. Tension ratios for the same angle and tiedown material were similar for the different dunnage samples and baseline dunnage and therefore data was compatible for analysis purposes.

The plane and magnitude of tiedown displacement is not identical to that arising from cargo shifting along the deck of a truck. It serves here as a mechanism to increase tension and thereby cause deformation in the dunnage. In an actual situation, cargo shift causes a change in the spanned perimeter of the cargo and thereby increases tension. Displacement was used in this analysis as a method to increase tension so that comparisons at differing displacements can be made.

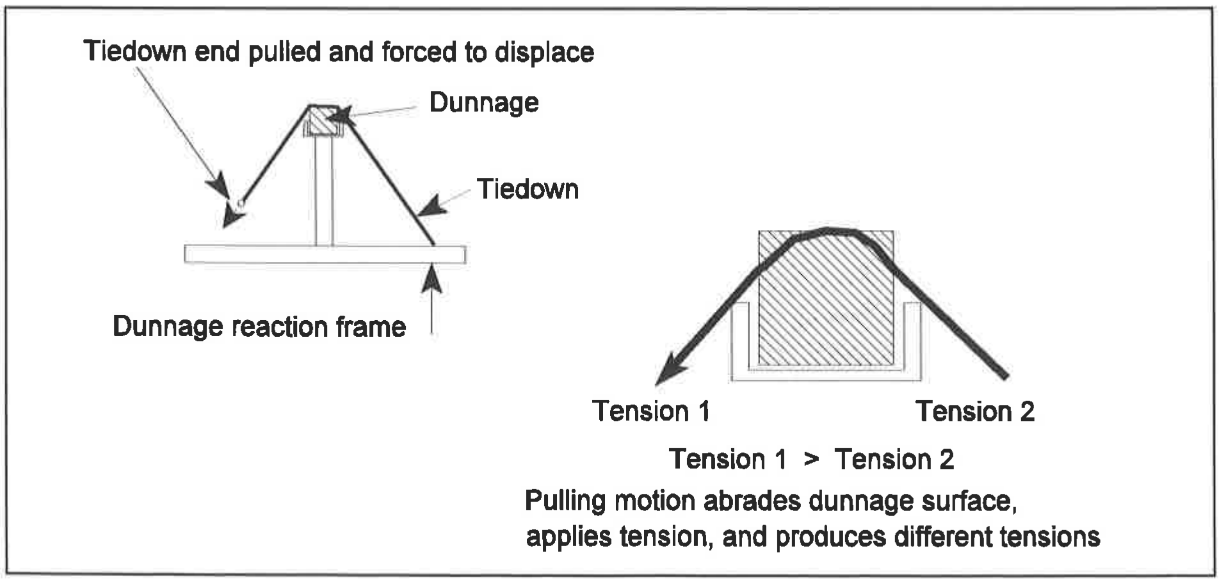

Figure 13/ Mechanism for Abrasion of Dunnage

5.2/ Effect of Tiedown Type

Each tiedown has its own cross section that interacts with the corner of the dunnage when the tiedown is under tension. The 0.64 cm (1/4 in) chain, because of its small link diameter, imposed higher point loads on the surface and corners of the dunnage and indented further than the larger 0.95 cm (3/8 in) chain, as seen from Figure 14.

A similar relationship is also seen for wire rope in Figure 14. The horizontal distance between the two chain curves and the two wire rope curves represent the span between 0.64 cm and 0.95 cm (1/4 and 3/8 in) chain and, 0.64 cm and 1.27 cm (1/4 and 1/2 in) wire rope. The wire rope had the largest overall displacement because it had uniform contact along its length with the dunnage. It tended to cut rather than crush the dunnage corners, whereas each link of chain contacted the dunnage in a different way, leading to several areas of high indentation, cracking and splintering.

Webbing appeared to have the shallowest slope, indicating larger displacements and a lesser tension increase per unit of displacement. This would have the effect of a lower increase in tension as the load shifted, reducing corner damage. The chain tended to hold the dunnage in a more restrictive manner than the other tiedowns, but because of its high point loading, caused significant local damage like splintering, splitting and cracking to the corners. An example of chain corner damage is shown in Figure 15.

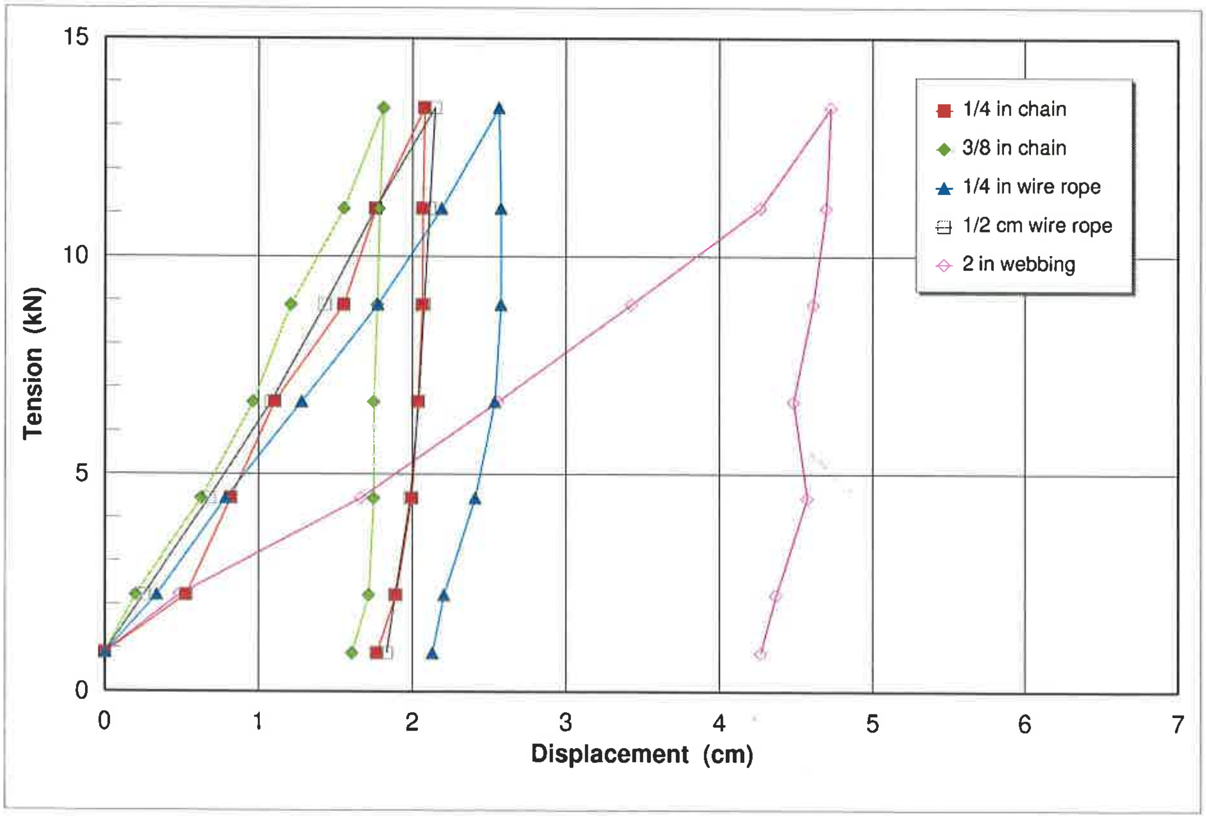

Figure 14/ Tension vs Displacement for Spruce Dunnage, All Wrap Angles Averaged

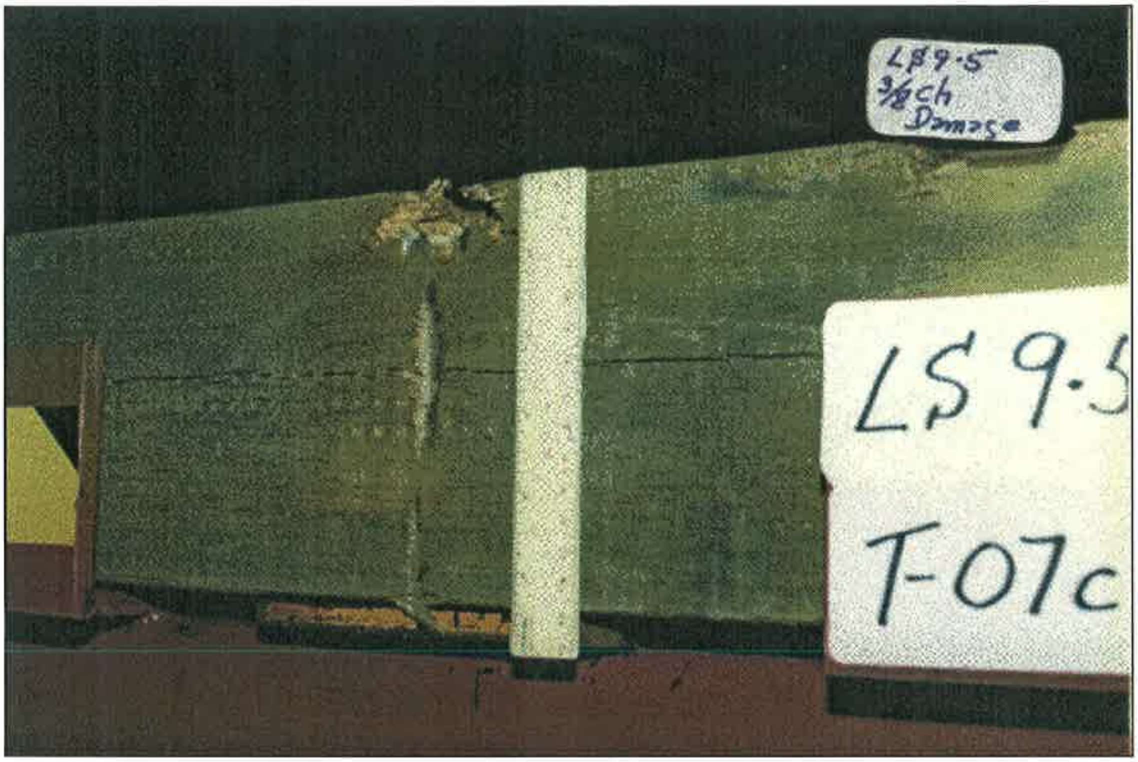

Figure 15/ Damage to Spruce by Chain Tiedown

Figure 16/ Damage to Spruce by Wire Rope Tiedown

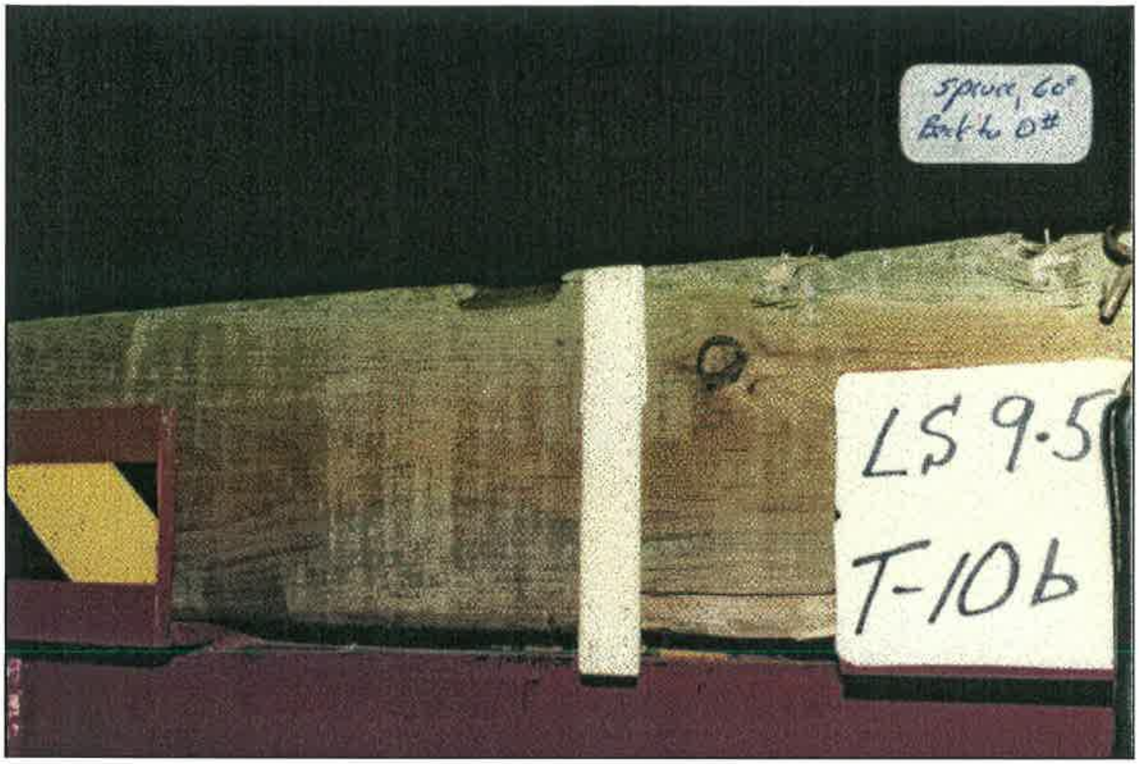

Figure 17/ Damage to Spruce by Webbing Tiedown

The wire rope tended to cut into the corners in a more controlled manner, usually damaging the wood only under the tiedown, as shown in Figure 16. Webbing compressed the surface, usually without much cracking and splitting, and left a smooth surface when it was removed, as shown in Figure 17.

All tiedowns suffered almost total loss of tension when the displacement was relieved by less than 1 cm (0.4 in).

5.3/ Effect of Wrap Angle

When a tiedown is wrapped over a dunnage block and tensioned, the force imposed on the corner is the resultant of the force vectors of the tensions in the spans of tiedown on each side of the corner. The magnitude and direction of the resultant force vector reacts on the dunnage corner to produce deformation of the dunnage. This, as represented by tiedown end displacement, is shown in Figure 18 for all tiedowns at 45, 60 and 90 deg wrap angles. The maximum average displacement from Figure 18 is the maximum average displacement reaction for maple and spruce dunnage samples. As expected, the lowest displacements arose for a tiedown wrap angle of 45 deg, and the highest for 90 deg.

5.4/ Effect of Dunnage Material

Harder dunnage resisted indentation, splitting and notching that leads to destructive deformation under the tiedown. The softer dunnage allowed the tiedown to cut and indent the surface causing splitting and splintering. The displacement data for the two dunnage woods tested are compared in Figure 19. Spruce allowed about twice the displacement of maple.

The surface damage of the maple contained less splitting than did the spruce and the indentations caused by chain, wire rope and webbing were clearly defined areas with very little exposed areas of grain fracture. The indentations with maple were more "denting" rather than "breaking".

When the maximum tiedown tension was achieved, and the tiedown was reduced, the dunnage showed very little stored energy. Stored energy manifests itself in dunnage recovering by allowing a "springing back" reaction. Figure 20 shows the recovery curves for both wood dunnage samples tested. The steepness of the curves and little, if any motion toward the left as the tension diminished indicates that a permanent set had "taken" in the wood and there is little or no resilience left. Both samples showed similar loss of resilience, for all tiedowns and wrap angles.

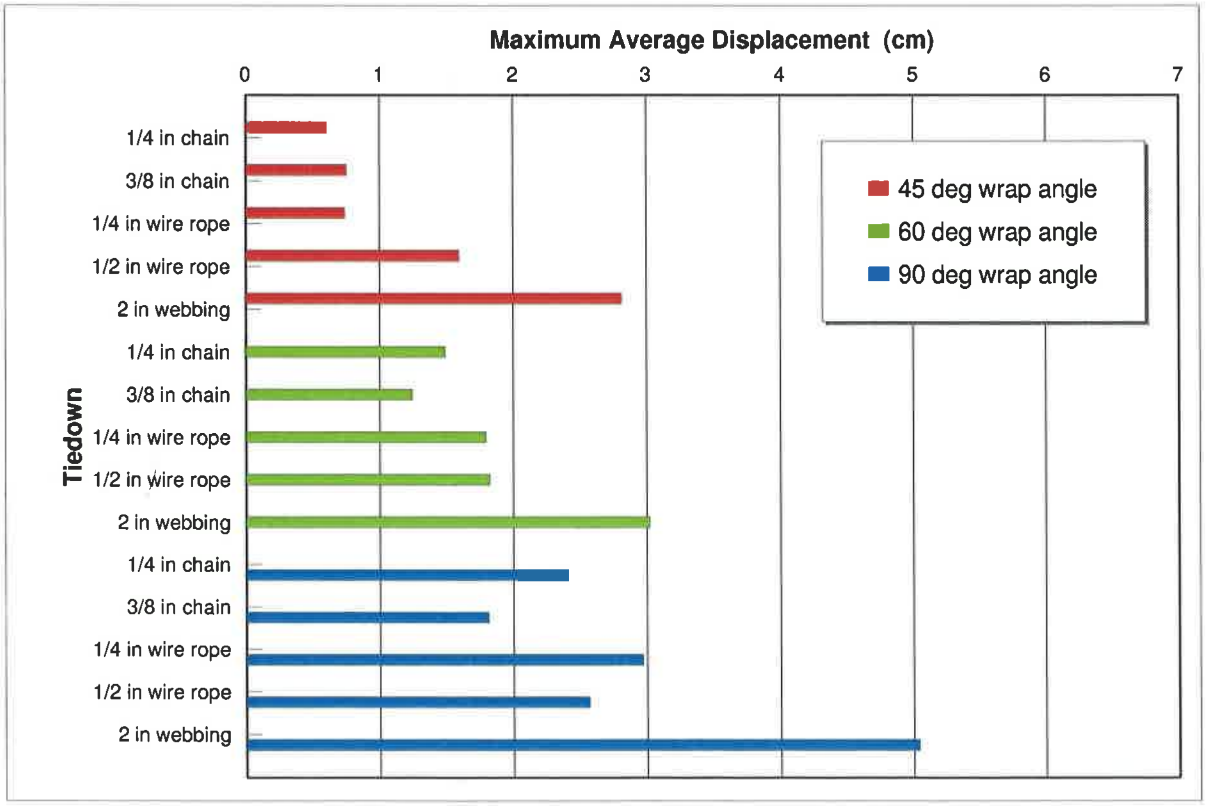

Figure 18 / Maximum Average Displacement, 45, 60 and 90 Degrees

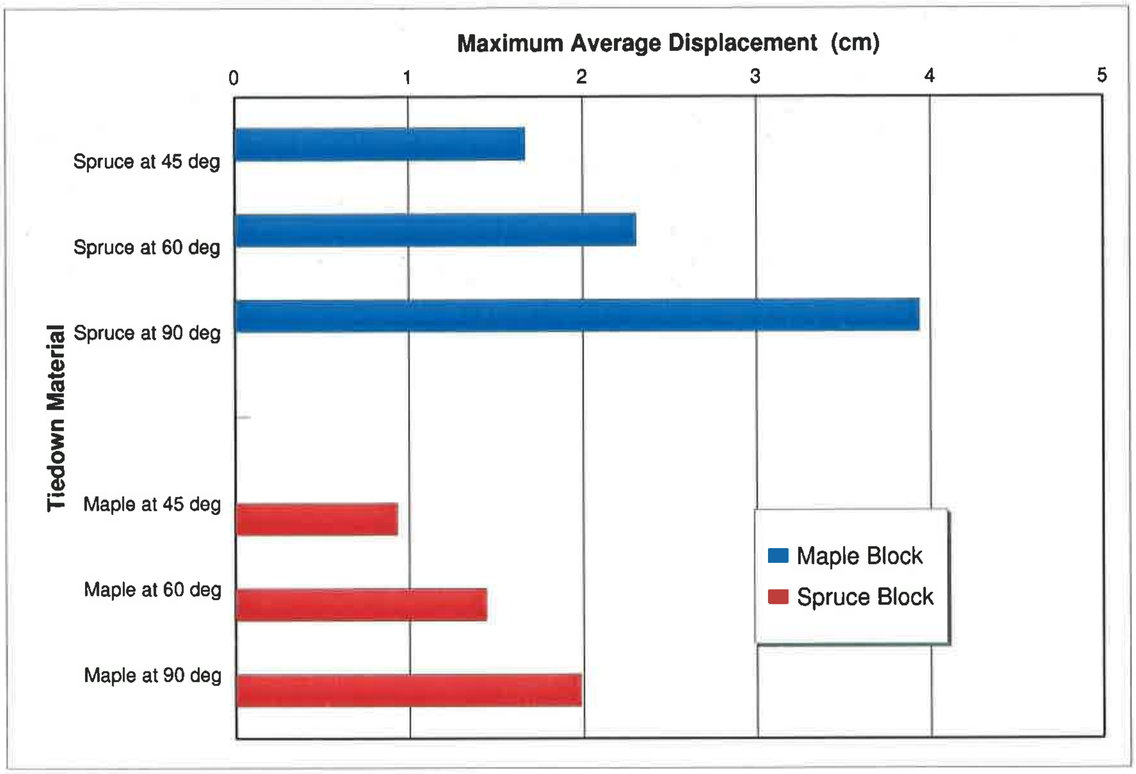

Figure 19 / Maximum Average Displacement of Maple and Spruce Dunnage Blocks

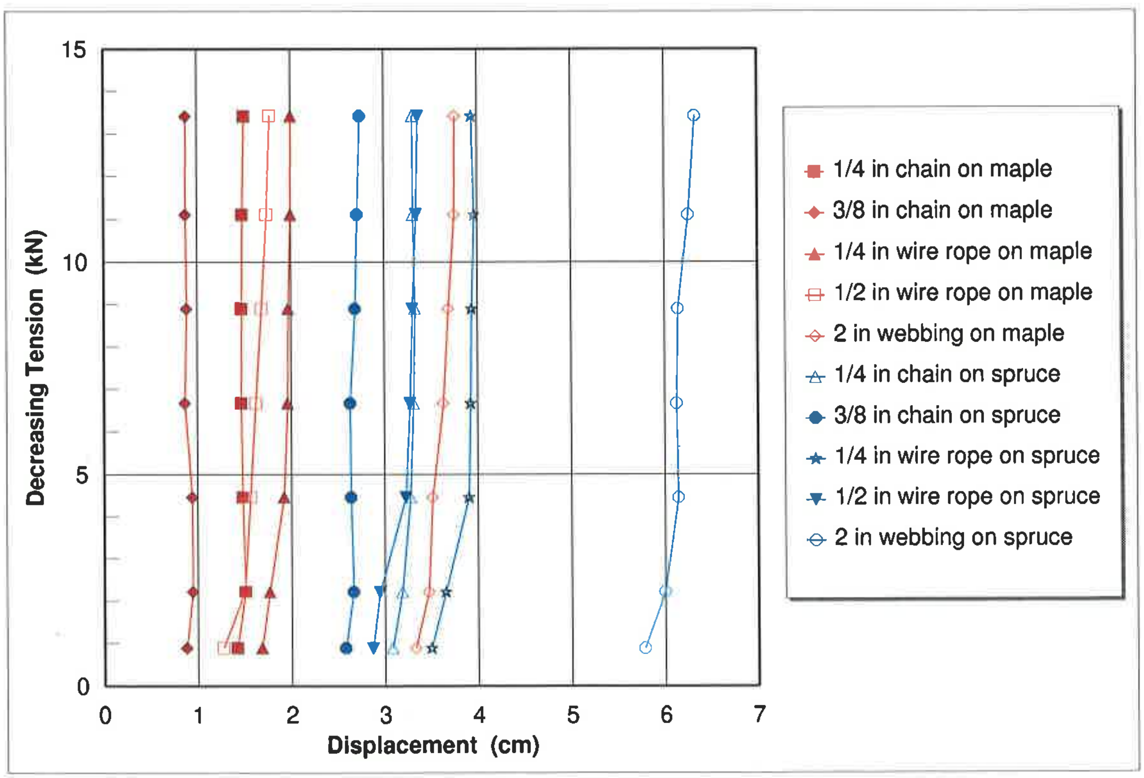

Figure 20/ Elastic Recovery Curves for Tiedowns on Maple and Spruce Dunnage

6/ Conclusions

A series of tests were conducted to examine effect of tiedown tension on wood blocks used as dunnage. These serve to distribute the force of tiedowns over a larger area of cargo than the tiedown, and to protect the tiedown from a rough or sharp edge on the cargo. The wood dunnage deformed plastically under the tiedown and was permanently damaged. The tiedown with the smaller cross-section in a group indented further into the dunnage than that with the larger cross-section. Chain indented less than wire rope of the same diameter. Webbing deformed the dunnage to produce the largest displacement. Chain tended to cause splitting and gross surface damage. Wire rope tended to slice into the wood dunnage, usually with only local damage. Webbing tended to compress the corner uniformly without causing any splitting. Tiedowns wrapping dunnage at shallow angles imparted less crushing load on the corner than when wrapped at larger angles.

The harder maple dunnage material resisted indentation, splitting and surface abrasion better than the softer spruce. The maple allowed lower displacement of the tiedown at for a given tension and wrap angle. Both dunnage samples offered virtually no elastic recovery when the loads were removed.

Corner deformation of the wood dunnage resulted in an increased effective radius of the corner that increased continuously with tiedown tension during an increase in tension. When the tension was allowed to decrease, it did so abruptly. This mechanism is the cause of tiedowns becoming slack with minor load shifting and road vibration when dunnage is used.

Dunnage may primarily be intended to protect the cargo or tiedowns from each other. However, there is clearly an interaction between cargo, dunnage and tiedowns, and a consequence of this could, in some circumstances, result in the tiedowns becoming 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 [5].

7/ Recommendations

1/ Dunnage should be at least as hard as the tiedown, so it is not damaged by it.

2/ If the cargo must also be protected, the dunnage should be fashioned with a softer and elastic inner surface to contact the cargo, but this should not be so soft that it can compress under load and also leave the tiedowns loose.

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