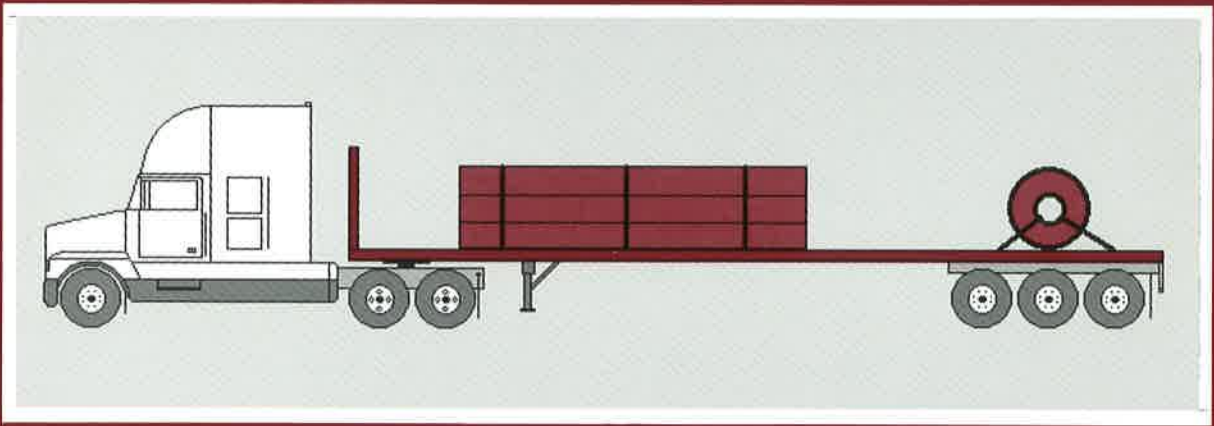
CCMTA Load Security Research Project

Report # 17

ANALYSIS OF HEAVY TRUCK CARGO ANCHOR POINTS



CCMTA • CCATM

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

Report # 17

ANALYSIS OF HEAVY TRUCK CARGO ANCHOR POINTS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

D.K.W. Leung, P.Eng.
3216 Cherry Tree Lane
Elkhart, Indiana
U.S.A. 46514

October 1998

Disclaimer

This report is one of a series commissioned by the sponsors of the ***CCMTA Load Security Research Project***. Readers are cautioned on the use of the data and the conclusions drawn from this particular aspect of the research program as this report is only one of a series related to this multi-faceted issue. The report and the results are not intended to be used in any way as a basis for establishing civil liability.

The material presented in this text was carefully researched and presented. However, no warranty expressed or implied is made on the accuracy of the contents or their extraction from reference to publications; nor shall the fact of distribution constitute responsibility by CCMTA or any of the sponsors, researchers or contributors for omissions, errors or possible misrepresentation that may result from use or interpretation of the material contained herein.

ISBN 0-921795-45-9

Canadian Council of Motor Transport Administrators
2323 St. Laurent Blvd.
Ottawa, Ontario
K1G 4J8

Telephone: (613) 736-1003
Fax: (613) 736-1395

E-mail: ccmta-secretariat@ccmta.ca
Internet Web site: www.ccmta.ca

North American Cargo Securement Standard

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

Those readers interested in participating in the development of the North American Cargo Securement Standard through 1998 are invited to visit the project Web site at www.ab.org/ccmta/ccmta.html to secure additional project information.

Table of Contents

Abstract

A series of tests were previously conducted to determine the strength and failure modes of various heavy truck cargo anchor points. 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 results showed a very wide range of load capacity, both between and within types of anchor point. In most cases, the load capacity also varied significantly with the direction of loading. Most anchor points were found to start 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 led to recommendations that cargo anchor points should be designated on heavy trucks, and should be provided with some load capacity rating.

The present work presents an attempt to derive Working Load Ratings for the various types of anchor point tested in the previous test program, on the basis of the data obtained from that test program.

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.

The preliminary work identified issues regarding cargo anchor points, to which tiedowns are attached. A series of load tests evaluated the strength and failure modes of typical anchor points like stake pockets, D-rings, winches, chain-in-tubes, welded rods, and rub rails, for various pull directions, including the effect of chain wrap on stake pockets.

The present work proposes "Working Load Ratings" for these types of anchor point, from the test program data. The methodology is based on considerations of both safety and practicability, with respect only to normal operating conditions. It does not consider the effect of fatigue. The anchor points exhibited significantly varied performance with load direction. The proposed ratings are based on the worst load direction, to avoid the confusion of a load rating depending on load direction.

Evaluation by conventional "Allowable Stress Design" procedures would preclude use of many of the anchor points tested in the many field conditions under which they are typically used, so the proposed methodology is developed only for application to *these* anchor points. On this basis, three load performance criteria are proposed, namely, the Normal Yield Criterion, the Extended Yield Criterion, and the Ultimate Load Criterion. These criteria are formulated to maximize the Working Load Rating for a given anchor point by allowing some material yielding through the Extended Yield Criterion, when this is feasible, while still providing reasonable safeguards. Thus, the Working Load Rating for an anchor point is taken as the load allowed by the Normal Yield Criferion, and the *lower* of the loads allowed by the Extended Yield and Ultimate Load Criteria, whichever is *higher*. For any anchor point, the yield load is the *lowest possible* Working Load Rating. With this approach, Working Load Ratings are proposed for the anchor points for which yield and/or ultimate load data were available. The accuracy of these results depends on accurate yield load and ultimate load data. However, for some anchor points, these data were either not available, or known to be inaccurate.

To address these concerns, recommendations are made with respect to the need to use a more cost-effective analytical tool, such as finite element analysis, to obtain more accurate data, and to develop the proposed methodology further by applying it to other anchor points not included in the earlier test program, and to refine the range of values to be assigned to the proposed Yield Load and Ultimate Load Factors. It is expected that new anchor points would be designed using conventional methods.

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.

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 had 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 cargo anchor point rating 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 would be required for the foreseeable future, until all vehicles are equipped with anchor points that meet the new vehicle standard. A test program developed for a number of typical heavy truck cargo anchor points, as outlined in Sections 7.2 to 7.8 of the project proposal [1]. The pertinent test data, supported by some limited finite element analysis, findings and recommendations are presented in a companion report [2]. The recommendations in the report were aimed at providing all anchor points with a load capacity rating, based on a correlation of test results with finite element structural analysis, to establish an analytical basis for ratings or rating standards for heavy truck cargo anchor points. This work could not be completed, so load ratings have been estimated based on the test results alone.

2/ Statement of Work

2.1/ Scope of Work

The objective of the present exercise is to assess suitable Working Load Ratings, where feasible, for six types of heavy truck cargo anchor point, namely, stake pockets, including the effect of various chain wraps, D-rings, winches, chain-in-tubes, welded rods and rub rails, under various loading conditions. The Working Load Rating is defined here as the highest load at which the anchor point can reasonably be expected to be used without concern for failure.

Some limited finite element analysis results were obtained as part of the previous work [2], and were available in the form of stress contour plots. However, finite element analysis results that were obtained subsequently were not available, and those that were available were insufficient for useful input. This assessment is therefore based solely upon a review of available test records and data from the test program. These data included "ultimate load" data, and strain gauge data from which "yield load" data were obtained.

The ultimate load for a given test specimen, in a given test, was the maximum load applied to the specimen at which the 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.

The yield load for a given test specimen is the load at which any part of the specimen exhibited permanent set or yield *as identified by the available strain gauge data*. This experimental "yield load" will never be lower than the true yield load, at which *any* strain-gauged or un-strain-gauged part of the specimen actually started to yield. It could conceivably be higher, if the strain gauge was not quite where yield first occurred.

2.2/ Assumptions

The assessment is with respect to "normal" operating conditions only, and excludes hard braking conditions, and crash conditions, such as a rollover or collision. This is done primarily for three reasons. First, the test data obtained were based on static loadings only. Second, with respect to those hard braking or crash conditions where a given anchor point does not come into contact with another vehicle, object, or obstacle, no data are available for the purpose of this study that would allow a reasonable estimation of the wide range of inertial effects that would arise in the stated conditions. Third, other possible crash conditions exist where the anchor points themselves may strike another object or obstacle, and cannot reasonably be made strong enough to resist the force of such an impact.

In addition, the effect of fatigue is not considered, because of the limited scope of the present work, and the lack of adequate data on load spectra.

3/ Assessment Methodology

3.1/ Safety and Practicability Considerations

In spite of the limited test data available, a reasonably sound basis needs to be established so that Working Load Ratings based solely on the data are both realistic and plausible.

The most important notion in determining the Working Load Rating for a given type of structural part is how "failure" should be defined. A second notion is how well the rating proposed -- and the rationale behind its selection -- will be accepted by the trucking industry.

In regard to the first notion, unfortunately, there are no lack of substantively different views in the broader engineering sector that define "failure". For instance, conventional "Allowable Stress Design" of steel structures, commonly used in the construction industry, calls for a maximum allowable stress between 40% and 66% of the yield stress of the material. In essence, this approach assumes that failure is considered at least imminent when *any part* of the material starts to yield, and that the "Working Load Rating" for the structure in question is the load at which no part of the structure will have stresses exceeding the maximum allowable stress. It has already been discussed in the earlier report how this approach would result in such low ratings as to preclude the use of many of the anchor points in the many field conditions under which they are typically used [2]. Thus, it is questionable how well this approach can be implemented in the heavy truck sector.

At the opposite end of the spectrum, as far as structural parts charged with restraining the movement of the occupants of an automobile *in a crash situation* are concerned, "failure" is generally accepted as complete severance of the part from its intended attachment point or points, or the severance of one or more components of the part, such that the part cannot fulfil its intended restraining function. Thus, a seat assembly is not considered to have "failed" as long as it is still attached to the floor, even though its structural material may have yielded grotesquely. In a way, the crash load, which may be 20 to 30 times as high as the normal operating load, constitutes the "Working Load Rating" under crash conditions. It is interesting to note that no loading criteria exist for how these parts should fare under normal operating conditions. It is assumed, apparently, that if a system does not "fail" under crash loads, it will perform satisfactorily under normal loads.

It is difficult to draw a clear cut analogy between the heavy truck cargo anchor point under normal operating conditions and the automotive occupant anchoring devices under crash operating conditions. However, one distinction is clear. The failure of an automobile's occupant anchoring devices under crash conditions primarily impact upon the lives of the automobile's occupants only, while the failure of a heavy truck's cargo anchor points has the potential of a fatal impact on the lives of other motorists. In addition, an automobile's occupants can reasonably expect to remain confined to the automobile's cabin even after the occupant anchoring devices have undergone substantial material yield, whereas a heavy truck will certainly have a strong prospect of losing its load -- with potentially disastrous consequences -- even if its cargo anchor points have undergone a much lesser extent of yielding. The rather liberal approach used in rating automobiles' occupant anchoring devices, therefore, may not be suitable for heavy truck cargo anchor points.

Thus, it is suggested that a more practical approach to finding a suitable Working Load Rating for heavy truck anchor points would be one that would seek a load level at which some amount of material yielding may be accommodated while still providing a sufficient safety margin before the ultimate load is reached.

3.2/ Load Direction Considerations

The task of designating suitable Working Load Ratings is further complicated by the fact that the performance of anchor points was found to vary significantly with load direction, except for D-rings and the medium- and heavy-duty welded rods. To designate a rating for each possible load direction, or to restrict use of the anchor point in question to a particular load direction or range of load directions, could conceivably cause confusion, unless the anchor point was designed or installed to restrict loading to a specific direction or directions. It is therefore proposed that a Working Load Rating should be based on the worst load direction that may feasibly be used in the field. As far as the previous test program is concerned, all loading directions that were tested are feasible, though some may be used quite infrequently, or only in particular applications.

3.3/ Load Performance Criteria

In light of the foregoing considerations, three load performance criteria are proposed to assist in determining the Working Load Rating for a given anchor point. These criteria are formulated in a way that will maximize the Working Load Rating for a given anchor point, as allowed by the available data, while still providing reasonable safeguards.

The first criterion is called the *Normal Yield Criterion*, and is essentially the yield load of the anchor point concerned. Thus,

Permissible Load based on Normal Yield Criterion = Yield Load -------------------------- *(a)*

The second criterion is called the *Extended Yield criterion*, and is represented by a factor, called the Yield Load Factor (Y.L.F.), that is to be applied to the yield load. A Y.L.F. of 1.0 implies that no yielding is permitted, while a Y.L.F. greater than 1.0 means some yielding is permitted. Thus,

Permissible Load based on Extended Yield Criterion = Yield Load x Y.L.F. ------------ (b)

The value of the Y.L.F. to be applied to a given anchor point is dependent on the ratio of the yield load to the ultimate load as calculated of the anchor point. In general, anchor points that exhibit low yield load-to-ultimate load ratios will be assigned higher values. Evidently, the accuracy of yield load data will affect the stringency of this criterion.

The third criterion is called the *Ultimate Load Criterion*, and is represented by a factor called the Ultimate Load Factor (U.L.F.). In general, this factor is assigned a value less than 1.0. The ultimate load multiplied by this factor is basically the load level at which some room is still reserved for further loading until failure of the anchor point occurs. Thus, a factor of 0.40 implies a "safety margin" of 1.5. By restricting loading to a specific level below the known ultimate load for a given anchor point, this criterion provides some safeguard against inaccurate yield load data that may have resulted from the lack of strain gauge data from the more critical areas of the anchor point. Thus,

Permissible Load based on Ultimate Load Criterion = Ultimate Load x U.L.F. ----- (c)

3.4/ Proposed Working Load Rating

For any given anchor point, the Working Load Rating will be taken as the load as obtained based on the Normal Yield Criterion (i.e., the yield load), and the *lower* of the load as obtained based on the Extended Yield Criterion (i.e., the yield load multiplied by the Y.L.F.) and the load as obtained based on the Ultimate Load Criterion (i.e., the ultimate load multiplied by the U.L.F.), whichever is *higher*.

Based on this formulation, the Normal Yield Criterion is the most stringent of the three criteria, as it provides the *lowest possible* Working Load Rating, i.e., the yield load. The Ultimate Load Crierion acts as a safeguard against the possibility of an unsafe rating by providing for the *maximum possible* Working Load Rating while maintaining a reasonable safety margin.

On the surface, the Extended Yield Criterion may cause some potential concern by permitting material yielding. Normally, when accurate yield load data are available and appropriate Yield Load Factors are used, there should not be a concern, as the premise of the criterion is based on the very *first* occurrence of yield anywhere in the anchor point in question, and for most structures, a substantial increase in load will be required before the amount of material yielding will reach an unsafe level. In light of the inaccuracies inherent in the available yield load data, this criterion could indeed result in unsafe Working Load Ratings for some of the anchor points *if and when the criterion is applied by itself only and/or with an inappropriate Yield Load Factor (Y.L.F.).* This possibility, however, is eliminated because of the safeguard that is provided by the Ultimate Load Criterion. It should be noted that, in spite of this potential for concern, the Extended Yield Criterion will benefit those anchor points that exhibit very low yield load-to-ultimate load ratios (say 5%-10%, as in the case of some of the steel stake pockets) by affording them the opportunity to be used at a higher load level than would be allowed by the Normal Yield Load Criterion.

4/ Review of Data

4.1/ Available Data

The available test data included ultimate loads attained by the various test specimens, and strain gauge data. The strain gauge data, which were available for most test specimens, allowed the yield load to be obtained for each anchor point specimen that had been tested. Yield load data were not available for some test specimens, specifically those for which no strain-gauges were installed. The highest load attained in some tests was not always the ultimate load. Testing was terminated between yield and ultimate loads in some cases, for a variety of reasons. In some cases, hooks on chain became jammed as the anchor point deformed, and the test became a test of the chain rather than the anchor point. In other cases, there were grounds for concern about the integrity of the test rig, and it was considered prudent to terminate the test to avoid risk of permanent deformation of the test equipment.

Ultimate load and/or yield load data were reviewed for the following types of anchor point:

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

4.2/ Major Observations

The following observations were reported earlier [2]:

1/ The ultimate load varied widely between types of anchor point, and within a given type, due to differences in strength and design.

2/ For all types of anchor point other than the D-ring and the medium- and heavy-duty welded rod, the ultimate load varied significantly with load direction.

3/ Most anchor points started to exhibit material yielding at loads that were substantially lower than the respective ultimate loads reached. In many instances, these loads were only 10-20% of the ultimate.

4.3/ Yield Load-to-Ultimate Load Ratios

Table 1 summarises the ranges of yield load to ultimate load for all anchor point types for all load directions.

As can be seen from this table, the yield load-to-ultimate load ratios exhibited great variations between and within the different types of anchor point. The possibility that some of the yield load and/or ultimate load data may not be reliable may contribute to this variance. Indeed, it was noted in the earlier report [2] that for some tests, the yield load and ultimate data were believed to be inaccurate because of, for instance, the inability to place strain gauges in the more critically loaded areas of the given anchor point.

5/ Determination of Working Load Ratings

5.1/ Yield Load Factors

In light of the great variance in the yield load-to-ultimate load ratios between and within the different types of anchor point, the Yield Load Factor is categorically assigned a value of either 1.0, which means no yielding is permitted, or 2.0, which allows some yielding. These values are so chosen primarily for the sake of generality and simplicity as the limited amount of data that is available would not allow more specific values to be reliably assessed for the various types of anchor points. If more accurate yield load data becomes available for the anchor points, the Y.L.F. can conceivably be refined further.

Thus, anchor points that demonstrated relatively high yield load-to-ultimate load ratios are assigned a Yield Load Factor of 1.0, and those that demonstrated relatively low ratios are assigned a Yield Load Factor of 2.0.

With reference to Table 1, Yield Load Factors have been assigned to various anchor points as follows:

1/ **Stake Pockets**

All steel and aluminum stake pocket types are assigned a Y.L.F. of 2.0.

2/ **D-rings**

All D-rings are assigned a Y.L.F. of 2.0.

3/ **Winches**

The welded and sliding winches are assigned a Y.L.F. of 1.0, while the clipped winches are assigned a Y.L.F. of 2.0. A lower Y.L.F. is assigned to the welded and sliding winches because of their very high ratios of yield load to ultimate load.

4/ **Chain-in-tubes**

All chain-in-tubes are assigned a Y.L.F. of 2.0.

5/ **Welded rods**

All welded rods are assigned a Y.L.F. of 2.0.

6/ **Chain wraps**

All chain wraps are assigned a Y.L.F. of 2.0.

7/ **Rub rails**

All rub rails are assigned a Y.L.F. of 2.0.

The Yield Load Factors proposed above are included in Table 1. The ranges of ratios of *factored* yield load to ultimate load for the various types of anchor point for all loading directions are also shown for reference.

5.2/ Ultimate Load Factors

For the purpose of the present exercise, an Ultimate Load Factor of 0.40 is assigned to all anchor points. This provides a "safety margin" of 1.5 against ultimate failure of the anchor point.

5.3/ Working Load Ratings

Based on the Yield Load Factors and Ultimate Load Factors proposed above, Working Load Ratings are derived for all anchor points as shown in Tables 2 through 10.

Some anomalies are apparent. The 3/8 in welded rod is assigned a higher Working Load Rating than its 1/2 in counterpart in Table 6, because of the lack of yield load data for the 3/8 in rod. It is also cautioned that the yield load data and ultimate load data for some of the anchor points tested, notably the rub rails, may not be accurate for a number of reasons, such as the lack of strain gauge data from the more critically loaded areas of the anchor point, or the chain getting caught in the test setup and hence giving rise to false data. In general, however, the derived Working Load Ratings appear to be quite reasonable.

6/ Conclusions

A methodology for determining Working Load Ratings for heavy truck cargo anchor points is proposed. This methodology takes into account safety and practicability considerations by employing three load performance criteria, namely, the Normal Yield Criterion, the Extended Yield Criterion, and the Ultimate Load Criterion, to assist in the determination. In view of the greatly varied load performance of the vast majority of the anchor points between different load directions, and after weighing the potential disbenefit of obtaining ratings that would be dependent on load directions, it is further proposed that the criteria be applied only to the worst load direction.

Applying this methodology to the anchor point test data available from the earlier test work, Working Load Ratings are derived for all types of anchor points.

It is believed that the proposed methodology is logical, reasonable and sound. When applied with reliable data, it should provide reasonably safe and practical Working Load Ratings for the types of anchor point tested under current use. It is expected that new anchor points will be designed using conventional criteria.

The usefulness of the methodology is dependent on the availability of relatively accurate test data. It has been noted that yield load data and/or ultimate load data were not available for some of the anchor points, and that some of the test data may not be as reliable as desired, for various reasons.

Accordingly, it is believed that, where test data are either lacking or in doubt, finite element analysis could be adopted as a cost-effective and efficient tool to provide the needed data for the proposed assessment methodology.

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 [3].

7/ Recommendations

The following recommendations arise from the work reported here:

1/ The finite element structural analysis of the anchor points initiated in the previous test program, based on linear and non-linear models, should be completed to provide more accurate yield load and/or ultimate load data for use with the proposed Working Load Rating assessment methodology, so that the accuracy and reliability of the ratings can be improved.

2/ Consideration should be made of applying the proposed assessment methodology to other anchor points not included in the earlier test program, in order to provide more confidence in the methodology.

3/ For the purpose of the present work, the Yield Load Factor and Ultimate Load Factor have been assigned values on a rather simplistic basis. Further work could refine these values so that more reliable Working Load Ratings can be obtained for other anchor points.

4/ This methodology is for assessing a Working Load Rating for the anchor points tested, and new anchor points should be designed using conventional methods.

References

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

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

[3] 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/ Ratio of Yield Load to Ultimate Load for All Anchor Points

Cate-gory	Test series (see [2])	Anchor Point	Yield Load to Ultimate Load	Yield Load Factor (Y.L.F.)	Factored Yield Load to Ultimate Load
1	1.x, 2.x, 3.x	Stake pocket - steel	5 - 19%	2.0	10 - 38%
1	4.x	Stake pocket - light-duty aluminum	10 - 62%	2.0	20 - 124%
1	5.x	Stake pocket - medium-duty aluminum	20 - 55%	2.0	40 - 110%
2	1.x, 2.x, 3.x	D-ring (heavy-duty only)	14 - 35%	2.0	28 - 70%
3	1.x	Winch - welded, high profile	54 - 64%	1.0	54 - 64%
3	2.x	Winch - welded, low profile	n/a	1.0	n/a
3	3.x	Winch - sliding, high profile	72 - 92%	1.0	72 - 92%
3	4.x	Winch - sliding, low profile	59 - 70%	1.0	59 - 70%
3	5.x	Winch - clipped, high profile	19 - 48%	2.0	38 - 96%
3	6.x	Winch - clipped, low profile	21 - 48%	2.0	42 - 96%
4	1.x, 2.x, 3.x	Chain-in-tube[1]	10 - 20%	2.0	20 - 40%
5	3.x	Welded rod - heavy-duty[2]	7 - 73%	2.0	14 - 146%
6	1.x, 2.x, 3.x, 4.x, 5, 6	Stake pocket - steel, chain wrap	13 - 63%	2.0	26 - 126%
6	7.x, 8.x, 9.x, 10.x, 11, 12	Stake pocket - aluminum, chain wrap	3 - 49%	2.0	6 - 98%
7	1.x, 2.x, 3	Rub rail - steel	30 - 99%	2.0	60 - 198%
7	4.x, 5.x, 6	Rub rail - aluminum	33 - 74%	2.0	66 - 148%

1 Yield load data were not available. The ratios are estimated based on test observations that all chain-in-tube specimens sustained gross plastic deformation of the pipe at about 10-20% of ultimate load.

2 No strain gauge data were available for light- and medium-duty welded rods, so yield load data were not available.

Table 2/ Working Load Ratings for Stake Pockets
(All loads in 1,000 lb)

	Steel Pockets						Aluminum Pockets			
	Light-duty		Medium-duty		Heavy-duty		Light-duty		Medium-duty	
Pull Directions	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load
- Vertical	25.00	44.70	18.00	44.80	35.00	44.90	13.00	21.10[1]	10.00	18.30
- Longitudinal forward	1.00	12.20	2.00	11.10	11.00	15.40	1.00	10.00[1]	1.00	4.84
- Lateral outboard	0.50	11.00	2.50	17.50	5.00	26.40	1.00	8.57[1]	1.20	5.92
- 45 deg outboard	n/a	28.00	n/a	33.90	n/a	30.00	n/a	15.50[1]	n/a	11.70
Weakest Pull Direction	Lateral OB		Long. forward		Long. forward		Lateral OB		Long. forward	
Lowest Yield Load (a)	0.50		2.00		5.00		1.00		1.00	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	1.00		4.00		10.00		2.00		2.00	
Lowest Ultimate Load	11.00		11.10		15.40		8.57		4.84	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	4.40		4.44		6.16		3.43		1.94	
Working Load Rating: - *max(a, min(b, c))*	1.00		4.00		6.16		2.00		1.94	

1 The smaller "light-duty" aluminum pocket was shown to be stronger than the "medium-duty" pocket. This was attributed to the former having a 3/8 in thick flange, versus the latter's 1/4 in.

Table 3/ Working Load Ratings for D-rings
(All loads in 1,000 lb)

	Light-duty		Medium-duty		Heavy-duty	
Pull Directions	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load
- Y	n/a	8.03	n/a	22.30	8.00	46.00
- X	n/a	6.42	n/a	17.60	6.50	36.00[1]
- Z	n/a	7.18	n/a	23.90	12.00	46.00[1]
- XY	n/a	9.25	n/a	20.40	12.00	46.00[1]
- YZ	n/a	7.22	n/a	20.50	12.00	46.00[1]
- ZX	n/a	7.78	n/a	21.70	16.00	46.00[1]
- XYZ	n/a	8.44	n/a	19.30	14.00	46.00[1]
Weakest Pull Direction	X		X		X	
Lowest Yield Load (a)	n/a		n/a		6.50	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	n/a		n/a		13.00	
Lowest Ultimate Load	6.42		17.60		36.00	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	2.57		7.04		14.40	
Working Load Rating: - *max(a, min(b, c))*	2.57		7.04		13.00	

1 Estimated values, as tests for were stopped at an applied load of about 20,000 lb to avoid damage to the test jig. Tensile deformation of the ring was very similar to that observed for medium-duty D-ring tests.

Table 4/ Working Load Ratings for Winches
(All loads in 1,000 lb)

	Welded Winches				Sliding Winches				Clipped Winches			
	High Profile		Low Profile		High Profile		Low Profile		High Profile		Low Profile	
Pull Directions	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load
- Vertical	9.50	14.80	n/a	17.10	n/a	12.40	n/a	12.70	4.00	16.50	5.70	18.70
- 45 deg outboard	7.50	14.00	n/a	11.70	7.50	8.14	7.00	10.00	2.30	12.00	3.00	14.10
- Lateral outboard	5.30	8.50	n/a	13.10	2.50	3.47	2.30	3.92	3.00	6.30	4.50	9.40
Weakest Pull Direction	Lateral OB		45 deg OB		Lateral OB		Lateral OB		Lateral OB		Lateral OB	
Lowest Yield Load (a)	5.30		n/a		2.50		2.30		2.30		3.00	
Yield Load Factor (Y.L.F.)	1.00		1.00		1.00		1.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	5.30		n/a		2.50		2.30		4.60		6.00	
Lowest Ultimate Load	8.50		11.70		3.47		3.92		6.30		9.40	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40		0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	3.40		4.68		1.39		1.57		2.52		3.76	
Working Load Rating - *max(a, min(b, c))*	5.30		4.68		2.50		2.30		2.52		3.76	

Table 5/ Working Load Ratings for Chain-in-tubes
(All Loads in 1 000 lb.)

	Model "A"		Model "B"		Model "C"	
Pull Directions	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**
-Vertical	n/a	14.60	n/a	10.30	n/a	17.40
- Lateral	n/a	4.67	n/a	3.18	n/a	7.45
- Angled	n/a	14.50	n/a	5.80	n/a	12.20
Weakest Pull Direction	Lateral		Lateral		Lateral	
Lowest Yield Load (a)	n/a		n/a		n/a	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	n/a		n/a		n/a	
Lowest Ultimate Load	4.67		3.18		7.45	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	1.87		1.27		2.98	
Working Load Rating: - *max(a, min(b, c))*	1.87		1.27		2.98	

Table 6/ Working Load Ratings for Welded Rods
(All loads in 1,000 lb)

	1/4 in.		3/8 in.		1/2 in.	
Pull Directions	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**
- Y	n/a	6.03	n/a	12.70	4.50	21.20
- X	n/a	3.68	n/a	8.64	2.50	17.90
- Z	n/a	2.27	n/a	11.60	1.50	20.40
- XY	n/a	4.88	n/a	9.93	4.90	17.00
- YZ	n/a	5.27	n/a	10.90	2.00	20.00
- ZX	n/a	1.57	n/a	11.00	4.00	15.20
- XYZ	n/a	4.14	n/a	10.60	12.50	17.00
Weakest Pull Direction	ZX		X		ZX	
Lowest Yield Load (a)	n/a		n/a		1.50	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	n/a		n/a		3.00	
Lowest Ultimate Load	1.57		8.64		15.20	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	0.63		3.46		6.08	
Working Load Rating: - *max(a, min(b, c))*	0.63		3.46[1]		3.00	

1 The apparent anomaly of a higher Working Load Rating for the 3/8 in. welded rod than for the 1/2 in. rod may be attributed to the former's lack of yield load data.

Table 7/ Working Load Ratings for Chain-wrapped Medium-duty Steel Stake Pockets
(All loads in 1,000 lb)

	Method "a"		Method "b"		Method "c"		Method "d"		Method "e"		Method "f"	
Pull Directions	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load
- Vertical	4.00	15.00	2.60	19.70	3.50	12.90	3.50	17.10	3.50	18.50	10.00	16.00
- 45 deg fore	2.00	15.30	7.50	15.00	2.00	12.00	4.00	20.20	--	--	--	--
- 45 deg aft	2.00	15.00	6.50	14.20	4.50	10.30	4.60	14.90	--	--	--	--
Weakest Pull Direction	45 deg aft		45 deg aft		45 deg aft		45 deg aft		Vertical		Vertical	
Lowest Yield Load (a)	2.00		2.60		2.00		3.50		3.50		10.00	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00		2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	4.00		5.20		4.00		7.00		7.00		20.00	
Lowest Ultimate Load	15.00		14.20		10.30		14.90		18.50		16.00	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40		0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	6.00		5.68		4.12		5.96		7.40		6.40	
Working Load Rating: - *max(a, min(b, c))*	4.00		5.20		4.00		5.96		7.00		6.40	

Table 8/ Working Load Ratings for Chain-wrapped Medium-duty Aluminum Stake Pockets (All loads in 1,000 lb)

	Method "a"		Method "b"		Method "c"		Method "d"		Method "e"		Method "f"	
Pull Directions	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load	Yield Load	Ult. Load
- Vertical	2.00	17.60	0.30	9.90	3.20	8.10	2.50	15.30	1.50	10.00	2.80	11.80
- 45 deg fore	2.00	10.40	2.50	7.57	2.00	8.00	2.50	9.51	--	--	--	--
- 45 deg aft	3.00	7.89	3.50	8.06	3.50	7.20	4.50	10.90	--	--	--	--
Weakest Pull Direction	45 deg fore		Vertical		45 deg fore		45 deg fore		Vertical		Vertical	
Lowest Yield Load (a)	2.00		0.30		2.00		2.50		1.50		2.80	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00		2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	4.00		0.60		4.00		5.00		3.00		5.60	
Lowest Ultimate Load	7.89		7.57		7.20		10.90		10.00		11.80	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40		0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	3.16		3.03		2.88		4.36		4.00		4.72	
Working Load Rating: - *max(a, min(b, c))*	3.16		0.60		2.88		4.36		3.00		4.72	

Table 9/ Working Load Ratings for Steel Rub Rails
(All Loads in 1 000 lb.)

	Chain Locations					
	Between spool & pocket		**At spool**		**Over spool**	
Pull Directions	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**
- Vertical	4.00	13.30	9.00	24.20	n/a	24.30
- 45 deg. I.B.	9.00	18.40[1]	22.00[2]	22.30[1]	not tested	not tested
Weakest Pull Direction	Vertical		Vertical		Vertical	
Lowest Yield Load (a)	4.00		9.00		n/a	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	8.00		18.00		n/a	
Lowest Ultimate Load	13.30		22.30		24.30	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	5.32		8.92		9.72	
Working Load Rating: - *max(a, min(b, c))*	5.32		8.92		9.72	

1 Chain was caught after rail became grossly deformed.
2 Chain was caught after rail became grossly deformed. The yield load may therefore not be reliable.

Table 10/ Working Load Ratings for Aluminum Rub Rails
(All loads in 1,000 lb)

	Chain Locations					
	Between spool & pocket		**At spool**		**Over spool**	
Pull Directions	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**	**Yield Load**	**Ult. Load**
- Vertical	3.50	5.30	3.00	10.30	10.50[2]	14.20
- 45 deg inboard	2.80	8.60[1]	6.50	18.00	not tested	not tested
Weakest Pull Direction	45 deg inboard		Vertical		Vertical	
Lowest Yield Load (a)	2.80		3.00		10.50	
Yield Load Factor (Y.L.F.)	2.00		2.00		2.00	
Lowest Yield Load x Y.L.F. (b)	5.60		6.00		21.00	
Lowest Ultimate Load	5.30		10.30		14.20	
Ultimate Load Factor (U.L.F.)	0.40		0.40		0.40	
Lowest Ult. Load x U.L.F. (c)	2.12		4.12		5.68	
Working Load Rating: - *max(a, min(b, c))*	2.80		4.12		5.68	

1 Chain was caught after rail became grossly deformed.
2 This yield load was likely much higher than the true yield load. The spool was seen to take most of the load. However, as the spool was not strain-gauged, a more accurate yield load could not be obtained. This situation highlights the need for an alternative, and more effective and accurate, tool such as finite element analysis.

North American Load Security Research Project Reports

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

---

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

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

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

---

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

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

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

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

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

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

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

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

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

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

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

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

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

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

---

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

---

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