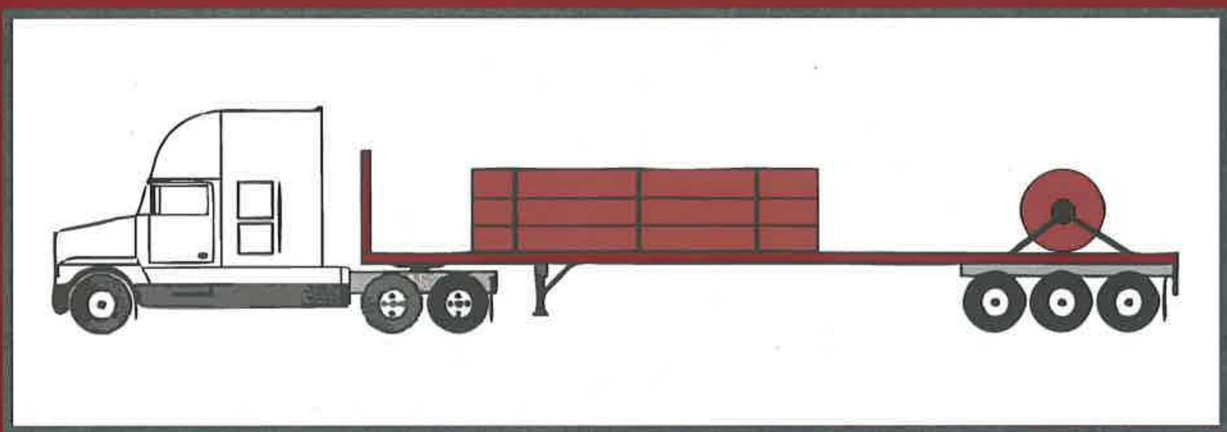
CCMTA Load Security Research Project

Report # 4

DRESSED LUMBER TIEDOWN TESTS



CCMTA • CCATM

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

CCMTA Load Security Research Project

Report # 4

DRESSED LUMBER TIEDOWN TESTS

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.

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EXECUTIVE SUMMARY

In 1993, the Canadian Council of Motor Transport Administrators formed a load security research management committee to address the lack of a sound technical basis for the existing rules. Based on an extensive consultation, the Ontario Ministry of Transportation prepared a report on the types of testing that would be required to fill in this knowledge gap. The results would then be used as the basis for a new national standard on load security.

The extensive body of research necessary to meet the committee's objectives was divided up among various research agencies. The Forest Engineering Research Institute of Canada (FERIC) was contracted by the Ministère des Transports du Québec to perform the portion of the tests that related to the security of dressed lumber. Nisymco Inc. was subcontracted by FERIC to assist in the research.

Three main forms of testing were performed to provide the necessary technical data for the proposed standard: load security was observed under static roll conditions, under static pitch conditions and under dynamic conditions. In each test, three levels of tiedown tension were used to determine their effect on slippage of the load, with loads arranged in several common configurations; in addition, load security was assessed under two sets of load-deck conditions: on wood and on Teflon® (which simulated a low-friction condition such as would occur with an icy deck). The angles at which load slippage occurred under static conditions were converted into acceleration values (g-forces) that served as the basis for calibrating subsequent dynamic testing.

The report presents the results of the testing in the following forms:

1. Tables of slippage angles or measured acceleration (g-forces) for various combinations of tiedown tension, number of tiedowns, load deck surface and load configuration.

2. Sample graphs of the data recorded by instrumentation during the tests.

Conclusions are drawn on the results of the tests that will help the task force to develop a technically sound standard on load security for dressed lumber.

ACKNOWLEDGMENTS

The work described in the present report is part of the Load Security Research Project of the Canadian Council of Motor Transport Administrators (CCMTA). Work was directed by the Ministère des Transports du Québec on behalf of CCMTA's Load Security Research Management Committee, chaired by Mr. M. Schmidt of the U.S. Federal Highway Administration (Albany, New York). The project was funded jointly by the following agencies:

- Alberta Transportation and Utilities;
- 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;
- Ontario Ministry of Transportation;
- Prince Edward Island Department of Transportation;
- Saskatchewan Government Insurance;
- Saskatchewan Highways and Transportation;
- 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.

Many individuals contributed to the project, including: Brian Allan, John Nicks and Jon Preston-Thomas of NRC; Patrick Bourdages, Phil Lachance, Doug MacGregor and Jan Michaelsen of FERIC; René Desaulniers of Societé de l'Assurance Automobile du Québec; Guy Desrosiers and Clair Basil of MTQ; and Mike Wolcowicz of MTO. The authors would like to recognize the direct contribution of the aforementioned to this work, but many others contributed indirectly.

The dressed lumber used in the tests was provided by Gestofor Inc., load cells were provided by the Ontario Ministry of Transportation, and Daishowa Forest Products Ltd. provided the use of their pitch table during the testing.

1. Background

In 1993, a task force on load security sponsored by the Canadian Council of Motor Transport Administrators (CCMTA) identified a lack of understanding of the technical basis for the existing rules for load security on heavy vehicles. The discrepancies were serious enough that it was not possible to develop an uncontested Canadian standard on load security. One of the recommendations of the task force was to perform the technical research necessary to develop consistent rules that would form the basis for a new standard on load security.

It was recognized that this research must cover different equipment and the load-securing methods actually used to secure loads. The Ontario Ministry of Transportation (MTO) prepared a proposal for this research, and after a broad series of consultations, the revised proposal became the technical work statement for the CCMTA Load Security Research Project.

The work reported in the present report is outlined in Section 11 (dressed lumber test series) of the project proposal (Billing et al. 1993). The research focused on a series of tests using the most common load patterns and tiedown method for dressed lumber. Two forms of static test (roll and pitch) and one series of dynamic tests were conducted. **The tiedown method, referred to in the general rules for load security under the North American regulations, uses overwrap webbing tiedowns disposed properly in relation to the length and weight of the load to be secured.** To completely evaluate this tiedown method, it was proposed that three different tiedown tensions (low, medium and high) and two different load bearing surfaces (wood and Teflon®) be used. Various tiedown configurations were also investigated. The reader is cautioned that the results relate only to the test configurations as studied and do not necessarily apply to other possible combinations of load, tiedown and deck surface (e.g., steel, aluminum).

The Ministère des Transports du Québec (MTQ) assumed responsibility for this investigation through the Load Security Research Management Committee, and issued a contract to the Forest Engineering Research Institute of Canada (FERIC) to carry out the testing. FERIC, a nonprofit research institute funded by the Canadian forest industry and the Canadian federal and provincial governments, was chosen because of its expertise in wood transportation research. Nisymco Inc. acted as the project manager, and the National Research Council of Canada (NRC) in Ottawa provided technical support throughout the project.

Appendix 2 lists the cases to be tested (107) under this contract, which comprise Chapter 11 of the revised MTO report (Billings et al. 1993). These conditions were modified as testing progressed, using the test results to reduce or expand the number of cases, as appropriate. In all, 127 cases were tested.

The present report provides detailed technical results based on the cases proposed in the MTO report. These results represent only one of the many areas that CCMTA proposed for investigation. The results of the testing program will be presented for interpretation by a separate group formed by the Management Committee that is responsible for revising the national standard on load security for heavy trucks. The committee hopes that this will eventually lead to the development of general regulatory principles for a North American standard on load security.

2. Objectives

The purpose of this project was to determine the conditions necessary to secure a load of dressed lumber under various combinations of load configuration and tiedown tension, using both static and dynamic testing. Another objective was to study the behavior of the tiedowns themselves (i.e., tension variations). The tests were designed to measure the angles and hence the accelerations on the cargo (called "g-forces" henceforth because they are expressed in terms of the acceleration due to gravity, "g") at which slippage of lumber occurs. The angles at which slippage occurs were chosen as the parameter to be measured because they provide a good indication of load security on hills, on banked curves and during braking; in the static tests, g-forces were calculated from the measured slippage angles so as to permit direct comparisons with the g-forces measured during the dynamic tests. The g-loads that led to slipping of the loads were collected from a series of three tests:

1. Load stability on a lateral (roll) table (conducted at NRC's facility in Ottawa, Ontario)
2. Load stability on a longitudinal (pitch) table (conducted at Daishowa Forest Products Limited's facilities in Quebec City)
3. Load dynamic stability on a speed track (conducted at Transport Canada's Motor Vehicle Test Centre in Blainville, Quebec)

3. Methodology

3a. Trailer and Load Configurations

The test bed for the study was FERIC's flatbed semi-trailer, a 14.6-m trailer with a standard three-axle configuration equipped with an air suspension. The semi-trailer's deck was made of laminated fiberboard (Transdeck®) coated with a phenolic resin to resist wear.

Bundles of lumber were loaded on the semi-trailer in various configurations with various tiedown patterns (Table 1). The lumber itself was 2-in. by 6-in. planks in lengths of 8 or 16 ft, and was assembled into 3-ft-wide by 38-in.-tall bundles using steel straps. Weights averaged 995 lb for 8-ft bundles and 1990 lb for 16-ft bundles. Wooden skids (4 × 4 in., 8 ft long) supported the bundles in all cases. Two skids supported the 8-ft bundles, and three skids supported the 16-ft bundles.

In the tests to simulate the effect of ice (i.e., low friction), strips of Teflon® were cut, machined and then screwed to the wooden skids (Figure 1). This provided the necessary low-friction surface for the tests. For load configurations with a single layer of bundles, Teflon® strips were placed only on the top surface of each skid. Where load configurations used two or more layers of bundles, the skids between layers had Teflon® strips placed on both surfaces of the skid. With a single layer of bundles, slippage was confirmed by testing to have occurred only between the load and the skid, and not between the skid and the trailer deck; thus, the trailer surface always remained in contact with the skid's wood surface. With Teflon® on both sides of the skid, slippage could occur on either surface of the skid, depending on the test conditions.

The tests used one of three nominal tension settings for the tiedowns: low (200 lb), medium (500 lb) and high (1000 lb). In each case, a single tension setting was used for all straps in a given test. Before testing, the tightening system was shaken down by releasing the straps and retightening them until a mean tension close to the nominal values was obtained in each tiedown. Overall, the variation in mean tensions applied to the tiedowns at the beginning of the test cycles was within 25% of the initial measured tension. The medium level was established as the most realistic tension that a driver or an operator could create using a crowbar to tension a tiedown on a heavy vehicle. Tests were also carried out on single bundles with no tiedowns to serve as a basis for comparison. For the purpose of the tests, zero tension was assumed to be the same as using no tiedown.

To permit equalization of tiedown tensions on either end of a strap, an unconventional setup was used. In this setup, tension was applied from an intermediate position on the strap. This setup also permitted the installation of strain gauges at each end of the strap.

Kevlar® ropes (Figure 1) were used successfully as a safety device to prevent loads from falling off the trailer when slippage occurred. In the pitch tests, a hollow rectangular bar was chained to the deck to prevent the bottom bundles from sliding off the trailer (Figure 2). The same device was used successfully in the dynamic and braking tests. Where more than one layer of bundles was tested, metal mesh (Figure 3) was used to prevent the upper bundles from sliding off the lower layer in the pitch and dynamic tests, but not in the roll test, for which the Kevlar® rope was adequate. When six bundles were tested in the pitch test, two cross-chains were also added for additional safety in case of serious slippage.

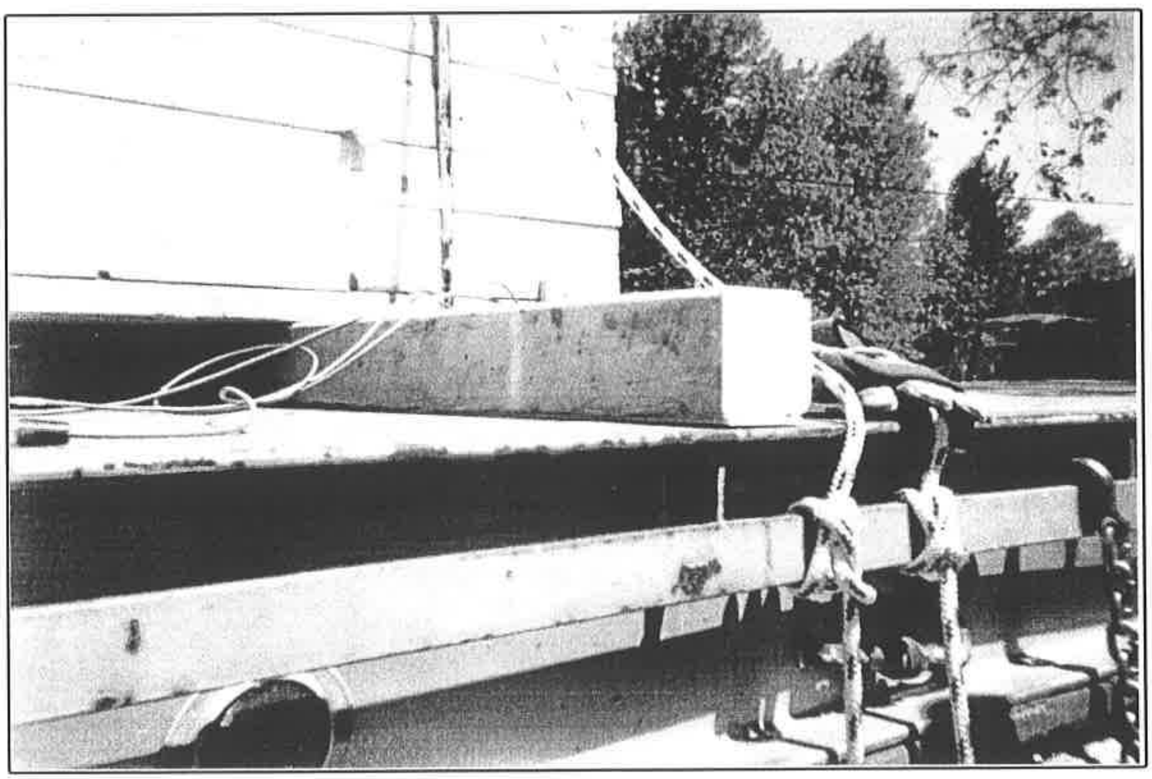


Figure 1. Teflon® was used to cover the skids that supported the lumber bundles in the low-friction test. Note the Kevlar® ropes in the foreground, used as a safety device.

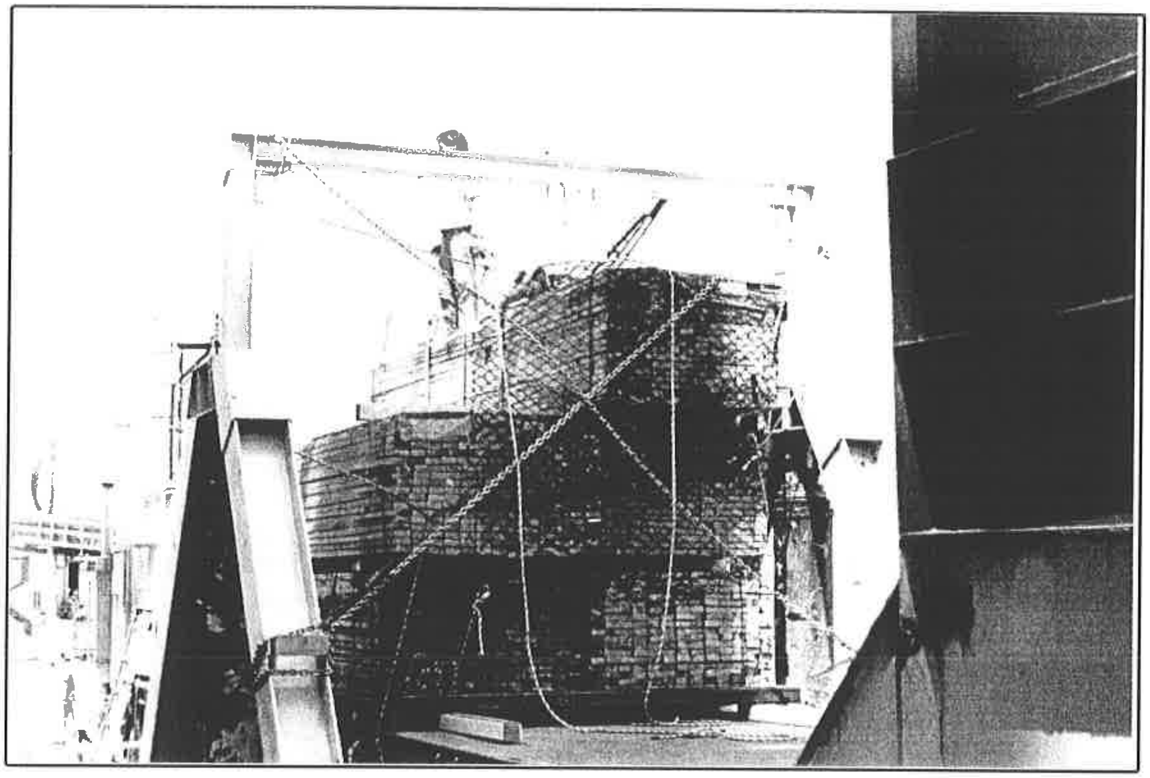


Figure 2. A steel bar was used to prevent lower bundles from slipping off the trailer; metal mesh was used to secure the top bundles.

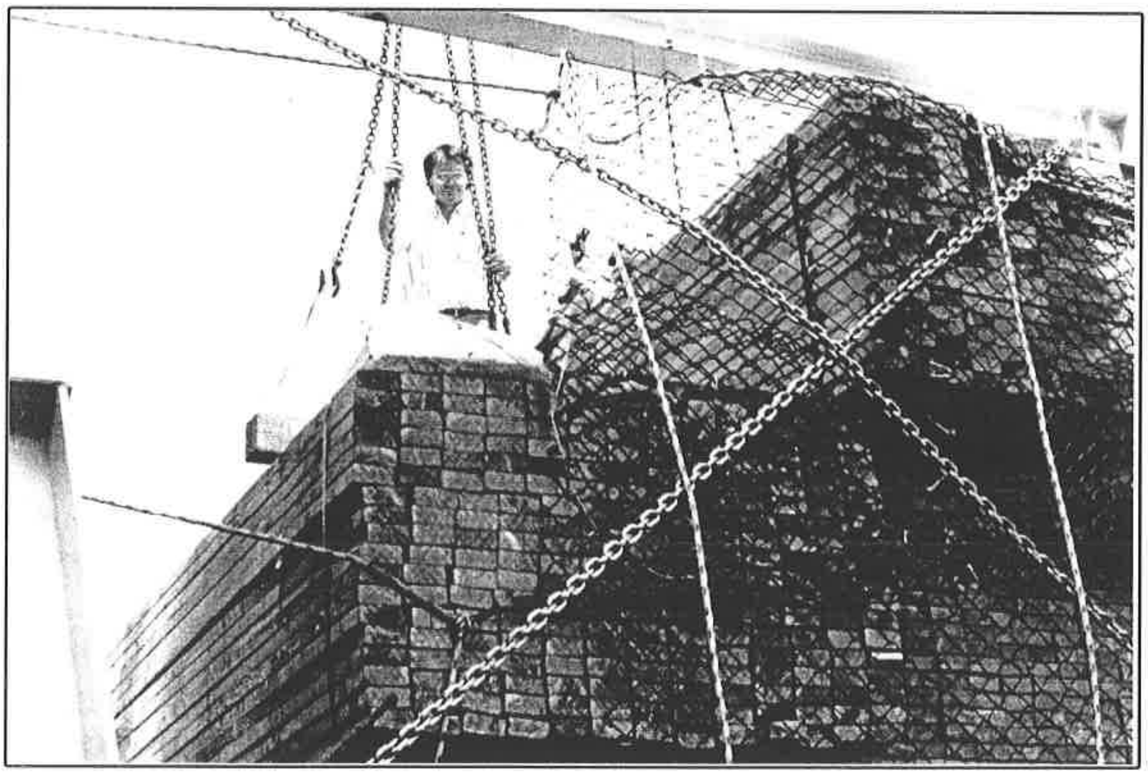


Figure 3. Metal mesh and chains provided additional safety in the pitch test.

3b. Instrumentation and Data Analysis

All measurement devices were connected to a computer to permit continuous recording of data, and the data were subsequently output by NRC for analysis. The instrumentation, the computer system and methods for the system's operation were jointly developed by NRC's staff and Nisymco, with assistance from FERIC and MTQ, and comprised the following components:

- Inclinometers that recorded inclination angles to the nearest 0.2° were fixed to the trailer's deck.
- Accelerometers for recording g-forces (to a precision of 0.2%) were fixed to the trailer's deck or to the main beams that supported the deck.
- Spring-loaded probes sensed the movement of the lumber during the tests. The probes were attached to wooden brackets (Figure 4) and responded immediately to any movement of the cargo.
- Load cells calibrated by MTO were incorporated in the tiedown system (Figure 5) and provided continuous readings of the tension in the tiedown straps with 1% linearity and 0.1% repeatability. Most tiedowns had one load cell at each end; for these tiedowns, the mean tension was used. In the results section of this report, the tensions reported represent overall means for all tiedowns in a particular configuration.

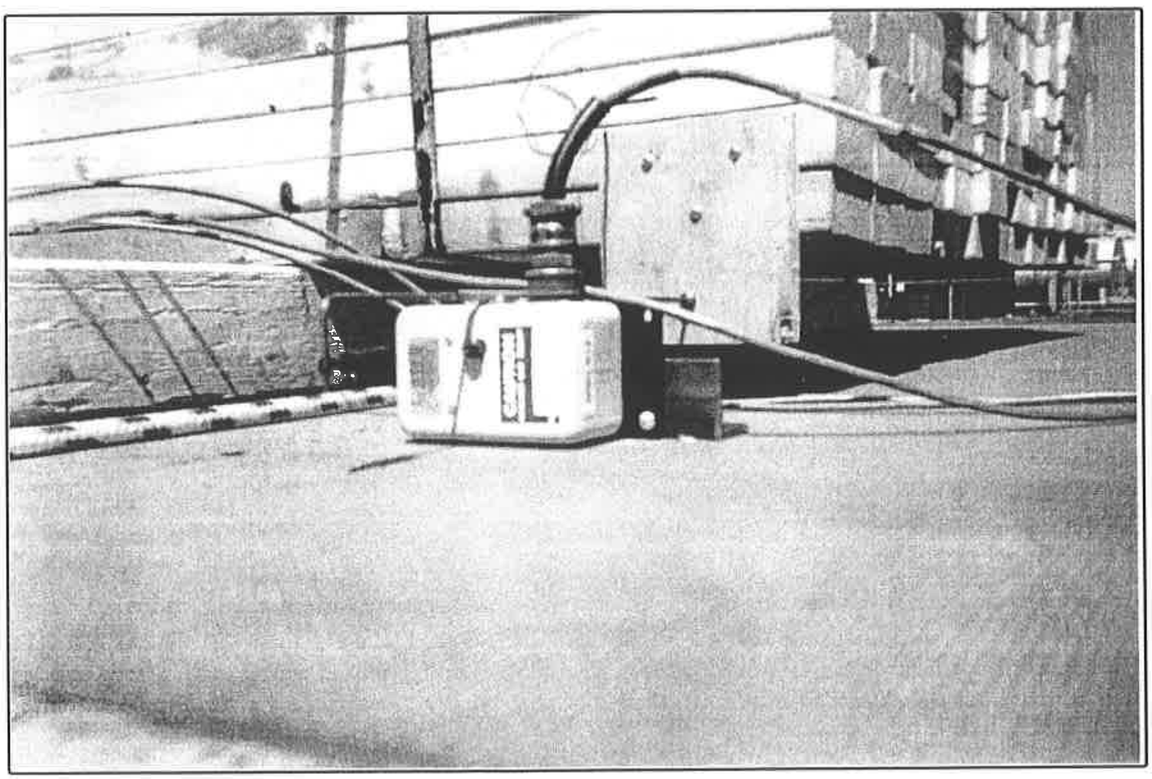


Figure 4. A spring-loaded movement sensor used in the study.

- New webbing with a width of 3 in. and a working load limit of 5000 lb was purchased for the tiedown system. Chains, D-rings, Kevlar® ropes, and all related hooks and cables adequate to support the load in case of slippage were used for safety. New ratchet-tightening mechanisms were purchased that facilitated the task of tightening the tiedowns. C-clamps secured with threaded pins (rather than cotter pins) were used to attach sensors to various parts of the tiedowns and the trailer. The system was designed to be capable of providing tiedowns for a single bundle or up to six bundles; with six bundles, the bundles were arranged in pairs in a single layer (8-ft lumber), or in two sets of three layers (16-ft lumber).

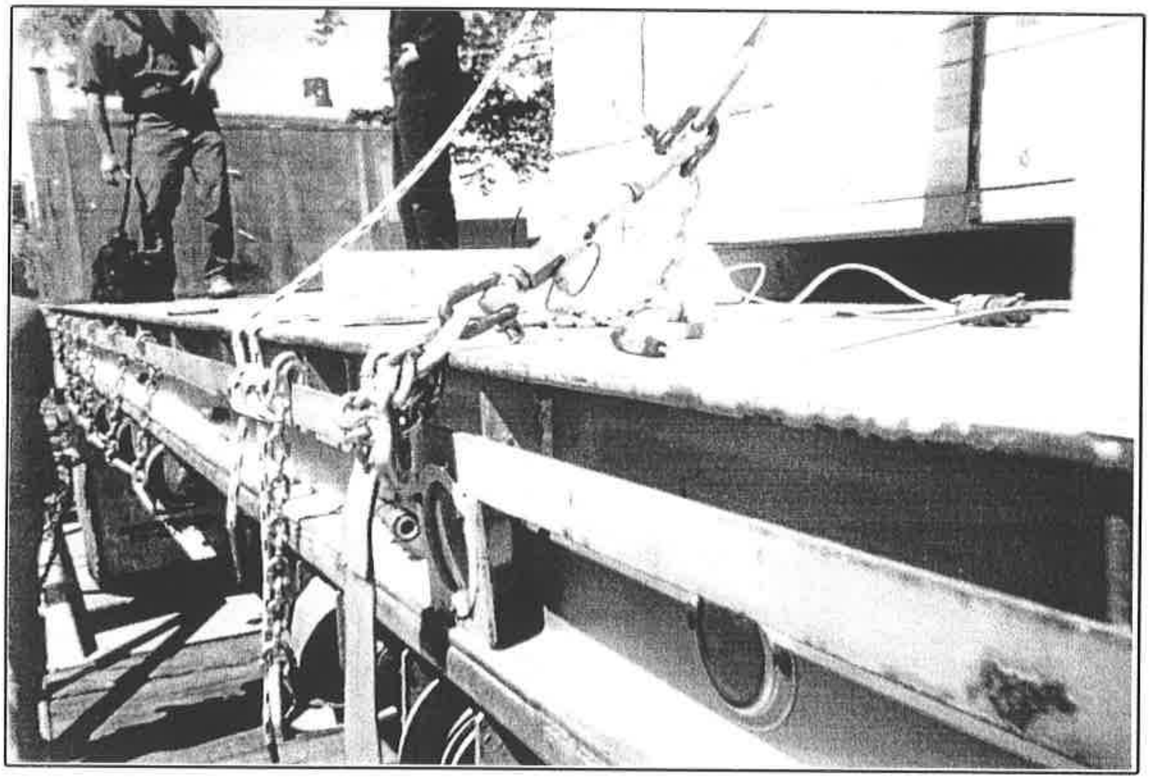


Figure 5. Calibrated load cells were incorporated in the tiedown straps.

Load displacements and deck angles were recorded continuously during the tests, and the results were graphed for subsequent analysis (i.e., to calculate the angle at which slippage occurred). Typical graphs from these measurements are presented in Figure 6. The three graphs in this figure demonstrate how angles were calculated when the data was relatively clear. The two graphs of load displacement reveal the point at which slippage began (the point at which the displacement curve becomes nearly vertical). From this point, researchers extrapolated a vertical line to intersect the curve in the graph of deck angle (top), and the point of intersection defined the angle of slippage. In this example, slippage occurred at about 60 seconds, for a slippage angle of just under 10°.

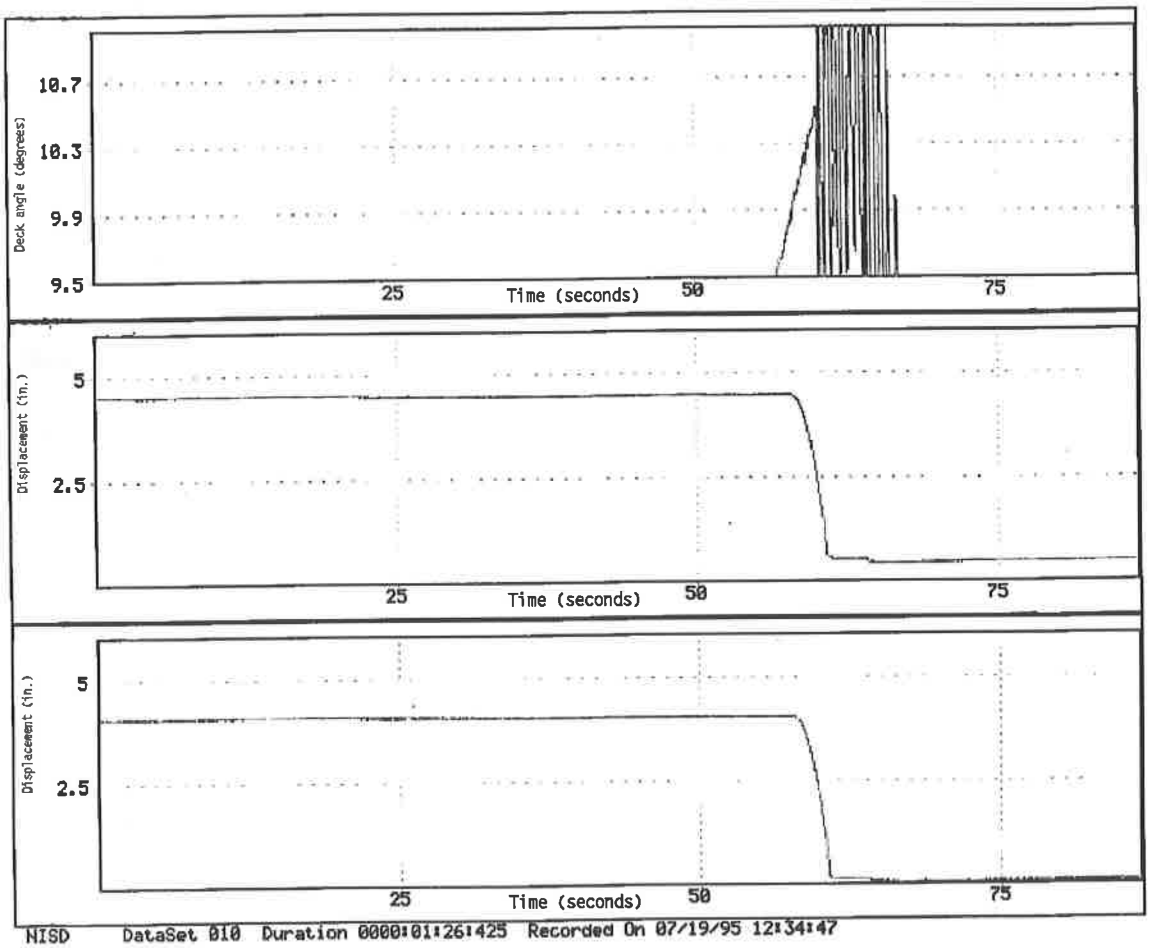


Figure 6. Sample graphs of load displacement and deck angle, showing a clear point of slippage.

Where the data were somewhat unclear (Figure 7), the task of determining the angle of slippage was more difficult. In this figure, the two displacement graphs show slippage that occurred over a range in time; as a result, the process of extrapolating vertically upwards to the graph for deck angle becomes more complex. The bottom graph indicates that slippage occurred over a range from about 120 to 132 seconds; the corresponding deck angles range between about 30° and 33°, for an average of about 31.5°. More detailed graphs were often used to calculate the slippage angle for data that were difficult to interpret. Figure 8 shows a more detailed graph of the relationship between load displacement and deck angle. In this example, slippage begins at about 85 seconds; extrapolating vertically downward from this point on the displacement curve to the corresponding point on the deck angle curve provides a deck angle of about 15°. The final decision on exactly when slippage occurred in problematic cases was also based on the magnitude of the slippage and an analysis of the tension variation within the tiedowns.

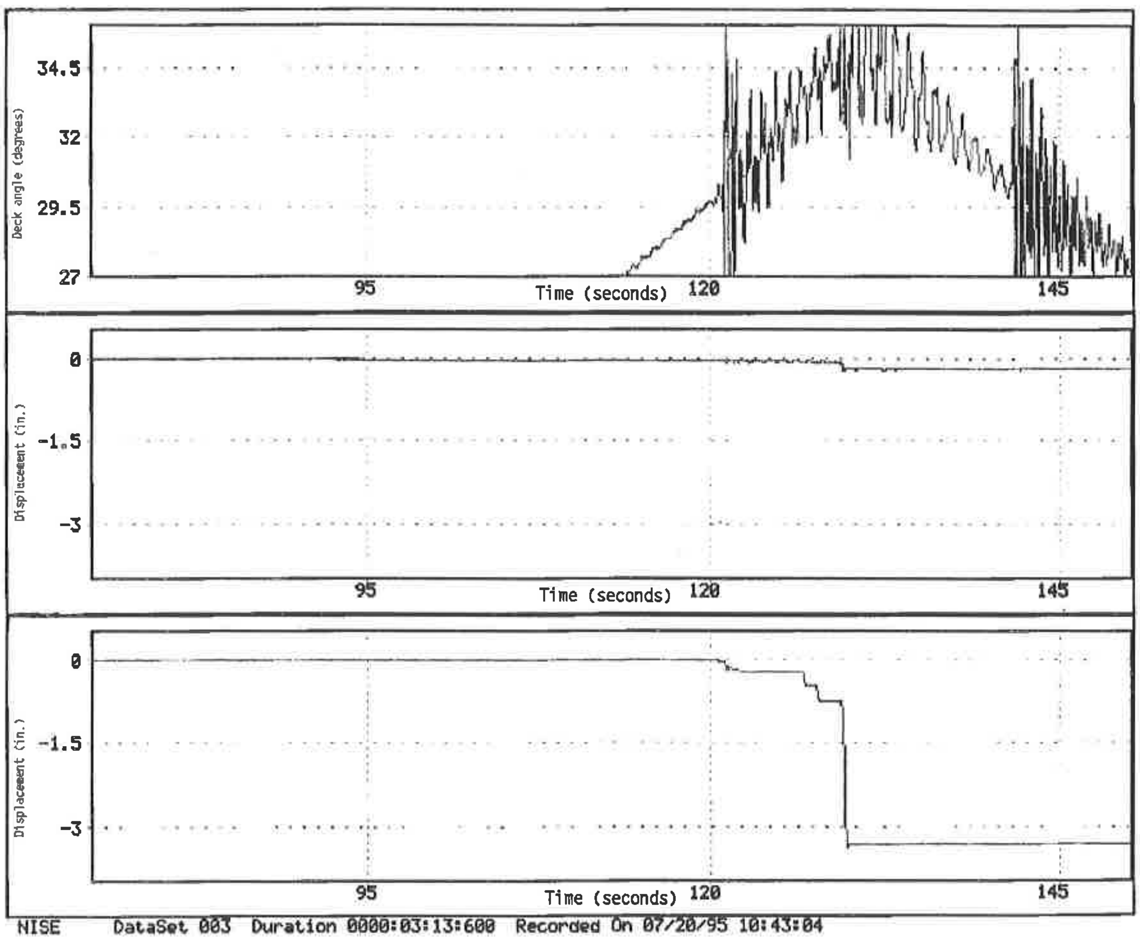


Figure 7. Sample graphs of load displacement and deck angle, showing an unclear point of slippage.

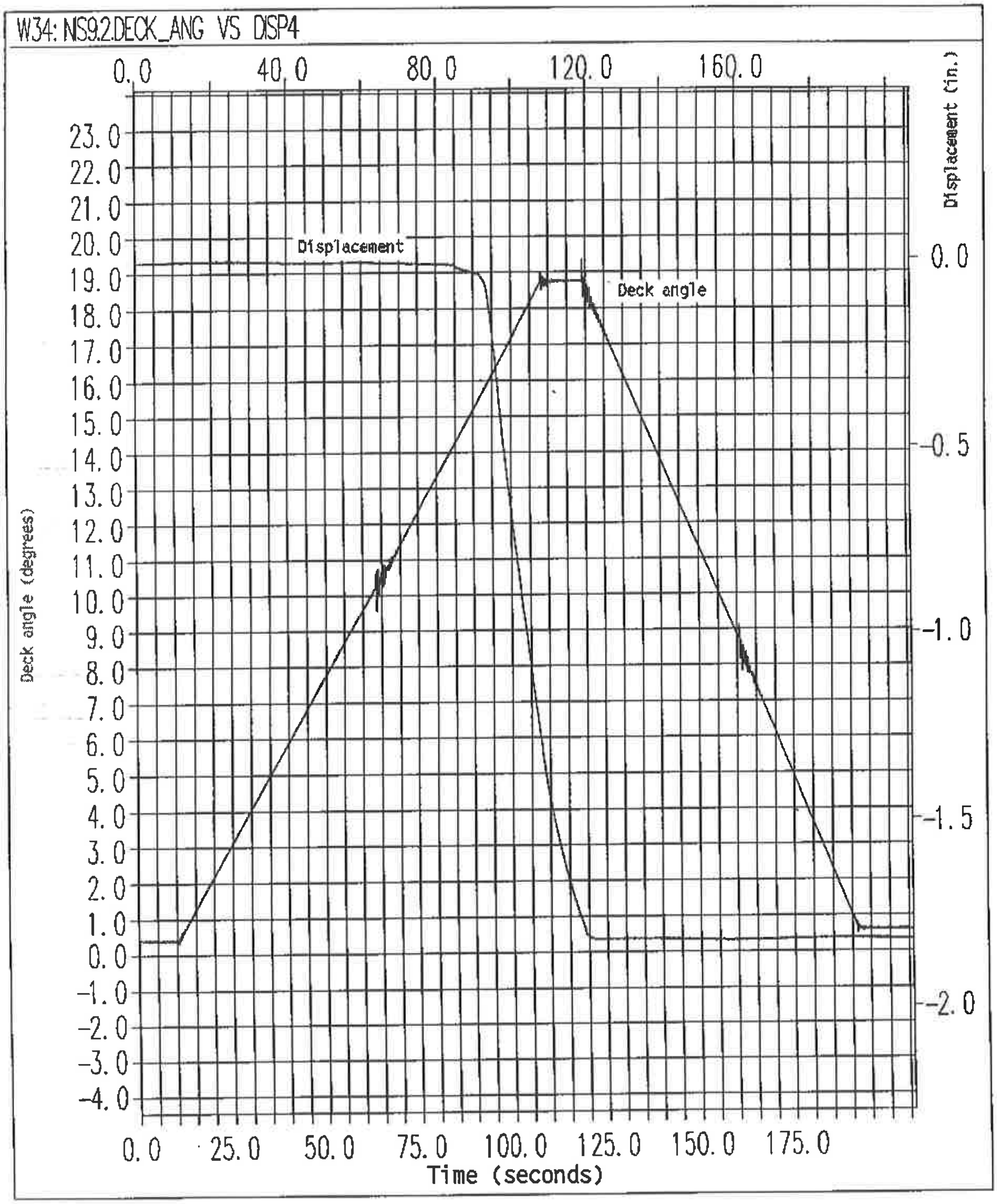


Figure 8. A more detailed graph of the relationship between load displacement and deck angle.

Graphs of the tension variations within the tiedowns were analyzed to assess tiedown comportment and to confirm the actual angles at which slippage occurred. Figure 9 provides two examples of the variations in tension that occurred during a single roll test (for a single 8-ft bundle with one tiedown on Teflon® skids). Figure 10 provides comparable examples for a single pitch test (for a single 8-ft bundle with two tiedowns on Teflon® skids). In both cases, tensions in a given tiedown can be read directly from the graphs at various stages in the testing.

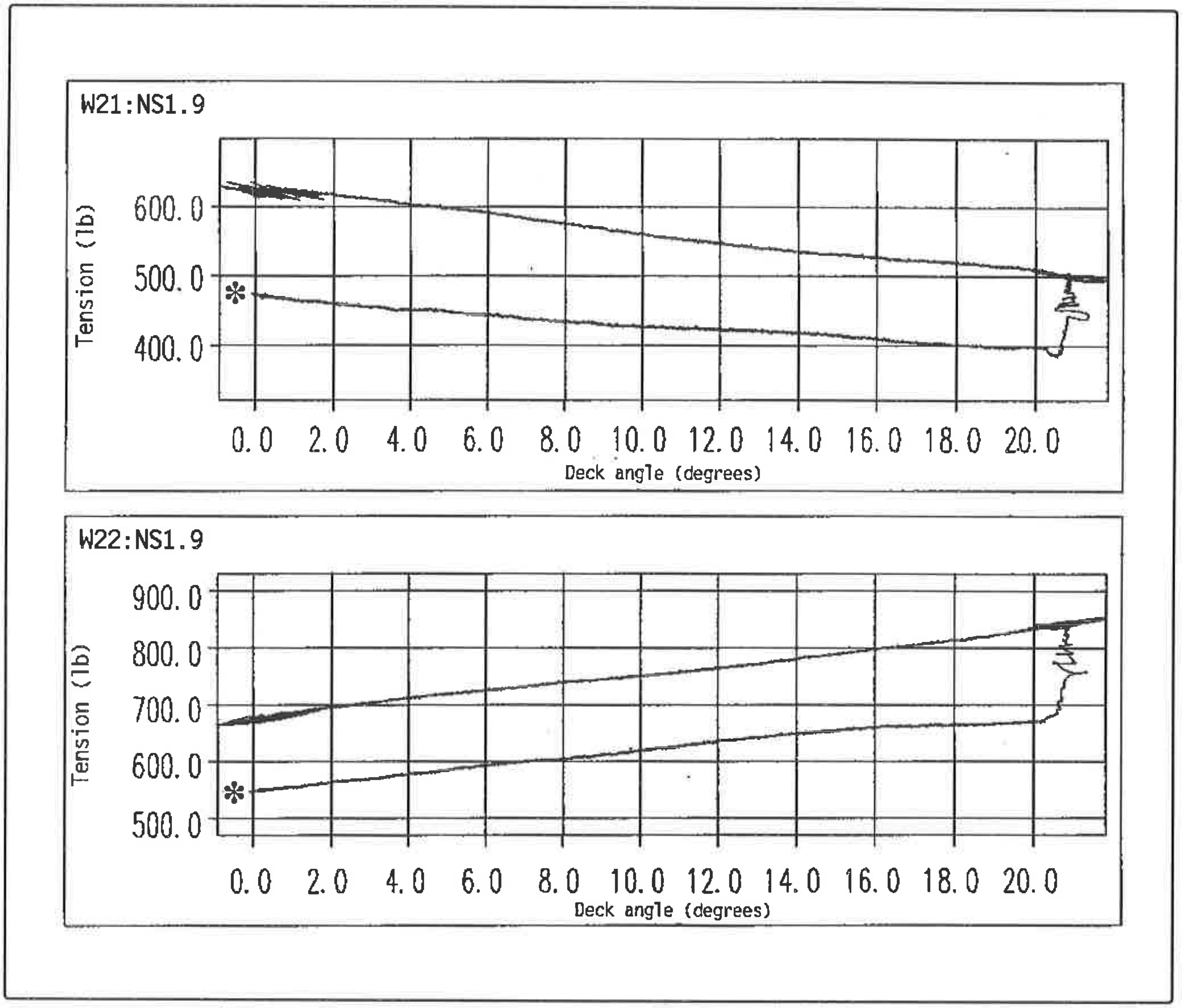


Figure 9. Examples of tiedown tension measurements in the roll test. (The asterisk indicates the starting point for the test.)

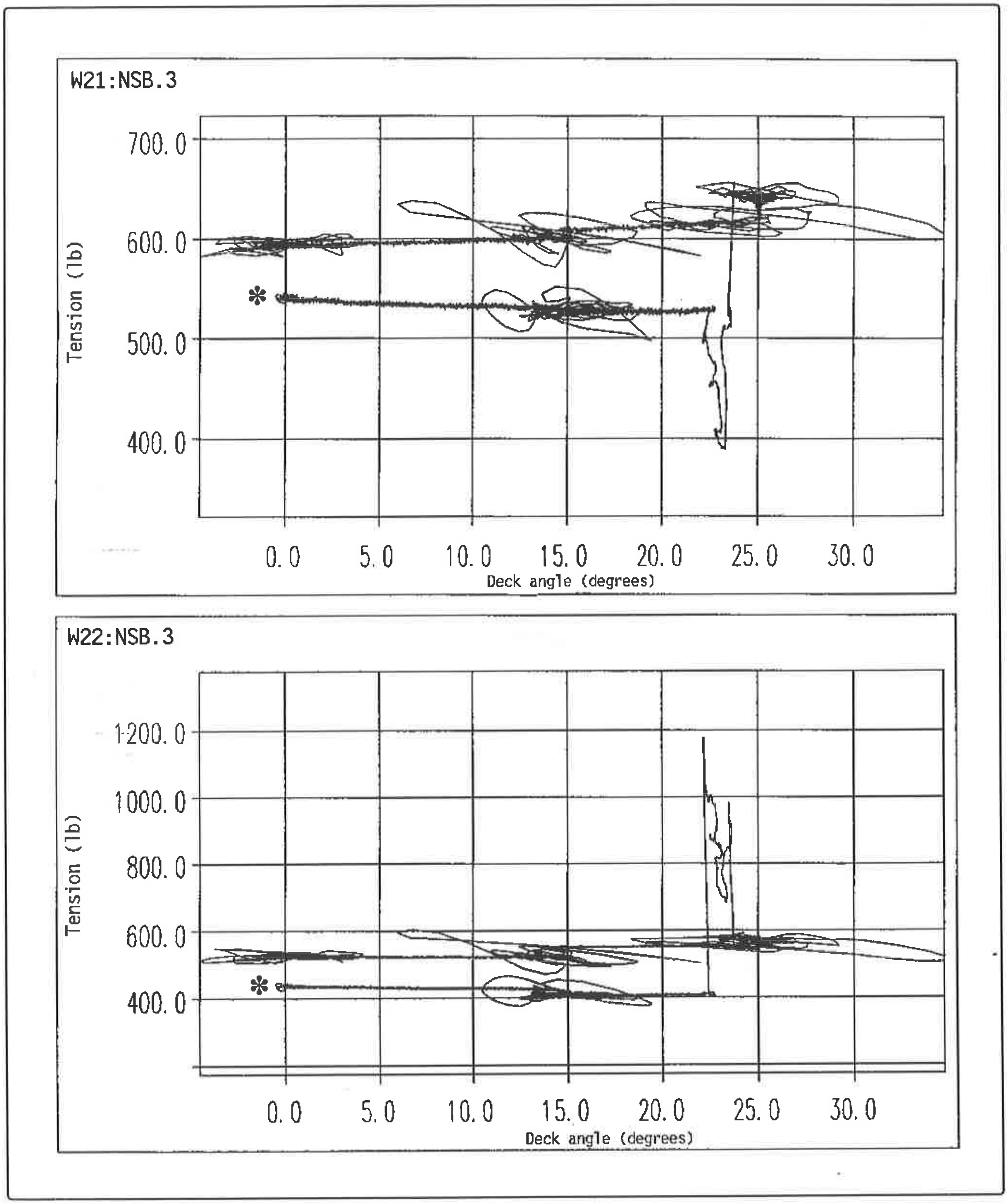


Figure 10. Examples of tiedown tension measurements in the pitch test. (The asterisk indicates the starting point for the test.)

3c. *Roll Tests*

NRC's roll table in Ottawa (Figure 11) was used to perform the roll stability tests. Safety precautions were taken to ensure that the vehicle was adequately chained and immobilized to avoid instability problems at higher roll angles. When stopped, the NRC table automatically returned to a horizontal position. The roll table's range limited testing to a maximum of about 35° with one or two tiers of wood, whereas vehicle stability limited testing to a maximum of about 22° with three tiers of wood.

Inclinometers were attached to the trailer's deck to measure the actual deck angle (rather than the roll table angle) during the tests. Visual examination and computerized sensors identified when slippage began to occur (i.e., the point of failure had been reached) so that the test could be stopped.

When slippage occurred at a low angle with the high level of tension in both the roll and pitch tests (i.e., generally at an angle close to that observed with no tiedown), the remaining tests at lower levels of tension were not continued since they would obviously have failed too.

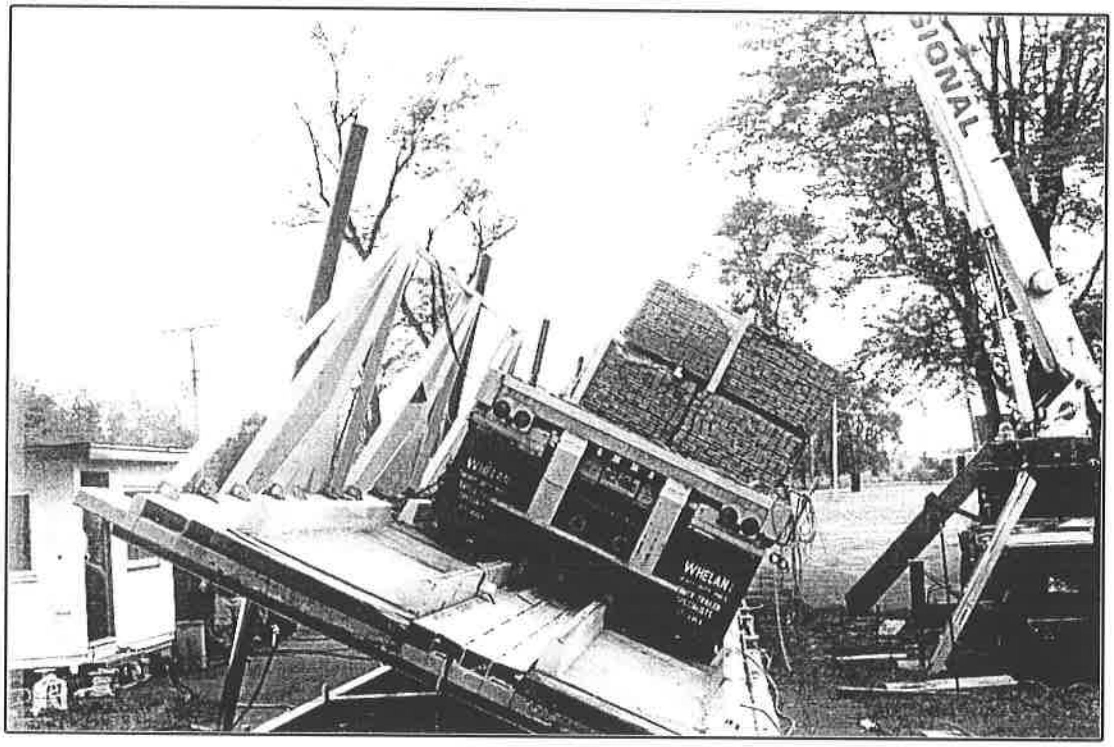


Figure 11. The NRC roll table used in the tests.

3d. Pitch Tests

The pitch table used for the tests was a discharge table for emptying wood chip vans into a bin at the Daishowa mill (Figure 12). The tractor-trailer was again chained to the table and the back of the trailer was supported firmly on the end of the table using 6-ft-long planks that were 2-in. wide by 8 in. in diameter. Vehicle stability, set at 0.7 g, limited testing on the pitch table to about 45°.

The table's hydraulic system introduced a shock load when the telescoping cylinders begin to move. Shocks occurred at 14°, 29° and 44° of inclination (Figure 13). Daishowa personnel stated that these shocks were inherent to the system and could not be eliminated. **As such, any slippage that occurred around these angles may have been premature.**

Figure 12. The Daishowa chip discharge table used as the pitch table in the study.

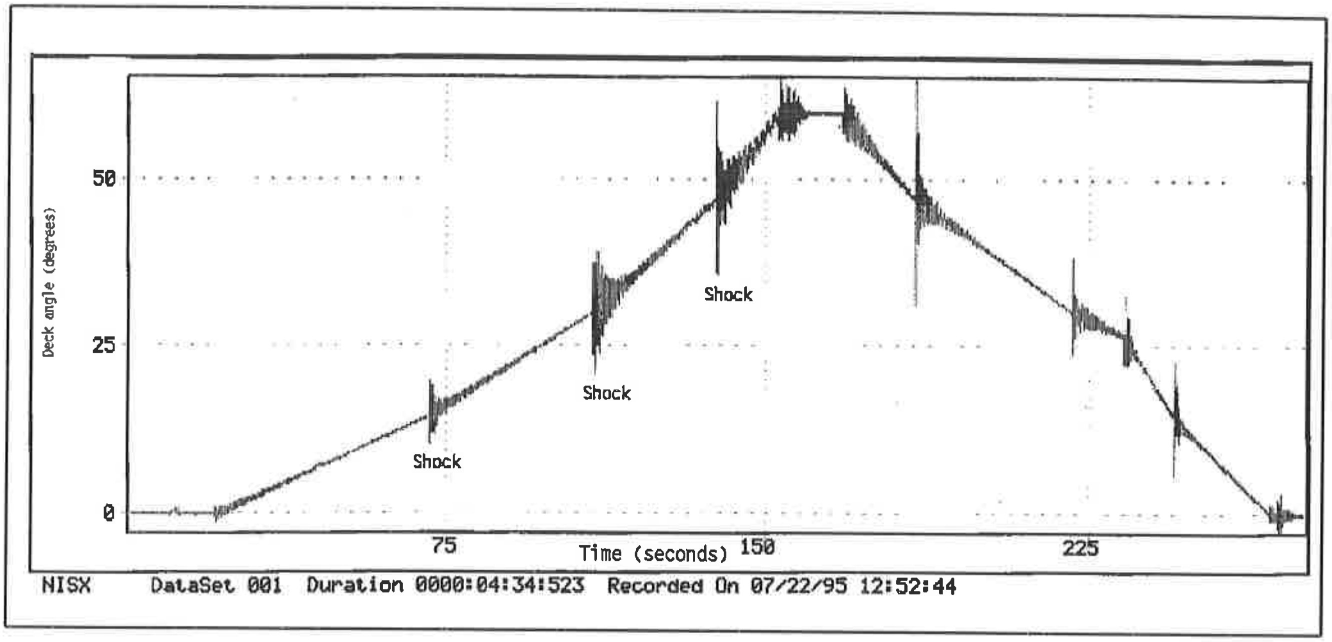


Figure 13. During the tests conducted on the pitch table, shocks occurred at three deck angles.

3e. Dynamic Tests

The g-forces calculated from the angles measured in the static tests served as the basis for the subsequent dynamic tests. Transport Canada's Motor Vehicle Test Centre at Blainville was the host for the dynamic tests. Accelerometers were attached to the trailer deck to measure g-loads in the transverse and longitudinal directions. Power was supplied to the tractor's onboard computer (which recorded the instrumentation data) using a generator powered by a small motor strapped to the deck of the semi-trailer.

The g-loads were generated by driving the truck in a series of concentric circles with decreasing radius, by braking from different speeds and by performing several lane changes. All tests were conducted with medium tension in the tiedowns. Samples of the recorded results are presented in Figure 14. The example in the figure represents the spiral driving pattern at 60 km/h, with four bundles and two tiedowns. Slippage started to occur at about 160 seconds, at a force of about 0.55 g in Figure 14.

Fuller details of the dynamic tests can be found in Table 3 and Appendix 2, but the main test configurations were as follows:

- one bundle of 8-ft wood with both 1 or 2 tiedowns on wood skids during both braking and circle maneuvers;
- one bundle of 8-ft wood with 2 tiedowns on Teflon® skids during both braking and circle maneuvers;

- two bundles of 8-ft wood with 2 tiedowns on wood skids during both braking and circle maneuvers;
- one bundle of 16-ft wood with 2 tiedowns on Teflon® skids during both circle and lane change maneuvers;
- four bundles of 16-ft wood with 2 tiedowns on wood skids during both braking and spiral maneuvers.

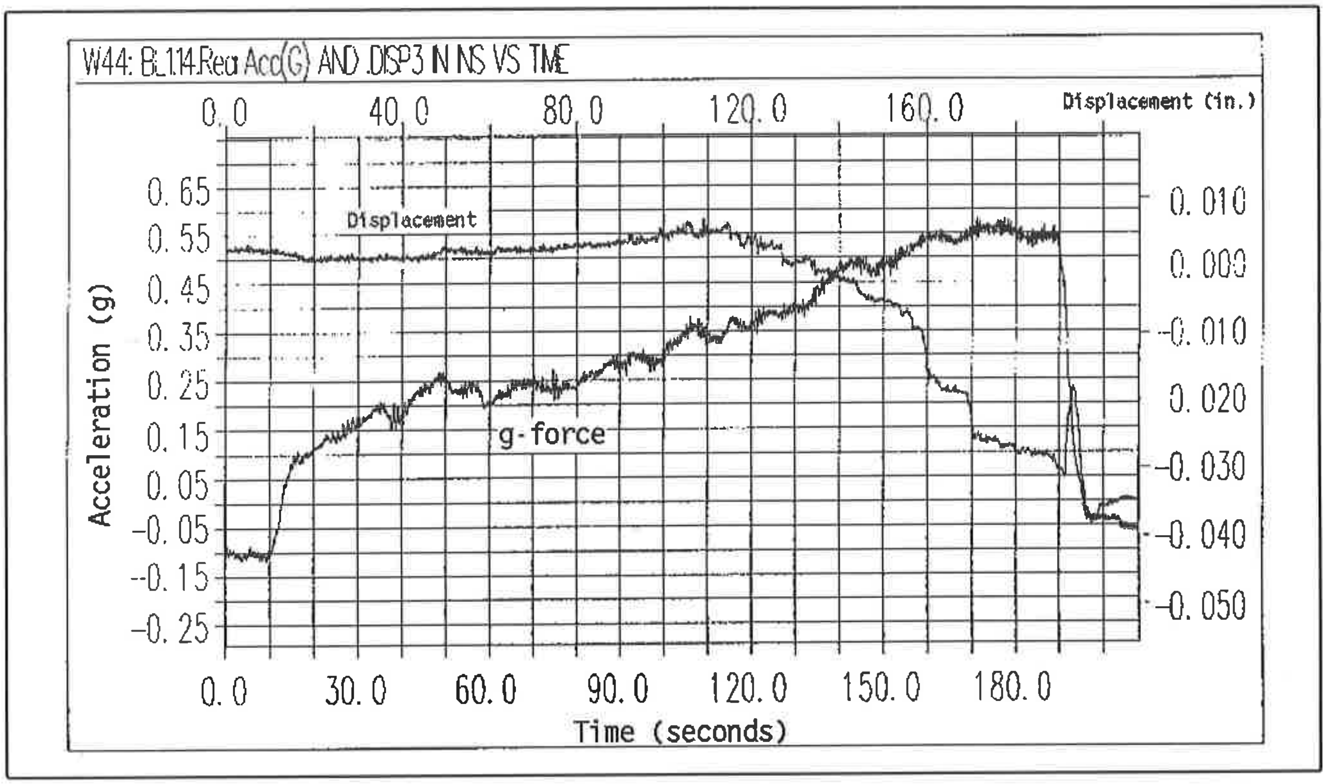


Figure 14. An example of the graph for the relationship between load displacement and g-force.

4. Results

4.1 Static Tests

The slippage angles and tiedown tensions for the full set of roll and pitch tests are reported in Table 1. The results of these static tests, expressed as the g-forces calculated from the measured slippage angles, are summarized in Table 2. Figure 15 shows the trends for static slippage angles as a function of tiedown tension for various combinations of skid surface and number of tiedowns. (In this figure, data are presented for a single 8-ft bundle which represents the most complete data set.)

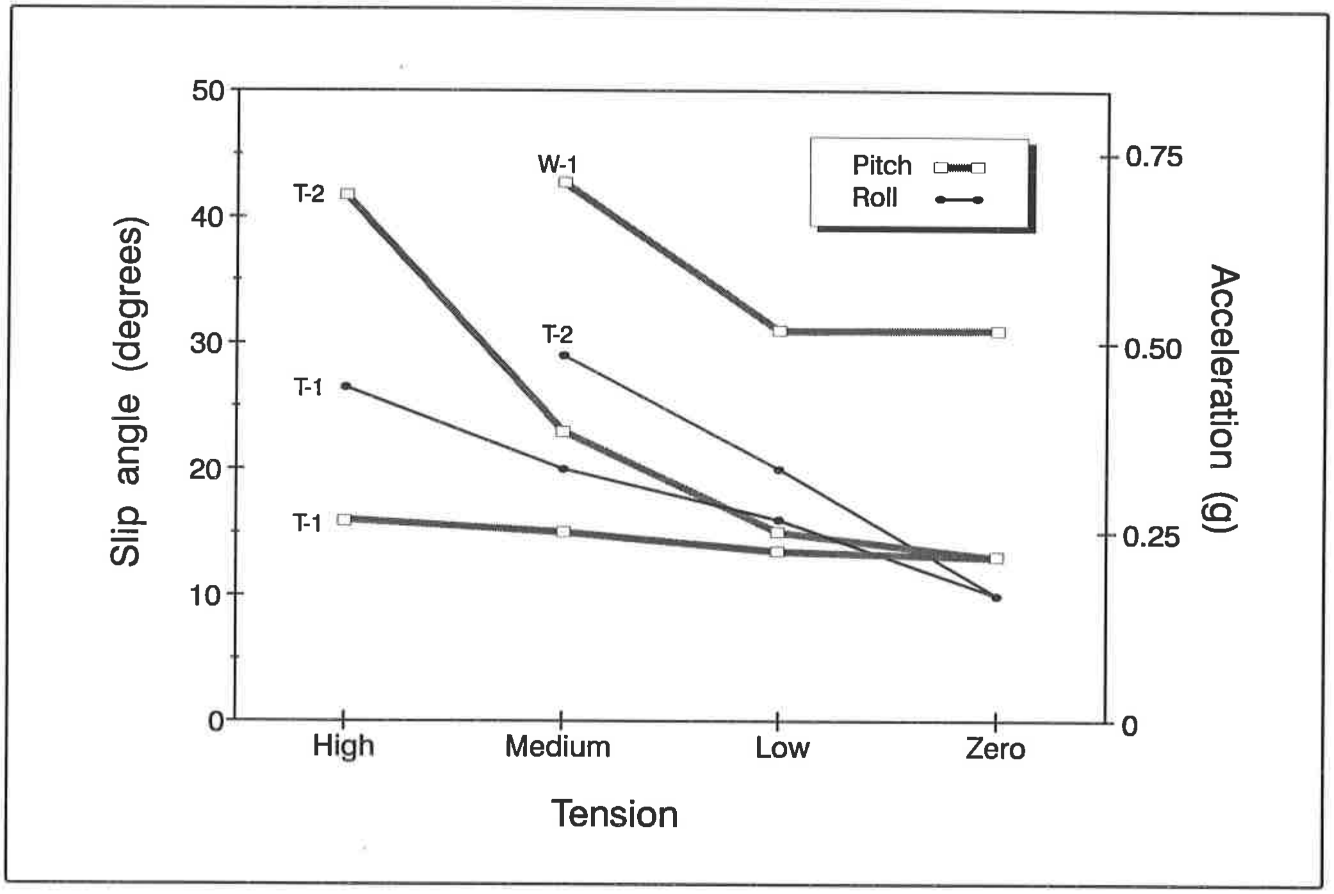
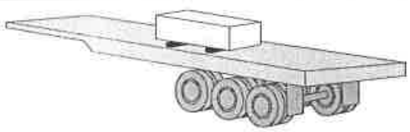
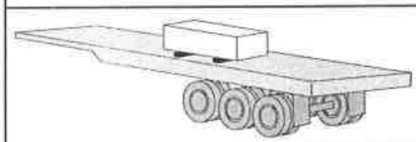
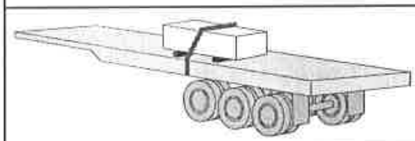
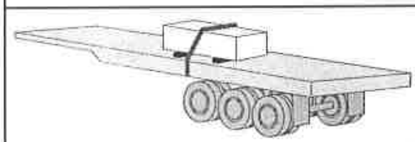
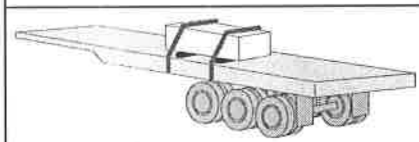
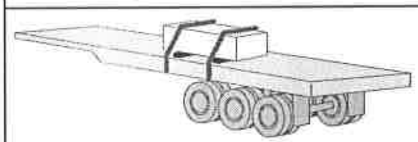
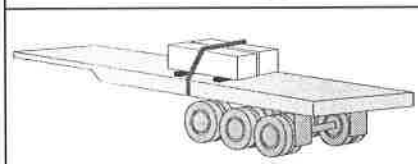
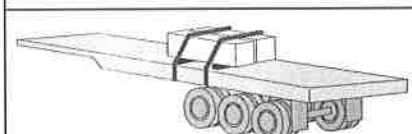


Figure 15. Slippage and g-forces for single 8-ft bundle (W-1 = wood skid with one tiedown; T-1 = Teflon® skid with 1 tiedown; T-2 = Teflon® skid with two tiedowns).

Note: W-1 - Roll: low >33°, medium >33°, high >35°
- Pitch: high >45°
W-2 - Roll: medium, high >35°
- Pitch: low, medium, high >45°
T-2 - Roll: high >35°

Table 1. Slip angles and mean tiedown tensions in static tests

(> indicates that no slippage occurred up to the angle indicated, which represents either the physical limit of the test apparatus or the limit of vehicle stability)

8-ft bundles	Skid surface	Roll tests		Pitch tests	
		Slip angle	Tension (lb)	Slip angle	Tension (lb)
	Wood	24.5°	zero	31°-37°	zero
	Teflon®	10°	zero	13°	zero
	Wood	>35° >33° >33°	845 430 200	>45° **45°**[a] 31°- 45°	915 545 240
	Teflon®	26.5° 20° 16°	985 520 250	16° **15°** 13.5°	860 580 230
	Wood	>35° >35.5° —	915 480 —	>45° >45° >45°	920 545 240
	Teflon®	>35° 29° 20°	958 545 241	**44°** 23° 15°	1103 503 205
	Wood	33.5° 26.8° 23.0° >35°[b]	1065 545 190 480	— **45.5°** 35.8° >41°	— 508 255 545
	Wood	— — >35°	— — 205	— — 41°	— — 346

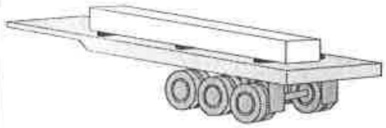
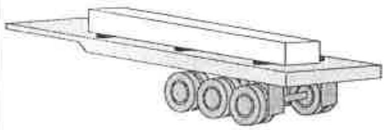
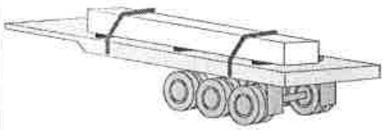
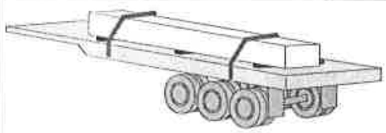
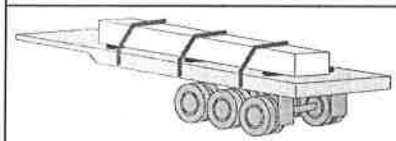
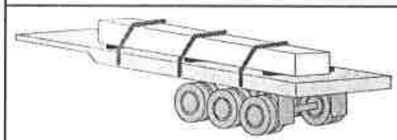
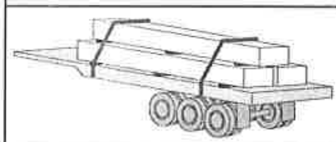
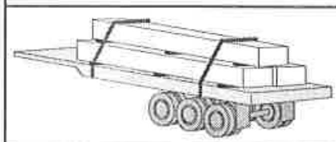
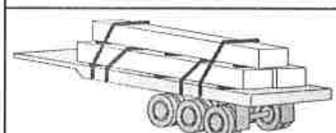
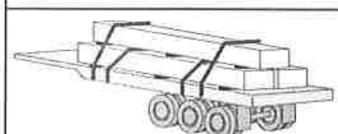
[a] Slip during the pitch tests at angles of 14°-15°, 29°-31°, or 44°-46° may have been premature because of shocks inherent in the test equipment, and should thus be viewed with caution. All such are indicated in bold.

[b] The test of this configuration at medium tension was repeated in both roll and pitch.

(continued)

Table 1. Slip angles and mean tiedown tensions in static tests

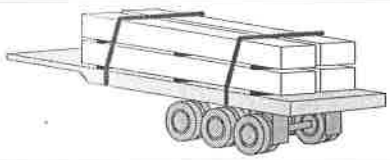
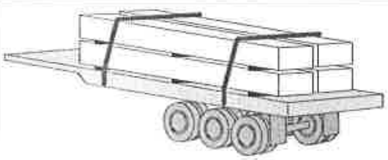
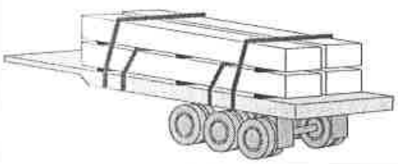
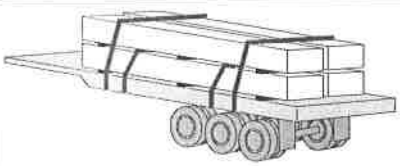
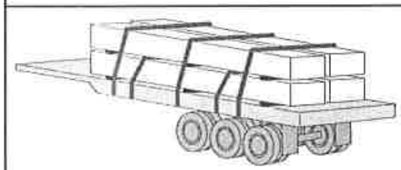
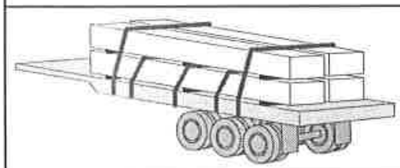
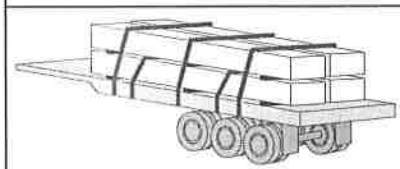
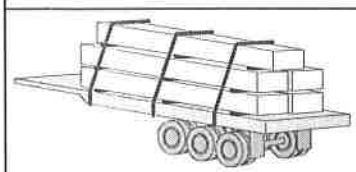
(> indicates that no slippage occurred up to the angle indicated, which represents either the physical limit of the test apparatus or the limit of vehicle stability)

16-ft bundles	Skid surface	Roll tests		Pitch tests	
		Slip angle	Tension (lb)	Slip angle	Tension (lb)
	Wood	25°	zero	27.5°	zero
	Teflon®	10.9°	zero	10°	zero
	Wood	>35° — >35°	915 — 240	>42° >42° 38°	950 510 255
	Teflon®	26° 19.8° 15.5°	967 470 200	**14.5°** 13.5° 12.2°	1015 505 235
	Wood	— — —	— — —	— — 42.5°	— — 280
	Teflon®	28° 19.8° —	945 465 —	22° **14°** —	958 578 —
	Wood	>34° >34° >34°	980 485 250	— **29.5°** **29.3°**	— 490 252
	Teflon®	12° 10° —	910 563 —	13.9° 12.5° —	993 498 —
	Wood	>34° >34° >34.5°	903 572 225	— 36° 28.5°	— 498 207
	Teflon®	18.4° 16° —	847 492 —	**14.5°** **14°** —	1018 515 —

(continued)

Table 1. Slip angles and mean tiedown tensions in static tests

(> indicates that no slippage occurred up to the angle indicated, which represents either the physical limit of the test apparatus or the limit of vehicle stability)

16-ft bundles	Skid surface	Roll tests		Pitch tests	
		Slip angle	Tension (lb)	Slip angle	Tension (lb)
	Wood	30° 26° —	1005 503 —	36° **30°** 30°	950 545 235
	Teflon®	— — —	— — —	13° — —	1040 — —
	Wood	>33° >33° 30° 26°[c]	973 507 199 965	42° 33° **29.5°** —	892 490 231 —
	Teflon®	15.5° 12.3° — 11.9°[d]	1012 488 — 458	13.5° 12° — —	940 541 — —
	Wood	>32° 34.4° —	974 563 —	— 34.5° **29.5°**	— 510 243
	Teflon®	18.5° 13.3° —	894 543 —	— — —	— — —
	Teflon®	— 13° —	— 483 —	— 13.3° —	— 515 —
	Teflon®	— 12.1° —	— 585 —	— — —	— — —

[c] The bundles on the upper layer of the load deformed before slippage occurred.

[d] In this test, the position of the tiedowns was changed with respect to the skids to determine if this had any effect on slippage. This was done because rain might have affected the skid surface in this test.

(continued)

Table 1. Slip angles and mean tiedown tensions in static tests

(> indicates that no slippage occurred up to the angle indicated, which represents either the physical limit of the test apparatus or the limit of vehicle stability)

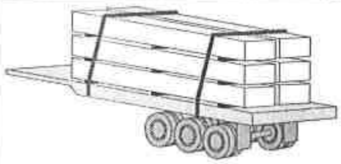
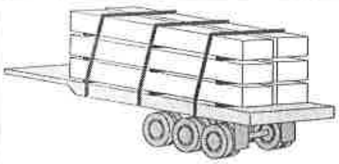
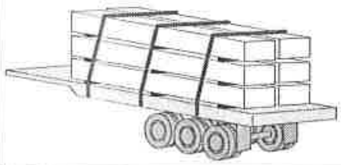
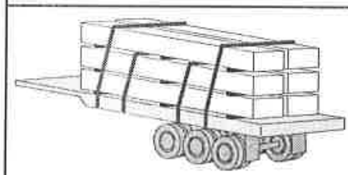
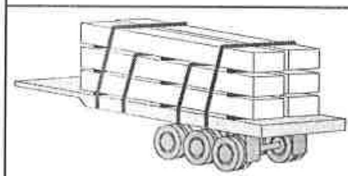
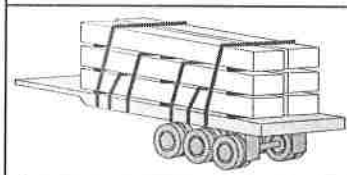
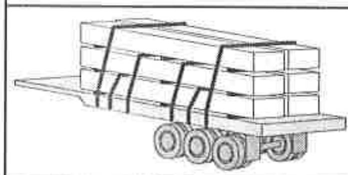
16-ft bundles	Skid surface	Roll tests		Pitch tests	
		Slip angle	Tension (lb)	Slip angle	Tension (lb)
	Wood	— >23.2° 24°	— 502 230	— — —	— — —
	Wood	— >23° >23.2°	— 464 223	— 26.4° —	— 590 —
	Teflon®	— 11.8° —	— 550 —	11.8° 11° —	996 520 —
	Wood	>22.5° >22.5° >22°	807 492 212	— 26° —	— 530 —
	Teflon®	— 13.3° —	— 493 —	— — —	— — —
	Wood	>21.5° >22.5° —	883 516 —	— **29.5°** —	— 541 —
	Teflon®	15.5° 14.9° —	855 516 —	**15°** 12° —	1010 514 —

Table 2. Calculated acceleration values (g-forces) at slip in the static (roll and pitch) tests at medium tiedown tension

(> indicates no slippage up to equipment limit or vehicle instability)

Lumber length	No. of bundles	Skid surface	No. of tiedowns	g-force at point of slippage	
				Roll	Pitch
8 ft	1	Wood	0	0.41	0.52-0.60
			1	>0.54	0.71
			2	>0.58	>0.71
		Teflon®	0	0.17	0.22
			1	0.34	0.26
			2	0.48	0.39
	2	Wood	1	0.45	0.71
			2	>0.57 (L)[b]	0.66 (L)[b]
16 ft	1	Wood	0	0.42	0.46
			2	>0.57 (L)[b]	>0.67
			3	not tested	0.68(L)[b]
		Teflon®	0	0.19	0.17
			2	0.34	0.23
			3	0.34	0.24
	3	Wood	2 or 4	>0.56	0.49-0.59
		Teflon®	2 or 4	0.17-0.28	0.22-0.24
	4	Wood	2	0.44	0.50
			4	>0.54	0.54
		Teflon®	2, 4 or 5	0.21-0.23	0.21-0.23
	5 or 6	Wood	2, 3, 4 or 6	>0.38	0.44-0.49
		Teflon®	3, 4 or 6	0.20-0.26	0.19-0.21

[a] The trend for slippage versus g-force for both roll and pitch tests, at different tensions, is presented in Figure 15. Note that tests with no tiedown (zero tension) on Teflon® give a cluster of data points between 0.17 and 0.22 g that serves as a point of reference.

[b] Only measured at low tiedown tension.

4.2 General Observations

- A bundle on wood skids with no tiedown slipped at 24.5° (0.41 g) and 31° (0.52 g) in the roll and pitch tests, respectively. The 4-in. skids on wood by themselves (i.e., with no lumber) slipped at around 22-23° (0.37-0.39 g).
- A load secured under high or medium tension on wood skids generally did not slip before the instability limit of the vehicle was reached, especially in roll.

- On Teflon® skids, a bundle with no tiedowns slipped at 10° (0.17 g) and 13° (0.22 g) in the roll and pitch tests, respectively. The 4-in. skids on Teflon® by themselves (i.e., with no lumber) would have slipped at even lower angles, and hence, no values are reported.
- Slippage over Teflon® skids occurred at low angles, as expected, and generally fell in the range from 15° to 29° (0.26 to 0.48 g) for a single 8-ft bundle except at high tension with two tiedowns (no slippage), 12° to 28° (0.21 to 0.47 g) for a single 16-ft bundle, and 12° to 18.5° (0.21 to 0.32 g) for piled 16-ft bundles.
- On Teflon®, slippage for bundles secured at a low tension tended to be very similar to the results with no tiedown (Figure 15).
- Friction between the load and its supports would appear to be the principal factor affecting the test results, as highlighted by the relative performance on wood and Teflon® skids.
- Tiedown tension also appeared to have an impact on the efficiency of the tiedown systems, particularly in pitch on wood skids and in both pitch and roll for a single tier of wood on Teflon® skids.
- Adding additional tiedowns beyond a certain minimum would appear to have a lesser impact on load security.
- It appears that various strapping configurations on wood skids had some level of tiedown tension that produced a slippage angle greater than the angle at which the vehicle would lose stability. For icy surfaces, simulated here by the results for Teflon® skids, this was not the case. Thus, the results for the icy surface should perhaps become the design condition on which to base future regulations.

4.3 Dynamic Tests and Comparison with Static Tests

The dynamic tests provided data on slippage, tiedown tension and g-forces under real-life conditions. Table 3 summarizes the g-force results from the 20 dynamic tests that were conducted; these include circular turns, braking and lane changes. Typical graphs of the results are illustrated in Figure 16.

The lane-change maneuvers generated higher g-forces than were expected (based on previous test results with other trailers), which could have affected the results and thus the conclusions. This observation suggests the need for further research to identify the cause of the unexpected results. However, it should be noted that it was also more difficult to control the increase in lateral acceleration during lane change maneuvers than in the circle of spiral tests. As such, it was sometimes more difficult to interpret the results with the same degree of confidence as in the other dynamic tests.

Appendix 1 combines the data from the static and dynamic tests for the most complete sets of load configurations in the study. The mean tiedown tension is also shown for reference. These results are also plotted in Figure 17 to permit an easy visual analysis of the trends. Some general observations follow:

- As shown in Figure 17, the trends for the dynamic and static results do not seem to differ between one and two tiedowns for a single 8-ft bundle resting on wood, although the dynamic results are lower than the static results. Similarly, for a pair of 8-ft bundles on wood skids with two tiedowns, the dynamic results are lower than the static results. Thus, slippage behavior on wood skids is similar for one bundle of lumber or two. A single bundle of 8-ft wood with two tiedowns under medium tension and resting on wood **never** moved, except for a minor slip (0.025 in.) during braking.

- The 8-ft bundle on Teflon® skids is more resistant to slippage with two tiedowns than with one (Table 2). Again, the dynamic results are similar to or lower than the static results.
- For the block of four bundles of 16-ft lumber on wood skids, the g-loads measured in the dynamic tests are higher than the static results measured in the roll and pitch tests (Figure 17). This result is inconsistent with the observations for 8-ft bundles, and this important difference needs to be addressed.
- For one 16-ft bundle on Teflon® skids, slippage is similar under static and dynamic conditions.
- In general, slippage in the lateral (roll) direction occurred at lower g-forces than in the longitudinal axis (i.e., braking) during dynamic testing, and also during the static tests on a wood surface. Conversely, on a Teflon® surface, loads generally failed at a somewhat lower angle in pitch than in roll during the static tests.

Table 3. Results (g-forces at the point of slippage) of the dynamic tests at medium tiedown tension

Maneuver	Lumber size	No. of bundles	Skid surface	No. of tiedowns	Speed (km/h)	g-force at point of slippage	Shifting (inches)
Braking	8 ft	1	Wood	1	40	0.45	0.4
					50	0.50	0.03
					>50	0.60	3.0
		1	Wood	2	>50	0.60	0.025
		1	Teflon®	2	42 (pedal brake only)	0.38	2.5
		2	Wood	2	50 (pedal and spike brake)	0.50-0.60	4.0
	16 ft	4	Wood	2	30	0.60	0.07
					40	0.63	4.0
Circle	8 ft	1	Wood	1	30/40/55	0.50	0.10
					30/40/55[a]	0.45	1.5
		1	Wood	2	30/40/55	>0.55	none
		1	Teflon®	2	approx. 30	0.30	1.5
		2	Wood	2	not measured	0.45	0.3
	16 ft	1	Teflon®	2	40	0.26	1.2
Spiral	16 ft	4	Wood	2	57	0.55	0.02
					60	0.55-0.57	0.02
Lane change	16 ft	1	Teflon®	2	70	0.30	0.02
					90	0.40-0.50	1.5
					90[a]	0.45-0.53	2.0

[a] Replication of previous test.

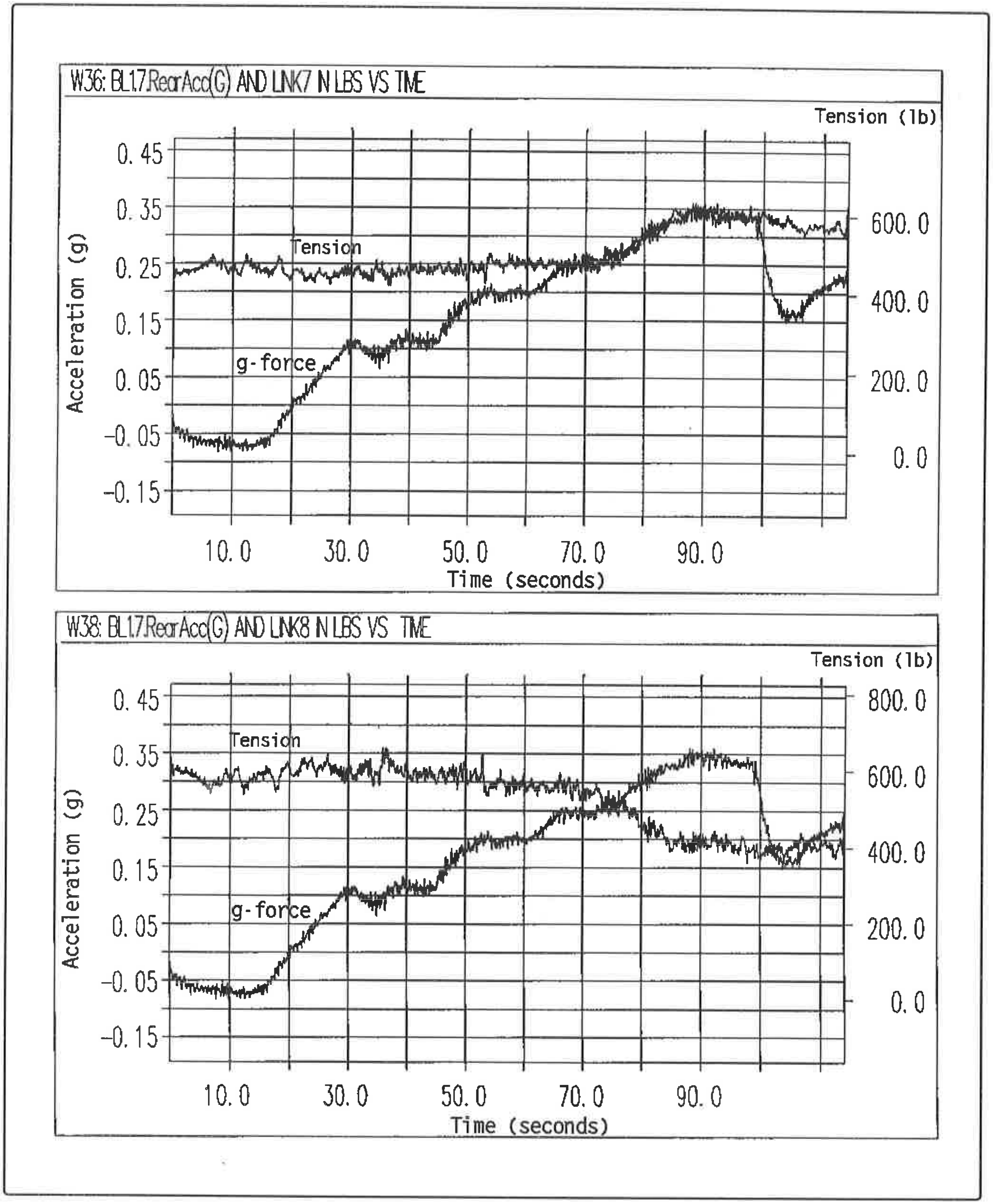


Figure 16. Typical tensions and g-forces measured in the dynamic tests.

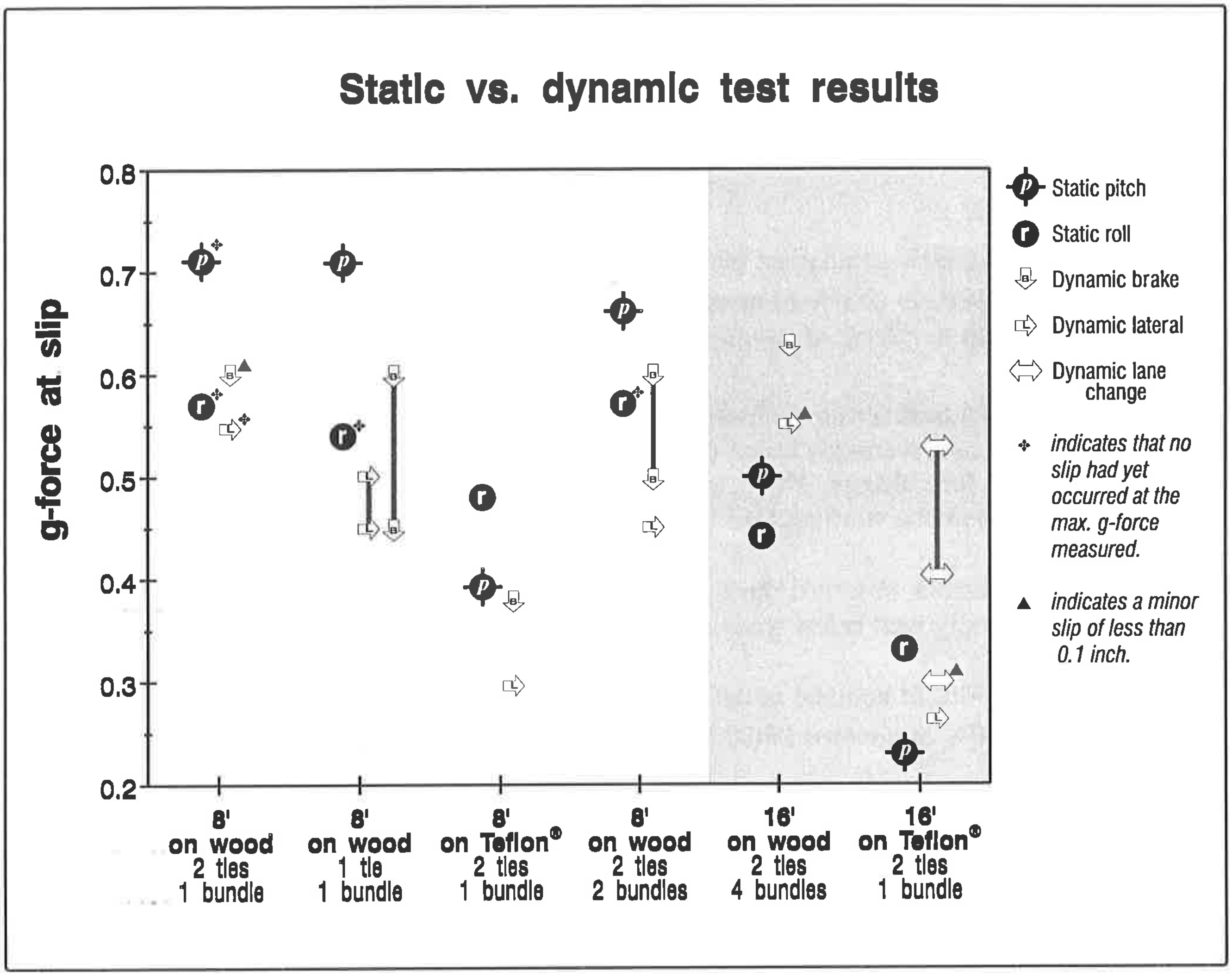


Figure 17. Comparison of the results from the static and dynamic tests at medium tiedown tension.

4.4 Tension Levels in Tiedowns

The maximum nominal tension applied was about 1000 lb during the static tests and 500 lb during the dynamic tests. For any test, **initial** tension varied within and between tiedowns. These variations were affected by friction from the strap, by the chain links and their positions, and by various other factors. The configuration of the bundles also affected the results. A mean tension was calculated by combining the measured tensions for each tiedown and bundle. The results showed that most of the *measured* tensions for the nominal 500-lb (medium) level were within 250 lb of the *nominal* tension. This range of values (250 to 750 lb) is realistic based on measurements for real operators using crowbars as a tensioning aid. The applied tension on the strap created by a typical operator using a crowbar was established to be around 500 lb.

Tiedown tension also varied **during** the tests, particularly at the point of load slippage. During the static pitch tests and dynamic braking maneuvers, tension increased on both sides of the tiedown assemblies, whereas it increased on one side only during the static roll tests and dynamic circle or lane change maneuvers. The overall *peak* tensions at slip observed during the *dynamic* testing, which most closely reflects onroad conditions, are reported below as related to the nominal initial tension (500 lb):

- Braking: 1600 lb (320% of nominal initial tension, 32% of working limit).
- Circle or spiral: 1000 lb (200% of nominal initial tension, 20% of working limit).
- Lane change: 1000 lb (200% of nominal initial tension, 20% of working limit).

For the most part, the peak tensions observed were considerably below those reported above, which represent the worst case scenarios tested (braking: 4 bundles of 16 ft at 40 km/h; spiral: 4 bundles of 16 ft at 57 km/h; lane change: 1 bundle of 16 ft at 90 km/h). Even here, the peak tensions were still considerably below the working load limit of the tiedowns.

The overall peak tensions observed during the *static* testing are reported below. Again, the peaks observed were generally well below these maximums:

- Pitch: 1200 lb (240% of nominal initial tension, 24% of working limit)
- Roll: 1050 lb (210% of nominal initial tension, 21% of working limit)

Please note that the tension variation results presented accrue only to the 500-lb nominal tension, and do not apply to other potential input tensions.

5. Factors that Affected the Results

The complexity of the tests and the wide range of variables that could have affected the results will require the committee that produces the standard to address several parameters that affect load security. Some of the pertinent parameters are listed below:

- The level of tension in the tiedowns (the 500-lb medium tension is adequate and realistic).
- The number and locations of the bundles on the skids. (The same performance was observed for three or four skids with 16-ft bundles.)
- The total weight of the load as well as the weight of each bundle.
- The configuration of the bundles, including the relationships (e.g., degree of support) between bundles. It is important that the bundles be in close contact so as to form a single load.
- The strapping angles and any tension losses due to twisting or positioning of the tiedowns.
- The size and nature of the skid surface on which the bundles rest.
- The adequacy of the steel strapping used to create each bundle before loading, so as to maintain the integrity of the bundle itself.
- The sensitivity and accuracy of the sprockets inside the ratchets that are used to tighten the tiedowns. This determines the incremental adjustment in tension that is possible.
- The surface of the flatbed trailer.
- The number of tiedowns.

6. Commentary

Although the committee that will develop a standard for load security will analyze the results in this report and draw the necessary conclusions, the following points should be considered:

6.1 Static Tests with 8-ft Lumber

- On wood skids, an untied bundle of lumber slipped at 0.41 g (roll) and 0.52 g (pitch).
- On wood skids, no slippage occurred for a single bundle of lumber with two tiedowns. As well, no slippage occurred with two tiedowns for two bundles placed side by side.
- On wood skids, slippage occurred with a single bundle secured with only one tiedown, but only in the pitch test at low tiedown tension.
- Slippage in the pitch test on Teflon® skids with one tiedown was similar to that of a free bundle of lumber with no tiedown. However, with two tiedowns, slippage on Teflon® skids improved substantially from 0.22 g (with no tiedowns) to 0.39 g at medium tension and 0.69 g at high tension.

6.2 Static Tests with 16-ft Lumber

On wood skids:

- An untied bundle of lumber slipped at 0.42 to 0.46 g.
- With two tiedowns on three wood skids, a single bundle did not slip below 0.57 g (roll test) or 0.62 g (pitch test). These levels exceed the stability of most trailers on the highway.
- There was little difference between using four tiedowns and using two tiedowns with a three-bundle configuration.
- No significant slippage (<0.55 g) occurred for four bundles when the lower two bundles and the upper two bundles were each secured with two tiedowns (for a total of four tiedowns) under high or medium tension.
- Slippage occurred for four bundles on wood skids with two tiedowns at 0.44 g (medium tension) and at 0.50 g (high tension) in roll, and 0.50 and 0.59 g respectively in pitch.
- For six bundles of lumber (roll test), the results were similar for two, three, four and six tiedowns: no slippage occurred to around 24° (i.e., 0.40 g) for all three tiedown tensions.

On Teflon® skids:

- An untied bundle slipped at 0.17 to 0.19 g.
- A single bundle with two tiedowns slipped at 0.26 to 0.44 g (roll), and 0.21 to 0.25 g (pitch) depending on tiedown tension.
- Using two or three tiedowns for a single bundle made little difference in the slippage angles.
- Four bundles at medium tension with two, four or five tiedowns all slipped at angles of 12° to 13° (i.e., 0.20 to 0.22 g).
- For a configuration of four bundles (roll test) secured under medium tension, increasing to high tension increased the resistance to slippage from 0.21 to 0.27 g with four tiedowns and from 0.23 to 0.32 g with five tiedowns. This represented a marginal improvement.

- For six bundles of lumber, the results for three, four and six tiedowns were within a range of 12° to 15.5° (i.e., 0.21 to 0.27 g) under roll conditions and a range of 11° to 15° (i.e., 0.19 to 0.26 g) under pitch conditions.
- There was little difference in behavior between five and six bundles of lumber for either roll or pitch conditions if each was secured with three tiedowns.

6.3 Dynamic Tests

The summary of the combined dynamic and static results (Figure 17) leads to the following observations:

- The data for pitch and roll for the 8-ft bundles on wood skids were consistent and the g-forces at which slippage occurred were always higher under static conditions than under dynamic conditions. Thus, static measurements could only be used as an estimate of dynamic performance after development of appropriate safety factors.
- The same trend was observed for the dynamic and static results with 8-ft bundles on Teflon® skids. Static data could again only be used to extrapolate the dynamic performance if appropriate safety factors are applied.
- The relationship between dynamic and static results for the 16-ft bundles seemed to be the reverse of that for the 8-ft bundles. With 16-ft bundles, dynamic g-forces seem to cause slippage at a similar or higher g level than that encountered under static roll or pitch conditions. This trend applied to both wood and Teflon® skids. As such, static measurements could be used as a conservative estimate of dynamic performance, but these unexpected results warrant further investigation.
- In general, slippage in the lateral (roll) direction occurred at lower g-forces than in the longitudinal axis (i.e., braking) during dynamic testing, and also during the static tests on a wood surface. Conversely, on a Teflon® surface, loads generally failed at a somewhat lower angle in pitch than in roll during the static tests.

CONCLUSIONS

Based on the study results, the following general conclusions appear evident:

1. Friction along the surfaces of contact between the load and its supports would appear to be the principal factor that affects load security. This is highlighted by the relative performance between the wood and Teflon® surfaces.
2. Tiedown tension would also appear to have a significant impact on the efficiency of tiedown systems. However, this factor is somewhat difficult to control given the nature of the manual winch systems that are presently most commonly used on transport vehicles.
3. Adding additional tiedowns, beyond a certain minimum needed to assure load integrity, would appear to provide only minor improvements in load security.

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Appendix 1

Slip angles and g-forces in the static and dynamic tests

(> indicates that no slippage occurred at the maximum angle or g-force recorded)[a]

Test	Nominal load-cell tensions										
	High			Medium			Low			Zero	
	Angle	g-force	Tension (lb)	Angle	g-force	Tension (lb)	Angle	g-force	Tension (lb)	Angle	g-force
8 ft on wood											
2 tiedowns											
Roll	>35°	>0.57	915	>35°	>0.57	480	—	—	—	24.5°	0.41
Pitch	>45°	>0.71	920	>45°	>0.71	545	>45°	>0.71	240	31°	0.52
Dynamic	—	—	—	—	0.60	—	—	—	—	—	—
1 tiedown											
Roll	>35°	>0.57	845	>33°	>0.54	430	>33°	>0.54	200	24.5°	0.41
Pitch	>45°	>0.71	915	45°	0.71	545	31°	0.52	240	31°	0.52
Dynamic											
- braking	—	—	—	—	0.45-0.60	—	—	—	—	—	—
- circle	—	—	—	—	0.45-0.50	—	—	—	—	—	—
8 ft on Teflon®											
2 tiedowns											
Roll	>35°	>0.57	958	29°	0.48	545	20°	0.33	241	10°	0.17
Pitch	44°	0.69	1103	23°	0.39	503	15°	0.26	205	13°	0.22
Dynamic											
- braking	—	—	—	—	0.38	—	—	—	—	—	—
- circle	—	—	—	—	0.30	—	—	—	—	—	—
1 tiedown											
Roll	26.5°	0.45	985	20°	0.34	520	16°	0.28	250	10°	0.17
Pitch	16°	0.28	860	15°	0.26	580	13.5°	0.23	230	13°	0.22
16 ft on wood											
2 tiedowns											
Roll	>35°	>0.57	915	—	—	—	>35°	>0.57	240	25°	0.42
Pitch	>42°	>0.67	950	>42°	>0.67	510	38°	0.62	255	27.5°	0.46
16 ft on Teflon®											
3 tiedowns											
Roll	28°	0.47	945	19.8°	0.34	465	—	—		10.9°	0.19
Pitch	22°	0.37	958	14°	0.24	578	—	—		10°	0.17
2 tiedowns											
Roll	26°	0.44	967	19.8°	0.34	470	15.5°	0.27	200	10.9°	0.19
Pitch	14.5°	0.25	1015	13.5°	0.23	505	12.2°	0.21	235	10°	0.17
Dynamic											
- circle	—	—	—	—	0.26	—	—	—	—	—	—
- lane change	—	—	—	—	0.30-0.53	—	—	—	—	—	—

4 bundles 16 ft on wood (2 tiedowns, medium tension)	Angle	g-force	Tension (lb)
Roll	26°	0.44	503
Pitch	30°	0.50	545
Dynamic - spiral	—	0.55	525
- braking (30 and 40 km/h)	—	0.60-0.63	520

[a] The "tension" values reported in the table represent the measured *mean* tensions in the tiedowns, not the nominal values.

Appendix 2

Chapter 11 of the CCMTA Report

11.2/ Dressed Lumber Test Series, 1 through 6

11.2.1 Purpose

This test investigates the effect of tying down combinations of bundles of dressed lumber. The purpose is to investigate the effect of tiering and tiedown method on the security of the bundles when subjected to static and dynamic loading.

11.2.2/ Method

Six test series as shown in Figure 11.2(a), (b), (c), (d), (e), and (f) respectively shall be subjected to various tests:

(a) lateral tilting,
(b) longitudinal tilting, and
(c) dynamic manoeuvres in the lateral plane.

The tiedowns shall be instrumented to measure tension. Three preload tensions shall be used in the webbing tiedowns:

(a) low tension (5% of WLL),
(b) medium tension (20% of WLL), and
(b) high tension (50% of WLL).

The bundles shall be 8 feet in length and consist of boards of dressed lumber. Two types of truck floor decking shall be tested:

(a) wood deck and
(b) a teflon low-friction sheet between the load and the deck.

Specific tests shall also be done with a sheet of low-friction material between the tiers to assess the likelihood of slippage. Changes in tiedown tension and tier deflection shall be measured.

11.2.3/ Results

The results of this test should determine the load capacity of the various tiedown methods and should illustrate the consequences of load movement.

Note: Actual number of test runs in test matrices may be shortened due to requirements becoming obvious during testing and thus eliminating a number of test configurations.

11.2.4 (a)/ Test Matrix – One Bundle 8' Dressed Lumber (Refer to Figure 11.2(a))

Test No. 11.2(a)	Number of Tiedowns	Tension L	Tension M	Tension H	Deck Material	Tilt Direction Lat.	Tilt Direction Long.	Dynamic Test Yes	Dynamic Test No
1(a)	1	X			Wood	X			X
1(b)	1	X			Wood		X		X
1(c)	1		X		Wood	X			X
1(d)	1		X		Wood		X		X
1(e)	1			X	Wood	X			X
1(f)	1			X	Wood		X		X

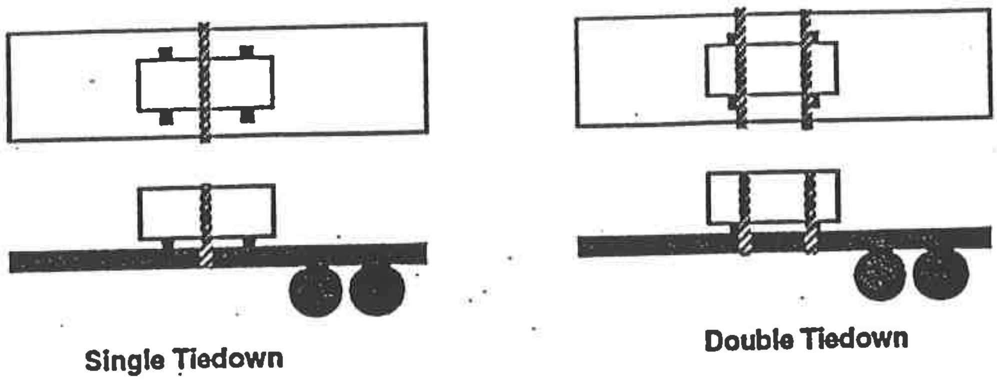
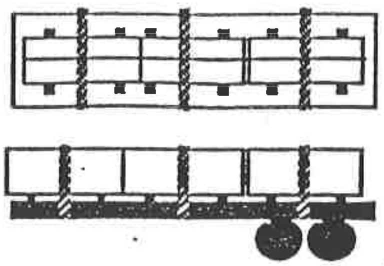


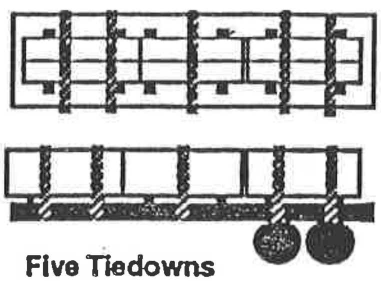
Figure 11.2(a)/ One Bundle 8' Dressed Lumber

11.2.4 (a)/ Test Matrix – One Bundle 8' Dressed Lumber (Refer to Figure 11.2(a))

Test No. 11.2(a)	Number of Tiedowns	Tension L	Tension M	Tension H	Deck Material	Tilt Direction Lat.	Tilt Direction Long.	Dynamic Test Yes	Dynamic Test No
2(a)	2	X			Wood	X			X
2(b)	2	X			Wood		X		X
2(c)	2		X		Wood	X			X
2(d)	2		X		Wood		X		X
2(e)	2			X	Wood	X			X
2(f)	2			X	Wood		X		X
3(a)	1	X			Teflon	X			X
3(b)	1	X			Teflon		X		X
3(c)	1		X		Teflon	X			X
3(d)	1		X		Teflon		X		X
3(e)	1			X	Teflon	X			X
3(f)	1			X	Teflon		X		X
4(a)	2	X			Teflon	X			X
4(b)	2	X			Teflon		X		X
4(c)	2		X		Teflon	X			X
4(d)	2		X		Teflon		X		X
4(e)	2			X	Teflon	X			X
4(f)	2			X	Teflon		X		X



Three Tiedowns



Five Tiedowns

Figure 11.2(b)/ Six Bundles 8' Dressed Lumber

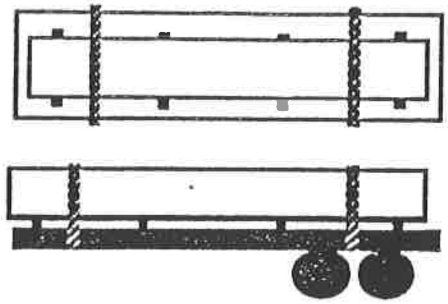


Figure 11.2(c)/ One Bundle 16' Dressed Lumber

11.2.4 (b)/ Test Matrix – Six Bundles 8' Dressed Lumber (Refer to Figure 11.2(b))

Test No. 11.2(b)	Number of Tiedowns	Tension determined in (a)	Deck Material	Tilt Direction Lat.	Tilt Direction Long.	Dynamic Test Yes	Dynamic Test No
1	3	X	Wood	X		X	
1(a)	3	X	Wood		X	X	
2	5	X	Wood	X		X	
2(a)	5	X	Wood		X	X	

11.2.4 (c)/ Test Matrix – One Bundle 16' Dressed Lumber (Refer to Figure 11.2(c))

Test No. 11.2(c)	Number of Tiedowns	Tension L	Tension M	Tension H	Deck Material	Tilt Direction Lat.	Tilt Direction Long.	Dynamic Test Yes	Dynamic Test No
1(a)	2	X			Wood	X			X
1(b)	2	X			Wood		X		X
1(c)	2		X		Wood	X			X
1(d)	2		X		Wood		X		X
1(e)	2			X	Wood	X			X
1(f)	2			X	Wood		X		X
2(a)	2	X			Teflon	X			X
2(b)	2	X			Teflon		X		X
2(c)	2		X		Teflon	X			X
2(d)	2		X		Teflon		X		X
2(e)	2			X	Teflon	X			X
2(f)	2			X	Teflon		X		X

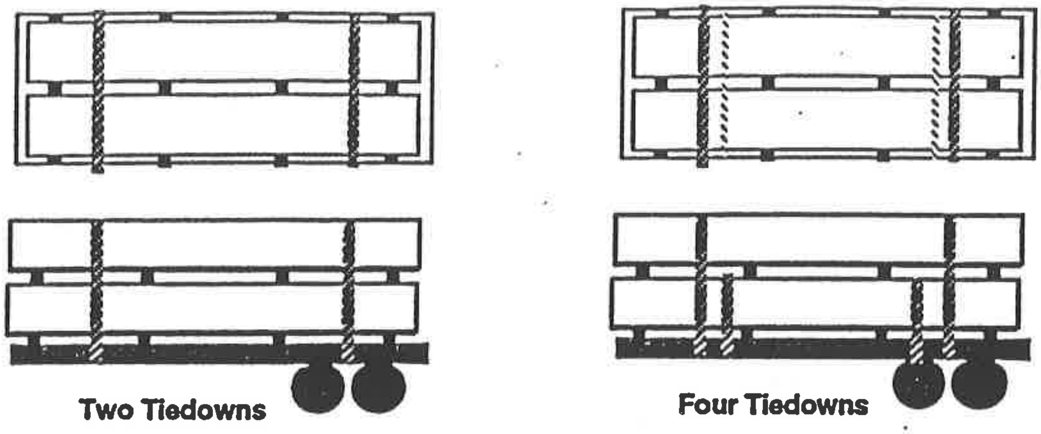


Figure 11.2(d)/ Four Bundles 16' (Tiered) Dressed Lumber

11.2.4 (d)/ Test Matrix – Four Bundles 16' (Tiered) Dressed Lumber (Refer to Figure 11.2(d))

Test No. 11.2(d)	Number of Tiedowns	Tension L	M	H	Deck Material	Tilt Direction Lat.	Long.	Dynamic Test Yes	No
1(a)	2	X			Wood	X			X
1(b)	2	X			Wood		X		X
1(c)	2		X		Wood	X			X
1(d)	2		X		Wood		X		X
1(e)	2			X	Wood	X			X
1(f)	2			X	Wood		X		X
2(a)	2	X			Teflon	X			X
2(b)	2	X			Teflon		X		X
2(c)	2		X		Teflon	X			X
2(d)	2		X		Teflon		X		X
2(e)	2			X	Teflon	X			X
2(f)	2			X	Teflon		X		X
3(a)	4	X			Wood	X			X
3(b)	4	X			Wood		X		X
3(c)	4		X		Wood	X			X
3(d)	4		X		Wood		X		X
3(e)	4			X	Wood	X			X
3(f)	4			X	Wood		X		X
4(a)	4	X			Teflon	X			X
4(b)	4	X			Teflon		X		X
4(c)	4		X		Teflon	X			X
4(d)	4		X		Teflon		X		X
4(e)	4			X	Teflon	X			X
4(f)	4			X	Teflon		X		X
5	as required				Wood			X	

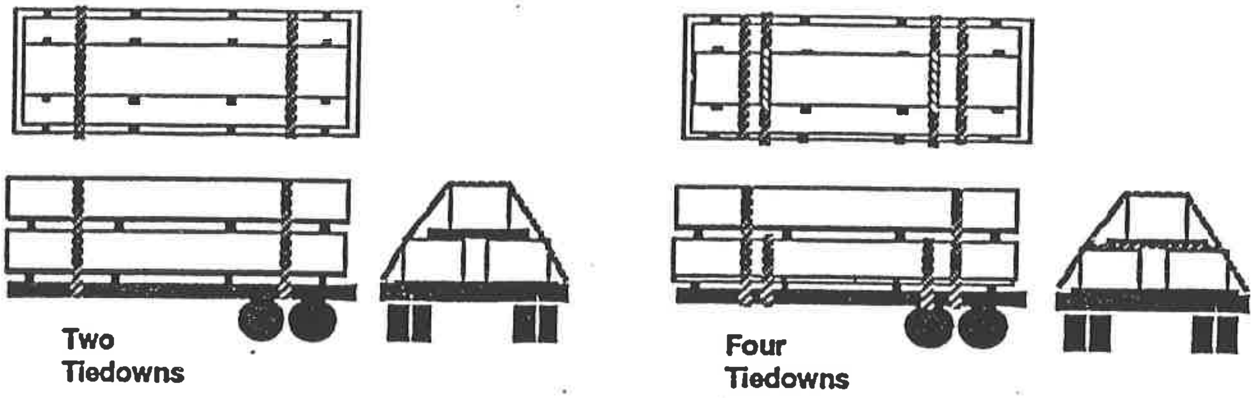


Figure 11.2(e)/ Three Bundles 16' (Tiered) Dressed Lumber

11.2.4 (e)/ Test Matrix – Three Bundles 16' (Tiered) Dressed Lumber (Refer to Figure 11.2(e))

Test No. 11.2(e)	Number of Tiedowns	Tension determined in (d)	Deck Material	Tilt Direction Lat.	Tilt Direction Long.	Dynamic Test Yes	Dynamic Test No
1	2	X	Wood	X			X
2	as required	X	Wood	X			X

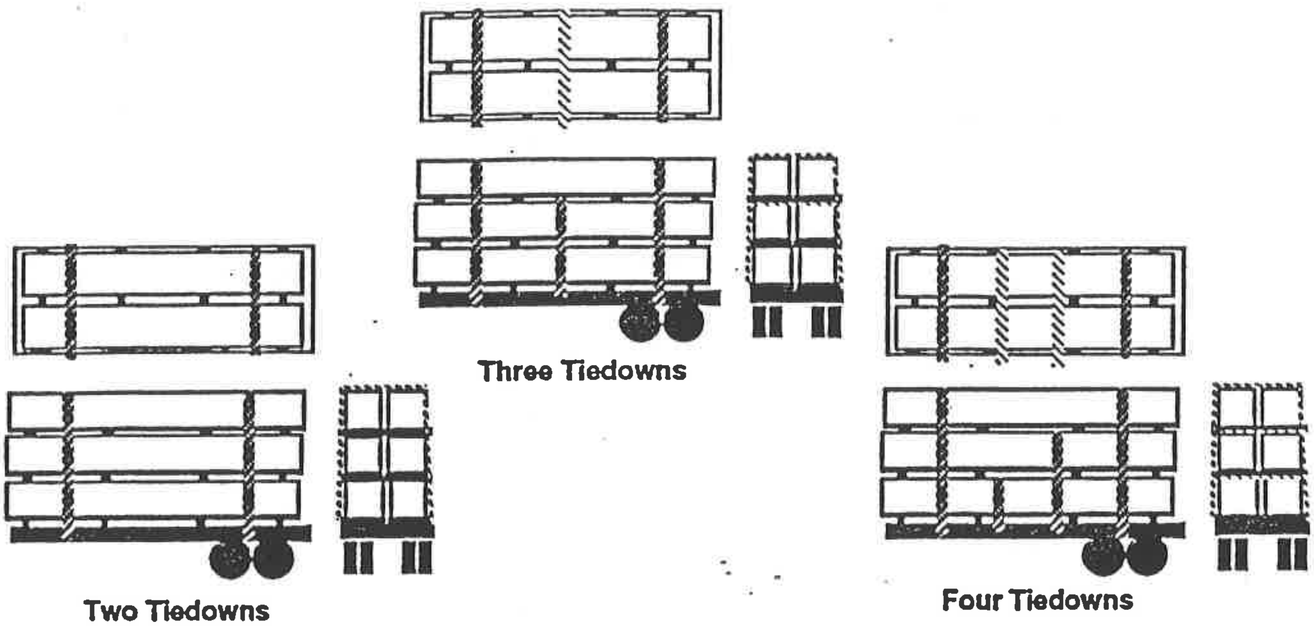


Figure 11.2(f)/ Six Bundles 16' (Tiered) Dressed Lumber

11.2.4 (f)/ Test Matrix – Six Bundles 16' (Tiered) Dressed Lumber (Refer to Figure 11.2(f))

Test	Number of	Tension			Deck	Tilt Direction		Dynamic Test	
No. 11.2(f)	Tiedowns	L	M	H	Material	Lat.	Long.	Yes	No
1(a)	2	X			Wood	X			X
1(b)	2	X			Wood		X		X
1(c)	2		X		Wood	X			X
1(d)	2		X		Wood		X		X
1(e)	2			X	Wood	X			X
1(f)	2			X	Wood		X		X

11.2.4 (f)/ Test Matrix – Six Bundles 16' (Tiered) Dressed Lumber (Refer to Figure 11.2(f))

Test No. 11.2(f)	Number of Tiedowns	Tension L	Tension M	Tension H	Deck Material	Tilt Direction Lat.	Tilt Direction Long.	Dynamic Test Yes	Dynamic Test No
2(a)	2	X			Teflon	X			X
2(b)	2	X			Teflon		X		X
2(c)	2		X		Teflon	X			X
2(d)	2		X		Teflon		X		X
2(e)	2			X	Teflon	X			X
2(f)	2			X	Teflon		X		X
3(a)	3	X			Wood	X			X
3(b)	3	X			Wood		X		X
3(c)	3		X		Wood	X			X
3(d)	3		X		Wood		X		X
3(e)	3			X	Wood	X			X
3(f)	3			X	Wood		X		X
4(a)	3	X			Teflon	X			X
4(b)	3	X			Teflon		X		X
4(c)	3		X		Teflon	X			X
4(d)	3		X		Teflon		X		X
4(e)	3			X	Teflon	X			X
4(f)	3			X	Teflon		X		X
5(a)	4	X			Wood	X			X
5(b)	4	X			Wood		X		X
5(c)	4		X		Wood	X			X
5(d)	4		X		Wood		X		X
5(e)	4			X	Wood	X			X
5(f)	4			X	Wood		X		X
6(a)	4	X			Teflon	X			X
6(b)	4	X			Teflon		X		X
6(c)	4		X		Teflon	X			X
6(d)	4		X		Teflon		X		X
6(e)	4			X	Teflon	X			X
6(f)	4			X	Teflon		X		X

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