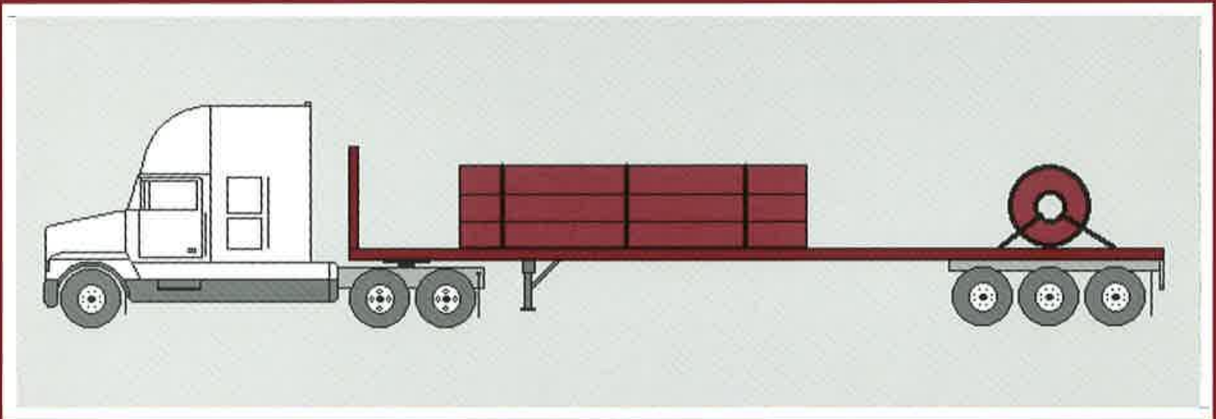
CCMTA Load Security Research Project

Report # 10

EVALUATION OF THE STRENGTH AND FAILURE MODES OF HEAVY TRUCK CARGO ANCHOR POINTS



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

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EVALUATION OF THE STRENGTH AND FAILURE MODES OF HEAVY TRUCK CARGO ANCHOR POINTS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

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North American Cargo Securement Standard

CCMTA is serving to coordinate the development of a revised North American Cargo Securement Standard. To this end the research results in this report are being reviewed and discussed by interested stakeholders throughout North America.

Those readers interested in participating in the development of the North American Cargo Securement Standard through 1997 are invited to visit the project Web site at www.ab.org/ccmta/ccmta.html to secure additional project information.

Table of Contents

Abstract

A series of tests were conducted to determine the strength and failure modes of a range of heavy truck cargo anchor points. It also investigated the effect of corner radius and chain link orientation on the strength of a tiedown chain stretched around a steel corner. The tests covered a range of types and grade of anchor point, for various tiedown attachments and a number of pull directions. Most test articles were strain-gauged to provide insight into their structural performance, and most were tested to failure. The maximum loads applied were collected, tabulated, and are presented graphically. Observations noted during the tests, and from the test data, are presented and discussed.

The results show a very wide range of load capacity, both between and within types of anchor point. In most cases, the load capacity also varies significantly with the direction of loading. Most anchor points started to yield at quite low loads, and deformed substantially as the test progressed. Limited finite element analyses compared well with corresponding strain data from tests.

This work leads to recommendations that cargo anchor points should be designated on heavy trucks, and should be provided with a load capacity rating.

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 issues related to cargo anchor points, to which tiedowns are attached. This work addresses these through a series of tests to evaluate the strength and failure modes of typical anchor points, including stake pockets, D-rings, winches, chain-in-tubes, welded rods and rub rails, even though it may not be an intended use of the latter. Tests were conducted for various pull directions, and also included the effect of chain wrap configuration on stake pockets. Another series of tests to examine the effect of corner radius and chain link orientation on the strength of a chain tiedown stretched around a steel corner was conducted concurrently, and are also reported here.

Most test articles were strain-gauged to provide insight into their structural performance. The strain gauges were located and oriented from the results of a preliminary finite element analysis of typical test articles and loads. Most tests continued loading until fracture occurred, and data included time-histories of applied load and strain responses. The maximum loads applied are presented and discussed, together with observations noted during the tests, and subsequently from analysis of the test data.

The ultimate loads varied widely between and within the various types of anchor point, and the achievable ultimate strength, except for D-rings, generally varied significantly with the direction of loading. Most anchor points started to yield at loads as low as 10-20% of their ultimate strength, and became severely deformed as the test progressed. A preliminary comparison of selected finite element analytical results with corresponding test data shows good correlation. Finite element analysis should be a viable tool for designing and rating heavy truck cargo anchor points.

The preliminary work to select anchor points found a great variety, for a wide range of purposes, at a wide range of load capacity, and formal load ratings may not always be readily available. This makes it difficult for motor carriers to be assured that cargo is adequately secured, especially when heavy individual articles are carried. For these reasons, it is recommended that vehicles that can carry heavy articles of cargo should have anchor points designated for securement of that cargo; that all anchor points should be provided with a load capacity rating that reflects the possible directions of loading; and that manufacturers of anchor points should be involved in the developing appropriate standards and ratings. It is also clear that a systematic method should be developed to evaluate when a damaged anchor point should be repaired or replaced.

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

Acknowledgments

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

The project was funded jointly by the following :

- Alberta Transportation and Utilities;
- Allegheny Industrial Associates;
- The Aluminum Association;
- American Trucking Associations;
- British Columbia Ministry of Transportation and Highways;
- Canadian Trucking Research Institute;
- Commercial Vehicle Safety Alliance;
- Forest Engineering Research Institute of Canada;
- Manitoba Highways and Transportation;
- Ministère des Transports du Québec;
- New Brunswick Ministry of Transportation;
- Newfoundland Ministry of Transportation and Public Works;
- New York State Department of Transportation;
- Nova Scotia Ministry of Transportation;
- Prince Edward Island Department of Transportation;
- Saskatchewan Government Insurance;
- Saskatchewan Highways and Transportation;
- Société de l'Assurance Automobile du Québec;
- Transport Canada, Road and Motor Vehicle Safety Directorate;
- Transport Canada, Transportation Development Centre; and
- United States Department of Transportation, Federal Highway Administration.

The project was conducted under the guidance of the Load Security Research Management Committee, formed by CCMTA with one representative of each of the funding partners and chaired by Mr. M. Schmidt of Federal Highway Administration, Albany, New York. Sean McAlister provided administrative support from CCMTA.

Stake pockets were provided by Dorsey Trailers of Atlanta, Georgia, and Great Dane Trailers of Savannah, Georgia. Winches and some D-rings were provided by Kinedyne Canada.

The test rig was designed by Walter Mercer; test specimens were strain-gauged and installed by Bob McCarville and Ron Oades; testing was conducted by Walter Mercer and Bill Stephenson, and video taping was performed by Mike Wolkowicz, all of the Strategic Vehicle Technology Office of MTO.

1/ Introduction

Security of cargo on heavy trucks is a matter of public safety, subject to a body of industry practice and government regulation. Cargo securement regulations are broadly similar across North America's many jurisdictions, but there are also some significant differences. When the time came for the Canadian Council of Motor Transport Administrators (CCMTA) 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 CCMTA Load Security Research Project [1]. This 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 to develop uniform North America-wide standards for cargo securement and inspection.

Cargo carried by flatbed, specialty or van trailers is often secured by tiedown assemblies attached to anchor points on the vehicle. Load ratings of tiedowns are generally available, but review of existing equipment and cargo securement regulations showed that the load capacity of anchor points was generally unknown [1]. This raised two issues :

1/ New vehicle standards; and
2/ Rating of existing vehicles.

Setting a new vehicle standard for rating cargo anchor points will resolve the issue of the adequacy of anchor points over the long term. This is a federal responsibility, and Transport Canada now has such a standard under development, so this issue needs no further attention here.

However, some means of rating the capacity of anchor points on existing vehicles will be required for the foreseeable future, until all vehicles meet the new vehicle standard.

A test program was therefore conducted of a number of typical heavy truck cargo anchor points, as outlined in Sections 7.2 to 7.8 and 8.3 of the project proposal [1]. It was supported by analysis using the finite element method to assist in the evaluation of the structural performance of these anchor points.

2/ Test Program

2.1/ Objective

The objective of the test program was to evaluate the strength and modes of failure of typical heavy truck cargo anchor points under different loading conditions, and to help establish a viable basis for devising a set of North America-wide guidelines or recommendations under which these anchor points can be used safely.

2.2/ Scope

The following types of anchor point were evaluated:

1/ Stake pockets;
2/ D-rings;
3/ Winches;
4/ Chain-in-tubes;
5/ Welded rods; and
6/ Rub rails;

For each of the above anchor point types, individual samples were tested in different loading directions that would emulate both typical and critical conditions under which these anchor points are being, or would be, used. These included tests to investigate the effect of the manner in which a chain would be hooked to or wrapped around a stake pocket or rub rail on the strength of the anchor point itself. An additional set of tests were conducted to evaluate the effect of the radius of a sharp corner and of the orientation of the chain link on the ultimate strength of a typical tiedown chain.

3/ Procedures

3.1/ Test Apparatus

All tests were conducted on a Tinius-Olsen (T.O.) loading machine with a maximum capacity exceeding 80,000 lb. A picture of the machine is provided in Figure 1.

The loading mechanism of the machine derives from its three major components: the bulkhead at the top, the crosshead in the middle, and the platform at the bottom. The bulkhead and the platform move as a unit while the cross-head remains stationary. The machine was originally designed to exert compressive loads by placing the test specimen between the platform and the cross-head and moving the platform upwards against the crosshead. Separate controls are available to adjust the initial location of the crosshead, and to adjust the rate of loading, which is measured as force per unit movement of the platform with respect to the crosshead. Digital readouts are provided for the magnitude of the load being applied and the rate of loading.

For the purpose of these anchor point tests, however, a pulling load was required. Thus, the test specimen was secured to the top of the crosshead and a high-strength loading chain or shackle was connected between the specimen and the bulkhead of the loading machine. By moving the platform, and hence the bulkhead, upwards, a pulling load was applied to the specimen. To facilitate the performance of all tests on a common test rig, a number of specially designed mounting assemblies and adapters were fabricated. These included the following:

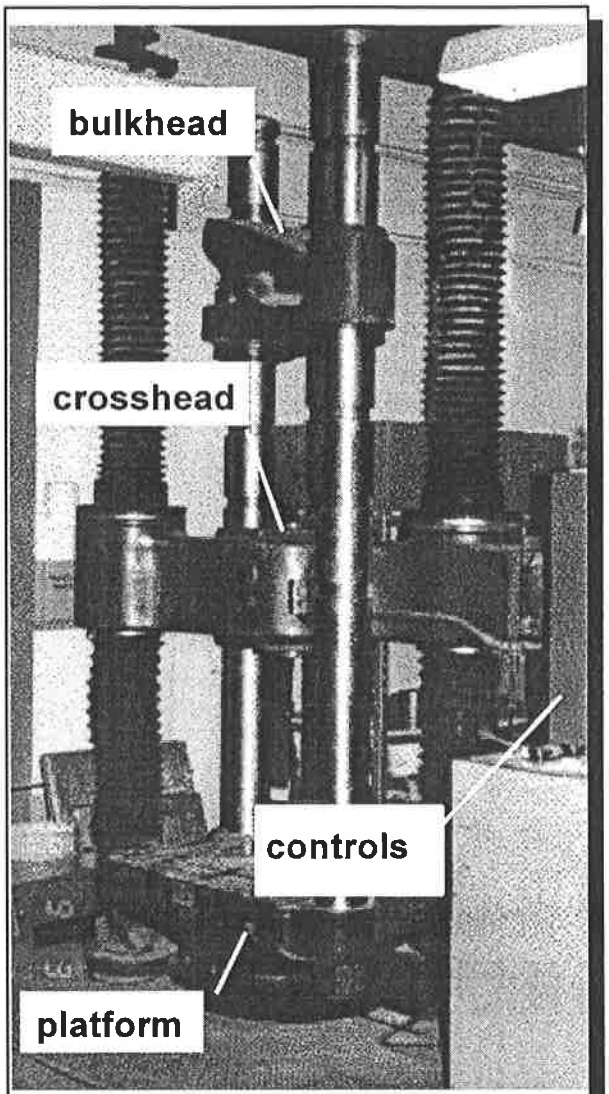

Figure 1: **Tinius-Olsen Loading Machine**

(i) Bi-directional Slide Table:

The slide table was comprised of a stack of three thick steel plates. As an assembled unit, overall dimensions of the slide table were 610x610x305 mm (24x24x12 in). Figure 2 shows the slide table assembly and the bolts that mount it to the crosshead, and Figure 3 shows it already mounted on the T.O. machine. The top plate was fitted with a number of threaded holes for bolting down test specimens, and thus was used as a universal mounting base for all test specimens. The middle plate was fitted with sliding guides on the top side to allow the top plate to slide in one direction, and on the underside to allow the bottom plate to slide in a perpendicular direction. Stop screws were fitted onto the middle plate to limit sliding when necessary.

(ii) Upper Anchor Assembly:

This is shown in Figure 4. The two huge bolts were used to mount the assembly to the underside of the bulkhead of the T.O. machine. It provided an anchoring point for the chain or shackle that was to be connected to the test specimen to exert the pulling force.

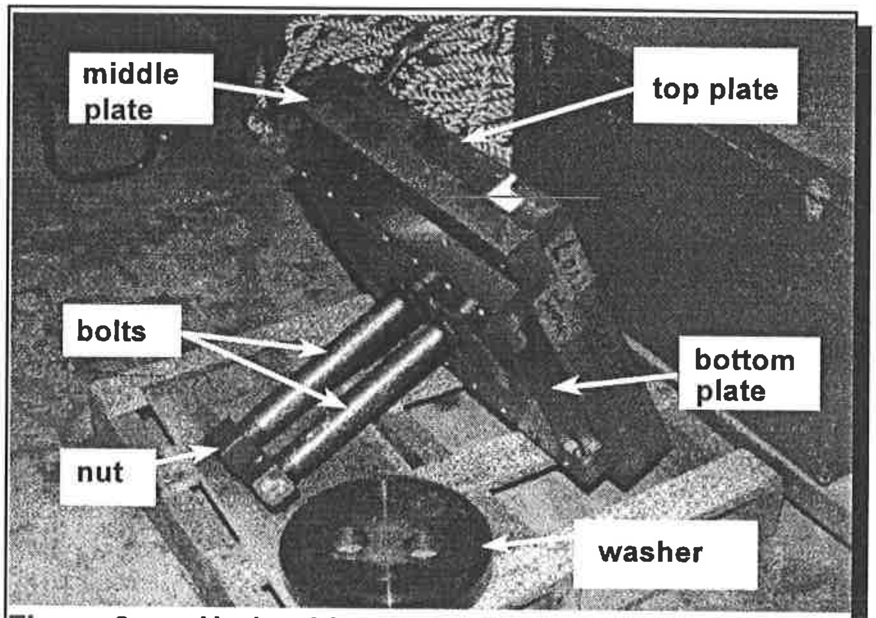

Figure 2: Underside of Slide Table Showing Huge Mounting Bolts

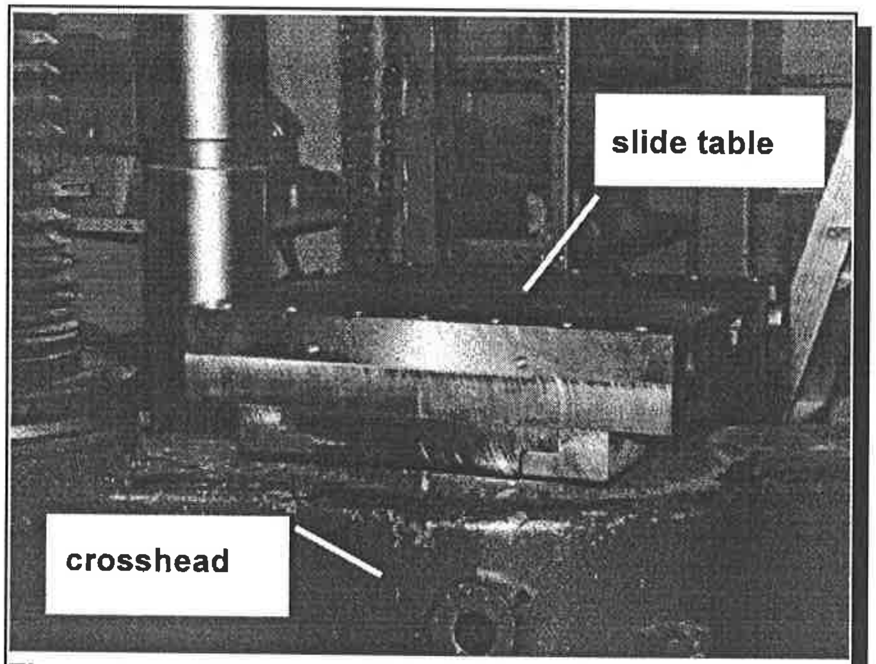

Figure 3: Picture of Slide Table as Mounted on Loading Machine

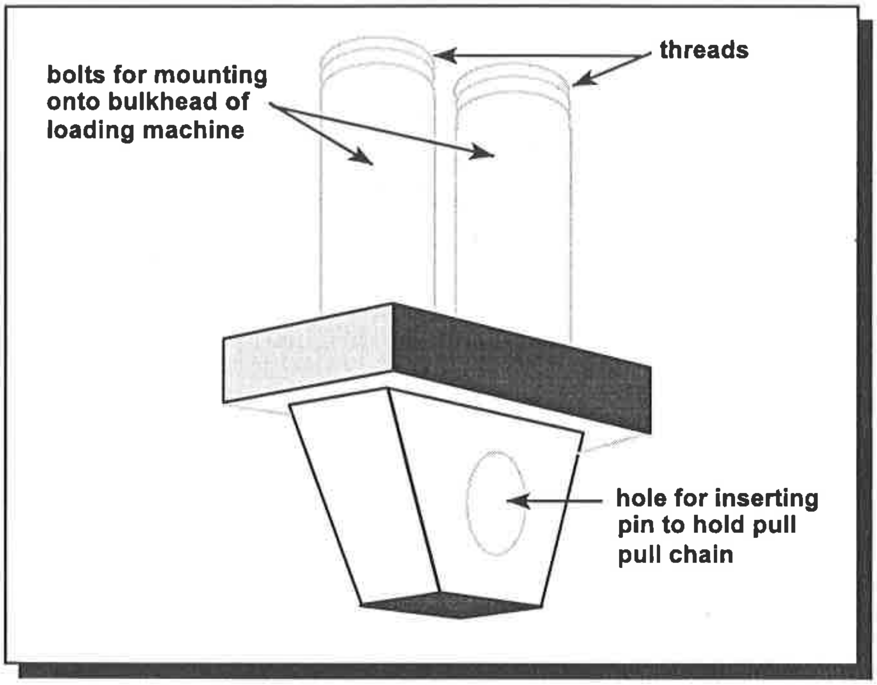

Figure 4: Upper Anchor Assembly

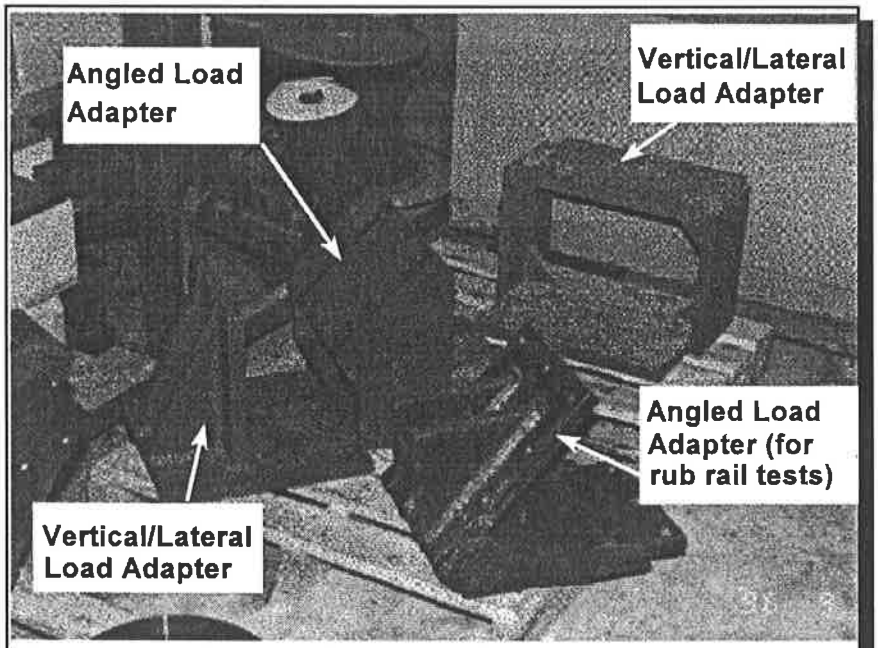

Figure 5: Load Orientation Adapters

(iii) Load Orientation Adapters:

Four adapters were built for mounting test specimens in specific orientations with respect to the vertical to achieve various prescribed loading directions. These included two adapters for vertical/lateral loads, and two for 45 deg angled loads, as shown in Figure 5.

(iv) Insert Load Connector for Stake Pocket Tests:

A special load connector was made for the stake pocket tests. This connector, consisting of a steel block insert with a large hole for hooking up to a shackle attached to the pull chain, was placed inside the pocket for one series of stake pocket tests. A "stop plate" was bolted onto the other end of this block insert. Depending on the specific size of the pocket, one or more steel inserts could be added between the block insert and the stop plate so that a constant distance was maintained between the base of the pocket and the point of attachment of the pull chain or shackle on the block insert for all stake pocket tests. Figure 6 shows the various components of this stake pocket load connector.

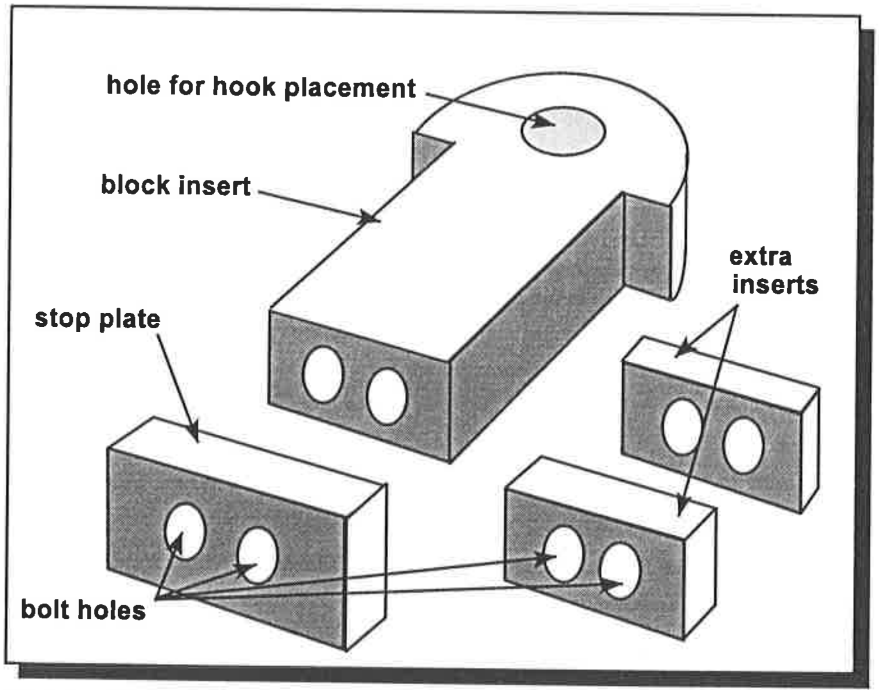

Figure 6: **Insert Load Connector for Stake Pocket Tests**

(v) Tiedown Adapter Plate and Corner Radius Dies (for Corner Radius and Chain Link Orientation Tests):

A rectangular plate fitted with an anchoring point at opposite ends of its length was made available for use in testing the effects of corner radius and chain link orientation, along with three dies each with a given corner radius, namely, 1.59 mm (1/16 in), 12.7 mm (1/2 in), and 25.4 mm (1 in), as shown in Figure 7. The plate was reinforced with a steel gusset welded along its edges lengthwise. It was to be bolted down onto the slide table, and was for tying down the test chain so that an angle of about 90 deg was subtended by the test chain around the corner radius die.

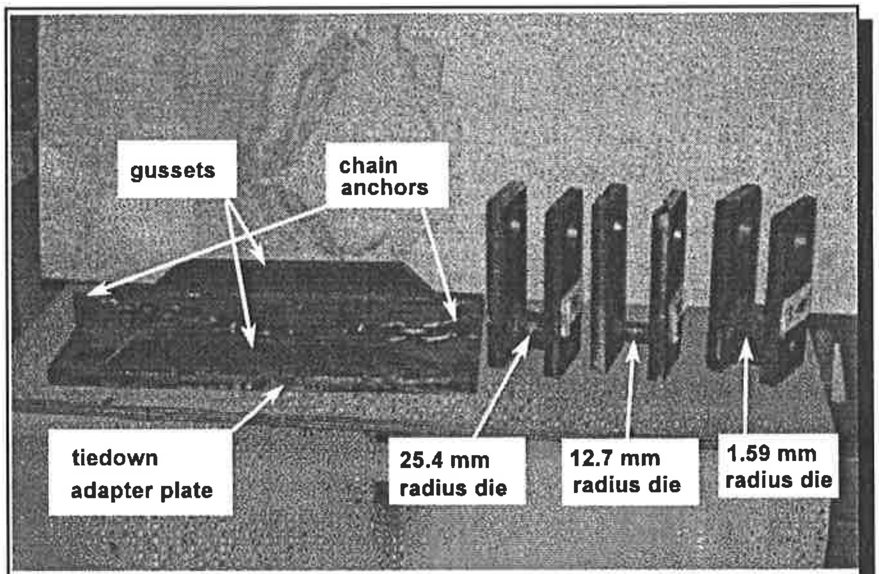

Figure 7: Tiedown Adapter Plate and corner Radius Dies

In addition, a number of high-strength pull chains, shackles in various lengths, and various sizes of hooks and other fittings were also made available. These all had load ratings adequate for the tests for which they were intended. Typically, chains were used in tests involving the rub rails, chain-wrapped pockets, chain-in-tubes, and the light-duty welded rods and D-rings, while shackles were used mostly in testing the stake pockets, winches, and the medium- and heavy-duty welded rods and D-rings. Figure 8a shows a typical test setup consisting of the loading machine, the slide table, and the upper anchor assembly, with a typical pull chain installed.

To simulate field mounting conditions and to facilitate setting up the test specimens for all tests onto the loading machine, all specimens, with the exception of the test chains used in testing the effects of corner radius and chain link orientation, were welded onto a 25.4 mm (1 in) thick mounting plate measuring 304.8x304.8 mm (12x12 in) in area (except for tests involving rub rails, where the mounting plates measured

304.8x914.4 mm, or 12x36 in, in order to accommodate two stake pockets). Nine 15.9 mm (5/8 in) diameter bolt holes were drilled into these mounting plates to allow easy and secure mounting onto the slide table or the load orientation adapters. Figures 8b and 8c show two such premounted test specimens, a rub rail and a chain-in-tube.

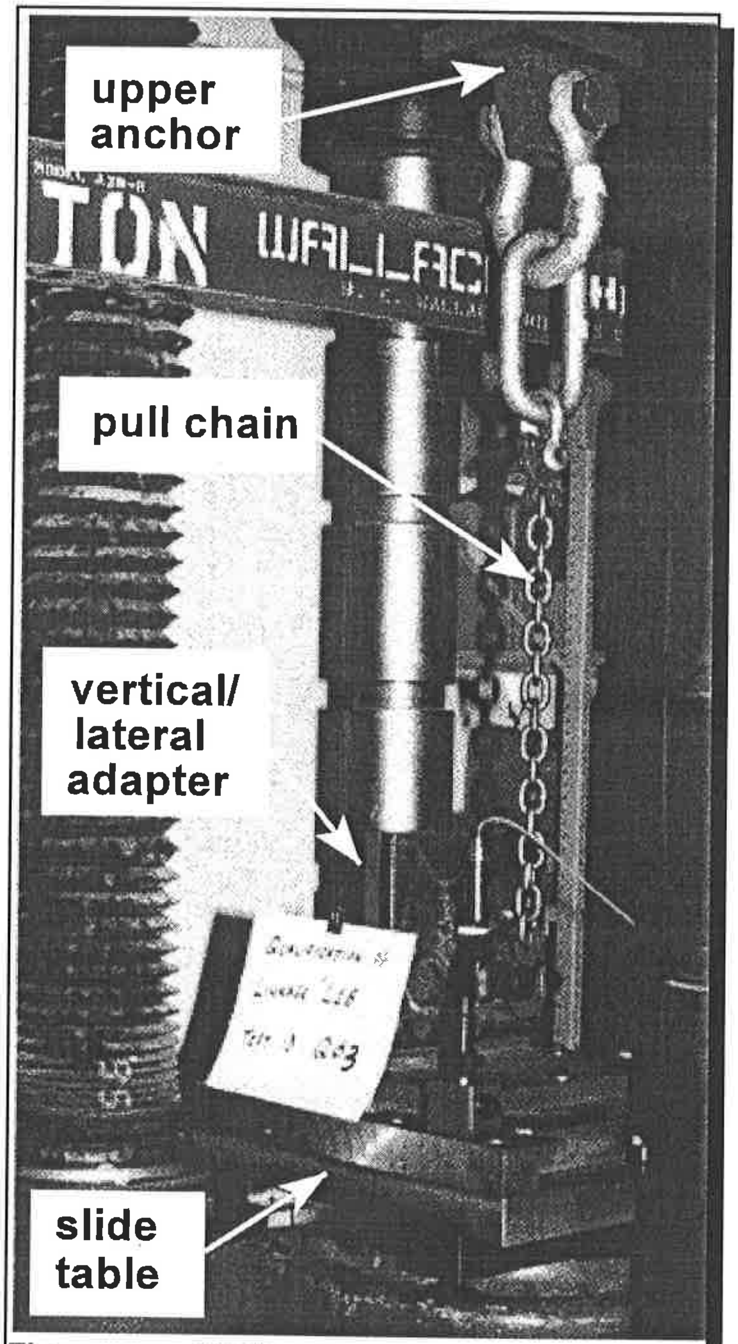

Figure 8a: Typical Test Setup

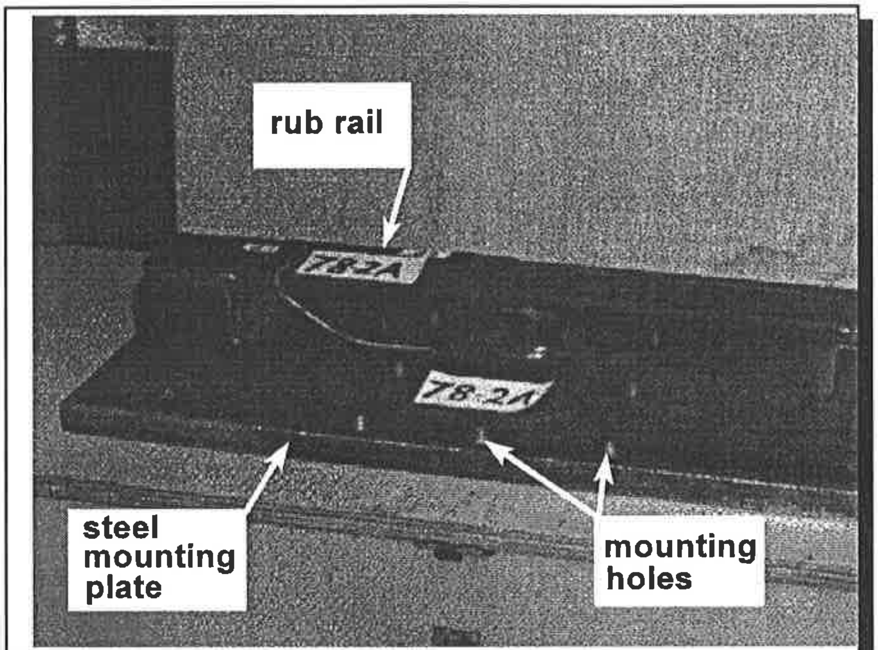

Figure 8b: Test Specimen (Rub Rail) Showing Premounting on Steel Plate

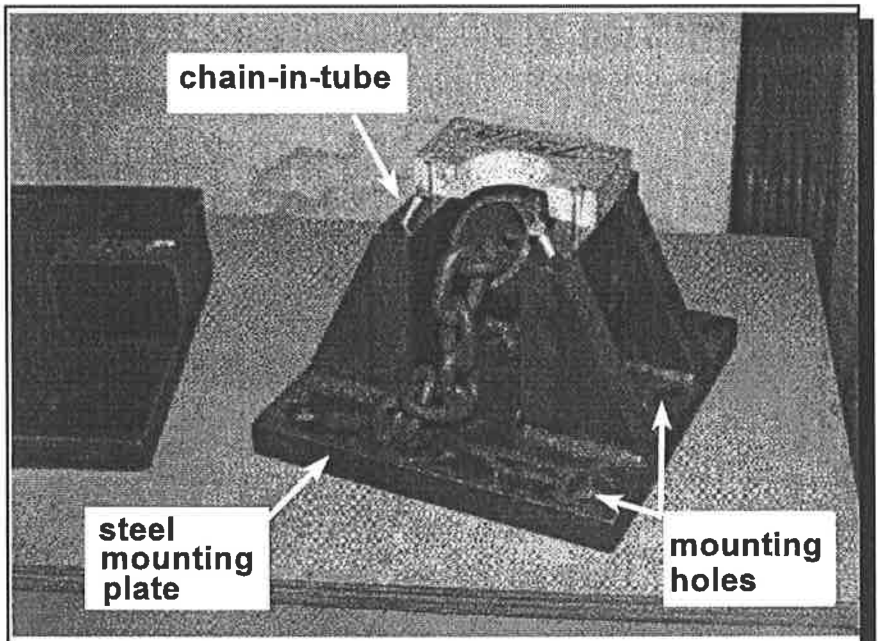

Figure 8c: Test Specimen (Chain-in-tube) Showing Premounting on Steel Plate

3.2/ Strain Gauging

In order to provide more data on the structural performance of the anchor points under different loading conditions, strain gauges were installed on the majority of test specimens, where feasible and practicable, in all categories of test except for the chain-in-tubes. Linear finite element analysis (F.E.A.) was performed on a typical specimen for each loading direction in each test category to help identify the locations and orientations in which these strain gauges should be placed and aligned, so that strain data would be captured from the most critical areas as much as possible. In all F.E.A. models, the typical element used was an 8-node solid element.

Figures 9a, 9b, and 9c show F.E.A. stress contours for the three orthogonal stress components, Sxx, Syy and Szz, for the heavy-duty steel stake pocket loaded in the longitudinal forward load direction. A load of 222.7 kN (50,000 lb) was assumed. The directions of the three stress components are as noted in the figures. Based on these results, strain gauges were installed on the test specimen as shown in Figure 9d. Figures 10a, 10b, and 10c show the corresponding stress contours for the case of the same pocket loaded in the lateral outboard direction. The layout of the strain gauges installed on this specimen is shown in Figure 10d.

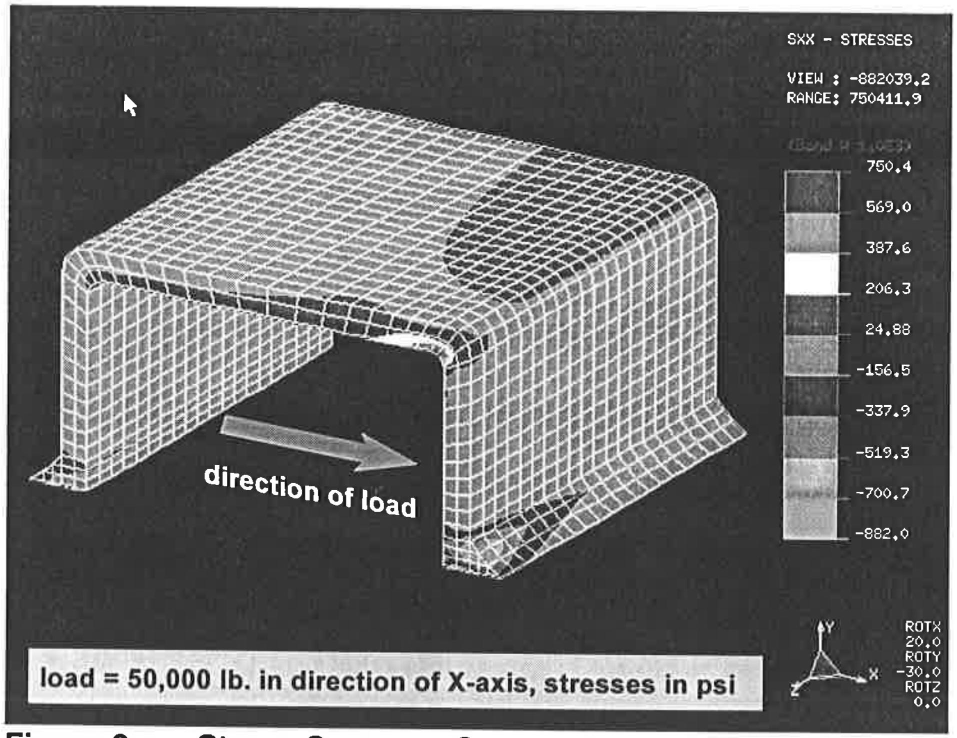

Figure 9a: **Stress Contours Sxx for Heavy-duty Steel Stake Pocket Loaded in Longitudinal Forward Direction**

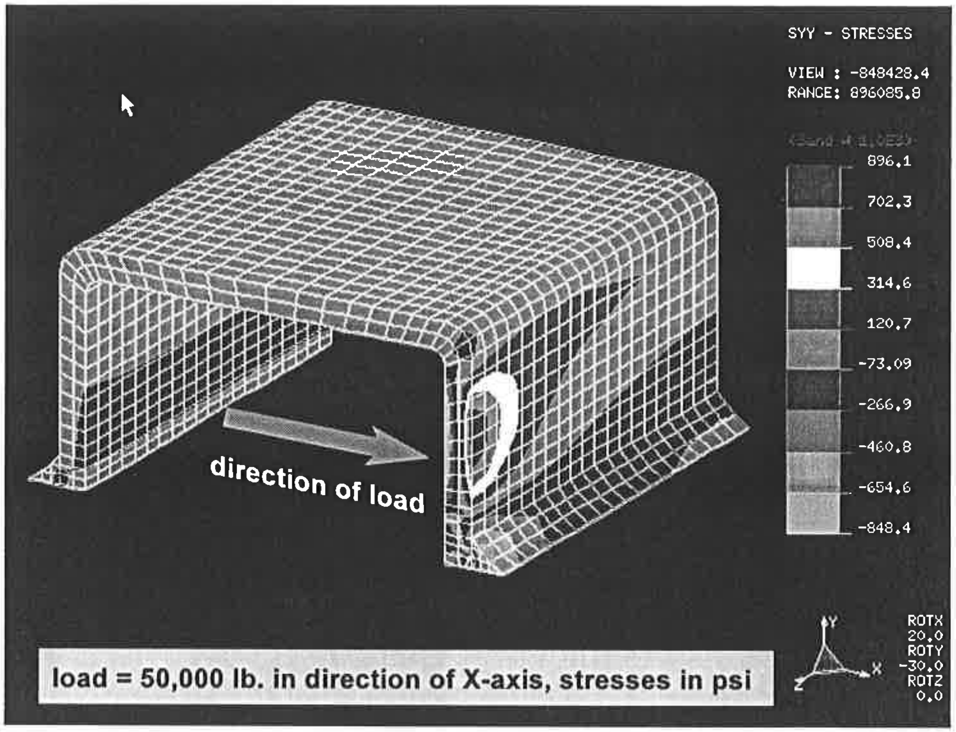

Figure 9b: Stress Contours Syy for Heavy-duty Steel Stake Pocket Loaded in Longitudinal Forward Direction

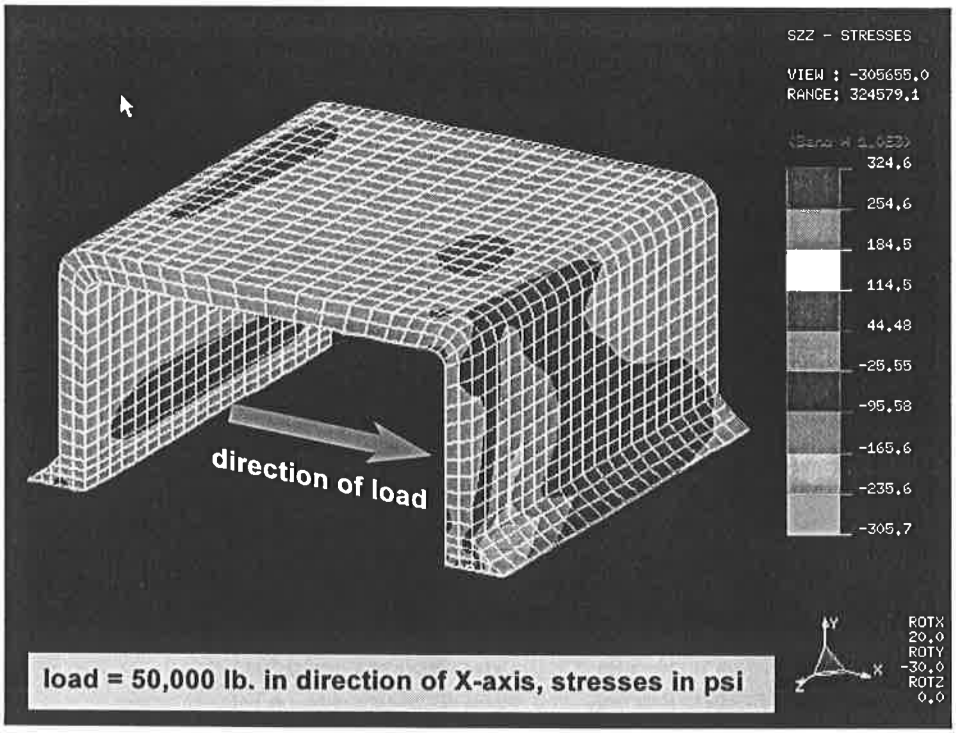

Figure 9c: Stress Contours Szz for Heavy-duty Steel Stake Pocket Loaded in Longitudinal Forward Direction

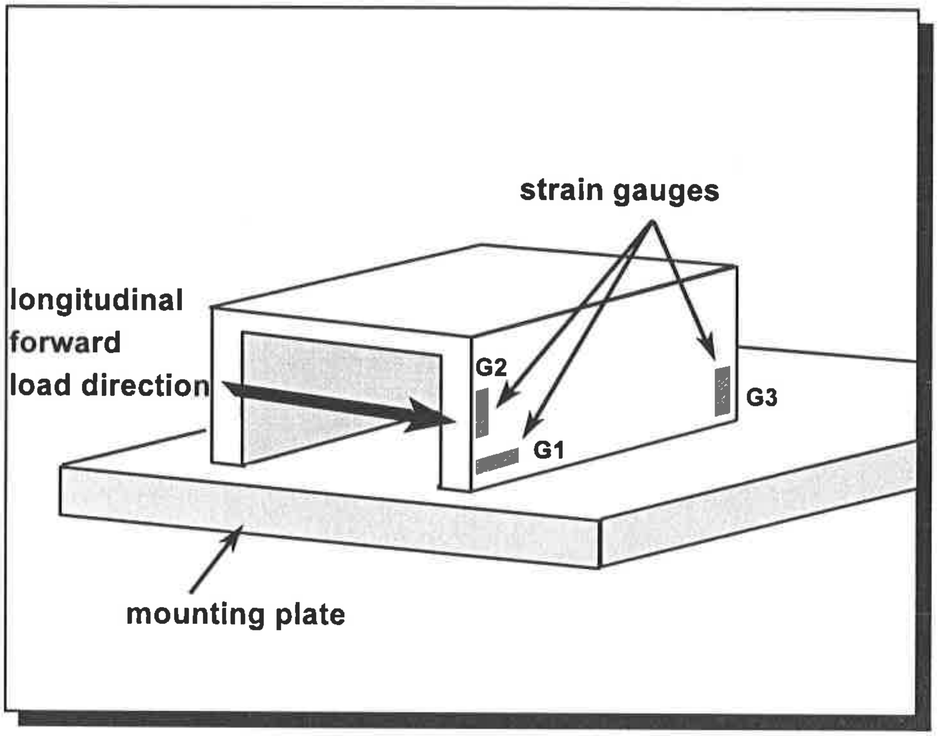

Figure 9d: Layout of Strain Gauges for Heavy-duty Steel Stake Pocket Loaded in Longitudinal Forward Direction

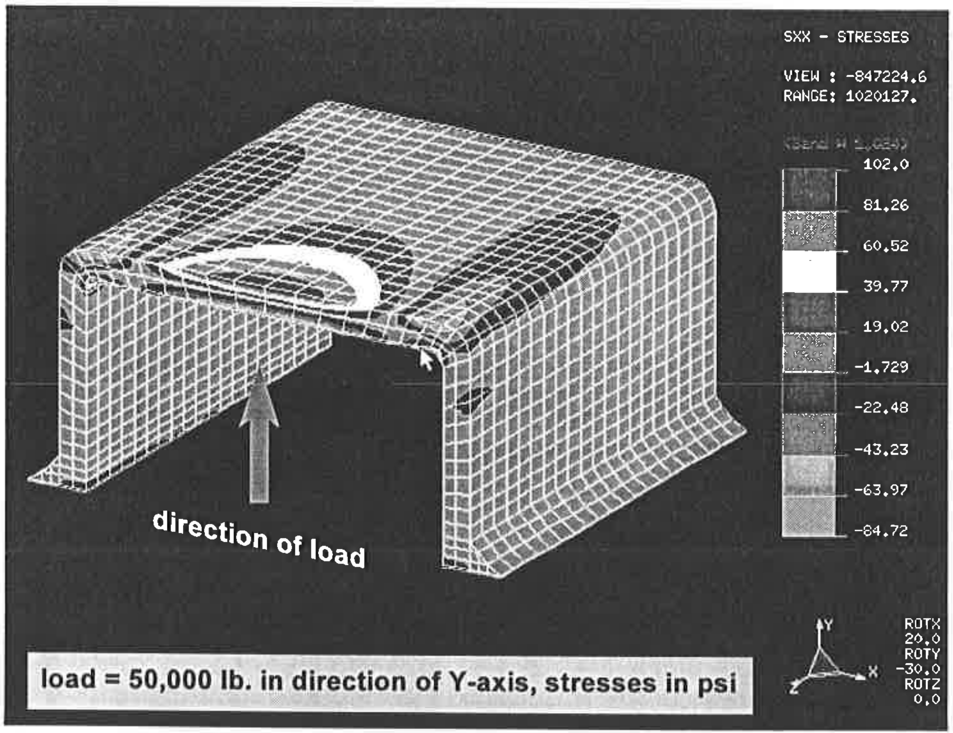

Figure 10a: Stress Contours Sxx for Heavy-duty Steel Stake Pocket Loaded in Lateral Outboard Direction

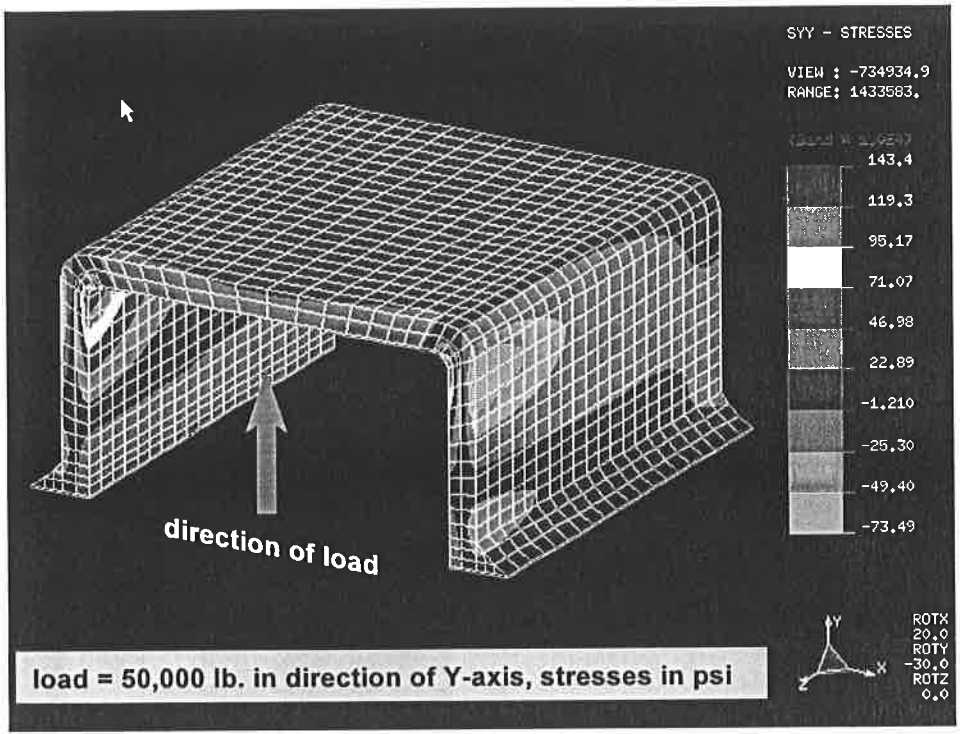

Figure 10b: Stress Contours Syy for Heavy-duty Steel Stake Pocket Loaded in Lateral Outboard Direction

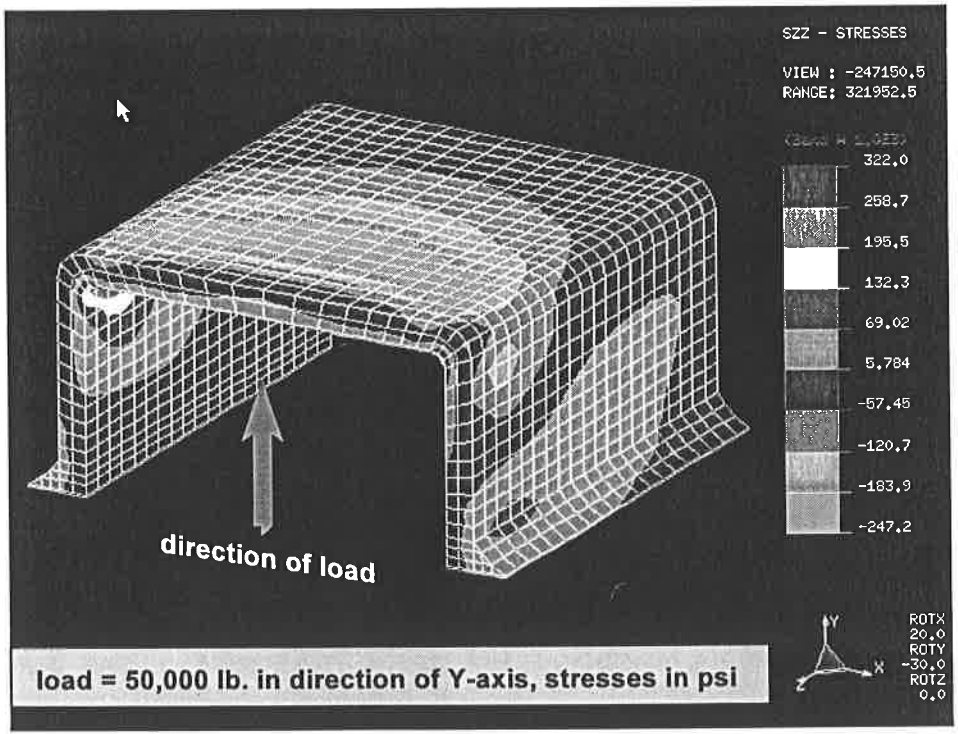

Figure 10c: Stress Contours Szz for Heavy-duty Steel Stake Pocket Loaded in Lateral Outboard Direction

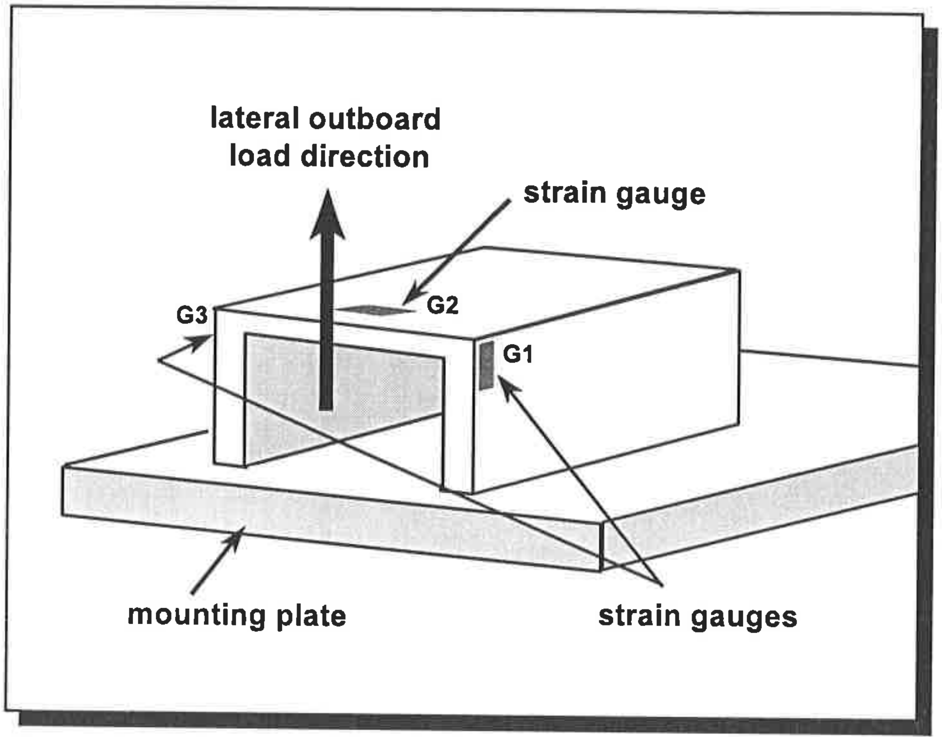

Figure 10d: Layout of Strain Gauges for Heavy-duty Steel Stake Pocket Loaded in Lateral Outboard Direction

3.3/ Instrumentation and Data Acquisition

A "pull-cord" displacement transducer was installed, with the help of magnetic bases, between the slide table and the bulkhead of the T.O. machine. It was intended to provide a measure of the deformation of the test specimen in the pertinent loading direction as the specimen was pulled. It was observed, however, that the measurement also included significant deformations and shifting of components in the pull chain or shackle. As attempts to account for these contaminations were largely unsuccessful, the pull-cord measurements could at best be used only as rough estimates.

For some test specimens, attempts were also made to install displacement transducers at selected locations on the specimen to provide additional data regarding deformations of the test specimen in specific directions in relation to the applied load. Several types of displacement transducers were used. The accuracy and consistency of the resulting measurements were found to be less than adequate. It was therefore also determined that these measurements could be used only as rough estimates.

An inhouse-built data acquisition system was used to capture data from the above-mentioned sensors, plus the digital load output from the T.O. machine. The system was based on a portable AT-class personal computer, and was capable of capturing eight channels of data. All channels were low-pass filtered at 1 Khz. At the beginning of the testing program, the sampling rate was initially set at 50 Hz. As testing progressed, it was found that, with a suitable loading rate at which load was increased or decreased on the test specimen, a lower sampling rate of 10 Hz was still adequate. Thus for some tests, a sampling rate of 10 Hz was adopted.

3.4/ Test Procedure

All eight categories of test were performed using the common test rig set up on the Tinius-Olsen loading machine, shown in Figure 8 previously.

a/ *Setting Up the Test Rig*

The stop screws on the slide table were set to prevent any movement of the sliding plates during installation. The slide table was lifted onto the top of the cross-head with the help of a block and pulley system mounted on an overhead crane. Once the table was centred properly over the cross-head, it was bolted down from the underside. The upper anchor assembly was then bolted onto the top bulkhead.

The initial position of the loading machine's platform was checked to ensure it was at a height that was within the calibrated loading range for the loading machine. The crosshead was set to a suitable height to allow sufficient clearance between it and the platform. Depending on the desired loading direction for a given specimen, a load orientation adapter was mounted onto the slide table if needed. A pull chain or shackle of a suitable length, and fitted with a hook of a suitable size, was installed onto the upper anchor assembly.

b/ *Installing the Test Specimen*

Stake pockets, D-rings, winches, welded rods, chain-in-tubes, and rub rails had already been attached to mounting plates, and these were bolted down either onto the slide table directly or onto the load orientation adapter, as appropriate. The height of the cross-head was adjusted. The specimen was loosely hooked up to the pull chain or shackle in the desired manner depending on the requirements of the specific test.

In the case of the corner radius and link orientation effects tests, the die for a given corner radius was suspended from the end of the pull chain or shackle. The tiedown adapter was bolted down onto the slide table. The test chain was passed over the corner radius die and connected to the two anchor points on this adapter plate. The length of the chain was selected so that the chain would subtend an angle of approximately 90 deg, with the selected chain link orientation, over the die when anchored down onto the adapter plate.

All stop screws on the slide table were then released, and remained so for the duration of the test to allow the pull chain or shackle to stay vertical as the test specimen changed its orientation with respect to the prescribed loading direction as it underwent deformation. The position of the specimen was adjusted by moving slide table components until the specimen was properly aligned with respect to the desired loading direction, as evidenced by the vertical position of the pull chain or shackle. Once alignment was achieved, the crosshead was given one final adjustment until there was only a slight slack in the pull chain or shackle.

c/ *Installing Sensors*

The pull-cord displacement transducer was installed, using magnetic bases, between the top bulkhead and the slide table, or the load orientation adapter, if one was used. The strain gauges were hooked up to the bridge completion boxes. Displacement transducers on the specimen, if any, were also installed. The pull chain or shackle was given one final check, and any necessary adjustments of the crosshead were made, to ensure it was not overly slack or tensioned as evidenced by the load readout on the T.O. machine. All instrumentation was then connected to the data acquisition system.

d/ *Test*

All sensors were zeroed as accurately as possible and calibrated, which consisted of recording the zero, half-scale, and full-scale outputs of each data channel, followed by several seconds of zero data. Loading was then started at a steady rate, generally between 2,000 kN/m (11,406 lb/in) and 4,000 kN/m (22,812 lb/in) of vertical movement of the bulkhead.

Typically, load was increased until visible breakage was observed in the specimen, which was usually accompanied by an audible cracking sound or bang depending on whether breakage was slow or quick, or until load was observed to have become constant over a sustained time period, or until load had exceeded about 89 kN (20,000 lb) (in order not to overload the pull chain or shackle unnecessarily), whichever occurred sooner. In a number of cases, such as some stake pockets, D-rings, and welded rods, loading was continued until either failure of the specimen was realized, or the applied load reached the maximum strength of the pull chain or shackle (about 125 kN (28,000 lb) and 200 kN (45,000 lb), respectively). In all cases, loading was immediately halted, and the cross-head raised sufficiently to release the tension in the pull chain. Data acquisition was also stopped.

The maximum load reached in any given test was noted. The test specimen was carefully inspected before it was removed. Observations were noted of any visible damage and of the mode of failure, if failure had occurred. The entire test setup, including the slide table, the load orientation adapter if one had been used, the pull chain or shackle, the hook, mounting bolts, and all other fittings were visually inspected for possible damage. If damage was found in any component, that component would either be repaired or replaced, as appropriate, before testing would continue. In cases where any component of the test setup had been found to have failed prematurely, the component would be repaired or replaced, as appropriate, and the test repeated.

Colour still photographs and slides were taken of all test setups and of the test specimens before, during, and after each test. Detailed records were kept of all test activities and observations. Selected test sessions were also recorded on video tape.

3.5/ Test Matrices

With small variations as necessitated by a given test, and as noted where appropriate, the test procedure described in Section 3.4 was applied to all eight categories of test. Typically, only one specimen was made available for each specific test. Each specimen was visually examined, as much as possible, for proper workmanship before testing. A total of over 150 test specimens were tested.

In the following, all eight categories of test are described briefly as to the associated materials, grades or sizes, loading directions, and other relevant information pertinent to each category of tests, as needed. The loading directions are shown in Figures A.1 through A.8, and the resulting test matrices tabulated in Tables A.1 through A.8, of Appendix A.

a/ Stake Pocket

Three grades of ASTM A36 steel stake pockets, namely, light-duty with dimensions of 76x102x4.76 mm (3x4x3/16 in), medium-duty with dimensions of 102x102x4.76 mm (4x4x3/16 in), and heavy-duty with dimensions of 102x102x6.35 mm (4x4x1/4 in), were tested in four different loading directions (vertical, longitudinal forward, lateral outboard, and at a 45 deg angle outboard). Similarly, a number of light-duty and medium-duty 6061-T6 extruded aluminum stake pockets were also tested. The light-duty aluminum pockets measured 88.9x102x6.35 mm (3 1/2x4x1/4 in), and the medium-duty 102x102x6.35 mm (4x4x1/4 in). These stake pockets are typical of those used on highway trailers. Stronger pockets may be used for load-bearing stakes on specialized trailers. A number of strain gauges, varying between three and six depending on the specific specimen, were installed on each pocket. A total of 20 specimens were tested.

b/ D-rings

Three grades, namely, light-duty, medium-duty, and heavy-duty, of steel D-ring were selected for testing. These measured 3.18 mm (1/8 in), 9.53 mm (3/8 in), and 12.7 mm (1/2 in), respectively. Each grade of D-ring was subjected to loading in seven directions. For each heavy-duty rod specimen, a number of strain gauges were installed on the clip and the ring itself. A total of 21 specimens were tested.

c/ Winches

Six models of commercially available winch encompassing two profiles (high and low) and three attachment methods (welded, sliding, and clipped) were tested in three loading directions, namely, vertical, lateral outboard, and at a 45 deg. angle outboard. A 152 mm (6 in) wide high-strength webbing with an ultimate strength of 1,403 kN/m width (8,000 lb/in) was used for all tests, so that the winch would fail, not the webbing.

All winches were instrumented with between two to four strain gauges. For each of the clipped and sliding winches, two additional stain gauges were installed on the clip and track on which these winches were mounted. A total of 18 tests were performed.

d/ Chain-in-tubes

Three commercially available models of chain-in-tube anchor points were tested in three pull directions, namely, vertical, lateral, and at a 45 deg angle, for a total of 9 tests. For ease of reference, these models were designated "A", "B", and "C". Models "A" and "B", supplied by the same manufacturer, shared a similar design, except for the way the steel clip, to which the chain was attached, was mounted: in Model "A", the clip was welded onto the supporting frame while in Model "B", it was bolted onto the frame. Model "C", supplied by another manufacturer, was of a different design. The clip to which the chain was attached was also welded onto the supporting frame.

No strain gauges were used on these test specimens.

e/ Welded Rods

Three sizes of ASTM A36 steel welded rod, measuring 6.35 mm (1/4 in), 9.53 mm (3/8 in), and 12.7 mm (1/2 in), were each tested in seven loading directions, for a total of 21 tests. Between two and three strain gauges were installed on each of the heavy-duty rod specimens.

f/ Chain Wraps on Stake Pockets

For these tests, a standard 8.53 mm (3/8 in) Grade 8 steel chain, with a 3,220 kg (7,100 lb) working load limit, was used on two types of pockets, one constructed of ASTM A36 steel, and the other of 6061-T6 extruded aluminum. The steel pockets were of the medium-duty grade, measuring 102x102x4.76 mm (4x4x3/16 in), while the aluminum pockets were also of the medium-duty grade, measuring 102x102x6.35 mm (4x4x1/4 in). Each pocket was instrumented with between two and four strain gauges depending on the specific test requirement.

For each pocket type, six wrap configurations were tested. Five of these pertained to a chain wrapped around or hooked onto a single pocket. The remaining one was for a chain wrapped around two pockets.

For four of the five single-pocket wrap configurations, three loading directions (vertical, 45 deg forward, and 45 deg aft) were used, whereas the fifth single-pocket method and the double-pocket method were both tested only in the vertical loading direction.

Thus, a total of 30 test configurations resulted.

g/ Rub Rails

A total of 10 tests were performed. These pertained to two materials (ASTM A36 steel and 6061-T6 extruded aluminum), two loading directions (vertical and 45 deg inboard) for each of the two chain locations of between the spool and the stake pocket, and at the spool, and the vertical loading direction for the around-the-spool chain location.

The steel rub rail specimens were each comprised of a 76.2x9.53 mm (3x3/8 in) rub rail welded onto two medium-duty steel pockets with dimensions of 102x102x4.76 mm (4x4x3/16 in) and a 50.8 mm (2 in) diameter steel pipe spool. The aluminum specimens were each constructed of a 50.8x9.53 mm (2x3/8 in) rub rail welded onto two medium-duty aluminum pockets, which measured 102x102x6.35 mm (4x4x1/4 in), and a 50.8 mm (2 in) diameter aluminum pipe spool.

For all steel and aluminum specimens, spacing between the spool and pockets was 305 mm (12 in) centre-to-centre. On each steel or aluminum specimen, two strain gauges were installed on the rub rail, one near the rub rail-to-pocket joint and the other near the rub rail-to-spool joint.

h/ Corner Radius and Chain Link Orientation Tests

Three sizes of chain were used in this series of test. They consisted of a 6.35 mm (1/4 in) Grade 40 chain with a working load limit of 1,180 kg (2,600 lb), a 7.94 mm (5/16 in) Grade 70 chain with a working load limit of 2,130 kg (4,700 lb), and a 9.53 mm (3/8 in) Grade 40 chain with a working load limit of 2,450 kg (5,400 lb). All were tested with three different corner radii of 3.18 mm (1/8 in), 12.7 mm (1/2 in), and 25.4 mm (1 in), and three chain link orientations (flat link, upright link, and link interlock) over the given corner radii.

One control test for each chain size was also performed. This test consisted of pulling the same make of chain without the corner radius die. To achieve this, the corner radius die was replaced by a clevis. One end of each of two separate lengths of chain was connected to the clevis while the other end was connected to one of the two anchor points on the tiedown adapter plate.

One strain gauge was installed about midway in each half-length of each of the chains tested. A total of 30 tests, including the control tests, were performed.

3.6/ Data Processing

All test data - applied load, strains, and displacements - were visually scrutinized to screen out any untoward or bad data. Filtering, if needed, and zero baseline correction were then performed to eliminate non-zero offsets, and plots were made of the data in the form of time-histories. Strain gauge and displacement data were also plotted against the pertinent applied load.

4/ Test Results and Observations

4.1/ Test Results

The maximum loads applied on individual test specimens are summarized in Tables B.1 through B.8 of Appendix B, for all eight categories of test. Observations of physical damage incurred in any part of a given test specimen, such as breakage or permanent set, and whether or not a given test specimen's ultimate strength had been reached are also noted in these tables.

The "maximum load applied" refers to the maximum load applied in a given test at which either (i) the given test specimen was seen to have suffered breakage, such as tearing of a weld or material or severance of a part, or, when no breakage was evident, substantial permanent set such that the specimen had become unusable or unserviceable, in which cases the damage would be noted accordingly in the respective tables, or (ii) the given test was stopped, either because no further information would be gained by continuing, or there was significant risk of damage to some component(s) of the test rig. For the vast majority of tests, the "maximum applied load" does represent the ultimate load. For a few others, it does not.

In addition, the load level at which any part of a given anchor point specimen exhibited permanent set or yield *as identified by the available strain gauge data*, referred to hereafter as the "yield load", has also been noted in the tables. It must be emphasized that this "yield load" was by no means the true yield load at which *any part of the given specimen actually reached yield*. In fact, this value would in general be higher than the true yield load.

All maximum applied loads are also presented in the form of bar charts as shown in Figures 11 through 39. For any given test, the respective "yield load", when this value was available, is denoted as appropriate by a white bar in these charts to allow an appreciation of how it compared against the respective ultimate load.

4.2/ Test Observations

Fracture failure was observed in the vast majority of specimens that were tested. Of all tests, only a few needed to be repeated because of equipment or instrumentation failure. While the tests were relatively limited in scope, as only one specimen was made available for each test, all test data collected appeared to be in good and consistent conditions.

Findings and observations pertinent to each category of test are described below:

a/ Stake Pockets

The maximum loads applied in various loading directions for all steel and aluminum stake pocket tests are shown in Figure 11. These loads are further broken down with respect to specific loading directions and shown in Figures 12, 13, 14, and 15 for the vertical, longitudinal forward, lateral outboard, and 45 deg lateral outboard load directions, respectively.

The following observations can be made:

o All three grades of steel pocket attained a load of over 200 kN (45,000 lb) without any breakage in the vertical load direction, although permanent set was observed at the lower end of each pocket where the pocket contacted the stop plate of the insert load connector.

- The steel pockets were generally stronger than their aluminum counterparts in any given loading direction by a factor of up to more than two, the greatest difference being observed for the vertical load direction.

- The steel and aluminum pockets were much stronger in the vertical loading direction than in the other directions for the same pocket grade, by a factor of as much as 4. The longitudinal forward load direction proved to be the most critical (i.e. weakest) loading direction for both steel and aluminum pockets, followed by the lateral outboard direction.

- Failure was typically characterized by breakage in the weldment area for all steel and aluminum pockets.

- The aluminum pockets were seen to be more "brittle" than the steel counterparts in that breakage would occur without much warning whereas the steel pockets would exhibit substantial ductility prior to the onset of breakage.

- Yield loads ranged from as low as 10% to 60% of the respective ultimate loads (Figures 12 - 14).

b/ D-rings

The maximum loads applied in all load directions for all three grades of D-rings are shown in Figure 16. For clarity, these are further broken down by the grade of the D-ring and shown in Figures 17, 18, and 19 for the light-, medium-, and heavy-duty D-rings, respectively.

The following observations can be made:

- The ultimate load attained by a given grade of D-ring appeared to be independent of the load direction.

- An ultimate load of just over 200 kN (45,000 lb) was exhibited by the one heavy duty D-ring specimen that was tested to failure in one load direction. Although the other heavy duty D-rings had not been tested to failure in order not to overload the test rig excessively, it is believed that a similar ultimate load would have been attained in the other load directions. Ultimate loads for the medium duty and light duty D-rings were about 89 kN (20,000 lb) and 33.4 kN (7,500 lb), respectively. It is worth noting that the ultimate loads recorded for the heavy- and medium-duty D-rings appeared to approximate the ultimate strength ratings provided by the manufacturers.

- The heavy duty D-rings were found to be stronger than the medium duty counterparts by a factor of about 2. In turn, the medium duty D-rings were generally stronger than the light duty ones by a similar factor.

- For all three grades of D-ring, ultimate failure was characterized by breakage of the clip in the weldment area and/or breakage of the ring - preceded by necking - in tension.

- Yield loads for the heavy-duty D-rings ranged from 15% to 30% of the respective ultimate loads (Figure 19).

c/ Winches

The maximum loads applied in all three loading directions for all winch tests are shown in Figure 20. These loads are further broken down with respect to specific loading directions, as shown in Figures 21, 22, and 23 for the vertical, lateral outboard, and 45 deg lateral outboard load directions, respectively.

The following observations can be made:

- For the welded winches, failure was precipitated by breakage of the pawl or the weldment. For the sliding winches, failure was typically precipitated by excessive deformation of the track such that the winch would separate from the track, or by breakage of the pawl. For the clipped winches, failure was typically by way of breakage of the pawl or the mounting bolts and/or frame. For most tests, regardless of the winch type and the mode of ultimate failure, excessive deformation of the bracket or mandrel of the winch itself that would render the unit unusable was also evident.

- In terms of attaining the highest ultimate loads with respect to loading directions, the vertical direction was the strongest direction while the lateral outboard direction was the weakest.

- With respect to attachment methods, the welded and clipped winches were comparable in ultimate strength while the sliding winches were significantly weaker as a result of the track opening up at fairly low loads (in the range of 3,000 to 4,000 lb), which rendered the winch unusable even though no part of the winch itself had yet sustained any physical damage such as breakage of weldment or permanent set.

- Yield loads ranged from 20% to 90% of the respective ultimate loads (Figures 21-23).

d/ Chain-in-tubes

The maximum loads applied in all three loading directions for all three types of chain-in-tube are shown in Figure 24. These loads are further broken down with respect to specific loading directions, as shown in Figures 25, 26, and 27 for the vertical, lateral, and 45 deg. load directions, respectively.

The following observations can be made:

- o Ultimate failure was precipitated by chain breakage, ripping of the pipe, or weld failure.
- o The vertical load direction was the strongest load direction, while the lateral was the weakest, for each type of chain-in-tubes.
- o Model "B", with a bolted-on clip, was significantly weaker than the other two models in all load directions.
- o Despite the relatively high ultimate loads recorded for the vertical and 45 deg. load directions, it was observed during testing that all specimens sustained gross plastic deformation of the pipe at loads that were only about 10% -20% of the ultimate.

e/ Welded Rods

The maximum loads applied in all seven loading directions for all three grades of welded rod are shown in Figure 28. The following observations can be made:

- o For all three grades of rod, ultimate failure was characterized by weld failure or breakage of the rod - preceded by necking - in tension.
- o The out-of-plane pull direction (Y-axis, Figure A.5 of Appendix A) was the strongest direction for all sizes of welded rods. However, no clear trend could be established regarding the impact of the other load directions on the ultimate strength of the welded rods.
- o The heavy-duty rods were found to be stronger than the medium duty counterparts by a factor of about 1.7. In turn, the medium-duty rods were generally stronger than the light-duty ones by a factor of 2.
- o For the heavy-duty welded rods, yield loads ranged from 10% to 80% of the respective ultimate loads (Figure 28).

f/ Chain Wraps

The maximum loads applied in all three loading directions for all chain wrap tests are plotted as shown in Figure 29. These loads are further broken down with respect to specific loading directions, as shown in Figures 30, 31, and 32 for the vertical, 45 deg. forward, and 45 deg. aft load directions, respectively.

The following observations can be made:

- For the aluminum pockets, failure was without exception characterized by weld failure accompanied by slight to moderate localized plastic deformation in the areas where the pull chain or hook contacted the pocket. For the steel pockets, however, "failure" was less precise as all specimens exhibited gross plastic deformation in the contact area as the chain or hook cut into the pocket material, with only three cases also exhibiting weld failure. Thus, the steel pockets provided more advance warning of failure than the aluminum counterpart.
- Chain wraps on steel pockets in general exhibited significantly higher ultimate loads than those on aluminum pockets.
- Wrap method "c" appeared to be the weakest among the six methods tested for both steel and aluminum pockets.
- For a given wrap method, the strongest load direction was in general the vertical direction.
- Yield loads ranged from 5% to 60% of the respective ultimate loads (Figures 30-32).

g/ Rub Rails

The maximum loads applied in all rub rail tests are shown in Figure 33. These loads are further broken down with respect to specific loading directions, as shown in Figures 34 and 35 for the vertical and 45 deg inboard load directions, respectively. The following observations can be made:

- The steel rub rails were stronger than the aluminum counterpart by a factor of as high as 2.
- For the steel rub rails, failure was typically in the fashion of gross plastic deformation of the rail to the extent that the pull chain became caught so that further testing would become only a test of the chain's strength. Weld failure was seen only in one case, Test 1.a. For the aluminum rub rails, failure was typically in the form of weld failure or gross plastic deformation of the metal in areas contacted by the pull chain
- The "over the spool" chain location appeared to offer the greatest ultimate strength, followed by the "at the spool" and then the "between the spool and pocket" chain locations.
- Yield loads ranged from 35% to 90% of the respective ultimate loads (Figure 33).

h/ Corner Radius and Chain Link Orientation Tests

The maximum loads applied in all tests performed in this category are shown in Figure 36. These loads are further broken down with respect to specific link orientations, as shown in Figures 37, 38, and 39 for flat link, upright link, and interlocked links, respectively. The following observations can be made:

- The two half-lengths of each test chain showed identical strain response, indicating continuous load transfer across the corner radius.
- There was little or no impact of link orientation on the ultimate strength of a given size of tiedown chain with a given corner radius.
- For the flat link configuration, the ultimate strength of the tiedown chain appeared to increase with smaller corner radii. This could perhaps be explained by the fact that with a large corner radius, the chain link failed more in tension while with the smaller radii, it failed primarily in bending. For the upright link and interlocked link configurations, the effect of corner radius was less clear. This may be due to the fact that these two link configurations shifted significantly in orientation during testing.
- Yield loads were typically about 35.6 kN (8,000 lb) to 40 kN (9,000 lb) for the 7.94 mm (5/16 in) chain tests, and 71.2 kN (16,000 lb) to 75.7 kN (17,000 lb) for the 9.53 mm (3/8 in) counterpart (Figures 37 - 39).

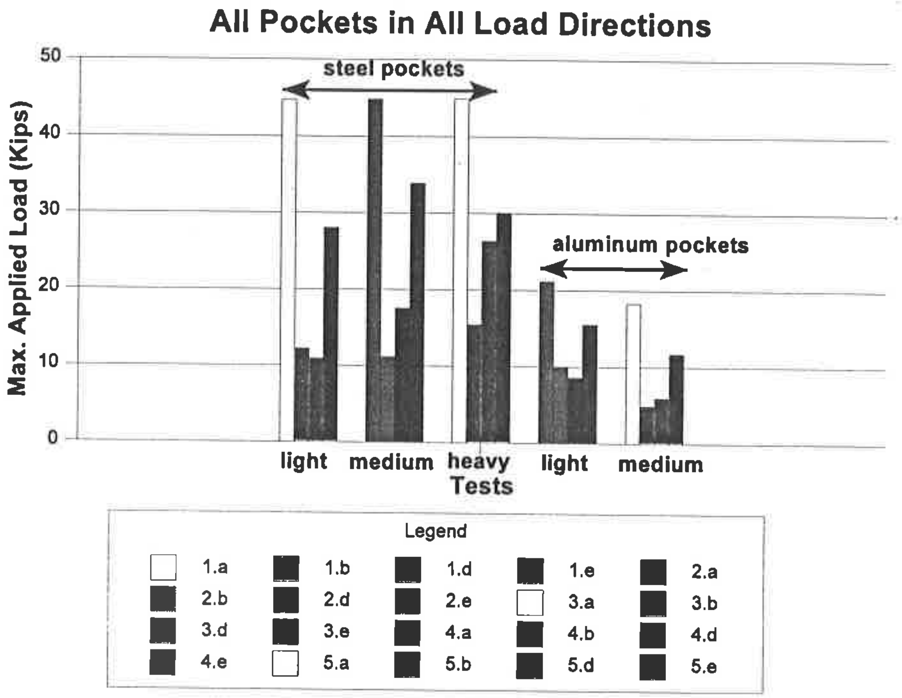

Figure 11: Maximum Applied Loads for Stake Pocket Tests - All Load Directions

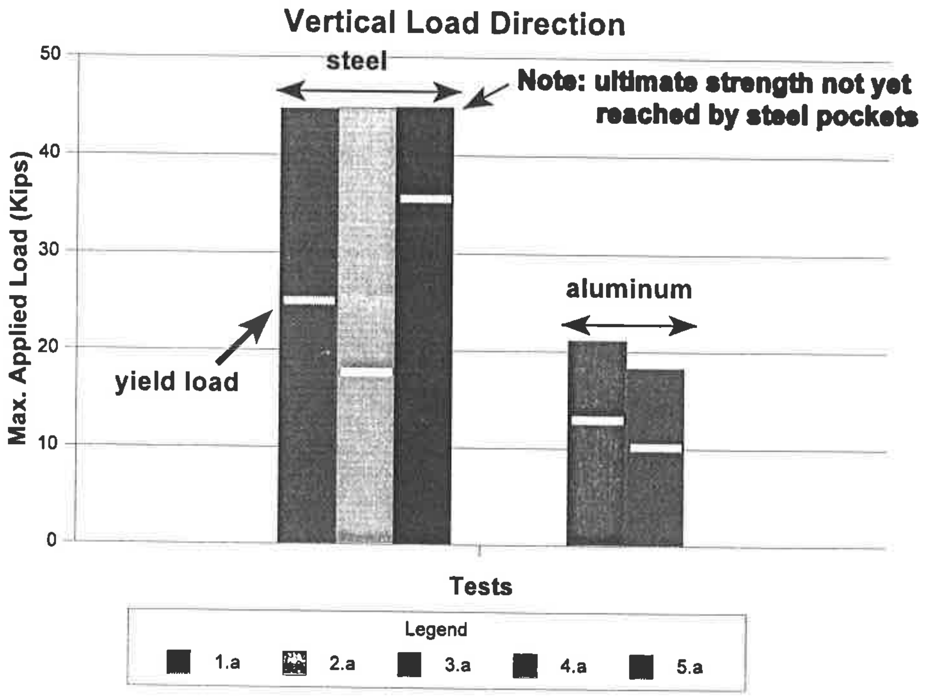

Figure 12: Maximum Applied Loads for Stake Pocket Tests - Vertical Load Direction

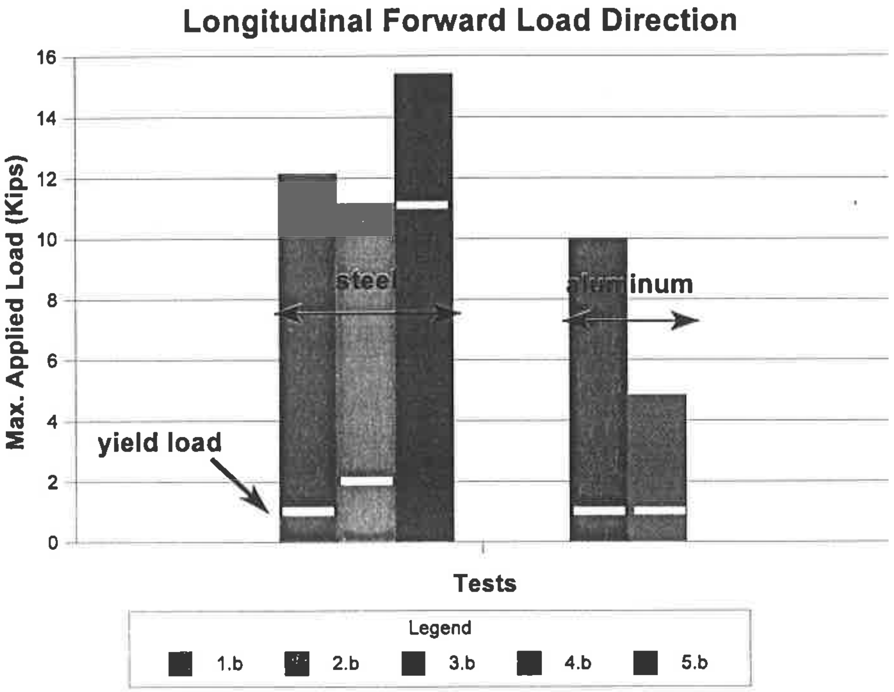

Figure 13: Maximum Applied Loads for Stake Pocket Tests - Longitudinal Forward Load Direction

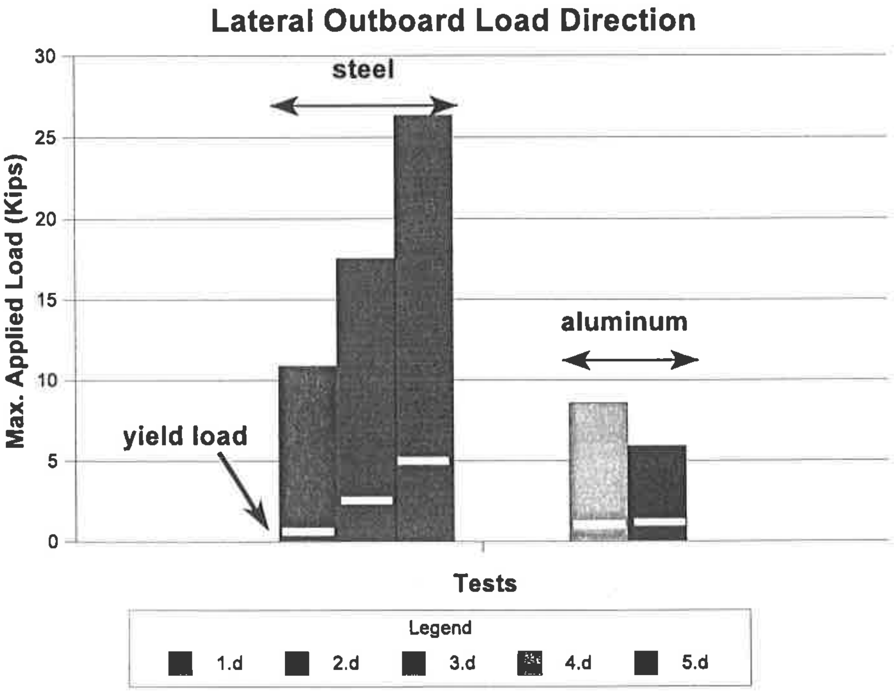

Figure 14: Maximum Applied Loads for Stake Pocket Tests - Lateral Outboard Load Direction

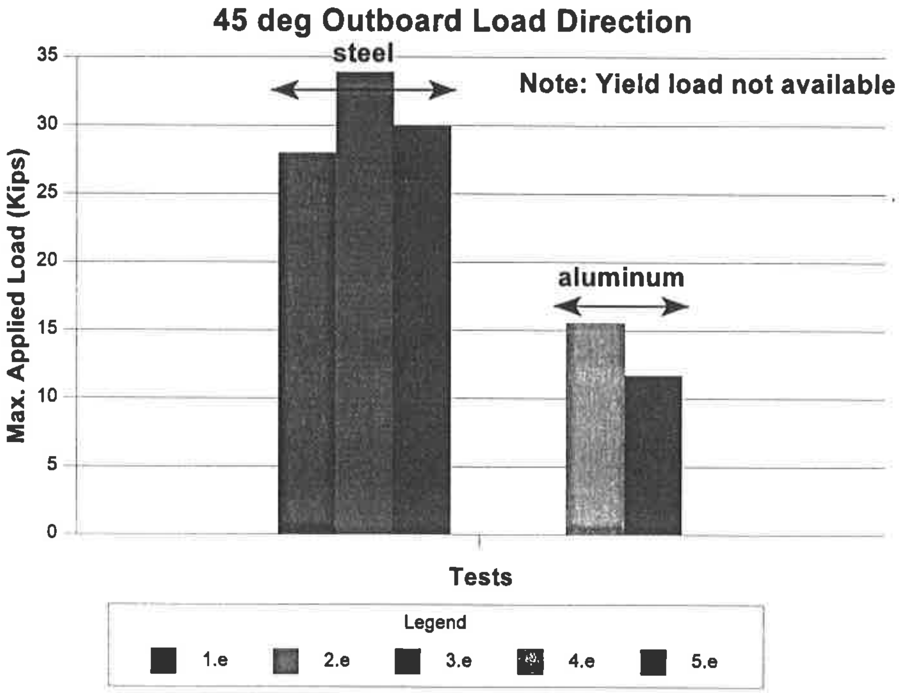

Figure 15: Maximum Applied Loads for Stake Pocket Tests - 45 deg Outboard Load Direction

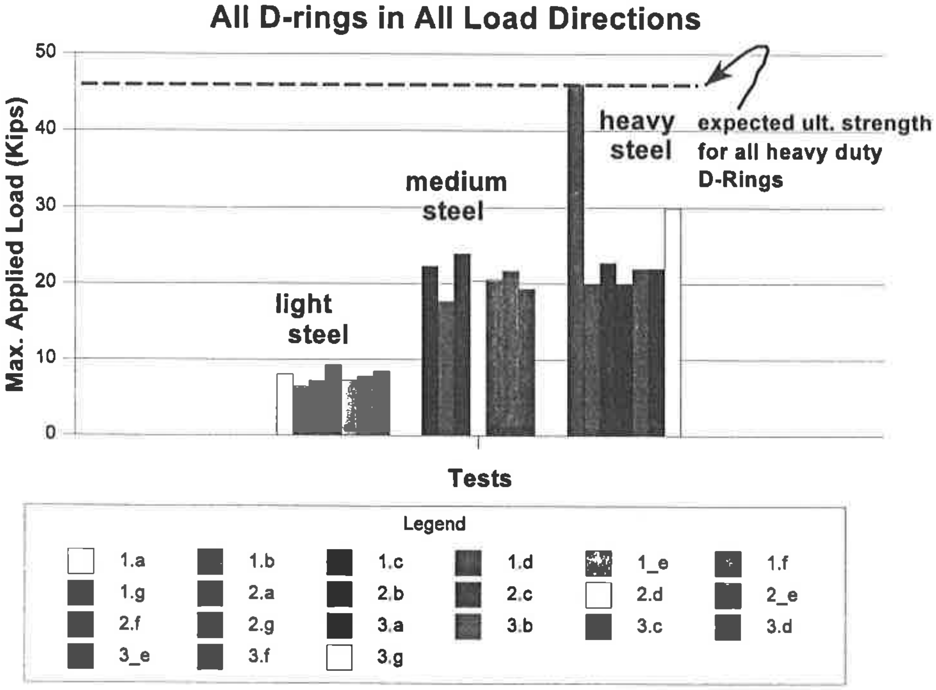

Figure 16: Maximum Applied Loads for All D-rings in All Load Directions

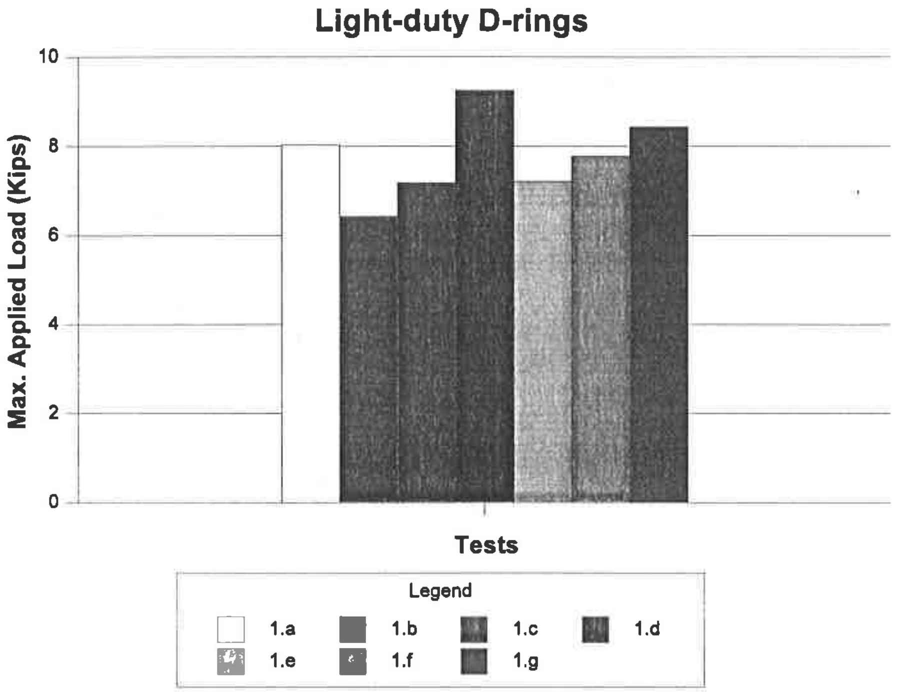

Figure 17: Maximum Applied Loads for Light-duty D-rings

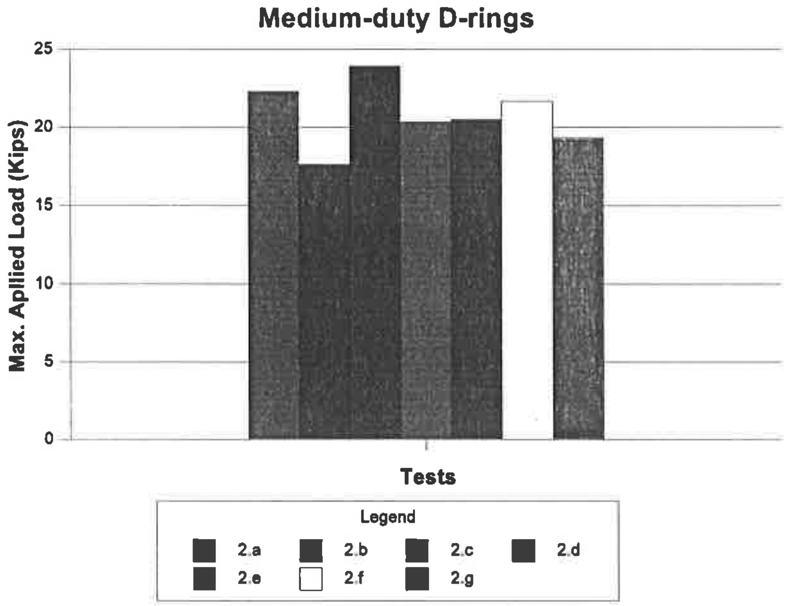

Figure 18: Maximum Applied Loads for Medium-duty D-rings

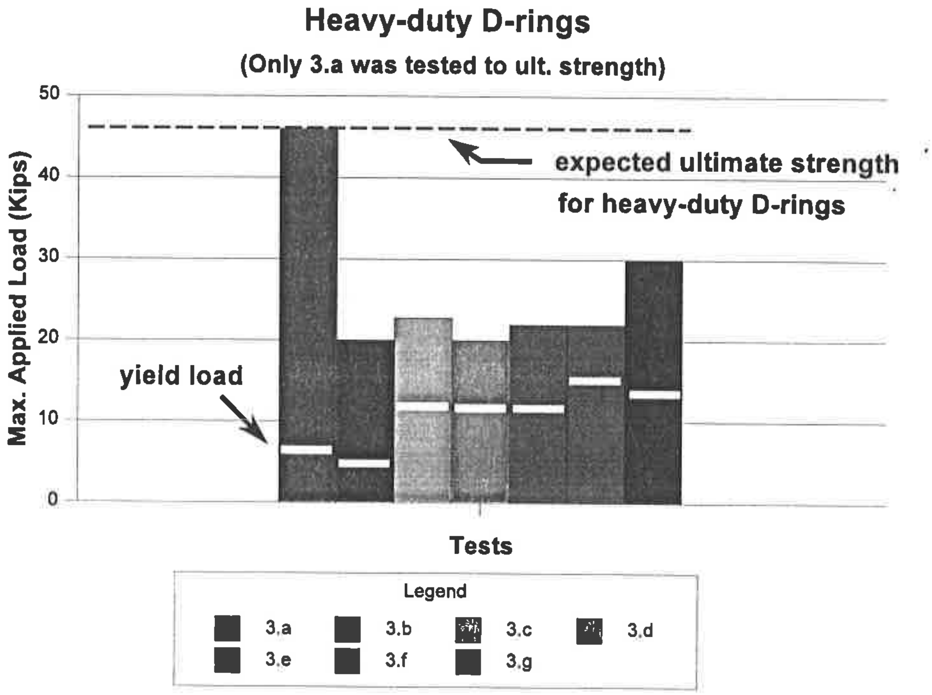

Figure 19: Maximum Applied Loads for Heavy-duty D-rings

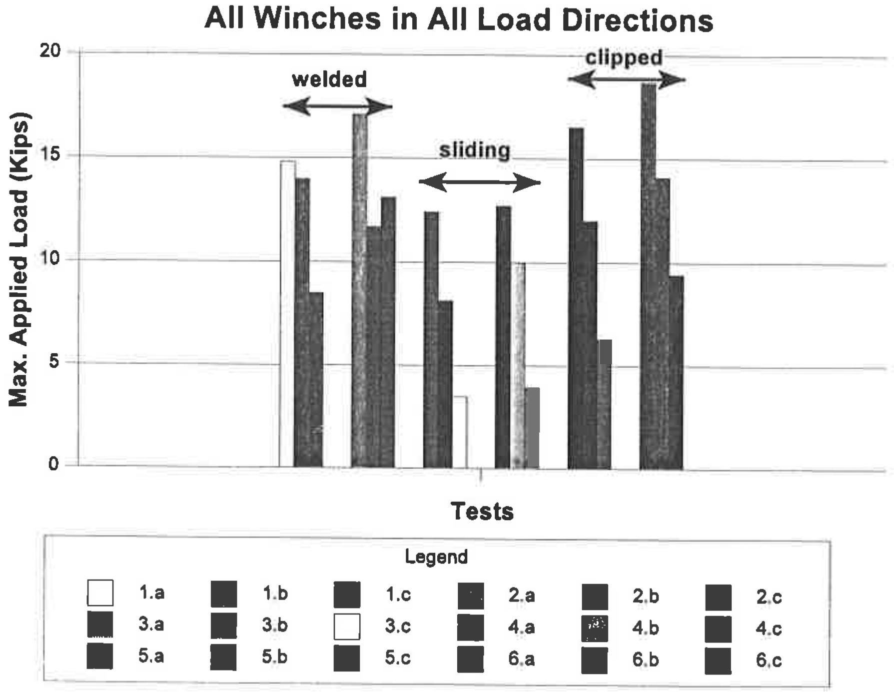

Figure 20: Maximum Applied Loads for All Winches in All Load Directions

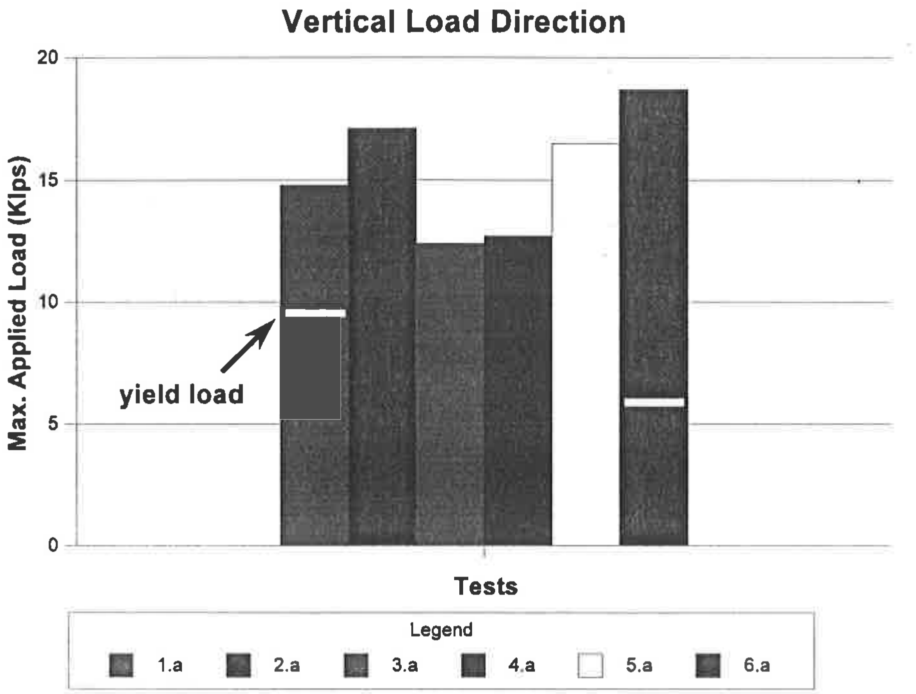

Figure 21: Maximum Applied Loads for All Winches in Vertical Load Direction

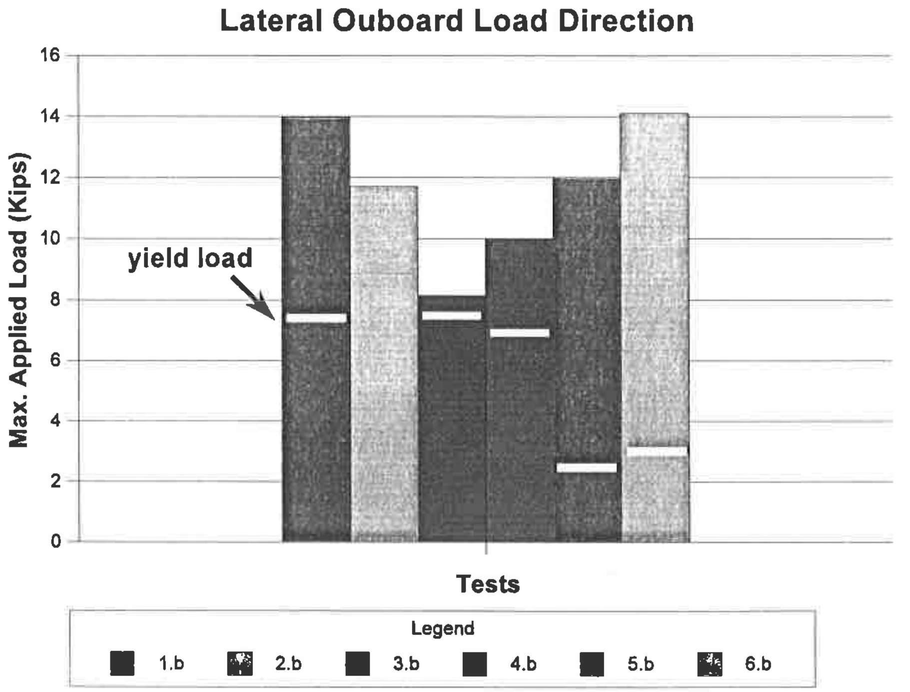

Figure 22: Maximum Applied Loads for All Winches in Lateral Outboard Load Direction

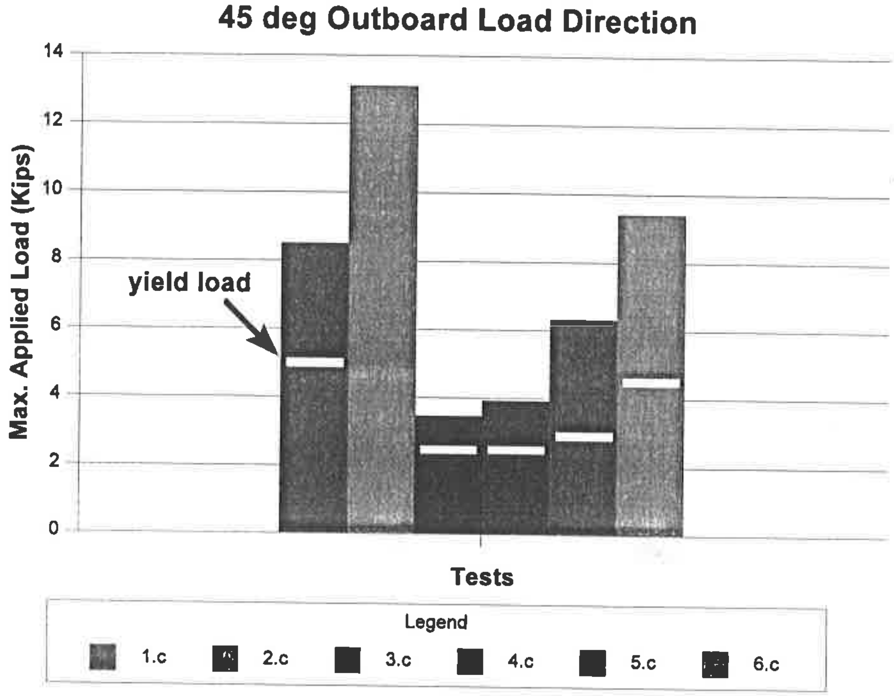

Figure 23: Maximum Applied Loads for All Winches in 45 deg Outboard Load Direction

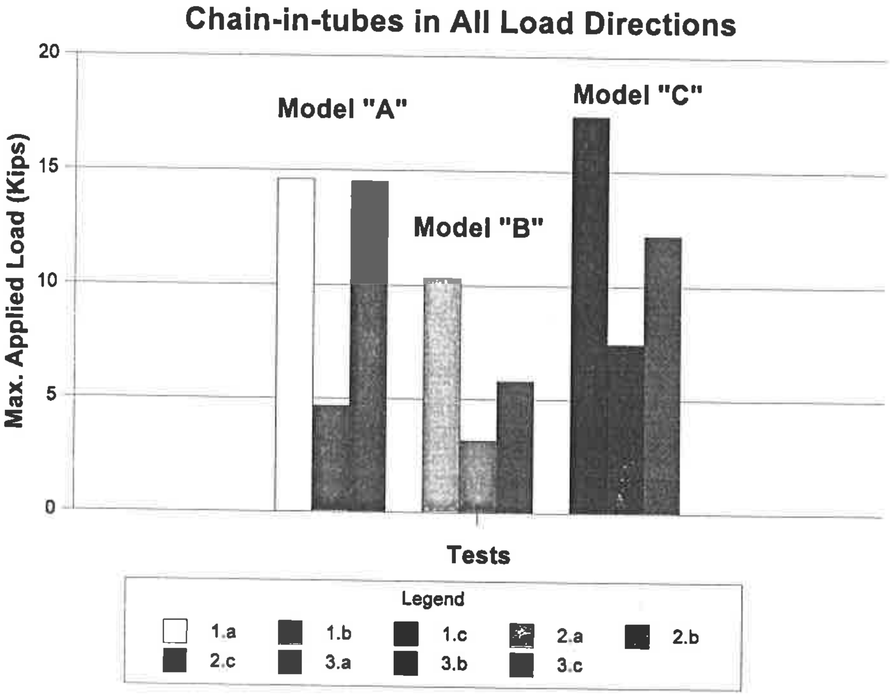

Figure 24: Maximum Applied Loads for Chain-in-tubes in All Load Directions

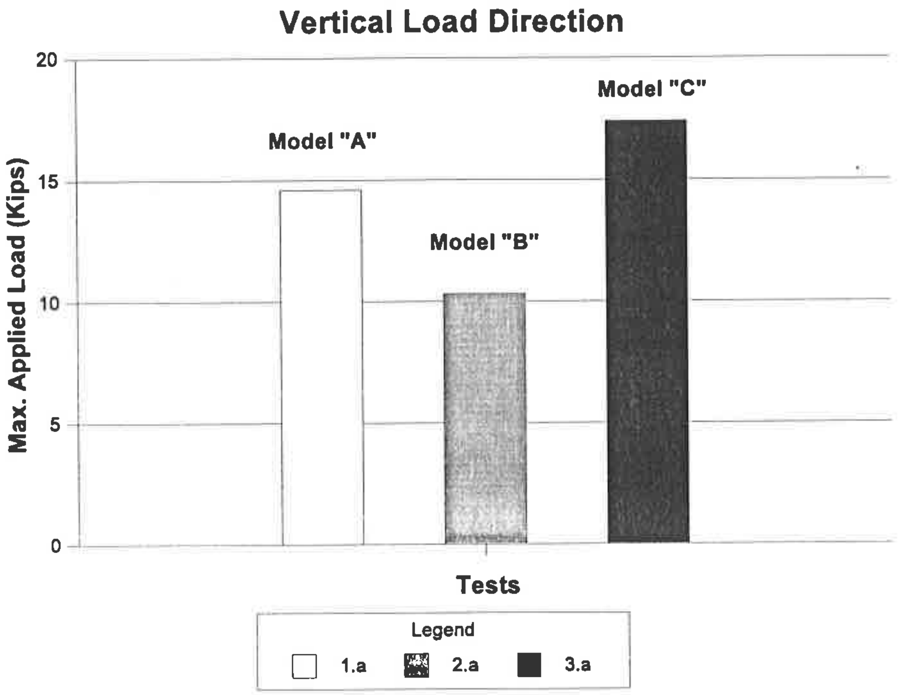

Figure 25: Maximum Applied Loads for Chain-in-tubes in Vertical Load Direction

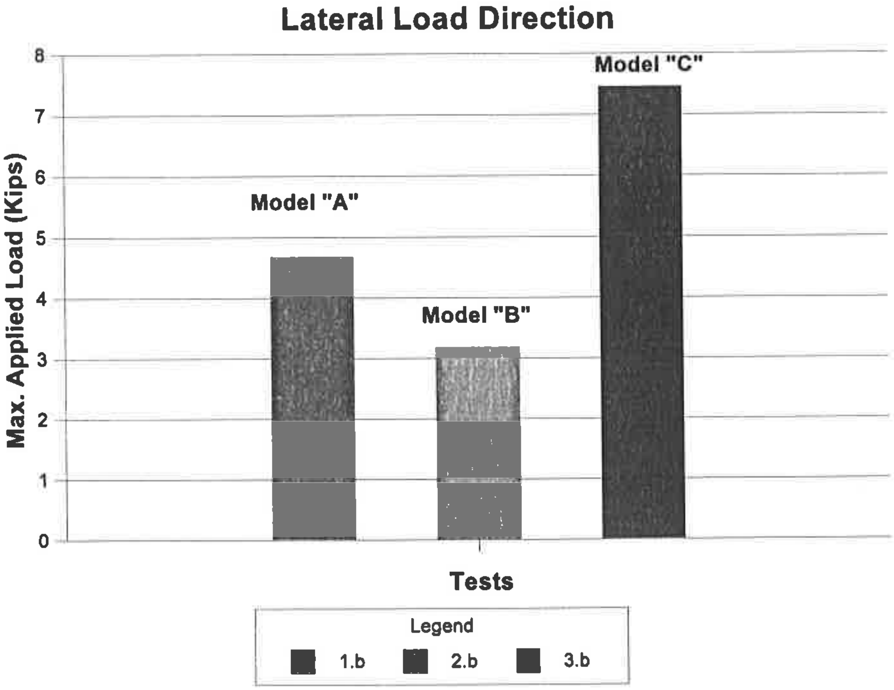

Figure 26: Maximum Applied Loads for Chain-in-tubes in Lateral Load Direction

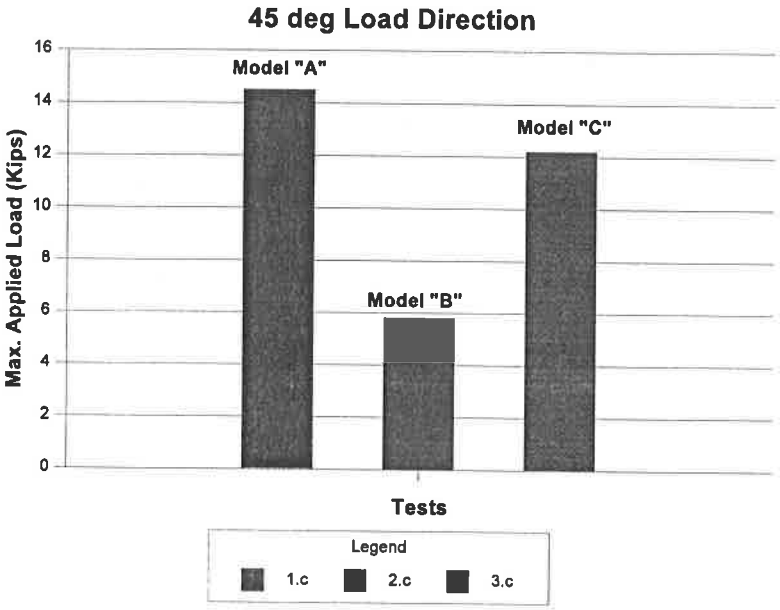

Figure 27: Maximum Applied Loads for Chain-in-tubes in 45 deg Load Direction

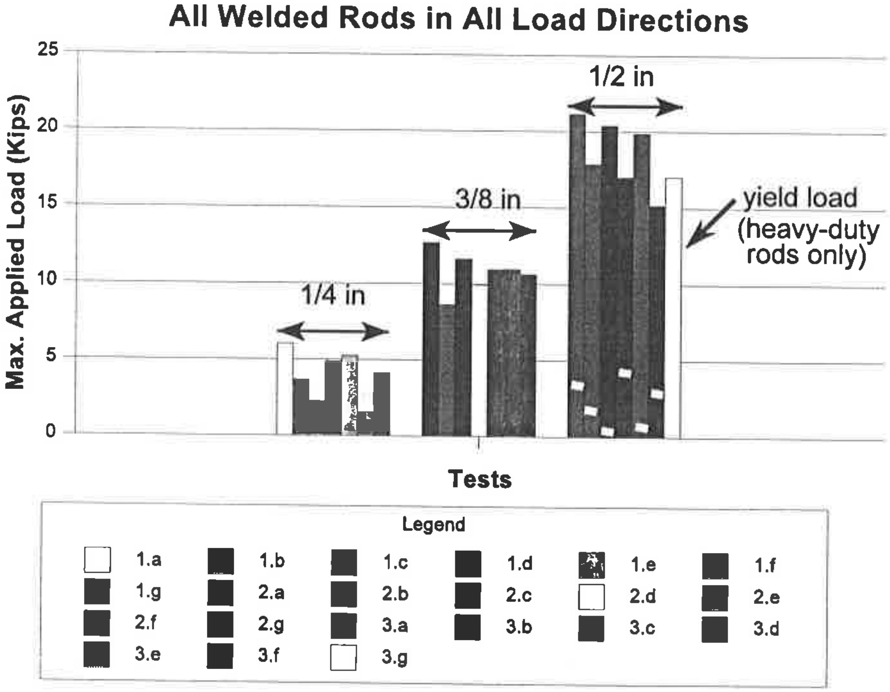

Figure 28: Maximum Applied Loads for All Welded Rods in All Load Directions

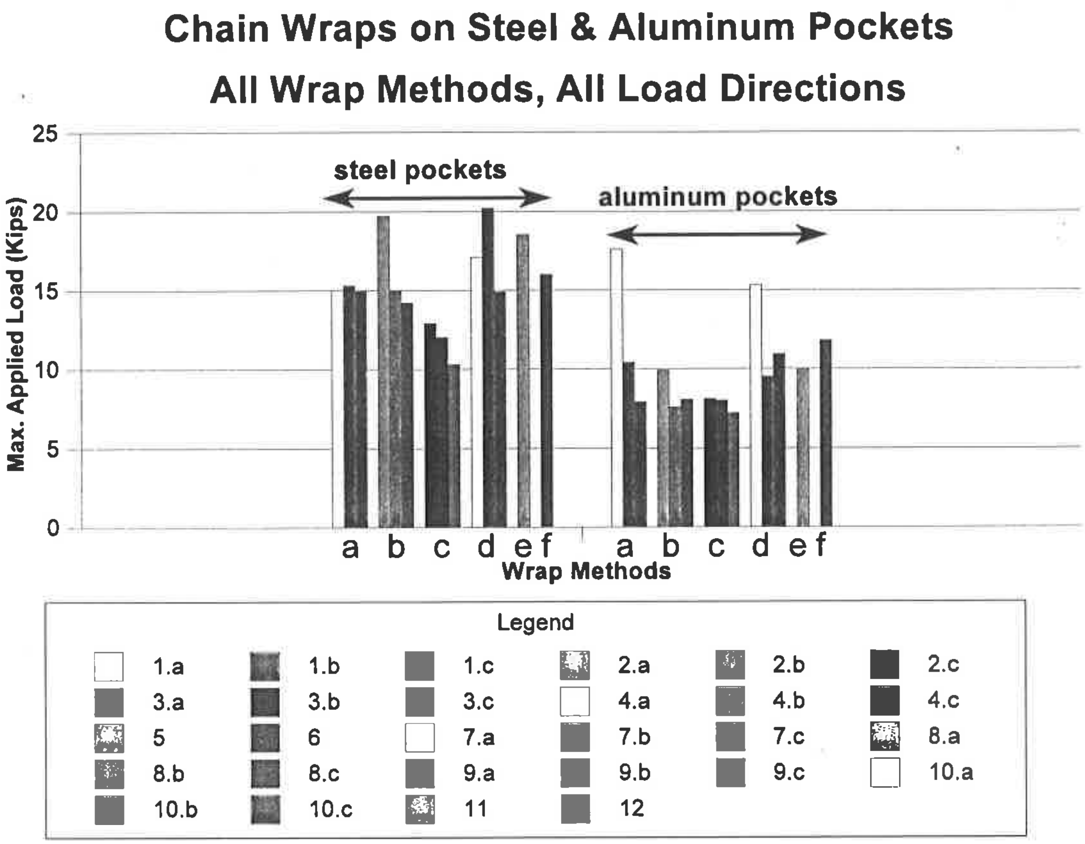

Figure 29: Maximum Applied Loads for Chain Wraps in All Load Directions

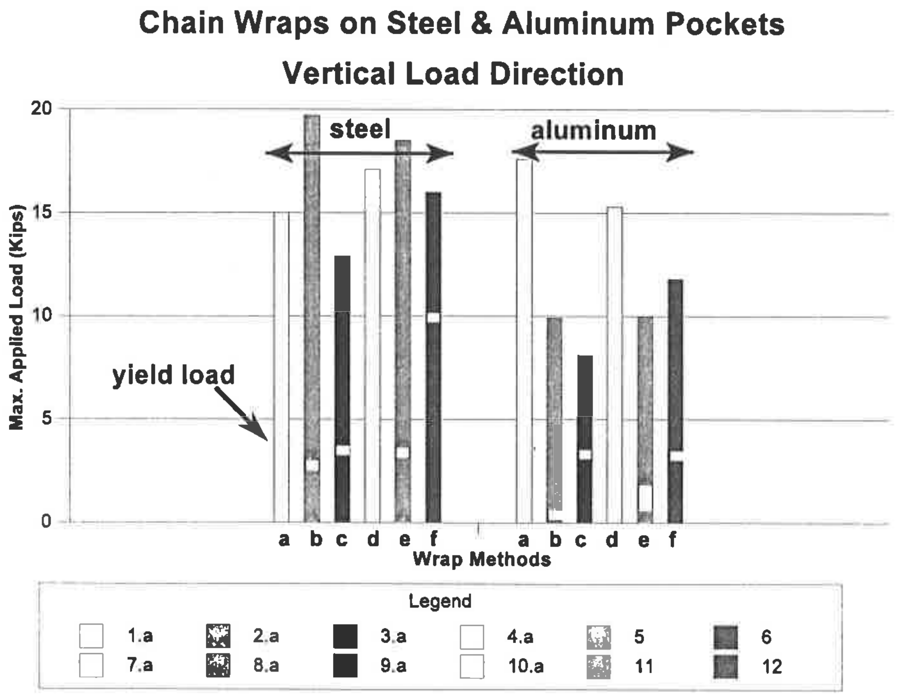

Figure 30: Maximum Applied Loads for Chain Wraps in Vertical Load Direction

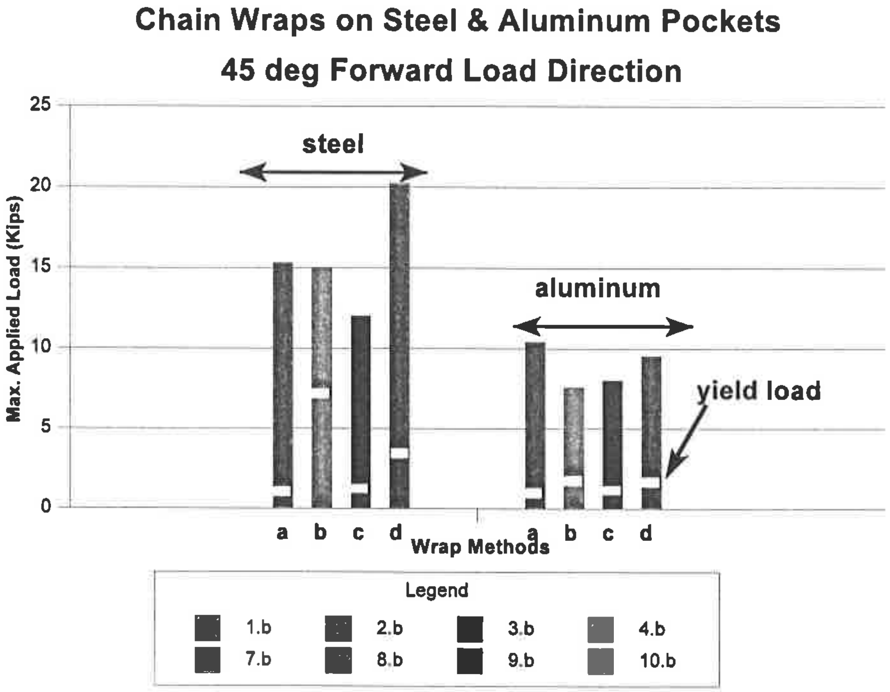

Figure 31: Maximum Applied Loads for Chain Wraps in 45 deg Forward Load Direction

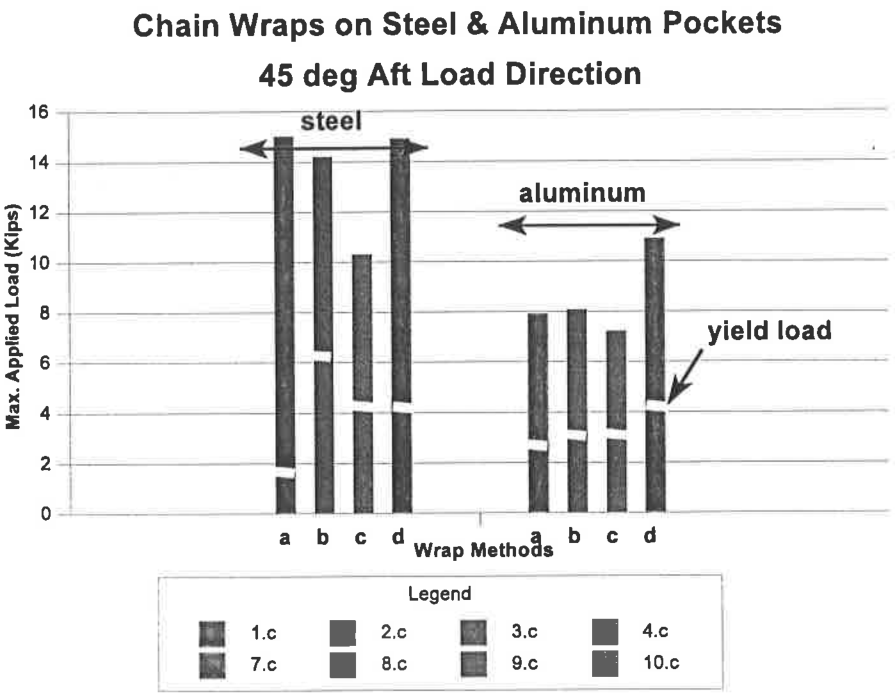

Figure 32: Maximum Applied Loads for Chain Wraps in 45 deg Aft Load Direction

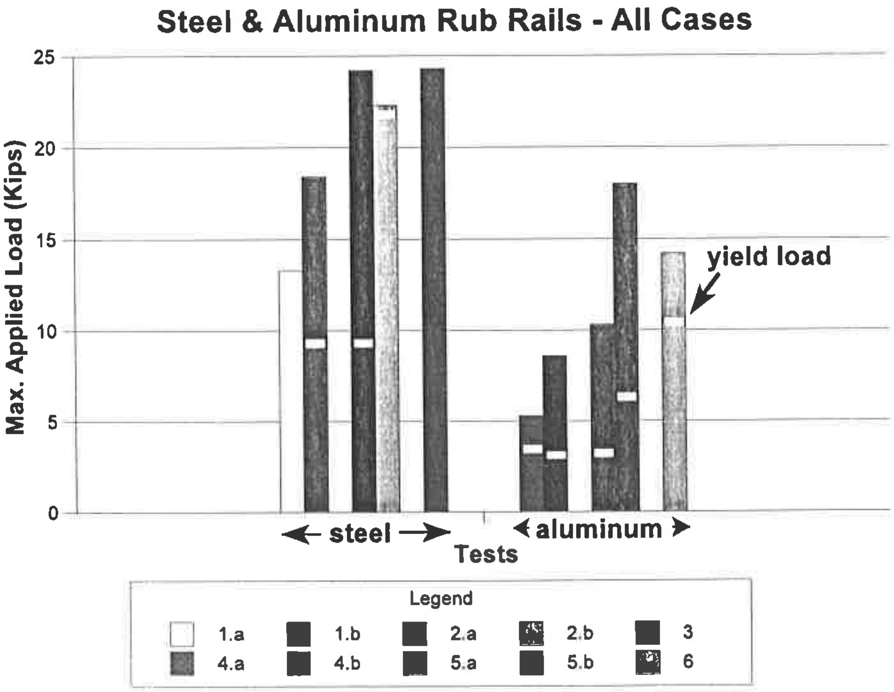

Figure 33: Maximum Applied Loads for Rub Rails - All Cases

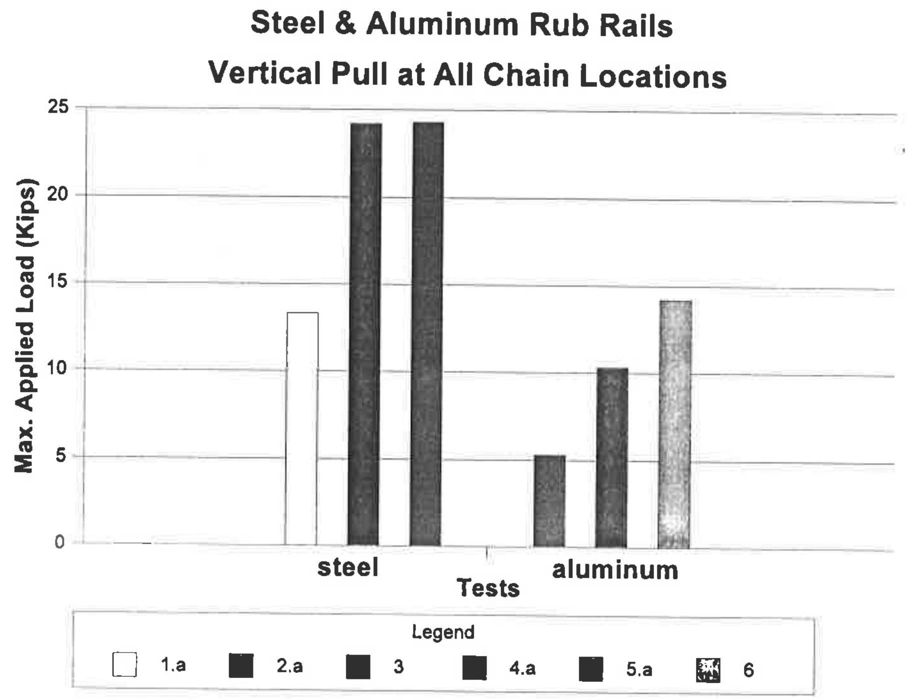

Figure 34: Maximum Applied Loads for Rub Rails - Vertical Pull at All Chain Locations

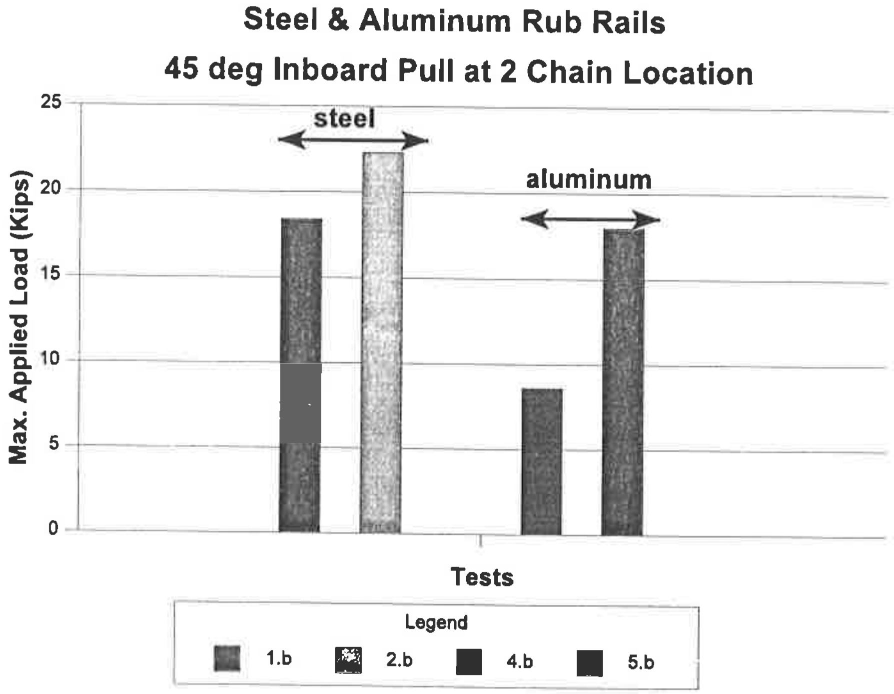

Figure 35: Maximum Applied Loads for Rub Rails - 45 deg Inboard Pull at Two Chain Locations

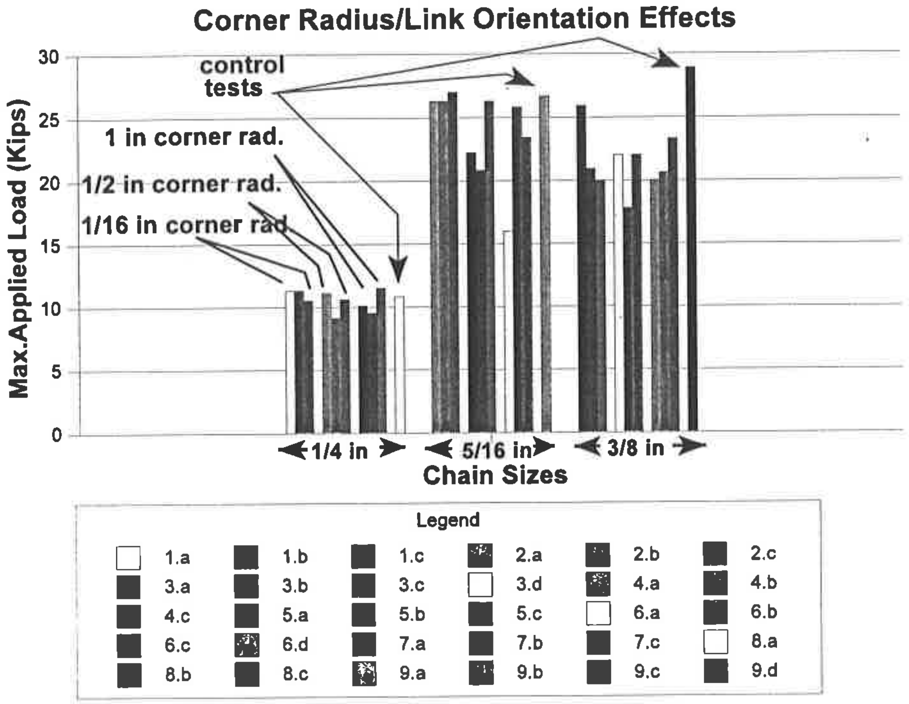

Figure 36: Maximum Applied Loads for Various Chain Sizes, Corner Radii and Link Orientations

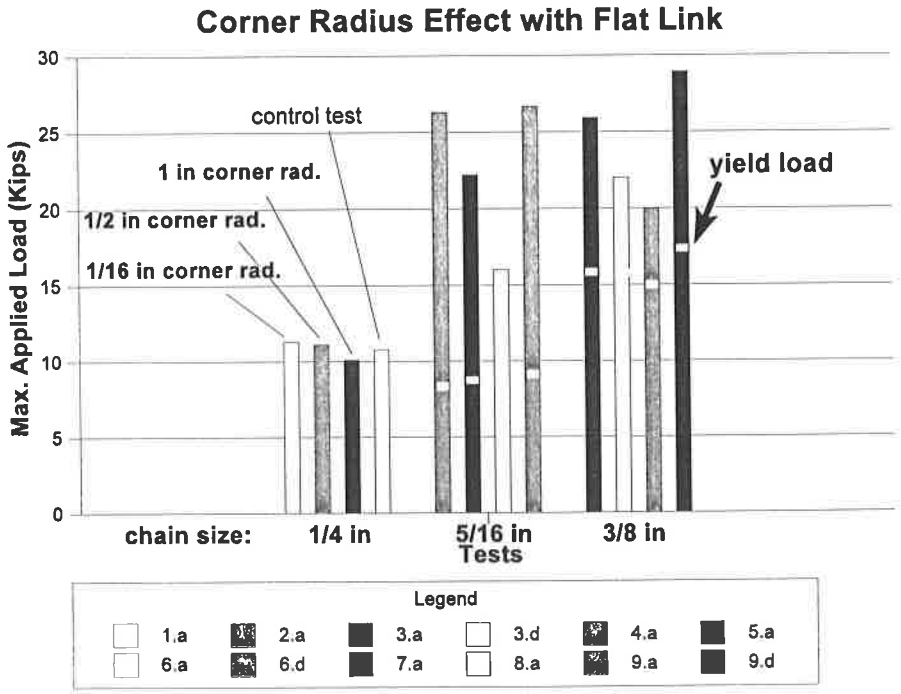

Figure 37: Effect of Corner Radius with Flat Link for All Chain Sizes

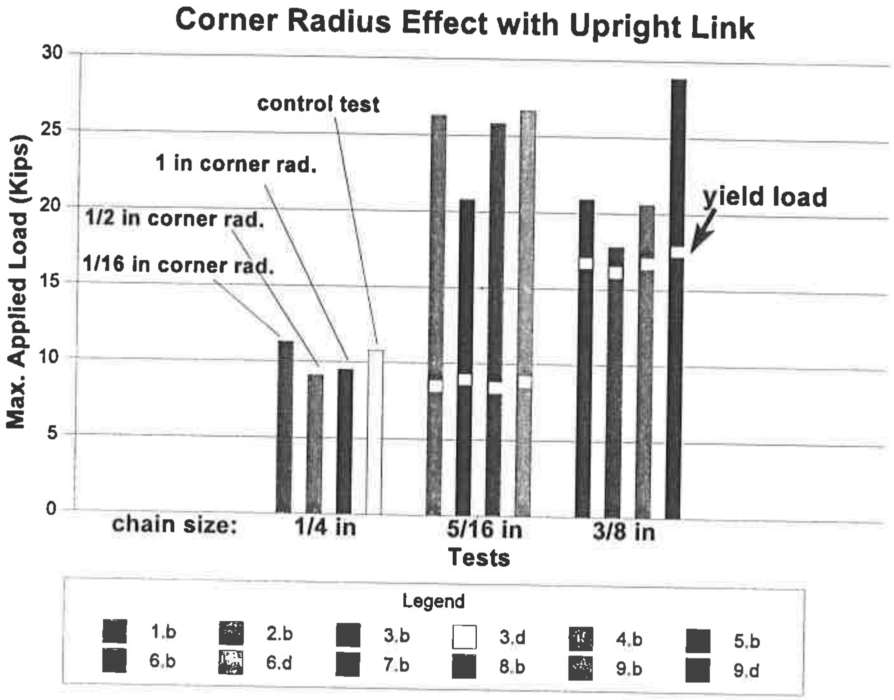

Figure 38: Effect of Corner Radius with Upright Link for All Chain Sizes

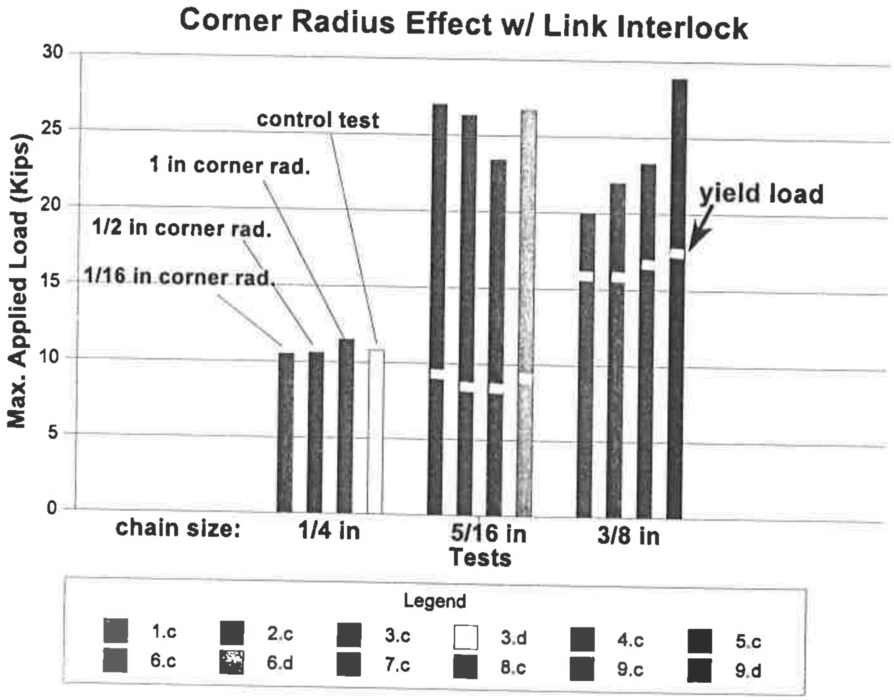

Figure 39: Effect of Corner Radius with Link Interlock for All Chain Sizes

5/ Discussion

5.1/ Ultimate Load and Allowable Load

While the ultimate loads reached by the individual test specimens as tested in the pertinent loading conditions present some notion of the ultimate strength of these anchor points, these should not be used or adopted as design parameters. As was evident in most of the tests performed, permanent set, or yield, was observed in some part of the specimens at relatively low loadings compared to the respective ultimate loads. In many instances, these loadings were as low as 10% - 20%of the ultimate loads.

By the same token, it may be viewed as unrealistic to use the lowest load at which yielding has started anywhere in the specimen as the allowable load. However, conventional "Allowable Stress Design" of steel structures calls for a maximum allowable stress of between 40% and 66% of the yield stress of the material. In light of the available test data, this latter approach would certainly preclude the use of many of the anchor points in the many field conditions under which they are typically used. Thus, it may be suggested that perhaps a more practicable approach would be one that would accommodate some amount of yielding in the structure concerned.

In any case, in order to be able to properly evaluate the allowable design load of a given anchor point, the first and foremost task will be to identify the "yield load", i.e., the load level at which yielding has started anywhere in the structure. Then one can begin to address the broader issue of allowable load properly.

5.2 Test vs Analysis

Under ideal conditions, the response-vs-load plots obtained from the test data would help find the yield load. Of these response-vs-load relationships, the displacement-vs-load ones are not very useful since, as was mentioned previously, the displacement data were affected by factors other than deformation of the test article.

In contrast, the strain-vs-load relationships are more useful. The effectiveness and accuracy of using these relationships in determining the yield load, however, is very much affected by the size of the strain gauges used, and the location and orientation of the strain gauges on a given test specimen. It has been noted previously that for many of the anchor point specimens involved in the present test program, strain-gauging was either difficult if not infeasible, or could be performed only on a very limited scale so that the strain data captured more often than not did not reflect the most critical state of the specimen concerned. Thus, it is believed that for all purposes and intents, experimental strain data was by itself not sufficient in allowing one to identify the yield load.

To help overcome such shortcomings, an alternate and more efficient means, such as finite element analysis (F.E.A.), is called for. It is recalled herein that the layout of strain gauges for all test specimens was determined with the aid of F.E.A. This alternate approach must pass the litmus test of being able to reproduce the test data with reasonable accuracy. Once such correlation is established, the models can be relied upon, along with experimental data, for establishing safety guidelines or recommendations for the use of anchor points and anchoring methods on heavy trucks.

5.3 Correlation of Test and Finite Element Analysis Results

To this end, finite element analyses were performed on a number of test specimens, using identical loading conditions for the respective test specimens. Most of these analyses were based on linear models that only represent structural response accurately at stresses below initial yield, while only a few were based on non-linear models that also represent the process of yield. The stress results from these F.E.A. models were then compared to the strain gauge data from the corresponding tests.

Table 1 shows a summary of the comparison of test and analysis results for all models analyzed. Good correlation can be observed between the two sets of results.

At present, it is premature to state that full confidence has been established in using the analytical method to recommend guidelines for the use of the anchor points in the field as the volume of correlation is still quite limited. However, a significant quantity of strain gauge test data has been collected. In view of the encouraging correlation, a more in-depth correlation study is being undertaken.

5.4 General Discussion

The test program described here has evaluated a variety of heavy truck cargo anchor points. It could not assess the universe of anchor points, and it could not even address the range of products and designs available. Those selected represent some range of type and capacity of anchor point commonly found on heavy trucks. A number were simply described for intended usage, such as "light duty" or "heavy duty". Some had a manufacturers rating. Others simply had no known description or rating. Some were provided by their manufacturers, some were purchased, and some were fabricated by MTO. The samples demonstrate a very wide variety of type of anchor point. The results show that there is wide range of capacity among and within types, especially as a function of direction of loading. The fact that one type of anchor point may have failed at a different load than another is not interpreted here, and should not be interpreted in any way, as an indication of relative merit. It simply leads to a conclusion that each should have its own defined range of application.

There are various parts of a vehicle structure that are used as anchor points, there are various designs of anchor point that are commercially available, are proprietary designs of trailer manufacturers, carriers or others, or are specially engineered for a specific securement system. Articles of cargo will only be secured adequately if the anchor points have the capacity to resist the highest likely operating load that will be encountered. Depending on the capacity of an anchor point, it should be possible to come up with a maximum load rating, perhaps as a function of direction of loading. This would determine the maximum weight of cargo that could be secured to that anchor point. It is clear that relatively "light" cargo, where that term remains undefined for now, can be adequately secured to any of the anchor points normally provided on heavy duty vehicles. It is equally clear that there is a much smaller range of anchor point that should be used when a single heavy article must be secured. It seems clear that these anchor points, at least, should be designated, and that all potential anchor points should be adequately rated for the cargo that will be carried. Since the tests showed clearly that a particular type of anchor point may have widely varying strength, depending on how it is loaded, the rating could either reflect the possible modes of use, or use could be restricted to a particular range of load direction. Where ratings do not exist, such as for some portions of the structure of vehicles, it may be possible for manufacturers of similar devices to develop consensus ratings for various product ranges.

The observation that many anchor points suffered substantial permanent deformation at quite low loads is a concern. It is possible, for instance, that a hard stop that results in cargo movement could jerk the tiedowns and cause such deformation, so that the tiedowns become loose as the cargo settles subsequently. It is clear that vehicles that can carry heavy articles of cargo should have anchor points that will be free of substantial deformation in any incident up to the most severe where the driver can continue driving without having to stop. Essentially, this means any incident within the performance capability of the vehicle and the space provided by the roadways, and this therefore is any incident short of a crash. It is also clear that any manufacturers original rating cannot be relied upon once an anchor point has become substantially deformed. It should therefore either be repaired or replaced. There would seem to be a need for (at least) a roadside inspection standard that would allow the effectiveness of a damaged anchor point to be assessed.

6/ Conclusions

A series of tests have been conducted, loading a variety of typical truck cargo anchor points in various directions, mostly until complete structural failure occurred. The results identify the mode of failure and allow an assessment of the load capacity of some of these anchor points.

The following group of conclusions emerged from the preliminary work of selecting and gathering the test articles.

1/ Tiedowns are attached to a variety of anchor points, which may be parts of the vehicle structure or devices attached to it.

2/ Cargo anchor points exist in a wide range of designs and load capacities.

3/ The load capacity rating of many cargo anchor points cannot readily be ascertained.

The following group of conclusions emerged from the tests reported here.

4/ The ultimate load varied widely between types of anchor point, and within a given type, due to differences in strength and design. This was expected, as the anchor points tested were clearly designed for different uses and had different load ratings.

5/ For all anchor points other than D-rings, the ultimate load varied significantly with load direction.

6/ While some anchor points were quite strong, there are many that would not meet Transport Canada's proposed 89 kN (20,000 lb) ultimate strength.

7/ Most anchor points started to exhibit permanent set, or yield, at loads substantially lower than the ultimate load reached. In many instances, this was only 10-20% of the ultimate load. Conventional allowable stress design generally calls for a maximum stress of 40-66% of the material's yield stress. If this approach were applied, many existing anchor points would have a very low rating.

8/ A preliminary comparison of finite element structural analysis against the available strain data showed good correlation. This suggests that such analysis may provide an efficient and cost-effective tool for developing ratings anchor points.

9/ There was little effect of corner radius and chain link orientation on the ultimate strength of a given size of tiedown chain when loaded around a tight corner.

This report presents technical results from just one task in this project. The results may be limited by the scope of this task, but are placed in context in the summary report [2].

7/ Recommendations

The following recommendations arise from an overview of the work reported here.

1/ The on-going correlation of test and finite element structural analysis, based on linear and non-linear models, should be completed to provide more confidence in use of this analytical tool to develop standards for rating and use of heavy truck cargo anchor points.

2/ Vehicles that can carry heavy articles of cargo require anchor points designated for securement of that cargo.

3/ All anchor points should be provided with a load capacity rating.

4/ The manufacturer of an anchor point is in the best position to specify its load capacity rating, so manufacturers should be involved in the range of these issues from anchor point standards to consensus ratings of existing equipment.

5/ The possible directions of loading should be considered in developing the load capacity rating of anchor points.

6/ A systematic method should be developed to evaluate when a damaged anchor point should be repaired or replaced.

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 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.

Table 1: Comparison of Test and F.E.A. Results

Anchor Type	Section No. of Proposal	Test No.	Strain Gauge Location	Load Applied (1000 lb)	Stresses (Ksi)	
					Test[1]	F.E.A.[2]
Stake Pocket	7.2	3.a	flange/weld junction, upper end	10.0	5.4	8.7-17.6
Stake Pocket	7.2	3.a	flange/weld junction, lower end	10.0	16.7	9.1-18.0
Stake Pocket	7.2	3.a	flange/weld junction, upper end	40.0	**39.1**	**42.0***
Stake Pocket	7.2	3.a	flange/weld junction, lower end	40.0	**77.6 (yielded)**	**37.0-64.0 (yielded)***
Stake Pocket	7.2	3.b	flange/weld junction	5.0	14.5	3.3-43.6
Stake Pocket	7.2	3.d	web centreline	2.5	39.2	33.9-44.8
Stake Pocket	7.2	3.d	flange near bend	2.5	32.0	23.2-35.0
Stake Pocket	7.2	3.d	web centreline	7.3	**65.3 (yielded)**	**43.7-72.9 (yielded)***
Stake Pocket	7.2	3.d	flange near bend	7.3	**84.8 (yielded)**	**34.0-91.5 (yielded)***
D-ring	7.3	3.a	clip/weld junction	20.0	40.3	44.0
D-ring	7.3	3.b	clip/weld junction	10.0	24.0	24.0
Winch	7.4	1.b	inside of flange/web junction	2.5	15.1	7.5-18.0
Winch	7.4	1.b	inside of flange/web junction	2.5	6.8	2.1-13.0
Welded Rod	7.6	3.b	at bend	2.0	46.4	38.0-54.0
Welded Rod	7.6	3.c	at bend	1.0	38.6	25.0-42.0
Welded Rod	7.6	3.d	at bend	2.0	29.0	22.0-42.0

* These F.E.A. results were based on non-linear models, with yield stress taken as 60 Ksi.

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[1] These were based on a simple calculation of stress = strain x elastic modulus. Thus the stresses that are shown here to be above the yield stress of steel (60 Ksi) may not have existed.

[2] These stresses were given as ranges by the F.E.A. program used. Scaling of these ranges was such that some of the ranges may include non-existent stresses.

Appendix A

Test Matrices and Test Setup Sketches

Table A.1: Test Matrix for Stake Pocket Pull-Out Strength Tests

Purpose	To determine the strengths of stake pockets when pulled in various directions, and ascertain the associated modes of failure.					
Test No.	Grade/ Material	Dimensions (in)	Loading Direction			
			Vertical	Longitud. Forward	Lateral Outboard	45 deg Outboard
1.a	Light Steel	3x4x3/16	X			
1.b	Light Steel	3x4x3/16		X		
1.d	Light Steel	3x4x3/16			X	
1.e	Light Steel	3x4x3/16				X
2.a	Medium Steel	4x4x3/16	X			
2.b	Medium Steel	4x4x3/16		X		
2.d	Medium Steel	4x4x3/16			X	
2.e	Medium Steel	4x4x3/16				X
3.a	Heavy Steel	4x4x1/4	X			
3.b	Heavy Steel	4x4x1/4		X		
3.d	Heavy Steel	4x4x1/4			X	
3.e	Heavy Steel	4x4x1/4				X
4.a	Light Aluminum	3-1/2x4x1/4	X			
4.b	Light Aluminum	3-1/2x4x1/4		X		
4.d	Light Aluminum	3-1/2x4x1/4			X	
4.e	Light Aluminum	3-1/2x4x1/4				
5.a	Medium Aluminum	4x4x1/4	X			
5.b	Medium Aluminum	4x4x1/4		X		
5.d	Medium Aluminum	4x4x1/4			X	
5.e	Medium Aluminum	4x4x1/4				X

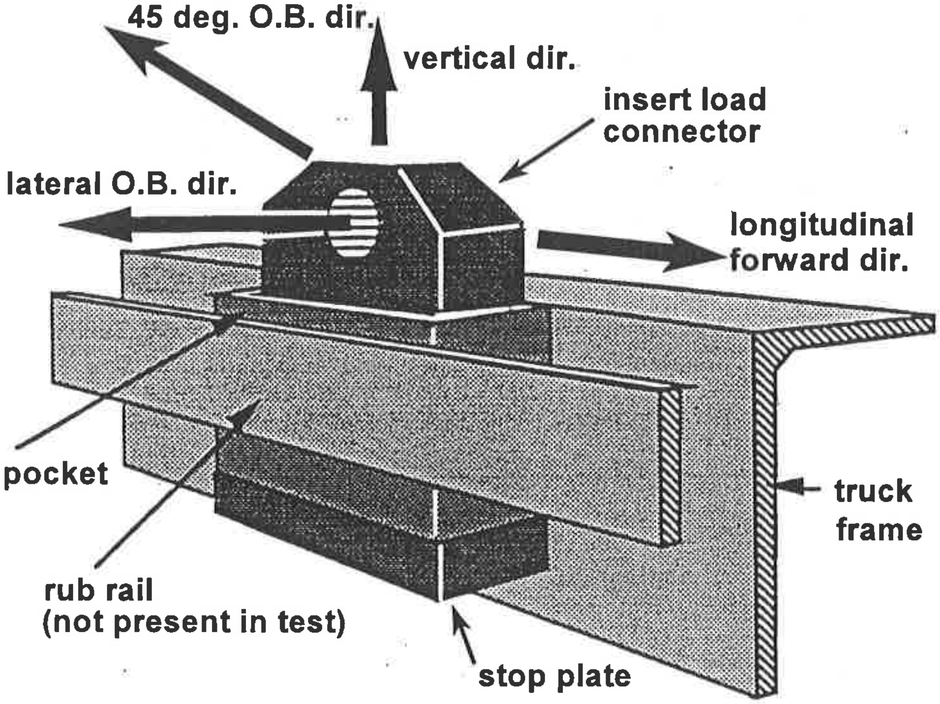

Figure A.1: Loading Directions for Stake Pocket Tests

Table A.2: Test Matrix for D-ring Pull-Out Strength Tests

Purpose	To determine the strengths of D-rings when pulled in various directions, and ascertain the associated modes of failure.							
Test No.	Grade/ Material	Loading Direction						
		Y	X	Z	XY	YZ	ZX	XYZ
1.a	Light Steel	X						
1.b	Light Steel		X					
1.c	Light Steel			X				
1.d	Light Steel				X			
1.e	Light Steel					X		
1.f	Light Steel						X	
1.g	Light Steel							X
2.a	Medium Steel	X						
2.b	Medium Steel		X					
2.c	Medium Steel			X				
2.d	Medium Steel				X			
2.e	Medium Steel					X		
2.f	Medium Steel						X	
2.g	Medium Steel							X
3.a	Heavy Steel	X						
3.b	Heavy Steel		X					
3.c	Heavy Steel			X				
3.d	Heavy Steel				X			
3.e	Heavy Steel					X		
3.f	Heavy Steel						X	
3.g	Heavy Steel							X

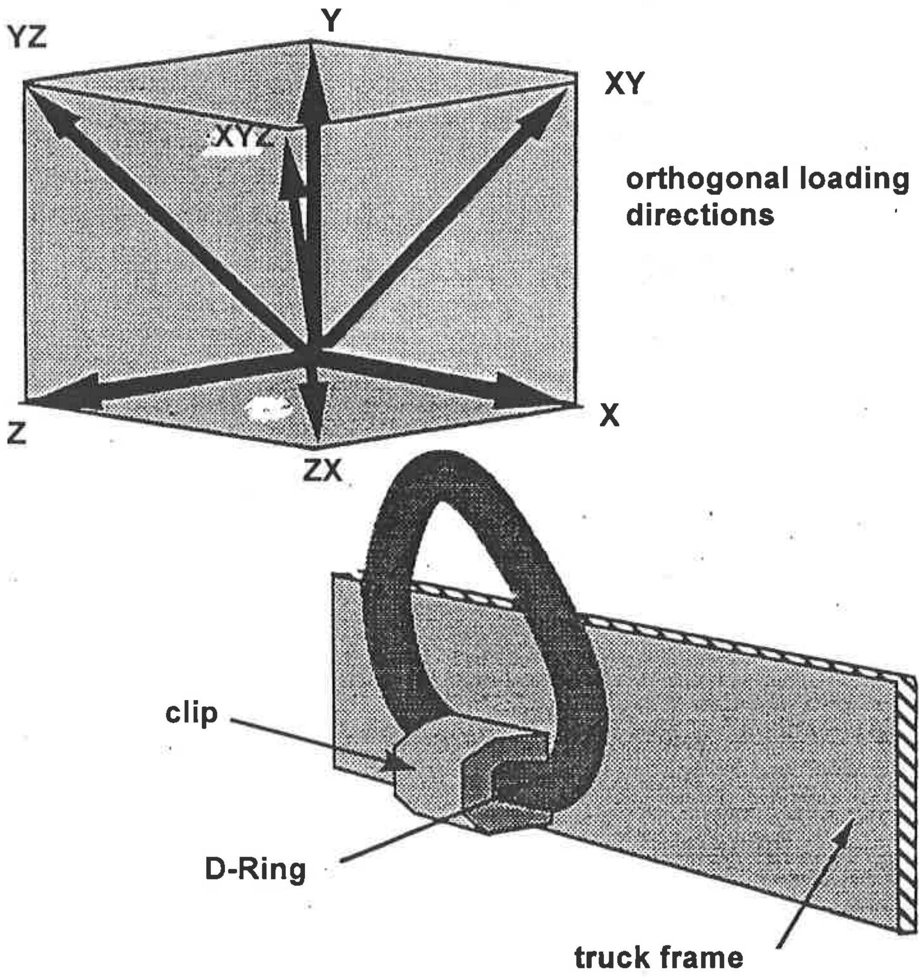

Figure A.2: Loading Directions for D-ring Tests

Table A.3: Test Matrix for Winch Pull-Out Strength Tests

Purpose	To determine the strengths of winches when pulled in various directions, and ascertain the associated modes of failure.				
Test No.	Winch Model	Attachment Method	Loading Direction		
			Vertical	Lateral Outboard	45 deg Outboard
1.a	High Profile	Welded	X		
1.b	High Profile	Welded			X
1.c	High Profile	Welded		X	
2.a	Low Profile	Welded	X		
2.b	Low Profile	Welded			X
2.c	Low Profile	Welded		X	
3.a	High Profile	Sliding	X		
3.b	High Profile	Sliding			X
3.c	High Profile	Sliding		X	
4.a	Low Profile	Sliding	X		
4.b	Low Profile	Sliding			X
4.c	Low Profile	Sliding		X	
5.a	High Profile	Clipped	X		
5.b	High Profile	Clipped			X
5.c	High Profile	Clipped		X	
6.a	Low Profile	Clipped	X		
6.b	Low Profile	Clipped			X
6.c	Low Profile	Clipped		X	

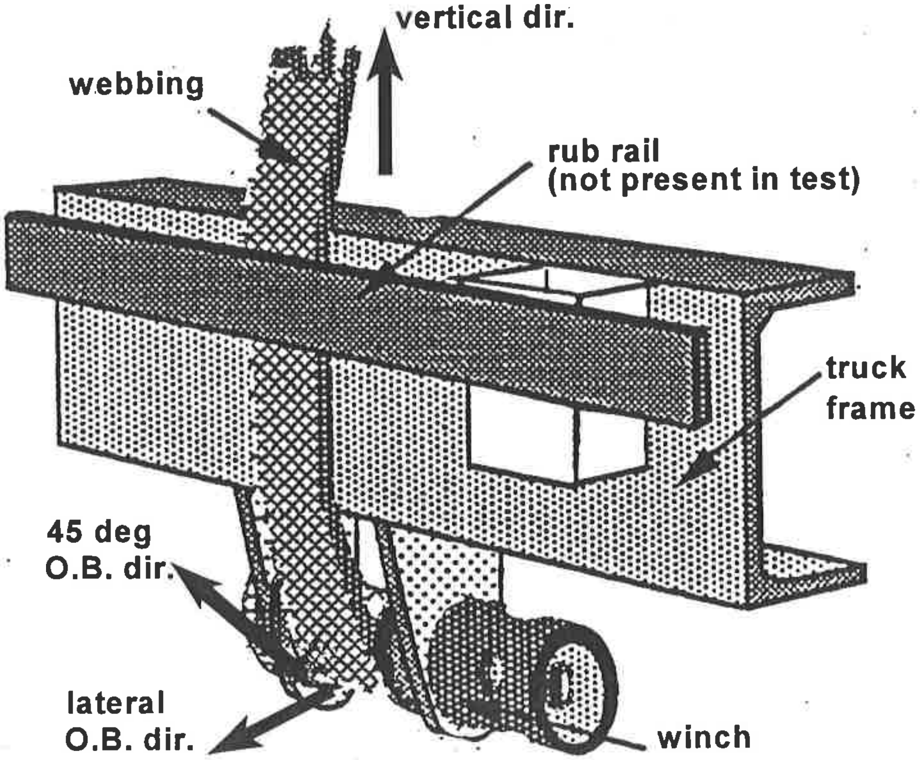

Figure A.3: Loading Directions for Winch Tests

Table A.4: Test Matrix for Chain-in-tube Pull-Out Strength Tests

Purpose	**To determine the strengths of chain-in-tube anchors when pulled in various directions, and ascertain the associated modes of failure.**				
Test No.	**Model**	**Attachment of Clip**	**Loading Direction**		
			Vertical	**Lateral**	**45 deg**
1.a	Model "A"	Welded	X		
1.b	Model "A"	Welded		X	
1.c	Model "A"	Welded			X
2.a	Model "B"	Bolted	X		
2.b	Model "B"	Bolted		X	
2.c	Model "B"	Bolted			X
3.a	Model "C"	Welded	X		
3.b	Model "C"	Welded		X	
3.c	Model "C"	Welded			X

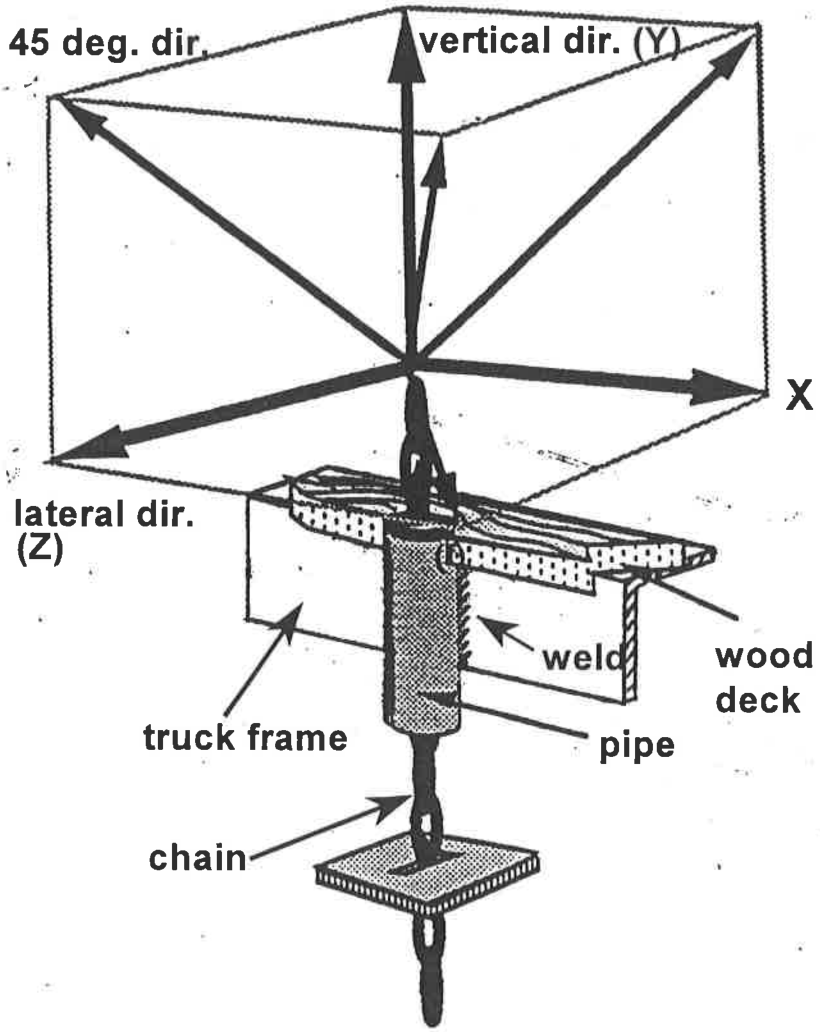

Figure A.4: Loading Directions for Chain-in-tube Tests

Table A.5: Test Matrix for Welded Rod Pull-Out Strength Tests

Purpose	To determine the strengths of welded rods when pulled in various directions, and ascertain the associated modes of failure.							
Test No.	Rod Size (in)	Loading Direction						
		Y	X	Z	XY	YZ	ZX	XYZ
1.a	1/4	X						
1.b	1/4		X					
1.c	1/4			X				
1.d	1/4				X			
1.e	1/4					X		
1.f	1/4						X	
1.g	1/4							X
2.a	3/8	X						
2.b	3/8		X					
2.c	3/8			X				
2.d	3/8				X			
2.e	3/8					X		
2.f	3/8						X	
2.g	3/8							X
3.a	1/2	X						
3.b	1/2		X					
3.c	1/2			X				
3.d	1/2				X			
3.e	1/2					X		
3.f	1/2						X	
3.g	1/2							X

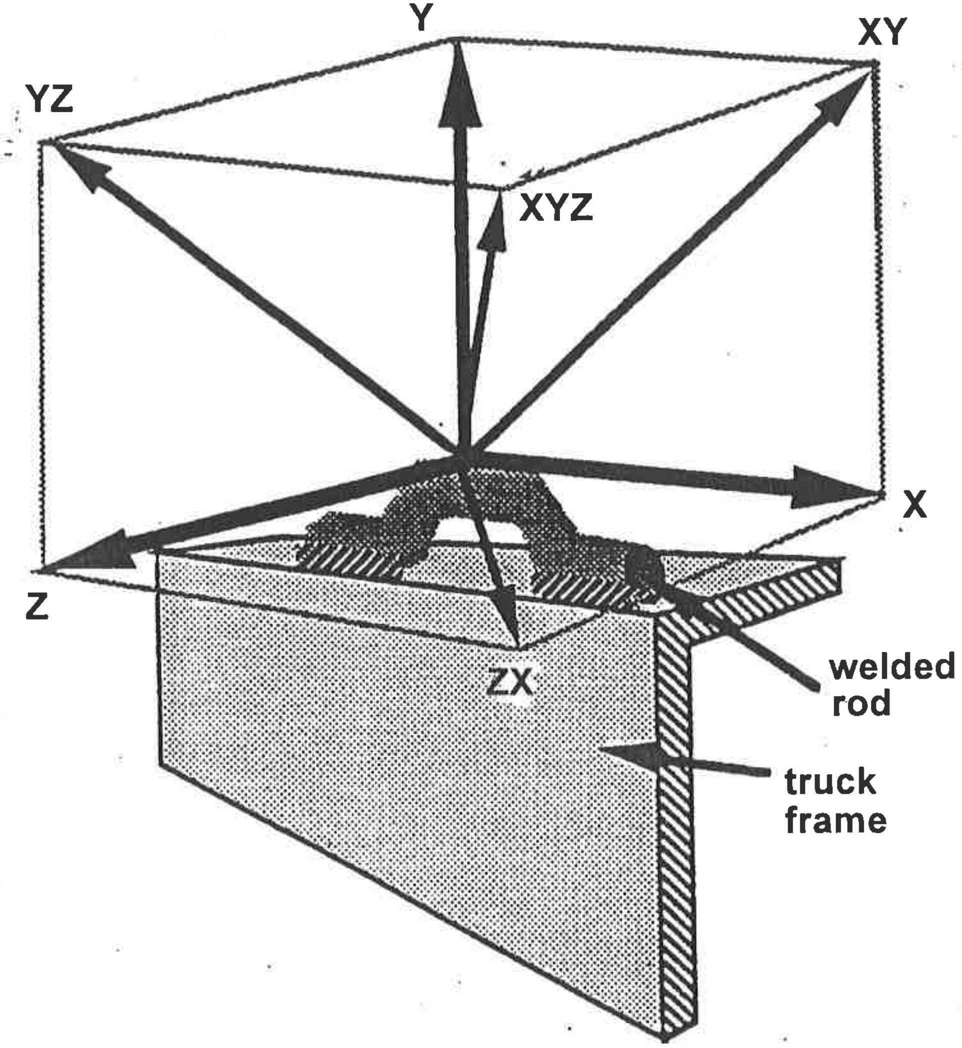

Figure A.5: Loading Directions for Welded Rod Tests

Table A.6a: Test Matrix for Chain Wrap on Steel Pockets Tests

Purpose	To determine the impact of the manner in which a chain is hooked to or wrapped around a stake pocket on the strength of the pocket.				
Test No.	Material	Wrap Method	Loading Directions		
			Vertical	45 deg Forward	45 deg Aft
1.a	Steel	a	X		
1.b	Steel	a		X	
1.c	Steel	a			X
2.a	Steel	b	X		
2.b	Steel	b		X	
2.c	Steel	b			X
3.a	Steel	c	X		
3.b	Steel	c		X	
3.c	Steel	c			X
4.a	Steel	d	X		
4.b	Steel	d		X	
4.c	Steel	d			X
5	Steel	e	X		
6	Steel	f	X		

Table A.6b: Test Matrix for Chain Wrap on Aluminum Pockets Tests

Purpose	**To determine the impact of the manner in which a chain is hooked to or wrapped around a stake pocket on the strength of the pocket.**				
Test No.	**Material**	**Wrap Method**	**Loading Direction**		
			Vertical	**45 deg Forward**	**45 deg Aft**
7.a	Aluminum	a	X		
7.b	Aluminum	a		X	
7.c	Aluminum	a			X
8.a	Aluminum	b	X		
8.b	Aluminum	b		X	
8.c	Aluminum	b			X
9.a	Aluminum	c	X		
9.b	Aluminum	c		X	
9.c	Aluminum	c			X
10.a	Aluminum	d	X		
10.b	Aluminum	d		X	
10.c	Aluminum	d			X
11	Aluminum	e	X		
12	Aluminum	f	X		

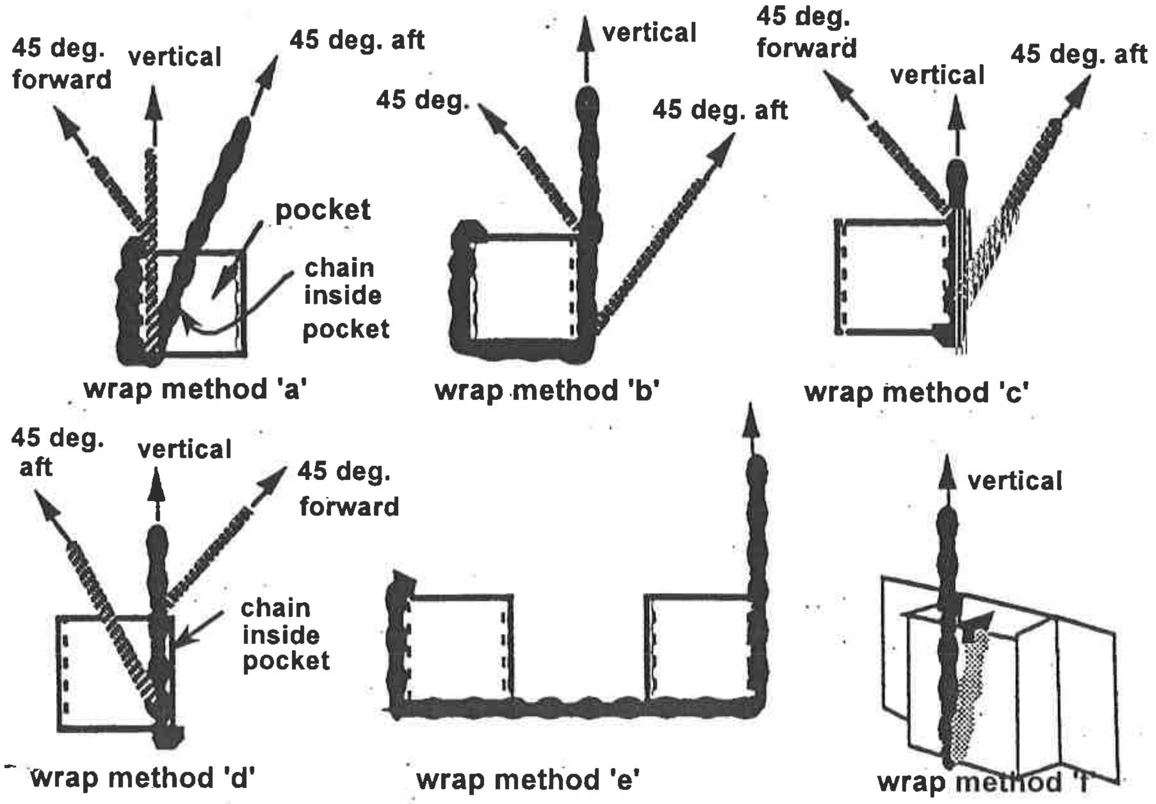

Figure A.6: Wrap Configurations and Pull Directions for Chain Wrap Tests

Table A.7: Test Matrix for Rub Rail Pull-Out Strength Tests

<table>
<tr><th>Purpose</th><th colspan="7">To determine the strengths of rub rails when used as anchor points by a chain.</th></tr>
<tr><th rowspan="2">Test No.</th><th rowspan="2">Material</th><th rowspan="2">Rail Size (in)</th><th colspan="3">Location of Chain</th><th colspan="2">Loading Direction</th></tr>
<tr><th>Between Spool & Pocket</th><th>At Spool</th><th>Over Spool</th><th>Vertical</th><th>45 deg Inboard</th></tr>
<tr><td>1.a</td><td>Steel</td><td>3/8 x 3</td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>1.b</td><td>Steel</td><td>3/8 x 3</td><td>X</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>2.a</td><td>Steel</td><td>3/8 x 3</td><td></td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>2.b</td><td>Steel</td><td>3/8 x 3</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>3</td><td>Steel</td><td>3/8 x 3</td><td></td><td></td><td>X</td><td>X</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4.a</td><td>Aluminum</td><td>3/8 x 2</td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>4.b</td><td>Aluminum</td><td>3/8 x 2</td><td>X</td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>5.a</td><td>Aluminum</td><td>3/8 x 2</td><td></td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>5.b</td><td>Aluminum</td><td>3/8 x 2</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>6</td><td>Aluminum</td><td>3/8 x 2</td><td></td><td></td><td>X</td><td>X</td><td></td></tr>
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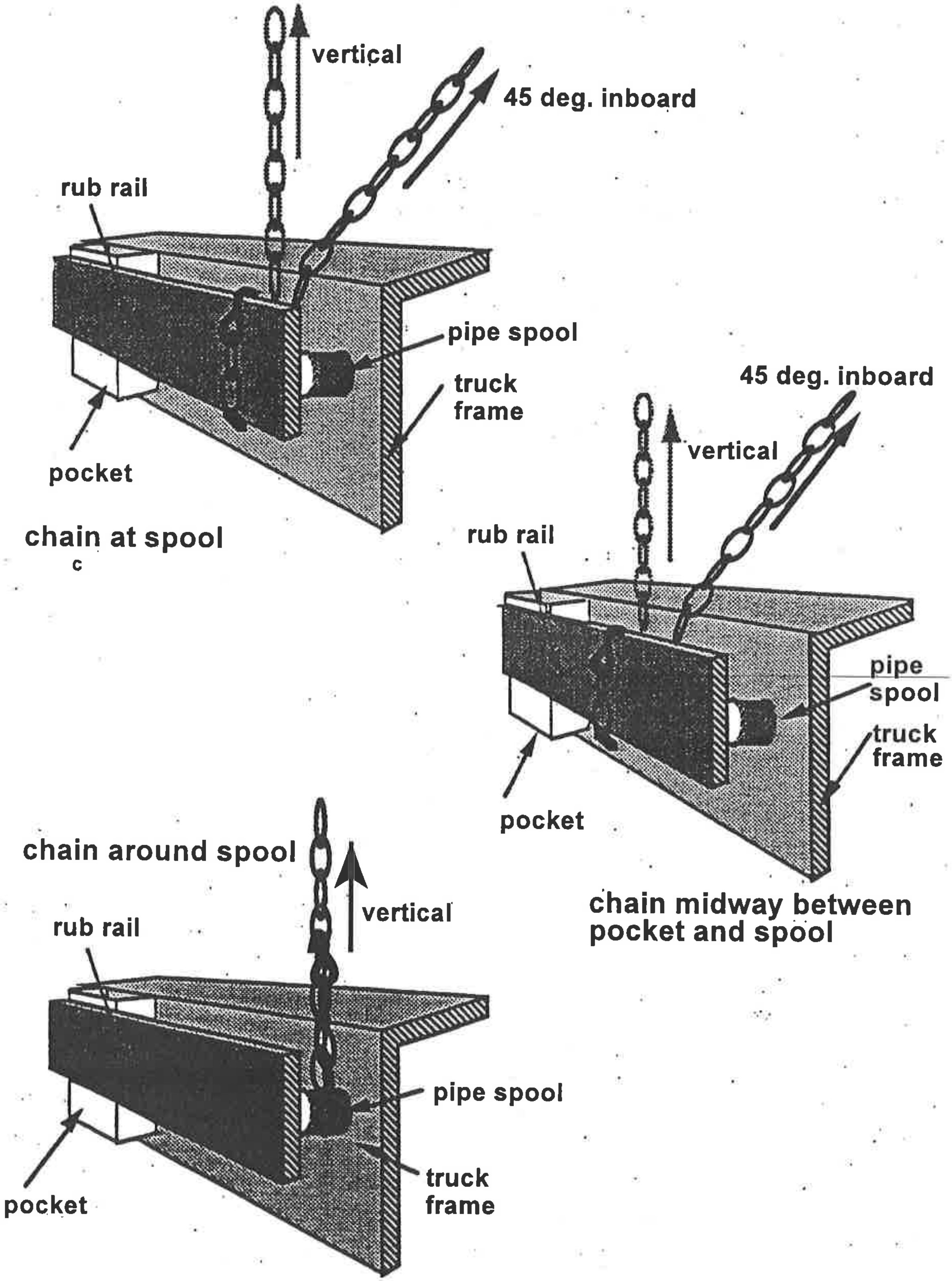

chain at spool

chain midway between pocket and spool

chain around spool

Figure A.7: Loading Directions and Chain Locations for Rub Rail Tests

Table A.8: Test Matrix for Corner Radius and Chain Link Orientation Effect Tests

Purpose	**To examine the effect of corner radius and chain link orientation on the strength of a tiedown chain.**

Test No.	**Chain size (in)**	**Corner Radius**			**Chain Link Orientation**		
		1/8 in	**1 in**	**2 in**	**Flat**	**Upright**	**Interlock**
1.a	1/4	X			X		
1.b	1/4	X				X	
1.c	1/4	X					X
2.a	1/4		X		X		
2.b	1/4		X			X	
2.c	1/4		X				X
3.a	1/4			X	X		
3.b	1/4			X		X	
3.c	1/4			X			X
3.d	1/4	CONTROL TEST FOR 1/4 IN CHAIN					
4.a	5/16	X			X		
4.b	5/16	X				X	
4.c	5/16	X					X
5.a	5/16		X		X		
5.b	5/16		X			X	
5.c	5/16		X				X
6.a	5/16			X	X		
6.b	5/16			X		X	
6.c	5/16			X			X
6.d	5/16	CONTROL TEST FOR 5/16 IN CHAIN					
7.a	3/8	X			X		
7.b	3/8	X				X	
7.c	3/8	X					X
8.a	3/8		X		X		
8.b	3/8		X			X	
8.c	3/8		X				X
9.a	3/8			X	X		
9.b	3/8			X		X	
9.c	3/8			X			X
9.d	3/8	CONTROL TEST FOR 3/8 IN CHAIN					

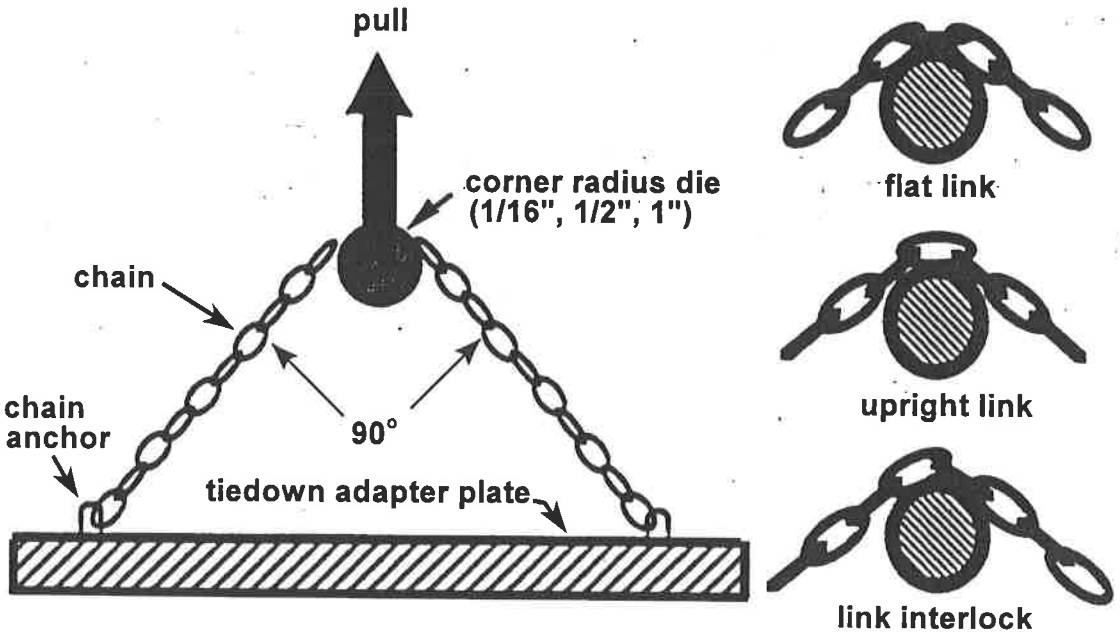

Figure A.8: Setup for Testing Effects of Corner Radius and Link Orientation

Appendix B

Tables of Test Results

Table B.1: Summary of Test Results for Stake Pocket Tests

Test No.	Grade and/or Material	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
1.a	light steel	vertical	44.71	no	no	yes	25.0
1.b	light steel	longit. forward	12.15	yes	yes	yes	1.0
1.d	light steel	lateral O.B.	10.87	yes	yes	yes	0.5
1.e	light steel	45 deg O.B.	28.00	no	no	yes	not available
2.a	medium steel	vertical	44.81	no	no	no	18.0
2.b	medium steel	longit. forward	11.16	yes	yes	yes	2.0
2.d	medium steel	lateral O.B.	17.53	yes	yes	yes	2.5
2.e	medium steel	45 deg O.B.	33.90	no	no	yes	not available
3.a	heavy steel	vertical	44.92	no	no	no	35.0
3.b	heavy steel	longit. forward	15.42	yes	yes	yes	11.0
3.d	heavy steel	lateral O.B.	26.35	no	jig	yes	5.0
3.e	heavy steel	45 deg O.B.	30.00	no	no	yes	not available
4.a	light aluminum	vertical	21.12	yes	yes	yes	13.0
4.b	light aluminum	longit. forward	10.00	yes	yes	yes	1.0
4.d	light aluminum	lateral O.B.	8.57	yes	yes	yes	1.0
4.e	light aluminum	45 deg O.B.	15.50	yes	yes	yes	not available
5.a	medium aluminum	vertical	18.30	yes	yes	yes	10.0
5.b	medium aluminum	longit. forward	4.84	yes	yes	yes	1.0
5.d	medium aluminum	lateral O.B.	5.92	yes	yes	yes	1.2
5.e	medium aluminum	45 deg O.B.	11.67	yes	yes	yes	not available

Table B.2: Summary of Test Results for D-ring Tests

Test No.	Grade and/or Material	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
1.a	light steel	Y	8.03	yes	yes (clip)	yes (clip & ring)	not available
1.b	light steel	X	6.42	yes	yes (clip)	yes (clip & ring)	not available
1.c	light steel	Z	7.18	yes	yes (clip)	yes (clip & ring)	not available
1.d	light steel	XY	9.25	yes	yes (clip)	yes (clip & ring)	not available
1.e	light steel	YZ	7.22	yes	yes (clip)	yes (clip & ring)	not available
1.f	light steel	ZX	7.78	yes	yes (clip)	yes (clip & ring)	not available
1.g	light steel	XYZ	8.44	yes	yes (clip)	yes (clip & ring)	not available
2.a	medium steel	Y	22.28	yes	no	yes (clip & ring)	not available
2.b	medium steel	X	17.64	yes	yes (clip)	yes (clip & ring)	not available
2.c	medium steel	Z	23.91	yes	yes (clip)	yes (clip & ring)	not available
2.d	medium steel	XY	20.35	yes	yes (ring)	yes (clip & ring)	not available
2.e	medium steel	YZ	20.50	yes	yes (ring)	yes (clip & ring)	not available
2.f	medium steel	ZX	21.67	yes	yes (ring)	yes (clip & ring)	not available
2.g	medium steel	XYZ	19.32	yes	yes (ring)	yes (clip & ring)	not available
3.a	heavy steel	Y	46.00	yes	yes (clip)	yes (clip & ring)	8.0
3.b	heavy steel	X	19.97	no	no	no	6.5
3.c	heavy steel	Z	22.76	no	no	ring	12.0
3.d	heavy steel	XY	19.99	no	no	no	12.0
3.e	heavy steel	YZ	21.95	no	no	no	12.0
3.f	heavy steel	ZX	21.98	no	no	no	16.0
3.g	heavy steel	XYZ	29.95	no	no	no	14.0

Table B.3: Summary of Test Results for Winch Tests

Test No.	Model & Method of Attachment*	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?**	Estimated Load at First Set (1000 lb)
1.a	high profile,welded	vertical	14.80	yes	yes (pawl)	yes(mandrel)	9.5
1.b	high profile,welded	45 deg O.B.	13.97	yes	yes (weld)	yes (w & m)	7.5
1.c	high profile,welded	lateral O.B.	8.50	yes	yes (weld)	yes (w & m)	5.3
2.a	low profile, welded	vertical	17.10	yes	no	yes(mandrel)	not available
2.b	low profile, welded	45 deg O.B.	11.70	yes	yes (pawl)	yes (w & m)	not available
2.c	low profile, welded	lateral O.B.	13.10	yes	yes (pawl)	yes (w & m)	not available
3.a	high profile, sliding	vertical	12.40	yes	yes (pawl)	yes (w & m)	not available
3.b	high profile, sliding	45 deg O.B.	8.14	yes	track opened up	yes (track)	7.5
3.c	high profile, sliding	lateral O.B.	3.47	yes	track opened up	yes (track)	2.5
4.a	low profile, sliding	vertical	12.70	yes	yes (pawl)	yes (w & m)	not available
4.b	low profile, sliding	45 deg O.B.	10.00	yes	track opened up	yes (track)	7.0
4.c	low profile, sliding	lateral O.B.	3.92	yes	track opened up	yes (track)	2.3
5.a	high profile, clipped	vertical	16.50	yes	yes (pawl)	yes (w & m)	4.0
5.b	high profile, clipped	45 deg O.B.	12.00	yes	yes (bolts)	yes (w & m)	2.3
5.c	high profile, clipped	lateral O.B.	6.30	yes	yes (angle)	yes (w & m)	3.0
6.a	low profile, clipped	vertical	18.70	yes	no	yes (w & m)	5.7
6.b	low profile, clipped	45 deg O.B.	14.10	yes	yes (pawl)	yes (w & m)	3.0
6.c	low profile, clipped	lateral O.B.	9.40	yes	yes (angle)	yes (w & m)	4.5

** w & m = winch and mandrel

Table B.4: Summary of Test Results for Chain-in-tube Tests

Test No.	Model	Clip Attachment	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
1.a	Model "A"	welded	vertical	14.60	yes	yes (chain broke)	yes	not available
1.b	Model "A"	welded	lateral	4.67	yes	yes (pipe ripped)	yes	not available
1.c	Model "A"	welded	angle	14.50	yes	yes (chain broke)	yes	not available
2.a	Model "B"	bolted	vertical	10.30	yes	yes (clip broke)	yes	not available
2.b	Model "B"	bolted	lateral	3.18	yes	yes (pipe ripped)	yes	not available
2.c	Model "B"	bolted	angle	5.80	yes	yes (weld)	yes	not available
3.a	Model "C"	welded	vertical	17.40	yes	yes (weld)	yes	not available
3.b	Model "C"	welded	lateral	7.45	yes	yes (pipe ripped)	yes	not available
3.c	Model "C"	welded	angle	12.20	yes	yes (pipe ripped)	yes	not available

Table B.5: Summary of Test Results for Welded Rod Tests

Test No.	Rod Size (in)	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
1.a	1/4	Y	6.03	yes	yes (weld & rod)	yes	not available
1.b	1/4	X	3.68	yes	yes (rod)	yes	not available
1.c	1/4	Z	2.27	yes	yes (rod)	yes	not available
1.d	1/4	XY	4.88	yes	yes (weld & rod)	yes	not available
1.e	1/4	YZ	5.27	yes	yes (weld)	yes	not available
1.f	1/4	ZX	1.57	yes	yes (weld)	yes	not available
1.g	1/4	XYZ	4.14	yes	yes (weld)	yes	not available
2.a	3/8	Y	12.66	yes	yes (rod)	yes	not available
2.b	3/8	X	8.64	yes	yes (rod)	yes	not available
2.c	3/8	Z	11.61	yes	yes (weld & rod)	yes	not available
2.d	3/8	XY	9.93	yes	yes (weld & rod)	yes	not available
2.e	3/8	YZ	10.93	yes	yes (weld & rod)	yes	not available
2.f	3/8	ZX	10.96	yes	yes (weld & rod)	yes	not available
2.g	3/8	XYZ	10.63	yes	yes (weld)	yes	not available
3.a	1/2	Y	21.15	yes	yes (weld & rod)	yes	4.5
3.b	1/2	X	17.86	yes	yes (rod)	yes	2.5
3.c	1/2	Z	20.39	yes	yes (weld & rod)	yes	1.5
3.d	1/2	XY	16.99	yes	yes (weld & rod)	yes	4.9
3.e	1/2	YZ	19.88	yes	yes (weld)	yes	2.0
3.f	1/2	ZX	15.17	yes	yes (weld)	yes	4.0
3.g	1/2	XYZ	17.02	yes	yes (weld)	yes	12.5

Table B.6a: Summary of Test Results for Chain Wrap on Steel Pocket Tests

Test No.	Material	Wrap Method	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
1.a	steel	a	vertical	15.00	yes	no	yes, pocket cut	4.0
1.b	steel	a	45 deg fore	15.30	yes	no	yes, pocket cut	2.0
1.c	steel	a	45 deg aft	15.00	yes	no	yes, pocket cut	2.0
2.a	steel	b	vertical	19.70	yes	no	yes, pocket cut	2.6
2.b	steel	b	45 deg fore	15.00	yes	no	yes, pocket cut	7.5
2.c	steel	b	45 deg aft	14.20	yes	no	yes, pocket cut	6.5
3.a	steel	c	vertical	12.90	yes	yes (weld)	yes	3.5
3.b	steel	c	45 deg fore	12.00	yes	no	yes	2.0
3.c	steel	c	45 deg aft	10.30	yes	no	yes	4.5
4.a	steel	d	vertical	17.10	yes	no	yes, pocket cut	3.5
4.b	steel	d	45 deg fore	20.20	yes	yes (weld)	yes	4.0
4.c	steel	d	45 deg aft	14.90	yes	yes (weld)	yes	4.6
5	steel	e	vertical	18.50	yes	no	yes, pocket cut	3.5
6	steel	f	vertical	16.00	yes	no	yes	10.0

Table B.6b: Summary of Test Results for Chain Wrap on Aluminum Pocket Tests

Test No.	Material	Wrap Method	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
7.a	aluminum	a	vertical	17.60	yes	yes (weld)	yes, pocket cut	2.0
7.b	aluminum	a	45 deg fore	10.40	yes	yes (weld)	yes, pocket cut	2.0
7.c	aluminum	a	45 deg aft	7.89	yes	yes (weld)	yes	3.0
8.a	aluminum	b	vertical	9.90	yes	yes (weld)	yes	0.3
8.b	aluminum	b	45 deg fore	7.57	yes	yes (weld)	yes	2.5
8.c	aluminum	b	45 deg aft	8.06	yes	yes (weld)	yes	3.5
9.a	aluminum	c	vertical	8.10	yes	yes (weld)	yes	3.2
9.b	aluminum	c	45 deg fore	8.00	yes	yes (weld)	yes	2.0
9.c	aluminum	c	45 deg aft	7.20	yes	yes (weld)	yes	3.5
10.a	aluminum	d	vertical	15.30	yes	yes (weld)	yes	2.5
10.b	aluminum	d	45 deg fore	9.51	yes	yes (weld)	yes	2.5
10.c	aluminum	d	45 deg aft	10.90	yes	yes (weld)	yes	4.5
11	aluminum	e	vertical	10.00	yes	yes (weld)	yes, pocket cut	1.5
12	aluminum	f	vertical	11.80	yes	yes (weld)	yes	2.8

Table B.7: Summary of Test Results for Rub Rail Tests

Test No.	Material	Chain Location	Loading Direction	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
1.a	steel	bet'n spool/pocket	vertical	13.30	yes	yes	yes (rail)	4.0
1.b	steel	bet'n spool/pocket	45 deg I.B.	18.40	yes	no (chain caught)	yes (rail)	9.0
2.a	steel	at spool	vertical	24.20	yes	no	yes (rail)	9.0
2.b	steel	at spool	45 deg I.B.	22.30	yes	no (chain caught)	yes (rail)	22.0
3	steel	over spool	vertical	24.30	yes	no	yes (spool)	not available
4.a	aluminum	bet'n spool/pocket	vertical	5.30	yes	yes	yes (rail)	3.5
4.b	aluminum	bet'n spool/pocket	45 deg I.B.	8.60	yes	no (chain caught)	yes (rail)	2.8
5.a	aluminum	at spool	vertical	10.30	yes	yes (rail)	yes (rail)	3.0
5.b	aluminum	at spool	45 deg I.B.	18.00	yes	yes (rail)	yes (rail)	6.5
6	aluminum	over spool	vertical	14.20	yes	yes (spool)	yes (spool)	10.5

Table B.8: Summary of Test Results for Effect of Corner Radius and Chain Link Orientation Tests

Test No.	Chain Size (in)	Corner Radius (in)	Link Orientation	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
1.a	1/4	1/8	flat	11.30	yes	yes (chain link)	yes (chain link)	not available
1.b	1/4	1/8	upright	11.30	yes	yes (chain link)	yes (chain link)	not available
1.c	1/4	1/8	interlock	10.50	yes	yes (chain link)	yes (chain link)	not available
2.a	1/4	1	flat	11.10	yes	yes (chain link)	yes (chain link)	not available
2.b	1/4	1	upright	9.11	yes	yes (chain link)	yes (chain link)	not available
2.c	1/4	1	interlock	10.60	yes	yes (chain link)	yes (chain link)	not available
3.a	1/4	2	flat	10.10	yes	yes (chain link)	yes (chain link)	not available
3.b	1/4	2	upright	9.50	yes	yes (chain link)	yes (chain link)	not available
3.c	1/4	2	interlock	11.50	yes	yes (chain link)	yes (chain link)	not available
3.d	1/4	CONTROL TEST		10.80	yes	yes (chain link)	yes (chain link)	not available
4.a	5/16	1/8	flat	26.30	yes	yes (chain link)	yes (chain link)	8.0
4.b	5/16	1/8	upright	26.3?	yes	yes (chain link)	yes (chain link)	8.5
4.c	5/16	1/8	interlock	27.00	yes	yes (chain link)	yes (chain link)	9.0
5.a	5/16	1	flat	22.20	yes	yes (chain link)	yes (chain link)	8.5
5.b	5/16	1	upright	20.80	yes	yes (chain link)	yes (chain link)	9.0
5.c	5/16	1	interlock	26.30	yes	yes (chain link)	yes (chain link)	8.5
6.a	5/16	2	flat	16.00	yes	yes (chain link)	yes (chain link)	8.0
6.b	5/16	2	upright	25.80	yes	yes (chain link)	yes (chain link)	8.5
6.c	5/16	2	interlock	23.40	yes	yes (chain link)	yes (chain link)	8.5
6.d	5/16	CONTROL TEST		26.67	yes	yes (chain link)	yes (chain link)	9.0

Table B.8 (cont'd): Summary of Test Results for Effect of Corner Radius and Chain Link Orientation Tests

Test No.	Chain Size (in)	Corner Radius (in)	Link Orientation	Max. Load (1000 lb)	Reached Ult. Strength?	Breakage Seen?	Permanent Set Seen?	Estimated Load at First Set (1000 lb)
7.a	3/8	1/8	flat	25.90	yes	no	yes (chain link)	16.0
7.b	3/8	1/8	upright	20.90	yes	no	yes (chain link)	17.0
7.c	3/8	1/8	interlock	20.00	yes	no	yes (chain link)	16.0
8.a	3/8	1	flat	22.00	yes	yes (chain link)	yes (chain link)	16.0
8.b	3/8	1	upright	17.80	yes	yes (chain link)	yes (chain link)	16.5
8.c	3/8	1	interlock	22.00	yes	no	yes (chain link)	16.0
9.a	3/8	2	flat	20.00	yes	no	yes (chain link)	15.0
9.b	3/8	2	upright	20.60	yes	no	yes (chain link)	17.0
9.c	3/8	2	interlock	23.30	yes	no	yes (chain link)	17.0
9.d	3/8	CONTROL TEST		28.90	yes	yes (chain link)	yes (chain link)	17.5

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