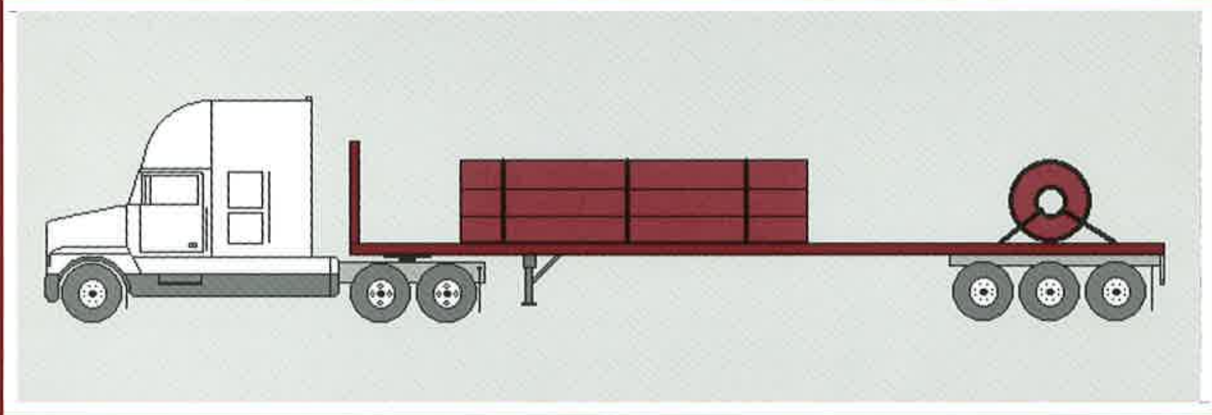
CCMTA Load Security Research Project

Report # 13

BENDING STRENGTH OF TRAILER STAKES



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

CCMTA Load Security Research Project

Report # 13

BENDING STRENGTH OF TRAILER STAKES

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

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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 bending reaction of typical sections used as trailer stakes made from various materials with different cross sections. A bending force was applied 1 m above, and parallel to, the trailer deck in an outboard direction and was increased until the stake material yielded. The applied force and accompanying stake deflection was measured.

The tests showed that wood stakes failed abruptly by cracking and splintering, metal channels failed in bending, and tubes buckled.

None of the sections typically used as trailer stakes has adequate strength for use as part of a cargo securement system.

Executive Summary

A lack of understanding of the technical basis for existing regulations on cargo securement meant it was not possible to resolve differences between them to revise a cargo securement standard for Canada's National Safety Code. This process identified a number of research needs, which are now being addressed through the North American Load Security Research Project.

This preliminary work identified a number of components that may be used in a cargo securement system that required testing. One of these components was stakes fitted into trailer stake pockets, and commonly used on stake and rack flatbed trailers. Such stakes may be used to contain cargo, so the bending resistance must react against the cargo. The ability of the stakes to resist bending was therefore examined to determine the maximum forces that could be applied and the resulting deflections due to bending, as outlined in Section 9.4 of the project proposal.

A pneumatically operated machine was used to apply a bending moment to the stake while measuring applied force and deflection. Sample stakes were inserted into the machine and the stakes were loaded until the material yielded or fractured.

Wood stakes failed abruptly by cracking and splitting. The bending moment to cause failure was less than any of the metal stakes tested, and they were the most flexible of any of the stakes tested. Thick web aluminum channel and steel tubes and channel allowed the highest bending moment and stiffest reaction before yielding. Hollow sections, such as steel and aluminum rectangular tubing kinked and buckled at loads in the plastic region of the characteristic curve. Once kinking and buckling occurred, the stake folded and offered little additional resistance.

All sections failed at quite modest loads, in accordance with the engineering theory of bending. None of the sections typically used as trailer stakes is adequate to serve as part of a cargo securement system.

This report presents technical results from just one task in this project. The results may be limited by the scope of this task, but are placed in context in the summary report.

Acknowledgments

The work reported here is part of the Load Security Research Project conducted on behalf of the Canadian Council of Motor Transport Administrators (CCMTA) by Strategic Transportation Research Branch of Ontario Ministry of Transportation. This section recognizes the direct contributions of those who organized and conducted this part of the work. It also recognizes that there have been many indirect contributions by others.

The project was funded jointly by the following :

- Alberta Transportation and Utilities;
- Allegheny Industrial Associates;
- The Aluminum Association;
- American Trucking Associations;
- British Columbia Ministry of Transportation and Highways;
- Canadian Trucking Research Institute;
- Commercial Vehicle Safety Alliance;
- Forest Engineering Research Institute of Canada;
- Manitoba Highways and Transportation;
- Ministère des Transports du Québec;
- New Brunswick Ministry of Transportation;
- Newfoundland Ministry of Transportation and Public Works;
- New York State Department of Transportation;
- Nova Scotia Ministry of Transportation;
- Prince Edward Island Department of Transportation;
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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 standard for cargo securement and inspection.

The outer frames and rails of many flatdeck trailers are equipped with pockets that are designed to take a vertical stake. Stakes may be wood, or standard metal sections like steel and aluminum structural sections, or may be custom-designed extrusions. Stake pockets are invariably open on the bottom, so stakes are tapered or equipped with a stop, or wedges are used to keep them in place. In some instances flat sections of wall material, usually wood or fibreglass, are connected between the stakes to provide a removable side wall to the trailer.

An article of cargo may be placed directly or indirectly against a stake inserted into a stake pocket on the trailer, as illustrated in Figure 1. If a stake is used in this manner, it takes lateral loads due to a cargo shift across the deck, as shown in Figure 2. The stake reacts the applied load at one or several contact points along its length by producing a bending moment in the stake that is reacted at the stake pocket.

Flatdeck trailer stakes are diverse, and are not known to be rated. The purpose of this test was to examine the bending strength of typical sections that may be used as stakes, to determine the extent to which they might be considered part of a cargo securement system. The work was outlined in Section 9.4 of the project proposal [1]. It does not deal with engineered stakes, such as those used on log trailers, which are designed to restrain very heavy loads. The strength of the stake pocket is also beyond the scope of this test, but has been addressed in detail in another part of the project [2].

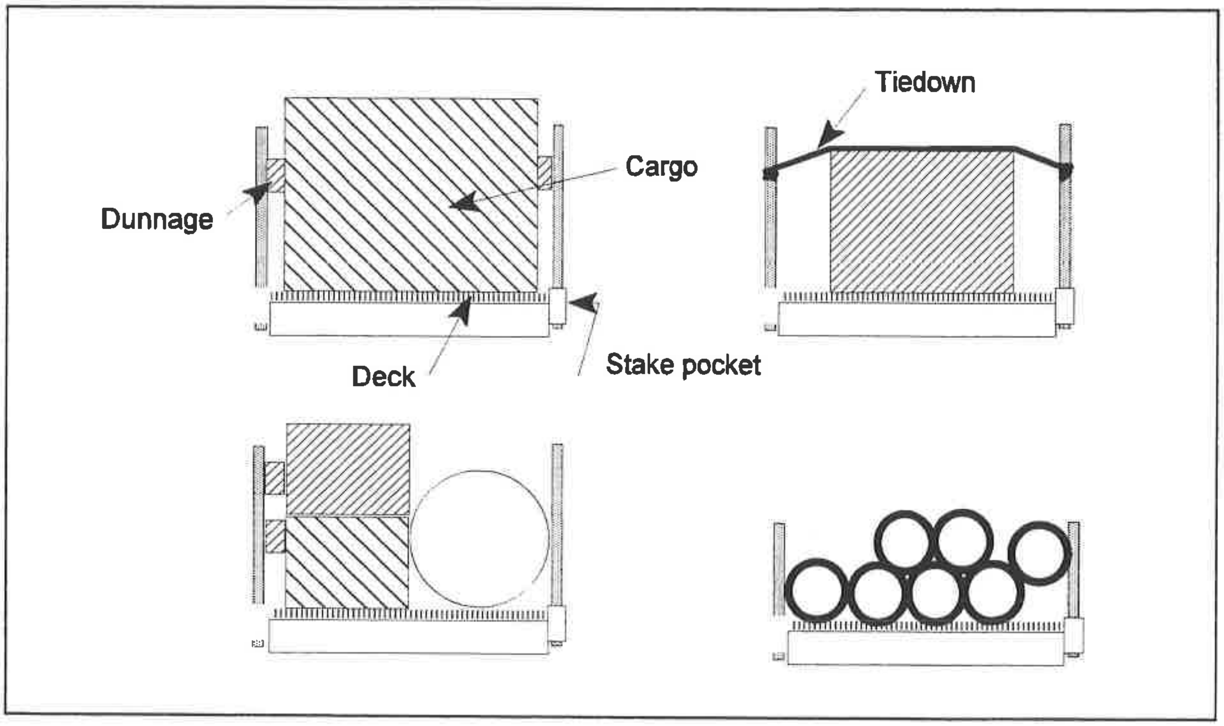

Figure 1/ Uses of Stakes to Secure Cargo

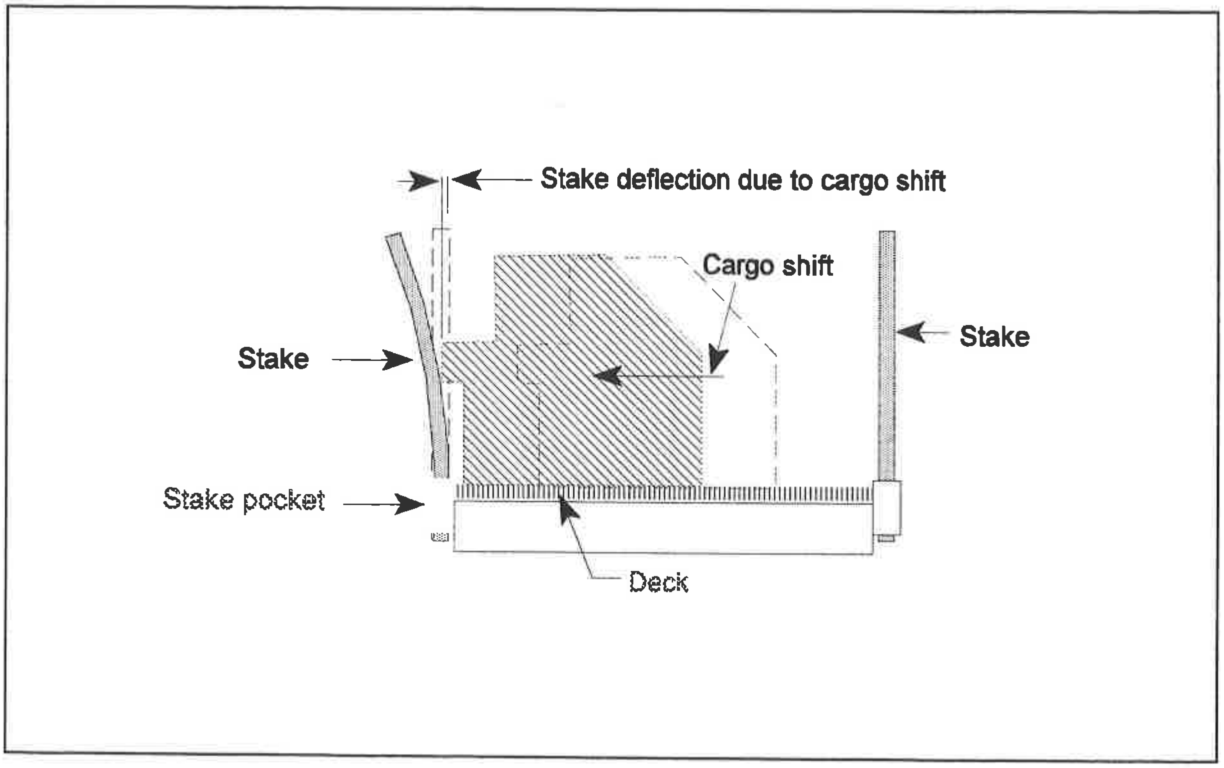

Figure 2/ Stake Reaction to Cargo Shift

2/ Test Program

2.1/ Objectives

The objectives of this test were to determine the bending strength of various typical trailer stakes, and to apply these data to determine the extent that stakes should be considered part of a cargo securement system.

2.2/ Scope

The test was conducted using eight different stakes, two of wood, two of steel, and four of aluminum. Stakes of asymmetric form that could be fitted in a pocket in either of two directions were tested in both directions.

3/ Procedures

3.1/ Test Apparatus

A machine built to determine the strength of nailed wood blocking was adapted for this series of tests [3], as shown in Figures 3 and 4. It was constructed with a steel framework, with a pneumatic cylinder that applied force to a ram, and guideways that constrained the ram to travel in a straight line. Ram travel was monitored by a displacement transducer, and the ram reaction force was measured by a force transducer. Ram speed was controlled by a manually operated pneumatic valve. The machine was adapted with a very heavy duty stake pocket, suitably reinforced to allow zero deflection at the pocket. The ram was adapted with a blunt knife edge at its centre to apply a point load perpendicular to the stake, 1 m from the stake pocket.

The stakes tested were:

1/ 5x10 cm (2x4 in nominal) construction grade oak with grain along length;
2/ 5x10 cm (2x4 in nominal) construction grade spruce with grain along length;
3/ ASTM A.36 structural steel channel with 7.6x0.64 cm (3x0.25 in) web and 3.8 cm (1.5 in) flange at 7.5 kg/m (5 lb/ft);
4/ ASTM A.36 welded steel rectangular hollow tube 7.6x3.8 cm (3x1.5 in), 0.32 cm (0.120 in) thick, at 5.2 kg/m, 3.48 lb/ft;
5/ 6061-T6 aluminum structural channel with 7.6x0.48 cm (3x0.19 in) web and 3.8 cm (1.5 in) flange at 2.3 kg/m (1.52 lb/ft);
6/ 6061-T6 aluminum structural channel with 7.6x0.64 cm (3x0.25 in) web and 5 cm (2 in) flange at 3.3 kg/m (2.24 lb/ft);
7/ 6063-T5 hollow aluminum rectangular structural tubing 7.6x3.8 cm (3x1.5 in), 0.32 cm (0.120 in) thick at 1.8 kg/m (1.19 lb/ft); and
8/ Extruded triangular aluminum wall kit stake, with guideways for wall sections and a reinforced base, taken from an operational wall system on a flatdeck trailer.

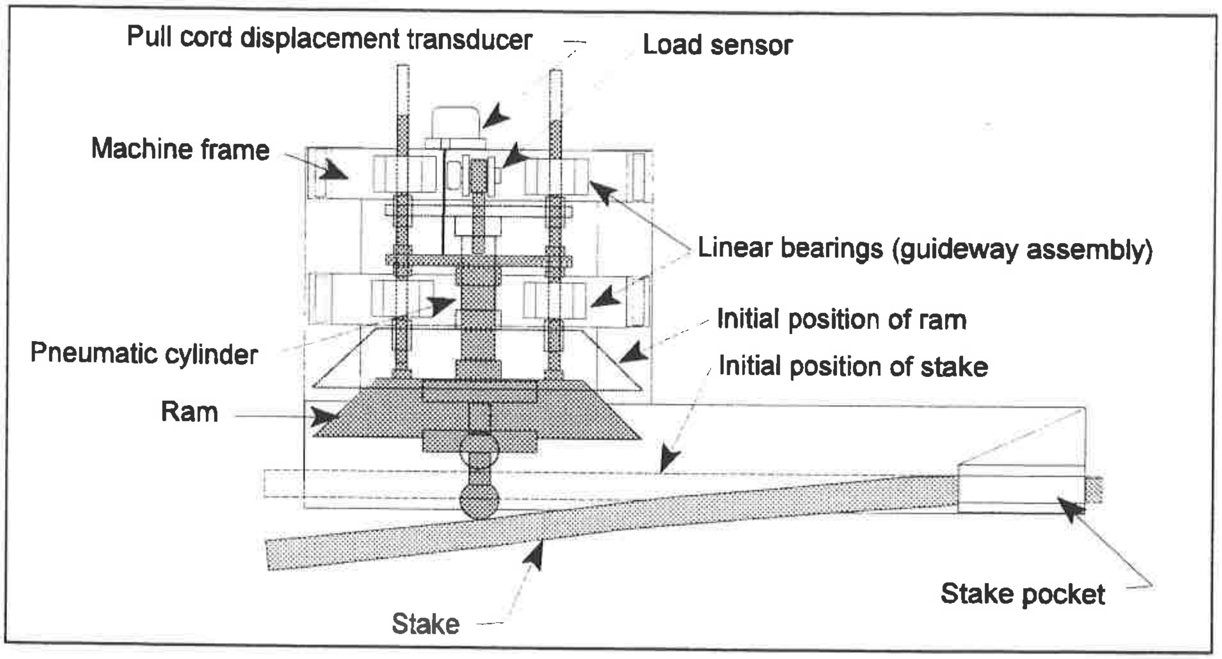

Figure 3/ Diagram of Main Components of Test Machine

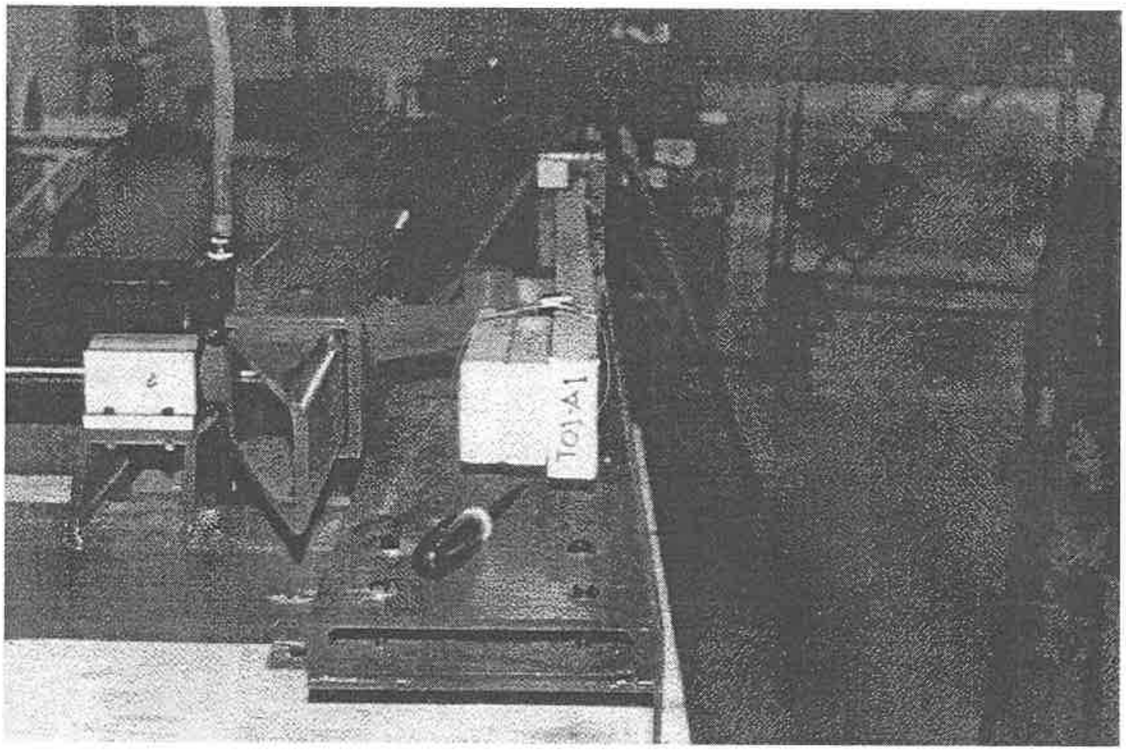

Figure 4/ Test Machine with Stake Installed and Ram Positioned

Table 1/ Stake Material Yield Stress

Material	**Lower Tensile Yield Stress in kg/cm^2 (lb/in^2)**
Oak	577-598 (8,200-8,500)at proportionality limit [4]
Spruce	456-472 (6,500-6,700) at proportionality limit [4]
Steel - ASTM A.36	2,534 (36,000) [5]
Aluminum - 6061-T6	2,851 (40,500) [5]
Aluminum - 6063-T5	1,971 (28,000) [5]

The stake material yield stresses are shown in Table 1.

All stake samples were cut to length to fit the test machine, with allowance for stake pocket depth, and ram clearance at maximum bending.

The maximum tensile stress for a uniform section stake supported as shown in Figure 5 occurs at the outer fibre of the stake, where the stake inserts into the stake pocket, on the side of the applied force. The maximum compressive stress occurs at the outer fibre of the stake where the stake inserts into the stake pocket on the other side of the stake.

Some of the stake sections were symmetrical in shape about their neutral axis in the bending plane. For these stakes a bend in either direction should produce similar characteristics unless there are internal flaws or inconsistencies in the material. For non-symmetrical channels, it was necessary to test in both directions about the bending plane, as shown in Figure 6.

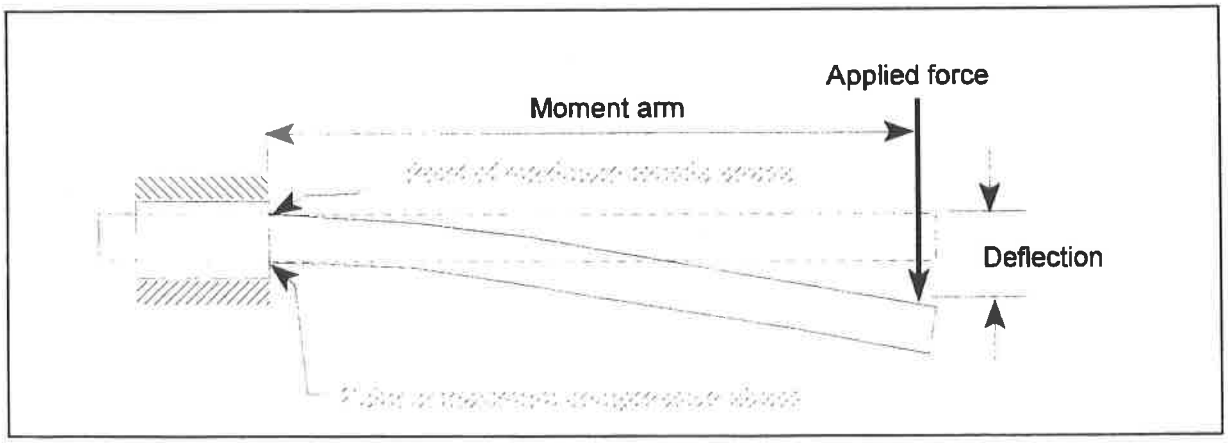

Figure 5/ Points of Maximum Stress

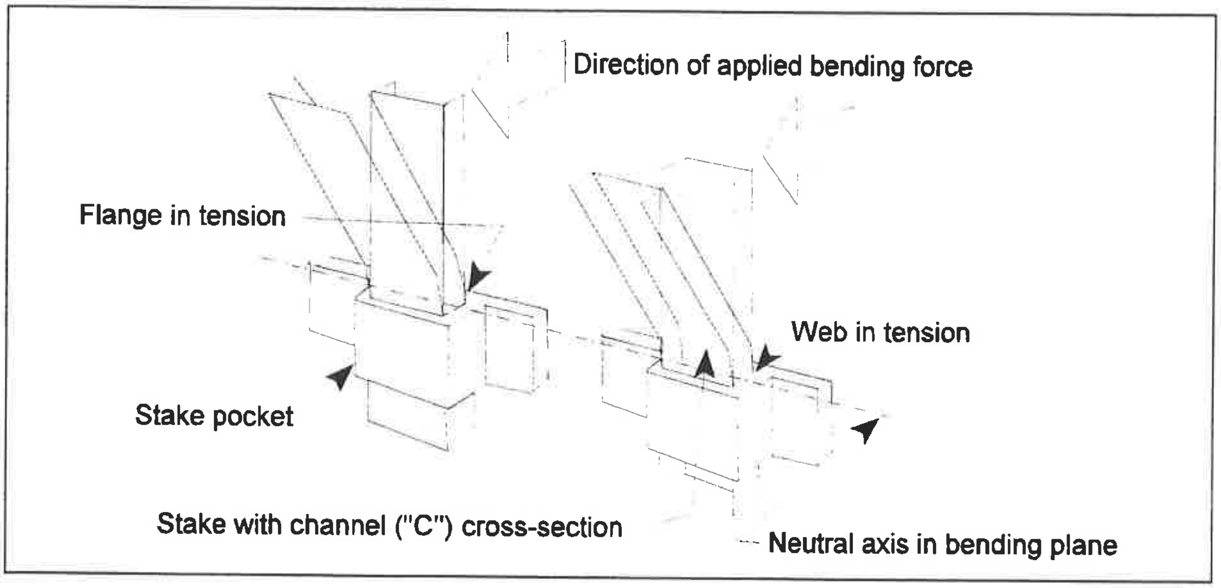

Figure 6/ Bending About Neutral Axis in Both Directions

3.2/ Instrumentation and Data Capture

A Strainsert model CPA-0.75-1 clevis pin load sensor, rated at 26.7 kN (6,000 lb), connected the ram and guide mechanism to the test machine frame to measure the reaction force of the ram on the stake. A Unimeasure model P510-2 pull cord transducer attached between the test machine frame and the ram mechanism measured the displacement of the stake at the point of application of the force.

Data from these instruments were captured into a PC-based data acquisition system using a sample rate which was adequate to define the applied force and displacements of the stake. 35 mm and video cameras were used to record procedures, characteristics and outcomes of the tests of general or particular interest.

3.3/ Test Procedures

A stake sample was placed into the stake test machine stake pocket, and was shimmed to remove any lateral play. Wedges were then hammered in to hold the stake secure. The ram was then moved slowly forward until it just touched the stake. The instruments were calibrated and set to zero. The ram was energised by manual operation of a pneumatic valve, and pushed on the stake until the stake failed. The ram was stopped, returned to its original position, and the stake was removed.

The force and displacement data were captured to a PC based computer system. The data in the PC were saved to a file on the hard disk, under a file name that completely described the test conditions. The data were retrieved, the calibrations were examined, adjusted if necessary, and a quick look assessed whether the data looked reasonable.

If there was any question, the run was repeated. The file was saved again, and a backup was saved immediately on a floppy disk.

Samples of equipment and test activity were recorded by photograph, slides and on video tape. A detailed log of test activities and observations was maintained.

3.4/ Data Processing

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

3.5/ Test Matrix

There were eight stake samples, including three channels with a non-symmetric cross section that were tested in two orientations. The test matrix is presented in Table 2.

Table 2/ Test Matrix

Test	Material	Size	Tension
1	Wood - oak	5x10 cm (2x4 in) nominal, solid section	
2	Wood - spruce	5x10 cm (2x4 in) nominal, solid section	
3a	ASTM A.36 steel structural channel	7.6x0.64 cm (3x0.258 in) web, 3.8 cm (1.5 in) flange at 7.5 kg/m (5 lb/ft)	Web
3b	As above	As above	Flange
4	ASTM A.36 steel rectangular tube	7.6x3.8 cm (3x1.5 in), 0.32 cm (0.12 in) thick at 5.2 kg/m (3.48 lb/ft)	
5a	6061-T6 aluminum structural channel	7.6x3.8 cm (3x1.5 in), 0.48 cm (0.19 in) thick at 2.3 kg/m (1.52 lb/ft)	Web
5b	As above	As above	Flange
6a	6061-T6 aluminum structural channel	7.6x5 cm (3x2 in), 0.64 cm (0.25 in) thick at 3.3 kg/m (2.24 lb/ft)	Web
6b	As above	As above	Flange
7	6063-T5 aluminum rectangular tube	7.6x3.8 cm (3x1.5 in), 0.30 cm (0.120 in) thick at 1.8 kg/m (1.19 lb/ft)	
8	Extruded aluminum wall kit stake	Triangular outside, circular inside with slots for wall sections and reinforced base	

4/ Results and Observations

When the oak and spruce stakes were tested, both fractured by splitting on the tensile side of the stake near the stake pocket. The oak stake is shown being loaded in Figure 7. The bending moment and deflection relationship for oak and spruce stakes is shown in Figure 8.

The steel channel flange buckled slightly when it was compressed. When tested with flanges in tension, they elongated at their edges. The steel channel characteristic is shown in Figure 9.

When the aluminum channel was tested with web in tension, elongation was noted in the web and compression was noted in the flange. There was no evidence of buckling as with steel channel. Testing with the flange in tension caused yielding of the flange edge. The aluminum stake bending characteristic is shown in Figure 10.

With both steel and aluminum tubes, the stake face under compression kinked and bent at maximum load. The extruded aluminum wall kit stake, with a hollow section, bent with a characteristic similar to the channel sections. The characteristics for the rectangular hollow tubes and wall kit stake are shown in Figure 11.

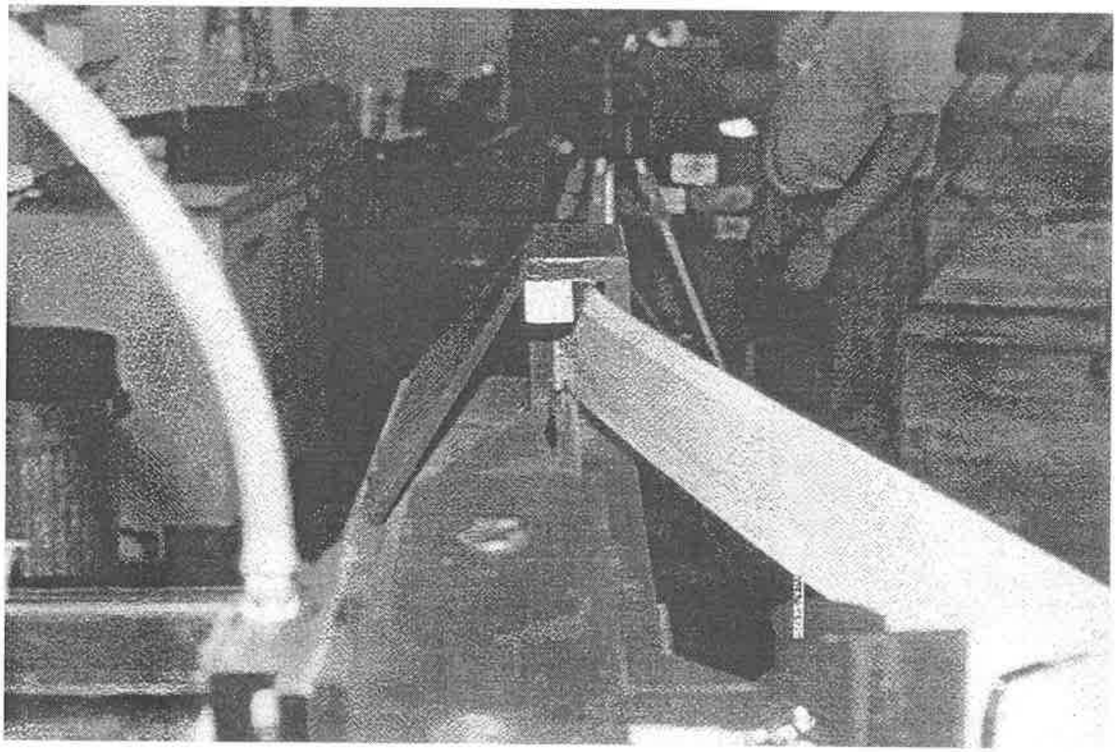

Figure 7/ Machine Loading Oak Stake Close to Failure

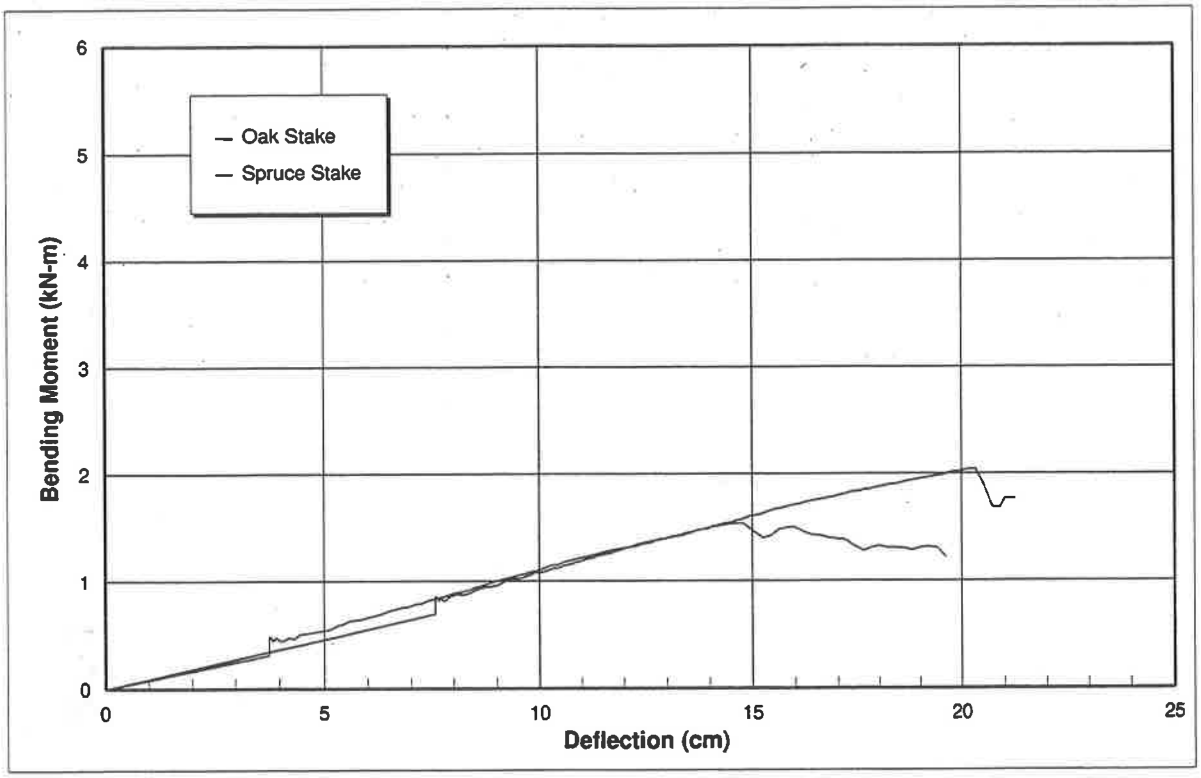

Figure 8/ Oak and Spruce Stake Bending Moment vs Deflection

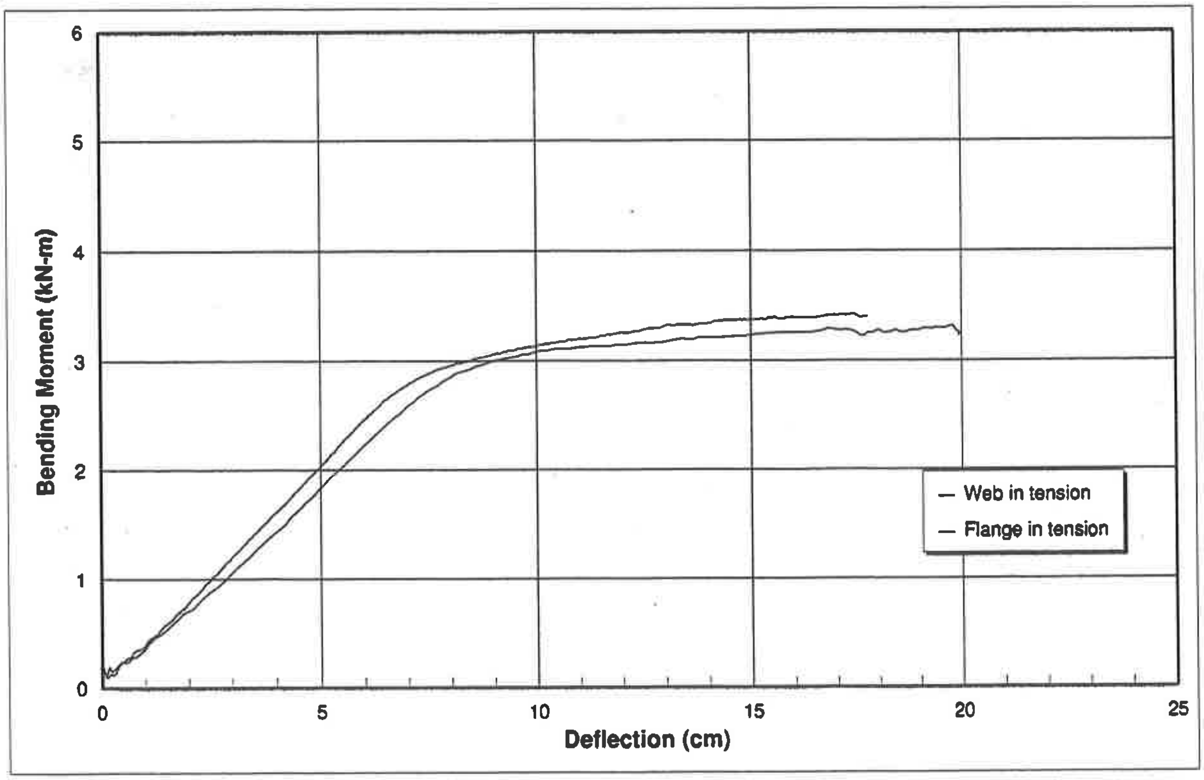

Figure 9/ Steel Channel Stake Bending Moment vs Deflection

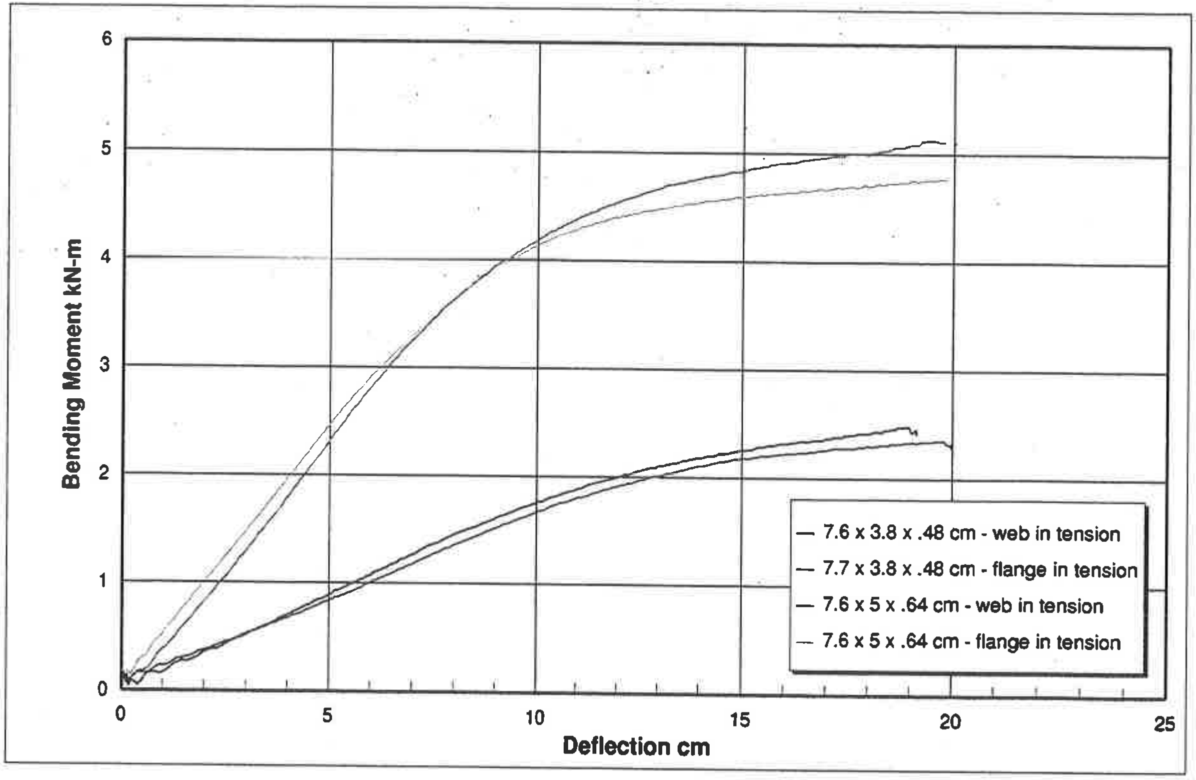

Figure 10/ Aluminum Channel Stake Bending Moment vs Deflection

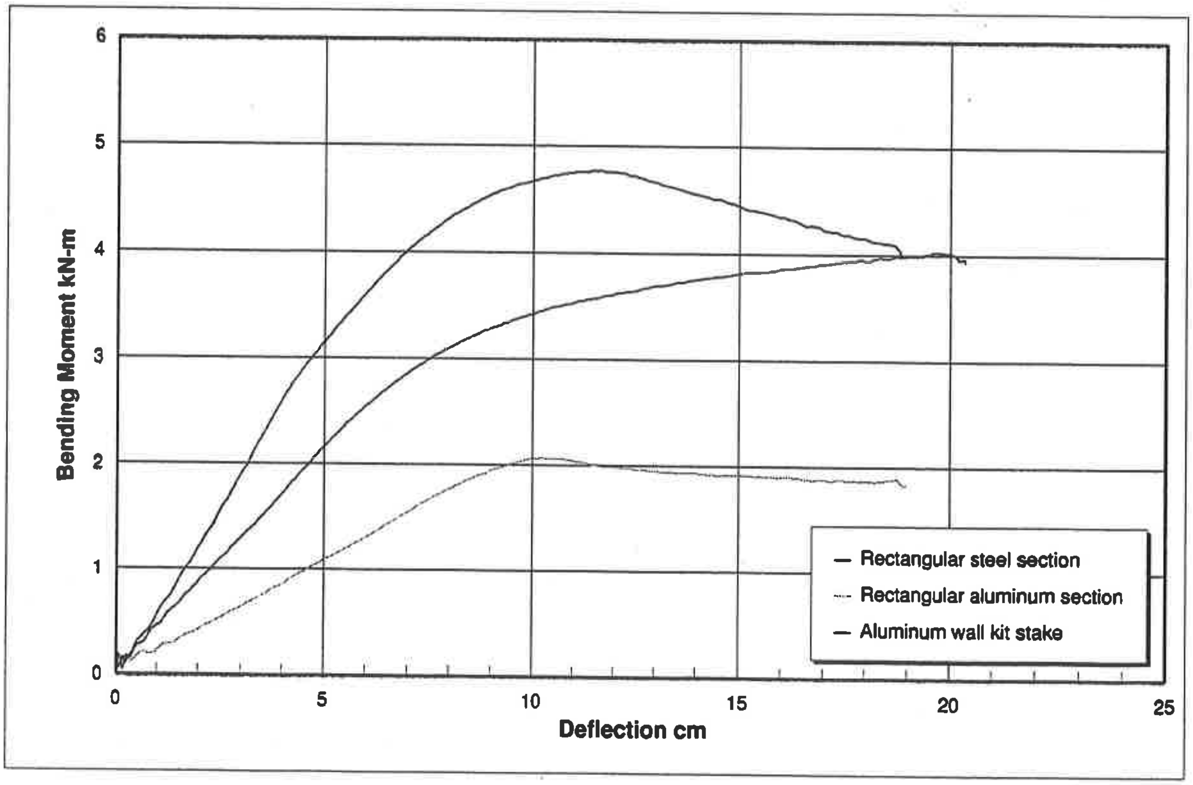

Figure 11/ Hollow Steel and Aluminum Stake Bending Moment vs Deflection

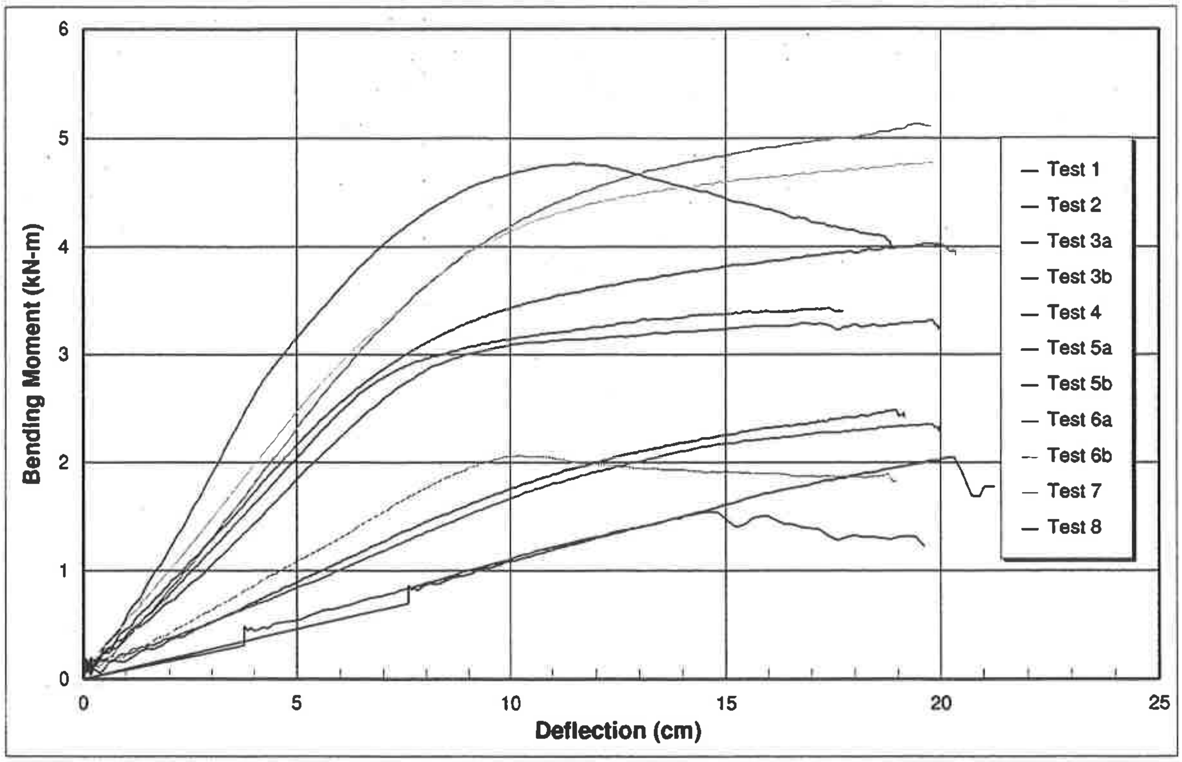

Figure 12/ Bending Moment vs Deflection Characteristics for All Stakes

The characteristics for all stakes tested are shown in Figure 12 referenced by test number. Clear breakage points (splitting) can be seen for the wood sample stakes, tests 1 and 2. Where failure occurred due to partial yield, buckling or kinking, the bending moment vs deflection curves display a decreasing change in slope, as seen for all the other tests. The slope decreases further as the area yielding becomes larger. Little difference in reaction is evident for channel sections tested in both directions about the neutral axis, tests 3a and 3b, 5a and 5b, and 6a and 6b. The rectangular hollow tube sections, tests 4 and 7, showed a peak followed by a negative bending moment characteristic slope. This was due to buckling, producing a kinking effect, which caused the stake to fold. The extruded wall kit stake, though hollow, had thick enough walls that they did not kink as to cause a decline in bending moment. Once the yield point was reached the slope of the characteristic gradually decreased.

5/ Analysis and Discussion

5.1/ General

When a stake is subjected to a bending moment, the fibres react in an elastic manner up to a stress point known as the yield stress. At stresses beyond the yield stress, the material may react either by breaking (severance, surface fracture), or by deforming plastically. If plastic deformation is allowed to progress, through a subsequent increase in stress, then a fracture will ultimately occur. In the case of a stake, the maximum bending stress occurs adjacent to the point where stake is secured, as shown in Figure 3. A deflection of the stake occurs at the point of loading. The maximum stress induced will be both compressive and tensile, immediately adjacent to the stake pocket, Figure 3. When the stress within the stake is less than the yield stress, the stake fibres are behaving in an elastic manner. If the stress were removed, the stake would spring back to its original shape and position. If the stress was in excess of the yield stress, and the stress removed the recovery would not be complete. Portions of the cross section would have experienced plastic deformation and a permanent bend would have occurred. The degree of permanent bend would be proportional to the amount of stress in excess of yield stress applied.

The characteristic of a stake subjected to a bending moment takes the form of a bending moment vs deflection graph. Typical plots are shown in Figure 12. A straight line relationship exists up to the point where the characteristic tends to curve to the right. This characteristic is shown broken down into its components, for different stake materials, in Figure 13.

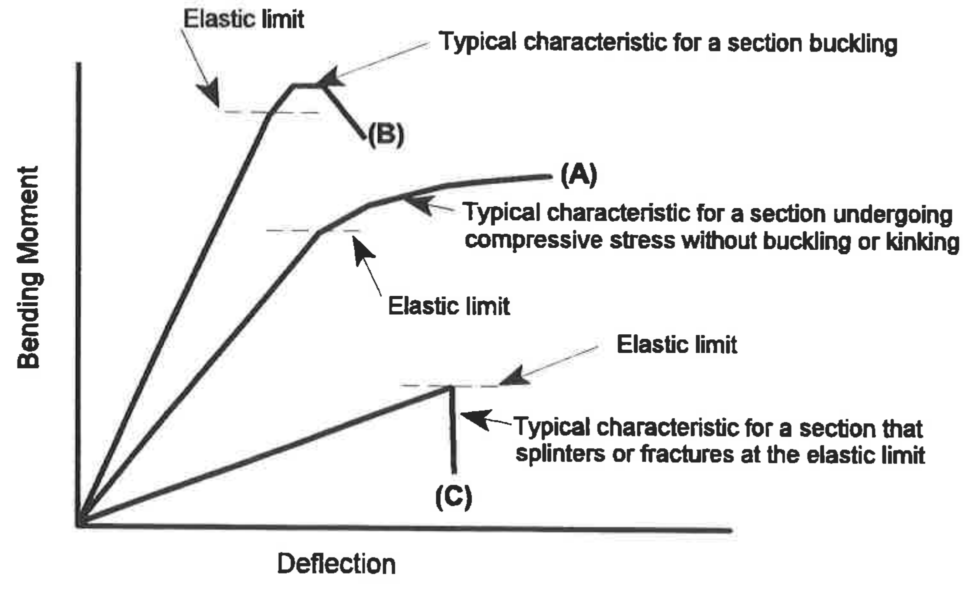

Figure 13/ Typical Stake Bending Characteristics

Applying a bending moment initially causes elongation of the fibres proportional to the deflection, a straight line relationship. This is the elastic region, and the material will return to its original shape once the bending moment is removed. The point where the bending moment begins to deviate from a straight line is the elastic limit, or yield point. Any loading beyond this point will cause permanent deformation and/or breakage.

The shape of the curve beyond the yield point is different for different materials and cross sections. A ductile material and section responds in the form of curve (A), up to the point of "necking", a thinning of the stressed fibres while undergoing plastic deformation. For a material or section that kinks or buckles, the characteristic takes the form of curve (B). This is an unstable characteristic, as once the maximum bending moment is achieved, the section collapses very quickly. Characteristic (C) represents a brittle material that breaks almost immediately when the elastic limit is achieved. In some cases, the characteristic may curve slightly as external fibres break and the internal fibres still provide elastic resistance, but such a condition is usually short lived.

5.2/ Peak Bending Moments and Deflections

Figure 14 shows the bending moments achieved at the yield point, and at a point where it either peaked or the slope became extremely shallow. Figure 15 shows the bending moment at the yield point. The heavier aluminum channel provided the greatest resistance, followed by the steel tube. The lighter aluminum channel and wood were on the lower end of the scale. The stake deflection at the yield point is shown in Figure 16. Wood had the largest deflection, and aluminum and steel had similar deflections at yield.

The bending moment at the yield point is the maximum moment that the stake can resist before it becomes permanently deformed. Although it may be able to withstand higher bending moments, and may appear undamaged, permanent changes have occurred and may have caused significant weakness. For the purpose of stake evaluation, once bending has gone beyond the yield point, the stake is considered to have failed. The yield point data presented in Figure 16 can therefore rank the stakes tested.

5.3/ Spring Constant Consideration

Another criterion in measuring a stakes ability to resist a load is the force/deflection relationship, or spring constant. This is the amount of bending moment (or force at a fixed height) to produce a unit deflection in the stake. The spring constants are shown in Figure 17.

The smaller the spring constant, the more flexible the stake. The higher the spring constant the stiffer the stake. The wood stakes and the light aluminum channel are the most flexible, and the steel tube is the stiffest. The channels have similar spring constants in either direction. The tubes and channels are the stiffest, but are also the ones most susceptible to kinking and buckling failure.

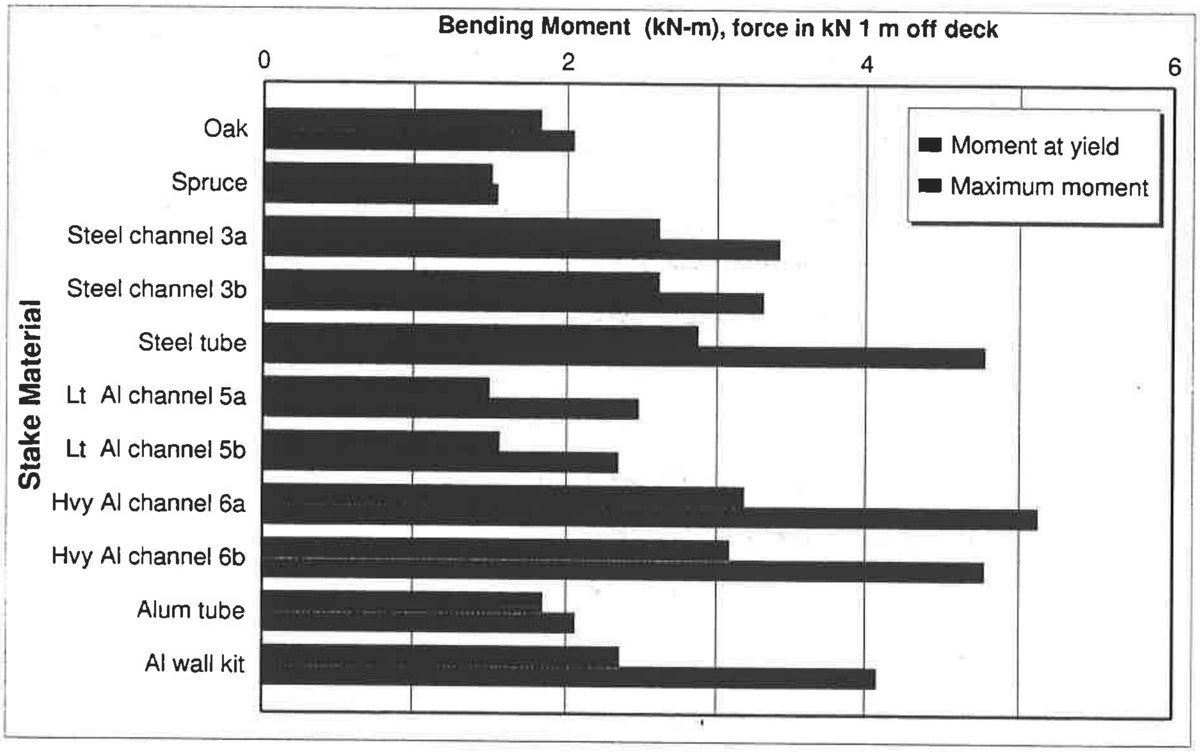

Figure 14/ Maximum Bending Moments at Yield Point

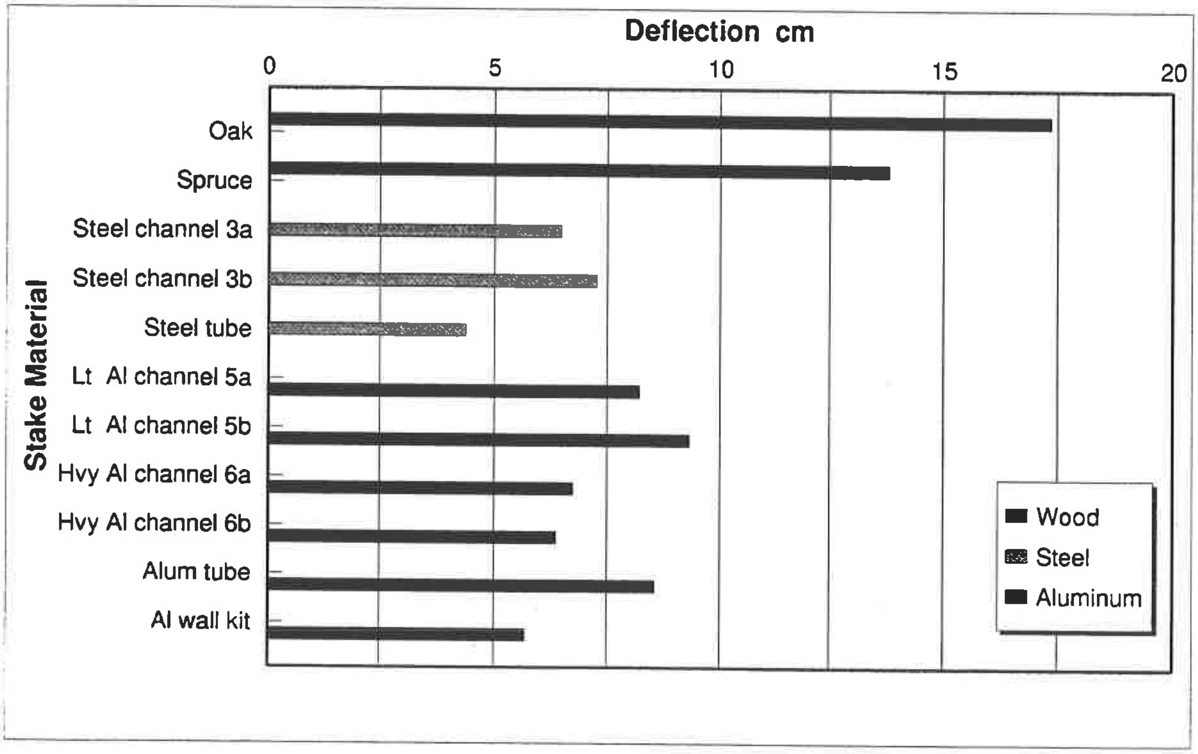

Figure 15/ Deflection at Yield Point

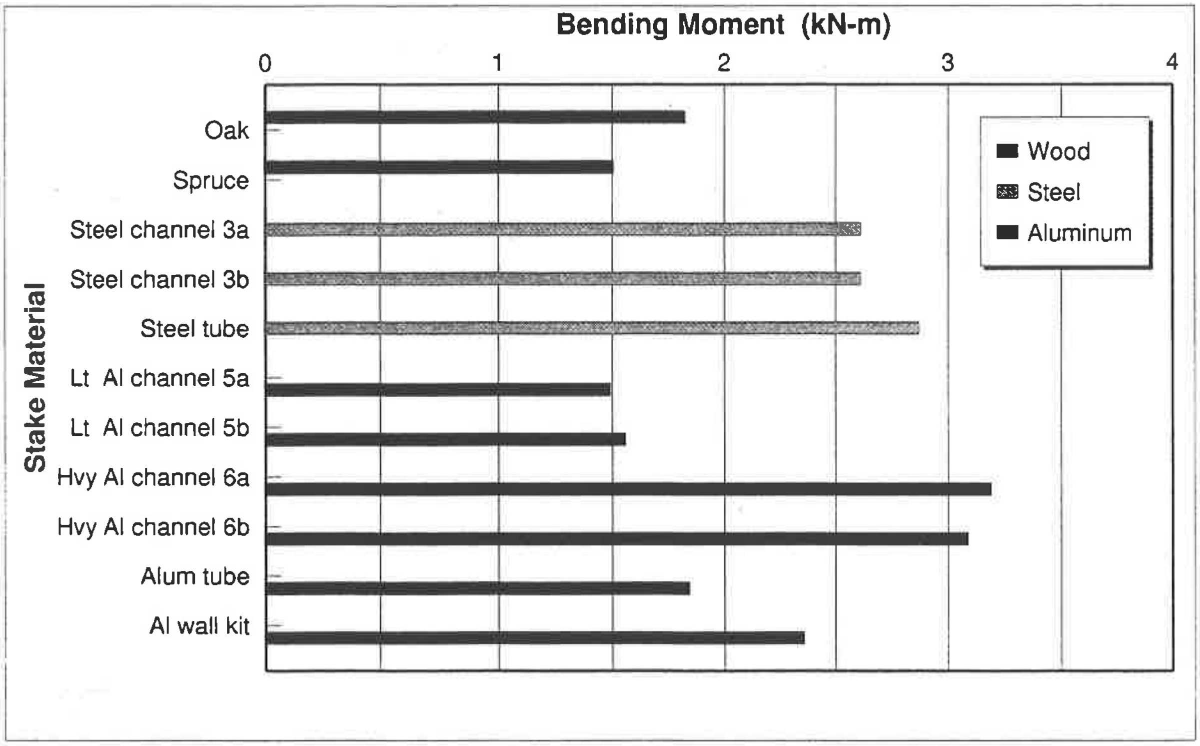

Figure 16/ Bending Moment at Yield Point

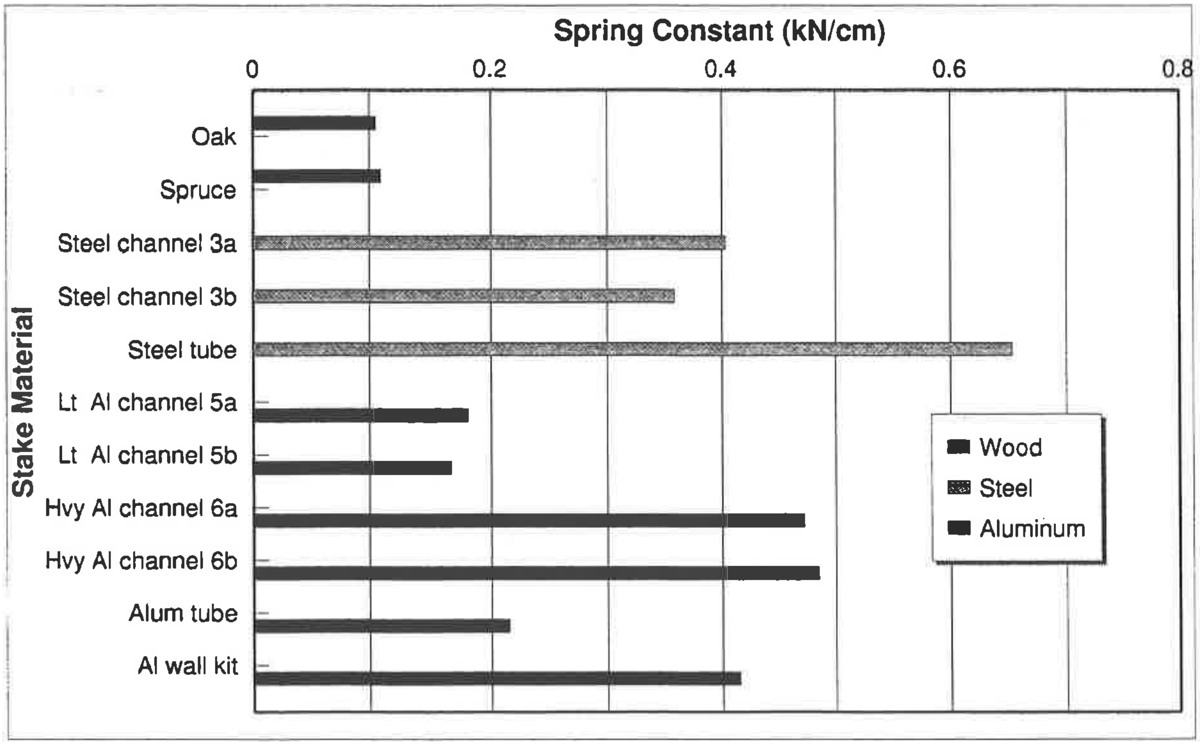

Figure 17/ Spring Constant for Force 1 m above Deck

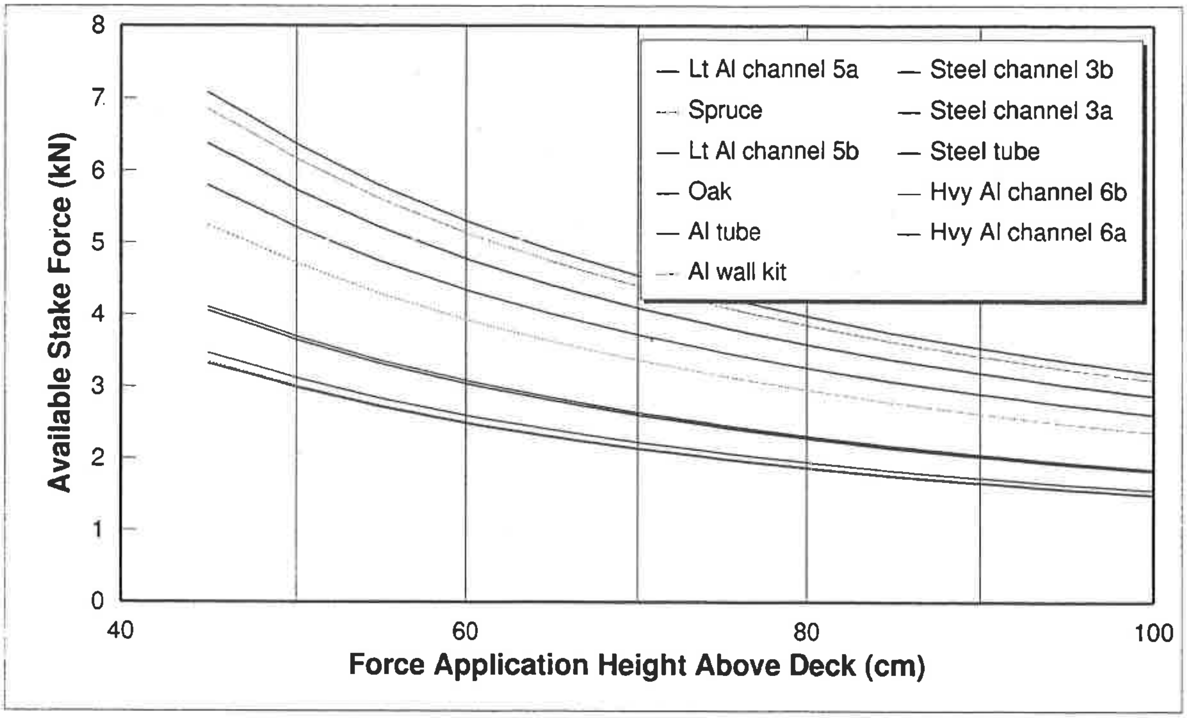

Figure 18/ Available Force at Stake for Various Heights, Based on Yield Point

5.4/ Projection of Data for Different Heights Above Deck

The loading was applied at a point 1 m above the trailer deck. However, the data can be applied to other heights by adjusting the moment arm length in the bending moment. Below about 45 cm (18 in), shear increasingly alters the principal stress orientation and reduces the failure predictability significantly. The force at yield is shown in Figure 18 for heights 45 cm to 1 m above the deck for all stakes tested.

5.5/ Load Capacity of Stakes

General purpose flatdeck trailer stakes are generally not known to be provided with a load capacity rating comparable to the working load limit for tiedowns. Other parts of cargo securement systems are typically rated by dividing their breaking strength by a safety factor, in many cases a number around 3. Taking the data of Figure 14, then, and dividing the maximum bending moment by 3 gives values in the range 0.5-1.7 kN-m (368-1,253 ft-lb). At a height of 1 m (39.37 in), this corresponds to resistance in the range 0.5-1.7 kN (112-382 lb), which increases as the height of contact diminishes, as shown in Figure 18. These values are insignificant compared to the weight of much of the cargo carried on flatdeck trailers. These sections clearly can contribute little of the resistance required to secure such cargo.

6/ Conclusions

A series of tests were conducted to determine the forces and reactions experienced by vertical stakes, made from various materials with different cross sections mounted in stake pockets. A bending force was applied one meter high above, and parallel to, the trailer deck in an outboard direction and was increased until the stake material yielded. The applied force, converted to a bending moment, and accompanying stake deflection displacement was measured.

Wood stakes failed abruptly by cracking. The bending moment to cause failure was less than any of the metals tested. Wood was the most flexible (lowest spring constant) of any of the stakes tested. Thick web aluminum channel , steel tubes and steel channel provided the highest reactive bending moment and possessed the stiffest reaction (high spring constant) before yielding. Hollow sections, such as steel and aluminum rectangular tubing kinked and buckled at peak loads in the plastic region of the characteristic curve. Once kinking and buckling occurred, the stake folded and offered little load restraining qualities. When channel deformed, the characteristic gradually levelled providing a uniform restraining moment as the material yielded. The available restraining force of the stakes changed little with respect to height above deck for lower strength stakes, and significantly for the higher strength stakes.

The sections tested all performed in accordance with the engineering theory of bending. Typical sections used as flatdeck trailer stakes had such low resistance to bending that they are only suitable for use as a means of cargo securement for light articles of cargo. They will provide greater resistance in shear for cargo butted against the bottom of a stake.

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 [6].

7/ Recommendations

1/ Typical sections used as stakes for flatdeck trailers used in bending are only suitable to provide securement for quite light articles of cargo, and can only provide a modest amount of the securement required for heavy articles of cargo.

References

[1] Billing J.R., Mercer W.R.J. and Cann W., "A Proposal for Research to Provide a Technical Basis for a Revised National Standard on Load Security for Heavy Trucks", Transportation Technology and Energy Branch, Ontario Ministry of Transportation, Report CV-93-02, November 1993.

[2] Billing J.R. and Leung D.K.W., "Evaluation of the Strength and Failure Modes of Heavy Truck Cargo Anchor Points", North American Load Security Research Project Report 10, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[3] Mercer W.R.J. and Billing J.R., "Load Capacity of Nailed Wood Blocking", North American Load Security Research Project Report 8, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[4] Baumeister T. and Marks L.S., "Standard Handbook for Mechanical Engineers", seventh edition, Mc Graw-Hill Book Company.

[5] Drummond, McCall & Co., Limited., " Drummond McCall Reference Book 15.

[6] Billing J.R. and Couture J., "North American Load Security Research Project Summary Report", North American Load Security Research Project, Report 18, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

North American Load Security Research Project Reports

[1] Billing J.R., W.R.J. Mercer and W. Cann, "A Proposal for Research to Provide a Technical Basis for a Revised National Standard on Load Security for Heavy Trucks", Transportation Technology and Energy Branch, Ontario Ministry of Transportation, Report CV-93-02, November 1993.

[2] Rakheja S., P. Sauvé and D. Juras, "Experimental Evaluation of Friction Coefficients of Typical Loads and Trailer Decks under Vertical Vibration", North American Load Security Research Project, Report 2, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[3] Heidersdorf E. and E. Hay, "Slippage Tests with Anti-skid Mats", North American Load Security Research Project, Report 3, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[4] Hay E., W. Williams and E. Heidersdorf, "Dressed Lumber Tiedown Tests", North American Load Security Research Project, Report 4, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[5] Mercer W.R.J. and J.R. Billing, "Effect of Cargo and Tiedown Characteristics on Equalization of Tension in the Spans of Tiedowns", North American Load Security Research Project, Report 5, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[6] Mercer W.R.J. and J.R. Billing, "Effect of Binder Type and Chain Length on Tension in Chain Tiedowns", North American Load Security Research Project, Report 6, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[7] Billing J.R. and C.P. Lam, "Friction Coefficients between Typical Cargo and Truck Decks", North American Load Security Research Project, Report 7, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[8] Mercer W.R.J. and J.R. Billing, "Load Capacity of Nailed Wood Blocking", North American Load Security Research Project, Report 8, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[9] Billing J.R. and C.P. Lam, "Effect of Cargo Movement on Tension in Tiedowns", North American Load Security Research Project, Report 9, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1998.

[10] Billing J.R. and D.K.W. Leung, "Evaluation of the Strength and Failure Modes of Heavy Truck Cargo Anchor Points", North American Load Security Research Project, Report 10, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[11] Mercer W.R.J. and J.R. Billing, "Tests on Methods of Securement for Thick Metal Plate", North American Load Security Research Project, Report 11, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[12] Mercer W.R.J. and J.R. Billing, "Tests on Methods of Securement for Large Boulders", North American Load Security Research Project, Report 12, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[13] Mercer W.R.J. and J.R. Billing, "Bending Strength of Trailer Stakes", North American Load Security Research Project, Report 13, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1998.

[14] Mercer W.R.J. and J.R. Billing, "Effect of Tiedowns on Wood Blocks Used as Dunnage", North American Load Security Research Project, Report 14, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1998.

[15] Billing J.R. and C.P. Lam, "Tests on Methods of Securement for Metal Coils", North American Load Security Research Project, Report 15, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

[16] Mercer W.R.J. and J.R. Billing, "Tests on Methods of Securement for ISO Containers", North American Load Security Research Project, Report 16, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1998.

[17] Leung D.K.W. and J.R. Billing, "Analysis of Heavy Truck Cargo Anchor Points", North American Load Security Research Project, Report 17, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1998.

[18] Billing J.R. and J. Couture, "North American Load Security Research Project Summary Report", North American Load Security Research Project, Report 18, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

---

[19] Grandbois J., "Assessing a Securement Method for the Transportation of Heavy Machinery Using a Combination of Highway Vehicles", North American Load Security Research Project, Report 19, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.

---

[20] Billing J.R., "Performance Limits of Heavy Trucks", North American Load Security Research Project, Report 20, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1998.