

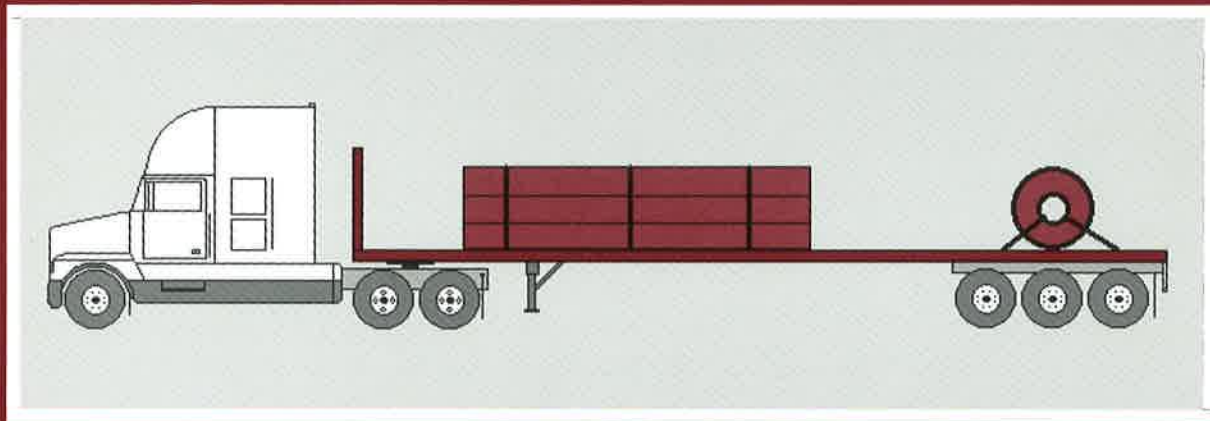
---

# *CCMTA Load Security Research Project*

---

Report # 18

## SUMMARY REPORT



**CCMTA • CCATM**

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

---

# *CCMTA Load Security Research Project*

---

**Report # 18**

## **SUMMARY REPORT**

*Prepared for*

Canadian Council of Motor Transport Administrators  
Load Security Research Management Committee

*By*

J.R. Billing  
Strategic Vehicle Technology Office  
Strategic Transportation Research Branch  
Ontario Ministry of Transportation  
1201 Wilson Avenue  
Downsview, Ontario M3M 1J8

J. Couture  
Direction du transport multimodal  
Ministère des Transports du Québec  
700, boul. René Lévesque Est  
Québec (Québec) G1R 5H1

July 1997

## 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.

©1997 Canadian Council of Motor Transport Administrators/  
Conseil canadien des administrateurs en transport motorisé

ISBN 0-921795-46-7

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](mailto:ccmta-secretariat@ccmta.ca)  
Internet Web site: [www.ccmta.ca](http://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 1997 are invited to visit the project Web site at [www.ab.org/ccmta/ccmta.html](http://www.ab.org/ccmta/ccmta.html) to secure additional project information.**



## **Table of Contents**

**Abstract**

**Executive Summary**

**1/ Introduction**

**2/ Definition of Terms**

**3/ Outline of the Research Project**

**3.1/ Objectives**

**3.2/ Scope**

**3.3/ Research Methodology**

**4/ Summary of Research Findings**

**4.1/ Anchor Points**

**4.2/ Tiedowns**

**4.3/ Blocking**

**4.4/ Friction**

**4.5/ Dressed Lumber**

**4.6/ Metal Coils**

**4.7/ Other Commodities**

**5/ Discussion**

**5.1/ Introduction**

**5.2/ Performance of Vehicles**

**5.3/ Current Standards**

**5.4/ Packaging Cargo for Shipment**

**5.5/ Approaches to Cargo Securement**

**5.6/ Anchor Points**

**5.7/ Tiedowns**

**5.8/ Blocking and Other Woodwork**

**5.9/ Friction**

**5.10/ Dunnage and Devices for Cargo or Tiedown Protection**

**5.11/ Designing for Safety and Reliability**

**5.12/ Cargo Shift**

**6/ Principles for Cargo Securement**

**7/ Conclusions**

**References**



## **Abstract**

The North American Load Security Research Project was undertaken to develop an understanding of the mechanics of securement of cargo on heavy trucks. It was intended to provide a sound technical basis for development of a uniform North American standard for cargo securement for heavy trucks.

Tests were conducted to examine the fundamental issues of anchor points, tiedowns, blocking and friction, and the issues related to securement of dressed lumber, representing cargo loaded lengthwise on a vehicle and secured with transverse tiedowns, large metal coils, and other commodities.

The work is summarized as a set of principles that, when combined with the best of current practice, and common sense, could form the basis for the cargo securement standard.



## Executive Summary

Requirements for securement of cargo on heavy trucks are set and enforced by the provinces in Canada, and the federal government and the states in the U.S. When Canada's National Safety Code standard on cargo securement was to be revised, a Canadian Council of Motor Transport Administrators (CCMTA) task force could not resolve some significantly different requirements between provinces. There were no tools to evaluate the capacity or effectiveness of cargo securement systems, and many key mechanisms were not readily amenable to simple analysis. It was therefore necessary to develop an understanding of the mechanics of the elements of cargo securement, and how these elements related to typical types of cargo. A test program was proposed, to address four fundamental areas of cargo securement : anchor points; tiedowns; blocking; and friction; and some specific types of cargo : dressed lumber, representing general cargo loaded lengthwise and secured by transverse tiedowns; large metal coils; and some other commodities.

The proposed project received broad technical support, and was managed by CCMTA for 21 funding partners from government and industry in both Canada and the U.S. It met the needs of the U.S. Federal Highway Administration, so the goal became a single uniform North America-wide cargo securement standard. The objectives were 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, which could contribute to a North American standard on cargo securement for heavy trucks. The conclusions and principles are summarized below.

As a prerequisite to securement, cargo offered for transportation must have sufficient structural integrity that it can withstand stacking, securement, and the forces arising from transportation. No component of the cargo securement system should exceed its working load limit up to the maximum accelerations a vehicle can achieve under any condition on a highway short of a crash.

Cargo should preferably be fully contained in a vehicle with sufficient strength to contain it. If there is insufficient cargo for it to be fully contained, the separate parts should preferably be contained and immobilized to prevent shifting or tipping. Cargo that cannot be contained should preferably be immobilized. If that is not possible, it must be secured. The method of securement should offer the greatest reliability, and preferably should provide redundancy so that cargo is not lost if there is a single failure in the securement system. Any method of securement where a single event or failure results in loss of cargo needs more stringent requirements than if there is redundancy.

Vehicles that can carry heavy articles of cargo require anchor points designated for securement of that cargo. All anchor points should be provided with a load capacity rating, and the possible directions of loading should be considered in developing the rating of an anchor point.

Tiedowns either resist applied forces, or increase friction between the cargo and the vehicle deck. The purpose and relative effectiveness of different means of using tiedowns needs to be clearly understood. Tiedowns are currently central to cargo securement, yet are not fully reliable. If greater diligence with other means of cargo securement can be encouraged, it may be possible to increase the actual level of securement without any change to tiedown requirements. The current requirement for aggregate working load limit of all tiedowns may be adequate for general commodities secured by transverse tiedowns, but other cases could require a different tiedown capacity, depending on the other securement provided or available. The hook on a tiedown should not be attached so that it could fall out if the tiedown became slack. A tiedown tension device that can take up slack in the tiedown and maintain tension as cargo settles would significantly improve the reliability of tiedowns. Where a vehicle is equipped with a rub rail, a tiedown should pass inside the rub rail on each side of the vehicle, to make use of the protection offered. Consideration should be given to a requirement for all vehicles with exterior tiedowns to have such protection.

Soft corner protection devices and dunnage can seriously degrade performance of the cargo securement system. Corner protection devices should conform fully to the edge of the cargo, with no space under the device; be at least as hard as the tiedown; and either be wide enough, or channelled, so that the device does not fall out if the cargo shifts or the tiedown slips along the edge of the cargo.

Nailed wood blocking provides modest resistance for practical numbers of nails. It is only suitable to provide a substantial part of the securement for an article of modest weight, or a modest part of the securement for a heavy article. The use of fillers depends upon the strength of those parts of a vehicle to which they might transfer load.

Friction is the principal factor that keeps most cargo from shifting, so its role should be formally recognized. Trailer decks, and cargo handling equipment like skids used during transportation, should be designed with high coefficients of friction. Rubber mats appear to increase the coefficient of friction over 0.5 for many typical combinations of cargo and deck, and their use should be encouraged. However, friction must continue to be considered inherently unreliable, and no matter how high, should never be the sole means of cargo securement.

Large metal coils are inherently incompatible with flatdeck trailers, so should preferably be transported on custom-designed trailers or in custom-designed compartments that provide sufficient longitudinal and lateral securement. Hardwood blocks should always be used in combination with bunks, forming a cradle, to prevent them from popping out under extreme loading conditions. The cradle should have as deep a well as possible. The cradle should preferably be immobilized so that it cannot slide on the deck, and the coil should preferably be immobilized so that it cannot slide on the blocks. If the cradle or coil are not immobilized, means should be used to increase the coefficient of friction at the cradle/deck or coil/block interfaces. When symmetric chain tiedowns are placed through the eye of a coil with its eye lateral on the vehicle, the chain angle should not

exceed 45 deg to the horizontal, and the initial tension in the tiedown should not exceed 20% of it's working load limit. Where an odd number of tiedowns are used, the last (odd) tiedown should be placed to the rear to resist the force of deceleration of the vehicle. For a coil with its eye longitudinal on the vehicle, chain securement angles should be kept as low as possible and should never be higher than 65 deg with respect to the horizontal line. There are cases where the resistance of chains crossed through the eye is significantly poorer than for chains straight through the eye, so chains straight through are preferred. Any desired level of lateral and longitudinal resistance can be achieved by making appropriate use of cradle dimensions, friction and chain tiedowns. Placing the cradle so that the coil has its eye laterally on the vehicle should, in general, provide the most reliable securement. Webbing tiedowns are generally too elastic, even over the top of a coil. Special measures should be taken to avoid surfaces becoming contaminated with oil, and if this arises, or an oil-soaked coil is being transported, the reduced friction resistance should be compensated by an increase in other forms of resistance.

Cargo securement practice varies widely, by type of cargo, personal preference of drivers, and motor carrier and shipper policies and procedures. Much of this practice meets current requirements, some exceeds it by a wide margin, and much should also meet the planned standard. Those whose current practices deliberately do not meet current regulations may not be affected by the new standard. Between these, there is a range of marginal or questionable practice. Combining the research findings above with common sense and the best of current practice provides a basis for a new standard that could eliminate this marginal practice. To achieve this, however, it will be necessary to resist arguments that may be advanced by some motor carriers and shippers to maintain that practice. In most cases, if the motor carrier has the proper equipment, it should take no longer to achieve an objective level of securement than it takes to secure it anyhow.

## **Acknowledgments**

The Load Security Research Project was conducted on behalf of the Canadian Council of Motor Transport Administrators (CCMTA) by Strategic Transportation Research Branch of Ontario Ministry of Transportation (MTO) and Direction du transport multimodal of Ministère des Transports du Québec (MTQ).

This section recognizes the direct contributions of those who organized and conducted the work, and the 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.

The dressed lumber tests were conducted by the Forest Engineering Research Institute of Canada, Montreal, under contract from the Ministère des Transports du Québec.

Friction tests under vibration were conducted by CONCAVE Research Centre of Concordia University, Montreal, under contract from CCMTA.

Walter Mercer of MTO conceived and designed all the jigs, fixtures and machines used for these tests. CSI Aerospace of Rexdale was responsible for final design and manufacture of the metal coil test rig, under contract from CCMTA. The metal coil tests were conducted at Taylor Steel in Stoney Creek, Ontario.

The remainder of the work was conducted by Norm Carlton, Gary Giles, Cheuk Lam, Damien Leung, Walter Mercer, Bill Stephenson, Mike Wolkowicz and other staff of Strategic Vehicle Technology Office of MTO, and by Guy Desrosiers and other staff of MTQ.

Equipment, services and materials used in this project were donated or lent by :

- Aragon Group, St. Paul, Minnesota;
- Daishowa Forest Products Ltd of Québec City, Québec;
- W.J. Deans Transportation of Delson, Québec;
- Dorsey Trailers of Atlanta, Georgia;
- Gestofor Inc of St-Raymond, Québec;
- Great Dane Trailers of Savannah, Georgia;
- Kinedyne Canada Ltd of Agincourt, Ontario;
- Lafarge Canada of Waterloo, Ontario;
- Ontario Ministry of Transportation, Downsview, Ontario;
- National Research Council of Canada, Ottawa, Ontario;
- National Rubber Company of Toronto, Ontario;
- Stelco Inc of Hamilton, Ontario;
- Stone Consolidated Company (Saguenay Division) of La Baie, Québec; and
- Waterloo Concrete Products of Waterloo, Ontario.

## 1/ Introduction

Securement of cargo on vehicles is a matter of public safety, and is therefore subject to government regulation and a body of industry practice. Setting and enforcing cargo securement regulations for vehicles is the responsibility of the provinces in Canada, and the U.S. federal government and the states to the south. U.S. federal responsibility for interstate commerce has resulted in a large measure of regulatory uniformity across that country. However, there are over sixty jurisdictions in Canada and the U.S. together, with more than one agency involved in many of them. It is not surprising that there are some significant differences in requirements, interpretation and enforcement between them. These create problems for motor carriers that are at least hindrances, if not barriers, to the free movement of goods.

The Canadian Council of Motor Transport Administrators (CCMTA) was charged to revise Canada's National Safety Code standard on cargo securement [1]. Their task force reviewed the standard, and the current regulations of the provinces. However, it was unable to resolve some significantly different requirements between provinces, because many were of unknown origin, and there was no ready means to evaluate the capacity and effectiveness of cargo securement systems. The task force therefore identified a number of areas for research [2]. Ontario Ministry of Transportation (MTO) conducted extensive consultations with staff and industry, prepared a draft research proposal, and circulated it widely throughout North America for review. A technical committee of government agencies, industry associations representing trailer and equipment manufacturers, shippers and carriers, and others, met to consider the proposal and review the comments on it. As a consequence of this discussion, a better understanding of the issues emerged that allowed MTO to finalize the research proposal [3]. This received significant technical support and funding from governments and industry in the United States, so the goal was extended from a Canadian standard to a single uniform North America-wide standard. The project proposal was approved by CCMTA at the end of 1993, when funding was secured, and a management committee was formed to steer the project. The research work was conducted principally by MTO and Ministère des Transports du Québec, from 1994 through 1996.

This report first provides some definitions of terms, then outlines the technical approach to the research project. It summarizes the scope and findings of the many technical reports produced. The remainder of the report is devoted to a synthesis of current knowledge and practice with the research findings. This leads to a set of principles for cargo securement, expressed in plain language. These are not a standard, but, when combined with the best of current practice, and common sense, could serve as a technical basis for a North American standard for cargo securement.



## 2/ Definition of Terms

This report uses a number of common terms. Some of them are also used in other contexts, and there may be other terms with similar or overlapping meaning. To avoid confusion, terms are defined in this section so that the report is interpreted in the intended context. Some definitions may differ from those in current regulations, standards or practice.

"Load security" has been Canadian terminology. However, "load" may be either a noun or verb, and has several meanings. The U.S. term "cargo securement" has therefore been adopted. The original project title has been retained for this report, but "cargo" and "cargo securement" are used throughout the text where "load" and "load security" might previously have been used.

The following terms are defined here for the purposes of this report :

**Anchor point** means part of the structure of a vehicle, or a device firmly attached to that structure, that is designed or commonly used to attach a tiedown assembly.

**Article** means a unit of cargo, other than a liquid or gaseous cargo, and includes articles grouped together so that they can be handled as a unit.

**Blocking** means a piece, usually of wood, secured to the vehicle deck against an article to prevent the article from shifting.

**Bracing** means a device placed against an article to prevent the article from tipping, and may also prevent it from shifting.

**Cargo** means all articles carried by a vehicle, including those used in operation of the vehicle.

**Chock** means a tapered or wedge-shaped piece used to secure round or irregular-shaped articles against rolling or shifting.

**Cleat** means a short piece, usually of wood, secured to the vehicle deck to reinforce blocking.

**Crib** means a structure placed under or against an article, and usually secured, to stabilize the article, hold it in position, or supplement its primary support.

**Contained** means that an article is in contact with or sufficiently close to the structure of the vehicle or other articles so that it cannot shift or tip if the other articles are also unable to shift or tip.

**Deck** means the floor or bed of a vehicle on which cargo is placed.



**Dunnage** means a device that distributes the forces of one or more tiedown assemblies over a greater area than that of the tiedown assemblies themselves.

**Emergency manoeuvre** means the maximum acceleration possible for any vehicle under any condition short of a crash.

**Filler** means a device placed between an article, or blocking against the article, and part of the vehicle or other articles of cargo or other blocking, to immobilize the article.

**Motor carrier** means the organization or person responsible for operation of a vehicle and the conduct of its driver.

**Normal driving** means the maximum acceleration that a driver might expect from hard braking or a turning manoeuvre.

**Restrained** means that an article is prevented from tipping or shifting by some combination of blocking, bracing or tiedowns.

**Secured** means cargo is contained or restrained.

**Settlement** means gradual downward movement of contained articles to a stable state.

**Shift** means a change in the longitudinal or lateral position or orientation of an article.

**Spacer** means material placed beneath an article, or between layers of a pile of articles, to simplify loading and unloading.

**Tension device** means a device used to produce tension in a tiedown.

**Tiedown** means a device capable of taking tension, including, but not limited to, cable, chain, strapping and webbing, that is attached to a vehicle and an article, or is attached to a vehicle, passes over, round or through one or more articles, then is attached again to the vehicle.

**Tiedown assembly** means a combination of a tiedown with one or more tension devices that secures cargo to the vehicle on which it is being carried.

**Tip** means that an article falls over.

**Vehicle** means a truck or truck tractor, alone or in combination with a trailer or trailers.

**Working load limit**, abbreviated as **WLL**, means the maximum load assigned by a manufacturer that may be applied to a tiedown or component during normal service.

### **3/ Outline of the Research Project**

#### **3.1/ Objectives**

The research project had three objectives [3] :

- 1/ To determine how parts of cargo securement systems contribute to the overall capacity of those systems;
- 2/ To demonstrate the adequacy of parts, and the overall capacity, of cargo securement systems; and
- 3/ To develop principles, based on sound engineering analysis, which could contribute to a North American standard on cargo securement for heavy trucks.

#### **3.2/ Scope**

The CCMTA task force charged to revise Canada's National Safety Code cargo securement standard [1] identified 15 research issues and two areas for development considered prerequisite to agreement on a standard [2]. The research proposal organized them into seven groups, four dealing with fundamental issues and three with specific commodities [3] :

- 1/ Anchor points;
- 2/ Tiedowns;
- 3/ Blocking;
- 4/ Friction;
- 5/ Dressed lumber;
- 6/ Large metal coils; and
- 7/ Other commodities.

#### **3.3/ Research Methodology**

It was evident from the preliminary discussions and analysis that many key mechanisms of cargo securement are nonlinear, so are not readily amenable to simple analysis. It was therefore necessary to develop an understanding of the mechanics of the elements of cargo securement systems, and to generate data that would be needed to make effective use of simple models of those systems. These issues were clearly most easily addressed by means of a test program [3], a conclusion previously reached by others [4].

Cargo securement systems are based on a design acceleration that is close to the limit of the capability of most heavy vehicles. Since the capacity of some cargo securement systems may exceed this by a wide margin, the only way to determine that capacity was by laboratory tests. The tests designed were mostly artificial, with conditions set up to

ensure that the characteristic of interest could be observed reliably, without the confounding influence of extraneous or uncontrolled factors. However, some tests were performed using trucks, either as stationary tests with artificially induced loads, or by driving the vehicle and monitoring vehicle and cargo securement system responses.

Simple cargo securement models have been developed for many generic combinations of cargo shape and tiedown geometry [4]. Computer simulation models of heavy vehicles are available for lateral/directional and rollover dynamics, and braking. It would be possible to combine cargo securement and vehicle dynamic models to compute cargo movements and forces in tiedowns for various types of cargo as vehicles make specified manoeuvres. It is much easier, and usually conservative, to apply quasi-static limiting accelerations to simple models based on cargo shape and tiedown geometry.

The fact that the research is based on a test program did not, of course, preclude the use of simulation and analysis. These tools were used as necessary, to move from specific test conditions to the principles that are the principal output from the work.

## **4/ Research Findings**

The previous chapter identified seven areas of activity. Some of these were subdivided, for logistical convenience. The results are presented in detailed technical reports, each prepared by the organization responsible for that part of the work [5-21]. This chapter presents a brief summary of the issues and scope, and summarizes the major conclusions and recommendations from the various technical reports, for each of the seven areas of activity. The individual technical reports are referenced at key points, and should be consulted for more detail.

### **4.1/ Anchor Points**

#### **4.1.1/ The Issues**

The load capacity of the anchor point and the tiedown assembly must be assessed separately, and only the lesser of the two can be used as the tiedown load capacity for cargo securement purposes. Load ratings of tiedowns are generally available, but review of the cargo securement regulations identified that the load capacity of anchor points was generally unknown [2]. This raised two issues, a standard for minimum strength rating of anchor points on new vehicles, and rating of anchor points on existing vehicles.

A manufacturing standard for strength of cargo anchor points on new vehicles should resolve the adequacy of anchor points over the long term. Manufacturing standards are a federal responsibility, with Transport Canada and the U.S. National Highway Traffic Safety Administration. Transport Canada was undertaking this task, so it needed no further attention.

However, some means is required to rate the capacity of anchor points on existing vehicles until all vehicles are fitted with anchor points that meet a new vehicle standard. A series of tests was therefore proposed to determine the strength of typical samples of the most common anchor points.

#### **4.1.2/ Scope**

The following types of anchor point were evaluated [13] :

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

Selected anchor points were purchased, obtained from their manufacturer, or fabricated to represent typical hardware. Each was mounted on a rigid backing plate in a laboratory load testing machine, and was loaded until failure occurred, in most cases. Each type of anchor point was tested with the load applied in several different directions. Tests also examined the effect of the manner in which a chain was hooked to a stake pocket or rub rail on the strength of that anchor point.

#### **4.1.3/ Conclusions**

The tests loaded a variety of typical heavy 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 [13].

From the preliminary work of selecting and gathering test articles, it became clear that tiedowns are attached to a variety of anchor points, which may be parts of the vehicle structure or devices attached to it. These anchor points exist in a wide range of designs, with evidently a wide range of load capacity, and the load capacity rating of many of them cannot readily be ascertained.

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. The ultimate load varied significantly with load direction for all anchor points, other than D-rings.

Most anchor points started to yield, and became permanently deformed, at loads substantially less than the ultimate load reached. Often, 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 is applied, many existing anchor points would have a very low rating. 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.

A preliminary comparison of finite element structural analysis against the test data showed good correlation. This suggests that such analysis may provide an efficient and cost-effective tool to develop a rating for anchor points.

#### **4.1.4/ Recommendations**

The following recommendations arose from this work [13] :

- 1/ A vehicle that can carry heavy articles of cargo requires anchor points designated for securement of that cargo.

- 2/ All anchor points should have a load capacity rating.
- 3/ The manufacturer of an anchor point is in the best position to specify its load capacity rating, so manufacturers should be involved in a range of issues from anchor point standards to consensus ratings of existing equipment.
- 4/ The possible directions of loading should be considered in developing the load capacity rating of anchor points.
- 5/ A systematic method should be developed to evaluate when a damaged anchor point should be repaired or replaced.

## **4.2/ Tiedowns**

### **4.2.1/ The Issues**

Most current regulations in one way or another effectively assume that a tiedown that passes over or through an article of cargo, without being attached to it, achieves equal tension in each span of the tiedown. In effect, it is assumed that the tiedown acts as a rope passing over a pulley, with the cargo acting as the freely rotating pulley. It is clear that a chain passing over or through a rigid article of cargo that is tightly restrained to prevent movement might hang up if links get caught on a sharp corner or bite into the cargo or dunnage. It was therefore necessary to examine how tension is developed in tiedowns, the extent to which tension equalizes in the spans of a tiedown, and how tiedown tension is affected by cargo movement, for various types of cargo and tiedown.

### **4.2.2/ Scope**

This series of tests addressed the following issues of tiedown assemblies :

- 1/ The effect of binder type, chain size and chain length on the ability to develop tension in a chain;
- 2/ The effect on chain strength of links bearing on hard corners;
- 3/ Equalization of tension in the spans of tiedowns; and
- 4/ The effect of cargo lateral and longitudinal movement on tiedown tension.

The first two relate strictly to the properties of typical tiedown assemblies, and were laboratory tests conducted on a specially built test rig [9], and a load testing machine respectively [13]. The third was conducted by instrumenting transverse tiedowns over cargo on a truck, and monitoring the tiedown tensions while driving for an extended period on a highway [8]. The last was also conducted in a laboratory, on another specially built test rig [12].

### **4.2.3/ Conclusions**

When lever type binders were used to tighten a chain tiedown with the assistance of a 0.61 m (24 in) long pipe the resulting tension in the chain could reach or exceed the working load limit of the chain. The length of the chain was found to be a significant influence on the resulting tension for fixed tension device set points. The ratchet type binder exerted reasonable loads when operated by personnel who were familiar with its mechanical advantage and capabilities, but excessive ratcheting could significantly over-tension a chain [9].

Corner radius and chain link orientation had little effect on the ultimate strength of a given size of tiedown chain when loaded around a tight corner, no matter what the failure mode of the chain [13].

When a chain or webbing tiedown was initially tensioned from one side of the vehicle over rigid cargo, the initial tensions on each side of the tiedown were markedly different, due to friction around the corners of the cargo, regardless of the geometry or hardness of the corner. When the vehicle was driven on the highway, there was some loss of tension from both sides, but the tensions never equalized, regardless of tiedown type, corner characteristics or initial tension. For the same test with a compliant cargo, a high initial tension would tend to compress the cargo and make it rigid, when the foregoing conclusions would apply. With a lower initial tension, the cargo remained loose and vehicle motions quickly caused it to settle, when the tiedowns became loose. When a tiedown was tensioned from the centre, tension was better equalized and less tension was lost than when it was tensioned from one side [8].

When cargo secured by chain or webbing tiedowns was moved, the tensions in the tiedowns increased as a consequence of the geometric movement. For longitudinal motion under transverse tiedowns, the tiedowns provided no initial resistance. The more elastic webbing tiedowns allowed greater movement than chains for a given proportional increase in tension, and also tended to slip, which relieved the tension and allowed the cargo to continue moving. For lateral motion, both types of tiedown slipped over the cargo and developed forces that resisted motion [12].

### **4.2.4/ Recommendations**

Regarding use of binders :

- 1/ Lever binders should not be used with devices intended to enhance their mechanical advantage, but should be secured using only the operator's strength.
- 2/ Ratchet binders should only be used with due care, without assistive devices, and with a knowledge of chain and cargo tiedown requirements.

Regarding application and use of tiedowns :

- 1/ Cargo should be loaded without internal space so that it is more closely rigid than compliant. If other considerations require lateral space between articles of cargo, then a filler or other means should be used to prevent the articles from moving together, and the filler should not be able to come loose.
- 2/ Tensioning a tiedown from its centre provides more equalized tension at anchor points, but this should only be done if the person doing the tensioning does not incur undue risk of falling from the cargo or vehicle.
- 3/ A chain tiedown should not be used in direct contact with cargo or dunnage that is much softer than the chain, as it will simply crush the corner as tension increases in the tiedown. Robust corner protectors should be used that are hard enough to resist local pressures of chain links.

Regarding transverse tiedowns over cargo loaded longitudinally :

- 1/ These provide no initial resistance to longitudinal cargo movement. The cargo should either be immobilized by placing it against the front structure of the vehicle or other cargo or by using a filler to achieve the same effect, or by ensuring there is adequate friction between the cargo and the deck.
- 2/ These appear to give adequate resistance to lateral motion.

#### **4.3/ Blocking**

##### **4.3.1/ The Issues**

Blocking refers to wood blocks placed against the cargo and secured, usually by nailing to the vehicle deck. Since the blocking may provide securement by itself, or may be used with other means of securement, it was necessary to investigate the restraint offered by typical arrangements of nailed wood blocking. Cargo may also be wedged against the stakes of a stake and rack trailer, and it was necessary to examine the strength of these. Wood blocks used as dunnage may be affected by tiedowns.

##### **4.3.2/ Scope**

This series of tests examined :

- 1/ The load capacity of nailed wood blocking [11];
- 2/ The shear and bending strength of stakes [16]; and
- 3/ The effect of tiedowns on wood blocks used as dunnage [17].

All of the tests were done in a laboratory, using two specially constructed test rigs.



### **4.3.3/ Conclusions**

A series of tests conducted to address various nailing methods, nail sizes, and species of block and deck found that blocks secured with nails driven perpendicular to the deck surface are stronger than blocks secured by any other nailing method. A nailed joint is stronger when the nails bend as the block moves, and is weaker when the block rolls and is able to extract the nails. The species of wood block did not affect the resistance to dislodgement, but a harder deck significantly increased the resistance [11].

A series of tests of the strength of typical stakes used in stake-and-rack assemblies for flatdeck trailers showed that these satisfied the engineering theory of beams. None would be suitable as restraint for a large and heavy article [16].

A series of tests of the effect of tiedown pressure on wood blocks used as dunnage found that a tiedown under high tension around the corner of dunnage (or cargo) can cut into the dunnage. The damage increases for a given tiedown tension as the difference between the hardness of the tiedown and the hardness of the dunnage increases [17].

### **4.3.4/ Recommendations**

The following recommendations emerged for nailed wood blocking [11] :

- 1/ The preferred nailing method is straight through the block, perpendicular to the deck, such that at least 3.18 cm (1.25 in) of the nail penetrates the deck.
- 2/ Blocking should be placed against the cargo, with no clearance, on all free sides of the cargo.
- 3/ The proposed standard should recognize that blocking helps immobilize cargo, so should provide values for nail resistance. It should also recognize that blocking alone is only practical for securing articles of cargo of moderate weight.

The following recommendation emerged for use of stakes [16] :

- 1/ Heavy articles should not be secured solely by being blocked against stakes, unless the stakes have been specially designed for that purpose.

The following recommendation emerged for use of dunnage [17] :

- 1/ Dunnage should be at least as hard as the tiedown.

## **4.4/ Friction**

### **4.4.1/ Issues**

Friction is always present between tiedowns and cargo, and between cargo and the vehicle deck. It appears to be a major factor in preventing cargo secured with tiedowns from shifting. There are very wide ranges of cargo and deck materials, and it was necessary to determine the range of friction that may occur in practice. It was also necessary to understand the magnitude and role of friction to be able to interpret many other tests in this work. Friction is not considered reliable [4], due both to the possibility of contamination of interfaces, and that the vehicle deck is a vibrating environment. Both factors were examined [10, 5].

### **4.4.2/ Scope**

This series of tests investigated the friction between some combinations of seven typical vehicle deck materials and nine cargo materials, with a clean, dry deck [10]. The reliability of friction was assessed by including tests with dirt, oil, water and anti-skid mats in the interface [10], and by placing the deck and cargo on a shaker table and assessing friction under pure sinusoidal vibration, and under typical vibration measured on a vehicle on both paved and unpaved roads [5]. Limited tests were also conducted with anti-skid mats during the dressed lumber portion of the project [6].

### **4.4.3/ Conclusions**

A series of tests was conducted to determine static and sliding coefficients of friction for typical cargo on typical vehicle decks. These tests were conducted at full scale, to represent the typical imperfections in materials seen at this scale, and without vibration. Friction coefficients were determined with the deck clean, and with the cargo-deck interface contaminated with sand, oil or water, or with a rubber mat placed on the deck beneath the cargo and the deck.

The coefficient of static friction, the level that must be overcome to start the cargo sliding, ranged from 0.18 to 0.71 for the various types of cargo tested on the various dry decks. The coefficient of sliding friction, the level that must be overcome to maintain the cargo at constant velocity once it has started to slide, ranged from 0.13 to 0.68 for the same case, and was 8 to 28% less than the coefficient of static friction. Some cargo had consistently high coefficients of friction on all decks, some had consistently low coefficients, and for others, the coefficients varied more or less widely, depending on the deck [10].

Coefficients of friction tended to increase if at least one of the surfaces was soft, so that sand could indent into it, or water could be absorbed by it. If both surfaces were hard, then sand or water in the cargo-deck interface tended to decrease coefficients of friction. Coefficients of friction tended to decrease if there was oil in the cargo-deck

interface, and tended to increase significantly if a rubber mat was placed between the cargo and the deck [10]

A subsequent series of tests evaluated the effect of vibration on coefficients of friction. It found that mean sliding friction coefficients measured under both sinusoidal vibration and vibration measured from a vehicle were comparable to those measured under static conditions. The minimum values of sliding friction coefficients decreased gradually with frequency up to 2 Hz, and remained almost constant for higher frequencies. Minimum and maximum values of friction coefficients varied considerably with both cargo weight and deck acceleration, and the variation was symmetric about the mean values up to the point where the cargo began to hop. The tendency to hop was governed by detailed dynamic characteristics of the cargo and the deck. Minimum values of friction coefficients depended upon the flexibility of both the deck and the cargo. Under vibration measured from a vehicle, the coefficient of friction fell below 75% of the mean value for as much as 25% of the time [5].

#### **4.4.4/ Recommendations**

The following recommendations emerged from this work [10] :

- 1/ A high coefficient of friction should be a consideration in specification of the deck for vehicles. This should also extend to consider the reliability of this friction over the life of the vehicle, due to the effects of wear and contamination of either the cargo or the deck by substances that may affect its friction properties.
- 2/ The plastic skid used in these tests exhibited rather low coefficients of friction. Cargo handling equipment that is also used during transportation, of which this skid is probably just one example, should also be designed with high coefficients of friction, on both surfaces.
- 3/ Rubber mats, and other materials with equivalent friction properties, appear to increase the coefficient of static friction over 0.5 (considered high) for all combinations of cargo and deck tested. Their use should be encouraged.
- 4/ The role that high friction coefficients play in inhibiting cargo movement should be formally recognized in the proposed standard.
- 5/ Credit should be given for friction where it clearly plays a substantial role in cargo securement.
- 6/ Friction, even high initial friction, must continue to be considered inherently unreliable.
- 7/ If friction requirements are set, then appropriate test methods should also be specified.

- 8/ No matter how high the level of friction, it remains inherently unreliable, and should never be considered the sole means of cargo securement.
- 9/ Probabilistic approaches can be used to determine a friction level that provides any required minimum level of risk [5].

#### **4.5/ Dressed Lumber**

##### **4.5.1/ Issues**

Dressed lumber is an example of a long article of cargo placed lengthwise on a vehicle and secured by tiedowns placed transversely over the cargo. There are significant differences in the numbers and spacing of tiedowns required by different jurisdictions, and it was necessary to conduct some objective tests to assess the actual load capacity of the various requirements.

##### **4.5.2/ Scope**

This series of tests investigated the effect of the number and spacing of tiedowns on securement of bundles of dressed lumber, including the difference between tiedowns over every tier and tiedowns only over all tiers where multiple bundles were stacked one upon another. Full-scale static tests were conducted on lateral and longitudinal tilt tables, and dynamic tests were conducted by driving through emergency manoeuvres [7].

##### **4.5.3/ Conclusions**

These tests found that friction along the surfaces of contact between the load and its supports were the principal factor that affects cargo securement. Tiedown tension also appeared to have a significant impact on the efficiency of tiedown systems. However, this was somewhat difficult to control given the nature of the manual winch systems that are commonly used on flatdeck vehicles. Additional tiedowns beyond the minimum needed to assure cargo integrity appeared to provide only minor improvement to securement [7]. Rubber mats that increased the coefficient of friction between the cargo and deck were found to inhibit cargo movement, but an open soft mat was much less effective than a dense solid mat [6].

##### **4.5.4/ Recommendations**

No recommendations were made from this series of tests.

## **4.6/ Large Metal Coils**

### **4.6.1/ Issues**

Because of their shape, large metal coils are a particular challenge for cargo securement systems. They can also be very damaging if they get loose, because of their weight. A coil has different resistance to motion depending on the way that it is oriented. Its inherent tendency to roll away when placed with its eye horizontal means that blocking and tiedowns together must provide all the restraint. This series of tests examined the separate effects of blocking, friction and tiedowns on large metal coils, and the combined effect of these components of the cargo securement system.

### **4.6.2/ Scope**

All tests were conducted with the eye of the coil horizontal. A lateral pull means the coil was subjected to a force at a right angle to the eye. A longitudinal pull means the coil was subjected to a force through the eye. The tests included the following [18] :

- 1/ Effect of friction for longitudinal and lateral pulls;
- 2/ Effect of blocking for longitudinal and lateral pulls;
- 3/ Effect of chain securement for lateral pull;
- 4/ Effect of chain securement for longitudinal pull;
- 5/ Effect of cradle for lateral pull;
- 6/ Effect of cradle and chains for lateral pull;
- 7/ Effect of friction with secured cradle for longitudinal pull;
- 8/ Effect of friction with unsecured cradle for longitudinal pull;
- 9/ Effect of cradle and steep angle chains for longitudinal pull;
- 10/ Effect of cradle and shallow angle chains for longitudinal pull;
- 11/ Effect of cradle and chain and webbing tiedowns over the coil for lateral and longitudinal pulls; and
- 12/ Effect of nailed wood blocking cradle.

### **4.6.3/ Conclusions**

The tendency of a large metal coil with its eye horizontal to roll on a flat surface is inherently incompatible with transportation on flatdeck trailers. It takes considerable effort to provide proper securement for an article that is so difficult to handle.

The metal coil and coarse oak deck combined for a static coefficient of friction for the coil in a longitudinal pull of about 0.27. With the coil on dry bevelled maple blocks, the static friction coefficient for a longitudinal pull was 0.23, and the presence of water or oil on the block surface did not greatly affect this value. Friction was significantly increased by inserting materials such as rubber mat, old tire treads or rubber conveyor belts between the coil and the blocks. However, water or oil on the surface of this friction material drastically reduced the friction between the coil and material. The

friction coefficient decreased from 0.23 to 0.20 as the length of blocking was increased from 75% to 125% of the coil width. The static friction coefficient for a longitudinal pull on a cradle formed from blocks placed in steel bunks on a dry deck was 0.34, increasing to 0.53 when the deck was wet. A rubber mat under the bunks increased this to 0.42. Wetting the rubber mat had no effect, but the presence of oil significantly reduced the static friction coefficient, to 0.21.

The rolling resistance of the coil was about 0.01. For a lateral pull, the static friction coefficient between the cradle and the dry deck was 0.31, and rubber mat under the bunks increased this to 0.35.

Blocking provides resistance to a lateral pull as the coil must rise over the block. The resistance depends on the block size, shape and spacing. The resistance provided by blocking increases as the coil sits deeper in the well created by the blocking. The blocks should be as large as possible, with the minimum chamfer, and placed as far apart as possible, subject possibly to a shipper requirement that the coil not contact the deck. The relationships are strictly those of statics. Unsecured blocking always popped out, and the coil crashed on the deck. Secured blocking always remained in place, and provided a resistance equivalent to an external acceleration in the range 0.3 to 0.8 g, depending on the geometric relationship between coil diameter and well dimensions.

The resistance of chain tiedowns to a lateral pull deteriorated as the securement angle to the horizontal increased. Considering the size of the coil and the limited width of the trailer deck for tiedown, the lowest securement angle used of roughly 45 deg generated the highest lateral resistance. Larger securement angles resulted in less resistance with the same chain tension level. A 90 deg (vertical) tiedown allowed large coil motions before it developed significant resistance when used alone, or added very little additional securement when used in combination with chains at more effective angles. For a symmetric tiedown arrangement, with chains at equal and opposite securement angles, an initial tension higher than 20% of the chain working load limit resulted in significantly lower resistance available before the chain reached its working load limit. As an example, the resistance generated by symmetric 9.5 mm (3/8 in) chain tiedowns at 45 deg at the chain working load limit was equivalent to an external acceleration of about 0.33 g.

Similarly, the effectiveness of chain tiedowns in providing resistance to a longitudinal pull decreased as the angle relative to the coil centre line increased, and angles higher than 65 deg resulted in lower resistance.

The crossed chain arrangement is equivalent to the straight through chain arrangement for a longitudinal pull, but markedly inferior for a lateral pull.

The resistance generated by combining a cradle and chain tiedowns could be computed fairly accurately as the sum of the resistance from each of these components. For an

unsecured cradle with chain tiedowns, the total lateral resistance is the sum of the chain resistance and the lesser of the blocking resistance and friction resistance between the cradle and deck interface. The total longitudinal resistance is the sum of the chain resistance and the lesser of the friction resistance at the coil/block interface and the cradle/deck interface.

There is no improvement in resistance to a lateral pull by inserting friction materials between the coil and the blocks.

Webbing provides significantly less resistance to longitudinal and lateral pulls than chain tiedowns.

Nailed wood blocking, even if reinforced with cleats, was not an effective way to restrain a heavy coil.

#### **4.6.4/ Recommendations**

- 1/ Because large metal coils are incompatible with flatdeck trailers, they should preferably be transported on custom-designed trailers or in custom-designed compartments that provide sufficient longitudinal and lateral securement.
- 2/ Hardwood blocks should always be used in combination with bunks, forming a cradle, to prevent them from popping out under extreme loading conditions.
- 3/ Blocks should be as high as possible, with the minimum chamfer necessary, and should be placed as far apart as possible so that the coil sits as deeply in the well as possible, without touching the deck.
- 4/ The cradle should preferably be immobilized so that it cannot slide on the deck.
- 5/ The coil should preferably be immobilized so that it cannot slide along the blocks.
- 6/ If the cradle or coil are not immobilized, then means should be used to increase the coefficient of friction at the cradle/deck and coil/block interfaces.
- 7/ When chain tiedowns are placed through the eye of a coil with its eye lateral on the vehicle, the chain angle should not exceed 45 deg to the horizontal.
- 8/ Where an odd number of tiedowns are used, the last (odd) tiedown should be placed to resist the force of deceleration of the vehicle.
- 9/ For a coil with its eye longitudinal on the vehicle, chain securement angles should be kept as low as possible and should never be higher than 65 deg with respect to the horizontal line.

- 10/ While the crossed chain arrangement appears equal to the straight through arrangement for the longitudinal pull, it is significantly poorer for the lateral pull, so the straight through arrangement is preferred.
- 11/ The initial tension in a chain tiedown should not exceed 20% of its working load limit.
- 12/ Any desired level of lateral and longitudinal resistance can be achieved by making appropriate use of cradle dimensions, friction and chain tiedowns.
- 13/ Placing the cradle so that the coil has its eye laterally on the vehicle should, in general, provide the most reliable securement.
- 14/ Webbing tiedowns are generally too elastic for use, even over the top of a coil.
- 15/ Special measures should be taken to avoid surfaces becoming contaminated with oil, and if this arises, or a oil-soaked coil is being transported, a likely reduced level of friction resistance should be compensated by an increase in resistance provided by other sources.
- 16/ Coil corner protectors should be at least as hard as the tiedown, should conform to the shape of the eye, with no clearance beneath, and should be large enough or channelized so that the tiedown does not slip off the corner protector if the coil moves under extreme loading.

#### **4.7/ Other Commodities**

##### **4.7.1/ Issues**

The size, shape, weight, stack-ability and pack-ability of the myriad of commodities shipped by vehicle each provides their own particular problems for cargo securement with tiedowns. This series of tests examines the securement of some commodities considered to have particular problems.

##### **4.7.2/ Scope**

The original proposal addressed the following specific commodities [3] :

- 1/ Palletized cargo;
- 2/ Thick metal plate;
- 3/ Large boulders;
- 4/ Coiled wire;
- 5/ One foot diameter pipe; and
- 6/ ISO modular containers.



After conducting other parts of the work, it became plain that the securement of palletized cargo and pipe as large rectangular articles of cargo, and of coiled wire as a large circular object, had already been addressed. Issues related to the integrity of the bundles of articles were beyond the scope of the work. Therefore, tests were only conducted on thick metal plate [14], large boulders [15] and ISO containers [19]. However, issues were subsequently raised concerning securement of large and heavy pieces of equipment that move under special permit on specialized heavy haul vehicles, and MTQ sponsored a separate test for this purpose [20].

#### 4.7.3/ Conclusions

From the tests to examine securement of thick metal plate of different widths using transverse chain or webbing tiedowns, the tiedowns could contain the test plate in all lateral loading situations. In the longitudinal direction, the tiedown held the plate through a friction mechanism that allowed slipping movement of the plate. The chain tiedown tended to dimple the edge of the plate, increasing the effective friction by interlocking the chain and the plate. Webbing tended to distort slightly, and since it could not dimple the steel, it slipped and allowed the plate to slide out, cutting, abrading or even severing the webbing. Analysis suggests that tiedown tensions should stay below the working load limit for both lateral and longitudinal accelerations up to 1.0 g [14].

From the tests to evaluate methods of securement for transportation of large boulders, it was found that without securement, the boulders would roll or slide at accelerations in the range 0.46 to 0.65 g. A single transverse tiedown of chain or webbing set to a nominal initial tension of 0.44 kN (100 lb) did not always prevent lateral motion, but always contained the boulder once movement occurred, up to 1.0 g. It also contained the boulder up to a longitudinal acceleration of at least 0.77 g. When the tiedowns were initially tensioned to 10% of their working load limit, approximately 1.77 kN (400 lb), the boulder was held motionless in most cases, and no motion occurred up to 0.88 g. In all tests where crossed chains and blocking were used, no boulder moved up to 1.0 g. More rounded boulders tended to slide and roll at lower accelerations than boulders with flatter or more irregular surfaces. The single transverse tiedown across a rounded boulder did not provide sufficient restraint against longitudinal acceleration, as the boulder tended to roll if it lacked at least three well-separated points of contact with the deck. It requires a more sophisticated securement system, which provides three points of contact that effectively prevents it from rolling. The crossed chain tiedown used with blocking was successful in this regard. Other securement systems could probably immobilize such boulders as effectively. When the rounded tapered boulder was oriented with its fat end in the direction of the acceleration, it slid out from under the tiedowns. However, when it was turned end for end, the tiedowns arrested motion of the boulder. The natural shape of the boulder should be used such that it forms a wedge, with its point facing forward on the truck. If a boulder is well-secured, it is expected that any movement that occurs due to an extreme brake application will not threaten the capability of the tiedowns [15].

Twist locks secure an ISO container in two ways. Each corner post of the container actually sits over a low pedestal so that the container is effectively immobilized. Engaging the lock prevents the container from lifting off the pedestal. Other methods of securement were evidently much less effective, unless alternate methods were used to immobilize the container. A container should never be transported overhanging the rear of the trailer unless it has interior posts on the trailer and is secured so that the container is immobilized [19].

#### **4.7.4/ Recommendations**

Regarding thick metal plate :

- 1/ Thick metal plate may be secured with transverse tiedowns tensioned initially to about 20% of the working load limit of the tiedown.
- 2/ The tiedowns should be tensioned from above the plate, so that the tension is shared across the tiedown as well as possible.
- 3/ Preferably, the plate should be placed against a bulkhead or other cargo so that it cannot slide forward. If this is not feasible, use of additional longitudinal tiedowns or fillers should be considered to ensure the plate does not slide.
- 4/ Where the plate surface is dirty or oily around the tiedown, it should be cleaned to maximize friction between the plate and the tiedown.
- 5/ Webbing tiedowns should only be used to secure thick metal plate if it cannot slide forward, and the tiedown is protected from contact with the plate by some means that cannot be cut or abraded, and will not slip out from between the tiedown and plate.

Regarding large boulders :

- 1/ Boulders that have a tapered cross-section should be oriented with the more pointed end facing forward.
- 2/ A transverse tiedown should cross a boulder where a natural indentation or notch occurs, or forward of the largest cross-section for a tapered boulder, so that the geometric constraint of forward motion will cause the tiedown to tighten.
- 3/ Crossed chain tiedowns provide greater securement than transverse tiedowns.
- 4/ A boulder that has no tendency to roll will have at least three well-separated points of contact with the deck, and may be secured with transverse tiedowns.

- 5/ A boulder that has a tendency to roll requires special care, and must have that tendency constrained. A crib, formed from nailed wood blocking to provide at least three well-separated points of contact for the boulder, is one satisfactory means to do this. The boulder should be secured with crossed chain tiedowns.
- 6/ Tiedowns should be tensioned to at least 10% of their working load limit.

Regarding ISO containers :

- 1/ An ISO (and other) container should preferably be transported only on a chassis that is compatible with and designed to provide proper securement for the container.
- 2/ If a container is transported on other equipment, the container should be immobilized so that it cannot move longitudinally or laterally.
- 3/ Chain tiedowns at the corners of the container are more effective than other forms of securement.
- 4/ A container should not be transported unless it has at least four vertical posts designed to engage twist locks resting completely on the vehicle, and these are used to immobilize and secure the container.

## **5/ Discussion**

### **5.1/ Introduction**

The research conducted during this project has necessarily been technical. Typically, it has not addressed the issues directly, but rather in a way that relates them to the underlying laws of physics. The individual technical research reports that have arisen from this project therefore may not be of direct benefit to the original plain language questions [2]. Not only may the results require some interpretation if they are to be a useful basis for a standard, but the separate parts of the work need to be integrated. This chapter takes the work summarized above, and adds some current practice that is not at issue, and some observations and commentary that became apparent during the work but were not directly part of it. It leads to the next chapter, which attempts to integrate the findings and discussion into a coherent set of principles that could serve as a basis for development of the North American cargo securement standard.

These principles will not be a finished standard, for two reasons. First, not all aspects of the standard have been covered by this research, so principles for the part that has been researched will need to be blended with the rest of current practice. Second, it may be necessary to simplify or adapt technical recommendations into a form that the motor carrier industry and enforcement staff can use on a daily basis.

The subsequent sections are placed in the most logical sequence possible, but it is important to realize that there are complex relationships between them. The next three sections discuss topics that bear on the outcomes of the research, but were not necessarily addressed directly during the research. These topics do need to be considered during development of the standard. It is necessary to bring them in at this point to provide context for the remaining topics, which were dealt with during the research. These sections are categorized more according to a perceived need for standard development, rather than formally covering the topics of the research.

### **5.2/ Performance of Vehicles**

The original work raised issues about the assumptions of existing regulations [2], but this was considered a role for the standard development process rather than for research [3]. It is necessary, nevertheless, to understand the performance of vehicles within the highway system to be able to place the research findings in context.

When a vehicle accelerates or brakes, and its cargo does not move on the deck, there is a longitudinal force on the cargo that produces the same acceleration or deceleration of the cargo as for the vehicle. When a vehicle changes direction, such as when following a curved road or ramp at constant speed, the vehicle experiences lateral acceleration and there is a corresponding lateral force on the cargo to produce the same acceleration for it. If the vehicle accelerates or brakes while turning, the longitudinal and lateral accelerations on the vehicle and cargo are combined. If the

force on the cargo exceeds the resistance provided by the securement system, the cargo will move. Once it starts moving, it is then simply a matter of whether the securement system has enough reserve of strength to arrest the movement before any component of the securement system fails, or the cargo slides off the vehicle.

Accelerations are commonly reported as a proportion of the acceleration due to gravity, in units of g. This acceleration is 9.81 m/s/s (32.2 ft/s/s), which means that the velocity of an object dropped from some high elevation increases by 9.81 m/s (32.2 ft/s) for every second it falls. An acceleration of 0.6 g, for example, is  $0.6 \times 9.81 = 5.89$  m/s/s (19.32 ft/s/s).

About 85% of all brake applications for heavy vehicles occur during normal driving, and result in decelerations under 0.19 g [22]. A deceleration above 0.3 g is quite a hard stop. Only about 0.11% of all brake applications exceed 0.4 g [22]. A typical loaded vehicle would not be expected to achieve a deceleration much above 0.6 g on a dry road. The highest deceleration likely for an empty or lightly loaded vehicle with an anti-lock brake system, with all brakes properly adjusted, and warmed to provide optimal braking, is in the range 0.8-0.85 g. Acceleration from a stop is typically in the range 0.1-0.2 g. A higher acceleration is possible for empty or lightly loaded vehicles, with momentary higher peaks during gear shifts. The largest longitudinal acceleration probably occurs when a vehicle backs into a dock, but this is momentary as the dock quickly stops the vehicle from a very low speed. If cargo is dislodged, it only slides a very short distance before it stops.

The lateral acceleration that occurs while driving a curve or ramp is proportional to the square of the vehicle's speed, and inversely proportional to the curve radius. Thus, for a given ramp, if the speed is doubled, the lateral acceleration increases by a factor of four. If the vehicle drives two curves at the same speed, one with half the radius of the other, then the lateral acceleration on the curve of smaller radius will be double that on the other. In reality, curves and ramps are often banked, which introduces small corrections to these general statements. Many ramps have posted yellow advisory speed signs, intended to ensure that vehicles are driven with an adequate margin of safety against skidding on a wet and slippery road. The typical lateral acceleration while driving a curve or ramp at the posted advisory speed is in the range 0.05-0.17 g. Loaded vehicles with a high cargo centre of gravity roll over at a lateral acceleration above about 0.35 g. Lightly loaded vehicles, or heavily loaded vehicles with a lower cargo centre of gravity, may not roll over even for a lateral acceleration above 0.50 g. However, it is almost certain that the driver of a vehicle entering a curve or ramp at a speed that would result in such a lateral acceleration would have great difficulty following the curve, and might be likely to run off the road.

The maximum deceleration due to braking is thus considerably more severe than longitudinal acceleration, and somewhat more severe than lateral acceleration.

### 5.3/ Current Standards

It is also necessary to review current cargo securement standards, briefly. The Canadian National Safety Code (NSC) standard [1] is not necessarily the rule in any province, but broadly represents Canadian practice. There are significant exceptions, and provinces are more stringent or less restrictive. Federal regulations apply to interstate commerce in the U.S., but are also widely used within many states [23]. California's regulations cover a number of specific commodities in some detail, but only apply for intrastate traffic [24].

The NSC standard and U.S. federal regulations require that where cargo is blocked or braced, the blocking and bracing can resist an acceleration of 0.6 g in any direction [1, 23]. However, there is no way to evaluate this in practice.

Alternatively, and most commonly, cargo is secured by tiedowns. The number of tiedowns is based on the dimensions of the cargo, and the aggregate working load limit of those tiedowns, is based on the weight of the cargo. There are more specific requirements for securement of metal coils. However, there is no requirement in either of these cases that the securement system provide any specific level of securement. Observation of the range of practice on the highway suggests that the requirement for tiedowns is satisfied in a variety of ways. It is clear also that the effectiveness of a tiedown may vary widely, depending on how it is used [18]. Consequently, there may be a wide range of actual level of securement for a set of tiedowns that meet the current requirements. Much of current practice is clearly quite adequate. However, there remains some practice that meets the tiedown requirement but clearly provides much less securement than other practice.

It is concluded that much of the freight that moves on the highway is secured by a required number and capacity of tiedowns, but without regard to the efficiency of securement that those tiedowns can provide. It is therefore unlikely that all shipments are secured against an objective standard of vehicle performance.

A standard recently developed in Australia addresses many deficiencies perceived in current North American standards [25], and represents closely many recommendations derived from this work. It could serve usefully as a model for the proposed North American cargo securement standard.

### 5.4/ Packaging Cargo for Shipment

Cargo offered for transportation is often composed of bundles, stacks or packages of articles held together in some way to form a single article. This article may itself be stacked onto other similar or different articles for shipment. It is clearly a prerequisite for satisfactory cargo securement that each article have sufficient structural integrity that it can resist the forces that arise from stacking, securement, and vehicle operation.

Problems arise with cargo that is difficult to secure, generally due to the size or shape of the article, and with articles that have inadequate structural integrity for securement. The project proposal did not distinguish clearly between these two cases. Current cargo securement regulations clearly assume that articles have sufficient structural integrity to withstand stacking, securement and transportation. It is also known that motor carriers have some difficulty with packages of cargo that are unable to withstand these forces. If a package of articles has inadequate structural integrity, it cannot be stacked or secured. It should therefore be treated as a group of loose articles, and should be contained.

Shippers usually package cargo for transportation. They and the intended recipient generally have an interest that it survives the trip intact. There are, however, cases where the packaging fails during transportation, which may result in damage to the cargo, loss of cargo, and even hazard to other road users. This leads invariably to the shipper, motor carrier and receiver making claims against each other. If a shipper's packaging is inadequate for transportation, then it should be the responsibility of the motor carrier to point this out, and ensure that it is re-packaged satisfactorily. This may be done either by the shipper or the motor carrier, but ultimately, whoever does it, the motor carrier accepts the cargo, the vehicle is loaded, the cargo secured, and the vehicle departs. If there are problems subsequently, the motor carrier would appear to carry the responsibility. In cases where a trailer is loaded by a shipper and sealed without the motor carrier being present, the shipper seems responsible for packaging and loading. If the motor carrier is nevertheless able to inspect the load, the motor carrier should have the right to require that inadequately packaged cargo be unloaded and re-packaged. If the motor carrier does not do this, the motor carrier again accepts the load and is responsible for the consequences.

Relationships between shippers and motor carriers are often very complicated, particularly when cargo passes through the hands of several parties having different roles and responsibilities between origin and destination. Cargo may be loaded and unloaded more than once, and may even be packaged or re-packaged after the initial portion of a trip. It is always possible to establish responsibility when cargo changes hands. Essentially, the party receiving it accepts it and agrees that it is in good condition, or identifies some problem. This requires a response, and possibly some action, by the party passing on the cargo, but ultimately the receiver must be satisfied with the actions of that party, must rectify the situation, or must simply accept the cargo. Whether the cargo is re-loaded, re-packaged, or not, the party receiving it at any stage before final delivery accrues essentially full responsibility for it. If, in fact, some part of a problem that arises is directly attributable to a party with whom the current custodian of the freight has had no direct dealing, the only recourse is probably legal or administrative. These issues parallel other similar chains of responsibility that apply to the motor carrier industry.

## **5.5/ Approaches to Cargo Securement**

### **5.5.1/ Cargo that is Fully Contained**

If cargo fills all the space in a vehicle, without significant space around the sides or between articles, the cargo has no space to shift around. If the sides or walls of the vehicle are close enough, high enough and strong enough to resist cargo that could tip over, the cargo is fully contained. This applies to loose bulk commodities like sand and gravel that travel in open top dump vehicles; cement and other powdered or granular commodities that travel in closed hopper vehicles; and a variety of articles ranging from small and light to large and heavy that are carried in vans. The key, in each case, is that the cargo occupies the entire floor area, so is fully contained. There is no evidence of problems with cargo that is fully contained and unable to move or tip, and there do not seem to be concerns with the structural integrity of vehicles that carry such cargo. Even loose bulk cargo does not seem to move, but simply settles [26]. There appears no need for any provisions for cargo that is fully contained, under conditions of both normal and emergency driving. The issue of a rollover or other crash, when a van trailer may split open and the cargo may spill [27], is a separate issue.

There is one possible exception, again dealing with vans. It is possible that some loose articles could end up resting against the doors. This gives the potential that they either push the door open when it is unlatched, or fall out when it is opened, which may be a hazard to the person opening the door. This might be categorized as an industrial rather than a transportation accident, as it would usually occur on private property, not a highway. However since the vehicle is loaded by transportation personnel, for transportation, it may be appropriate that the cargo securement standard give consideration to this matter.

### **5.5.2/ Cargo that is Partially Contained**

If cargo does not fill all the space on the vehicle, it cannot be fully contained. If it fills a substantial part of the vehicle, it may be partially contained if space is provided only at the front or rear of the cargo and there is no significant space on the sides. Now, additional means must be used to ensure that articles cannot move longitudinally into the open space. They may be immobilized, using fillers against other cargo or the structure of the vehicle, or may be secured, by such means as tiedowns or other cargo control hardware. In addition, if the cargo has a high enough centre of gravity compared to its base, it may be prone to tipping, and should be braced to prevent this.

There have been problems with liquid slosh in tankers, and movement of hanging meat, but these are not considered fundamental cargo securement issues, as they are well known and are dealt with by operational means by the specialist carriers in these fields.



### **5.5.3/ Cargo that Cannot be Contained**

If the cargo consists of one or more articles that have open space on all sides, even if multiple articles are grouped together, it does not fill all the space on a vehicle and cannot be contained. It is preferred that such cargo should be immobilized by placing it against other articles of cargo, or using fillers between it and the structure of the vehicle. If this is not possible, then the cargo must be secured by tiedowns or other means of cargo control.

Cargo must be contained, immobilized or secured against longitudinal movement and tipping, and must also be contained, immobilized or secured against lateral movement and tipping. Some common means of restraint may deal either partially or fully with requirements to avoid both movement and tipping, and may also deal either partially or fully with both lateral and longitudinal effects.

The research was principally concerned with cargo in this category, and the sections that follow try to outline how the findings may be applied.

### **5.6/ Anchor Points**

Tiedowns may be attached to points built into the vehicle intended for use as anchor points, like D-rings; to points that have other uses, like stake pockets, pipe spools or rub rails; or simply to parts of the structure, like side rails or frame members. An anchor point may be chosen as much for convenience and proximity to the cargo as any other consideration.

It is clear that tiedowns securing heavy articles of cargo should be attached to anchor points rated for that purpose. Tiedowns securing articles of moderate weight may be attached to unrated anchor points, provided they are strong enough for the purpose. Rub rails should not be considered as anchor points, first because they are not very strong, and second, because the tiedowns could all be wiped off if the vehicle struck a fixed object, as discussed in the next section. Tarps and other load covering devices that do not contribute to cargo securement may be attached to rub rails.

After these tests, some trailer manufacturers have conducted tests of anchor points attached to trailers. It has become clear, for some cases, that the vehicle structure may not be as strong as the anchor point attached to it. Other than this, the conclusions and recommendations from the testing stand on their own merit [13], with no immediate need for further discussion.

## 5.7/ Tiedowns

### 5.7.1/ How Tiedowns Work

For general freight, regulations require that the aggregate working load limit of all tiedowns equals half the weight of the article being secured [1, 23]. This is applied without regard to how the tiedowns are attached, and without distinction as to the purpose of the tiedowns. Tiedowns serve one of two purposes. They either provide direct resistance to an external acceleration, or they increase somewhat the coefficient of friction between the cargo and the deck of the vehicle.

Tiedowns placed at a shallow angle to the horizontal that are attached at one end to the vehicle and directly at the other to an article, or pass through an article and are attached on each end to the vehicle, provide an effective direct resistance to forces arising from an external acceleration. Tests on metal coils showed that a tiedown through the eye at about 45 deg to the horizontal was considerably more effective in providing resistance to a longitudinal force than an identical vertical tiedown through the eye [18]. However, both receive equal credit under current regulations. Where the purpose of tiedowns is to provide securement, the rules should specify how much securement is available from each choice of tiedown arrangement. Since human nature is to use the fewest possible tiedowns, that number will arise from the most effective use of tiedowns for the weight of a particular article. If this information can be conveyed in a new standard, without any change in the number of tiedowns, then marginal or ineffective use of tiedowns should diminish and the actual average level of securement used on the highway should increase.

Transverse tiedowns that pass across an article and are attached to each side of the vehicle simply increase somewhat the coefficient of friction between the cargo and the deck. Indeed, the dressed lumber tests found that friction was the principal factor resisting cargo shift [7], and the tiedowns provide no immediate or direct resistance to forces arising from an external acceleration [12]. These tiedowns only begin to develop tension to resist an external acceleration when the cargo begins to shift. If the objective is to prevent shift, this is probably a little too late. As the cargo moves, the tiedown is carried along with it, which stretches the tiedown and increases its tension. This increases the vertical force on the cargo, which increases the effective coefficient of sliding friction between the cargo and the deck, and may tend to arrest the motion. It also provides a small but increasing force to resist the motion. Since the force depends on how much the tiedown is stretched, and increases with the amount of stretch, it is quite possible that sufficient force to slow and stop an article may not be developed until the article has moved quite some distance. In this case, cargo securement is not significantly enhanced by requiring more or better tiedowns [7]. It is enhanced either by immobilizing the article, by butting it against another article or the structure of the vehicle, or by using a filler for that purpose, or by increasing the coefficient of friction between the cargo and the deck. Again, if more cargo can be immobilized, or the coefficient of friction can be increased, without change in the requirement for the

number of tiedowns, then the incidence of cargo shift on the highway should be reduced. If cargo does not shift so often, there will be less likelihood of loss of cargo.

At this time, the regulations give essentially no guidance on what tiedowns are doing when they are used to secure general commodities. There is more specific guidance for large metal coils. Right now, more safety is equated to more tiedowns, but as the dressed lumber tests showed, more tiedowns may really only amount to more work and little more than a false sense of security regarding a reduction in cargo shift [7]. Of course, more tiedowns may provide greater redundancy. It seems highly desirable to distinguish between the two purposes of tiedowns, to ensure that they are properly used, and the appropriate means is used to achieve an actual improvement in securement in each case.

It is important, however, that care should be taken in this. During the dressed lumber tests, anti-skid mats were placed above and below the 10x10 cm (4x4 in) spacers between the lumber bundles and the deck of the vehicle, in an attempt to increase the coefficients of friction between spacer and deck, and bundle and spacer [6]. The soft mat effectively rounded the corners of the spacers, and turned them into rollers at low tiedown tensions. This could be prevented by using a wider spacer, which would be too wide to roll.

Beyond all of this, tiedowns are placed by people, tightened by people, and checked (or not) by people. All of these may be subject to error or omission. The final tension in a tiedown depends on several factors, like how long the span is, whether a chain is rolled, which link a binder engages, how tight webbing is pulled before ratcheting starts, and so on. With no guidance for the operator, the initial tension may vary over a significant range [9, 7]. Some operators may try and be very diligent, and tension as tightly as possible, though clearly from the metal coil tests, this reduced the tiedown tension range available to resist applied force [18]. It was clearly quite easy to over-tension a chain with a ratchet binder [15], whereas it was difficult to achieve a tension much over 4.45 kN (1,000 lb) in a webbing tiedown in the dressed lumber tests [7]. In fact, the steps in tension may be quite large, depending on the ratchet tooth size. Further, as the vehicle drives, the cargo may settle or otherwise adjust itself to slacken the tiedowns slightly, reducing their tension [8]. This is why drivers are advised to check tiedowns during a trip, though the extent to which tiedowns are actually tightened unless they are visibly loose is unknown.

The conclusion, simply, is that tiedowns are not a completely reliable element of the cargo securement system. If this is accepted, then overall securement will be increased if other parts of the system can be used to reduce the reliance on tiedowns.

### **5.7.2/ How Much Tiedown Capacity?**

Current practice requires that tiedowns have an aggregate working load limit equal to at least half the weight of the article being secured [1, 23]. When securing an article

for longitudinal acceleration, the tiedowns are often disposed symmetrically to resist braking and acceleration. However, braking is the most critical case, and this may or may not be adequate, depending on how the tiedowns are applied, and what other sources of securement are used.

For cargo secured with transverse tiedowns, friction actually provides the primary securement [7], and tension in the tiedowns serves simply to increase the effective coefficient of friction. If the operator can provide an initial tension of 20% of the tiedown working load limit, it is possible that the effective static coefficient of friction could increase 10-20%. This is not a lot for a low initial coefficient, say below 0.2, but is more for a high coefficient, over 0.5. The effect of tiedown tension is to nullify partially the effect of vibration to reduce the effective coefficient of friction. For this case, current practice seems reasonable, as the initial tiedown tension will provide in most cases a positive hold-down force equivalent to about 0.2 g.

### **5.7.3/ The Wedge**

It was found from one of the tests of large boulders that a wedge-shaped boulder could slip out from under its tiedown if the large end was to the front during the equivalent of an emergency brake application, while it was successfully restrained if it was turned end-for-end [15]. Tests of the effect of cargo movement on tiedowns used a carriage to represent a large article of cargo, applied the tiedowns, and pulled the carriage. In some cases, the tiedowns slipped on the carriage, which relieved the tension in the tiedown, and allowed the carriage (cargo) to continue moving [12]. If the carriage had been placed on a slight downgrade toward the pull, the wedge shape created would have tended to inhibit the tiedowns from slipping, and would certainly not allow the tension to be relieved.

A wedge configuration can easily be created for cargo secured with transverse tiedowns simply by using a low spacer at the front and a slightly higher spacer at the rear. This configuration was not tested, other than in the atypical case of the boulder. The practical consequences of such an approach should be carefully considered. If it would work, it could help to deal with the inherent unreliability of tiedowns under longitudinal braking, the most critical case.

### **5.7.4/ The Automatic Slack Adjusting Tiedown**

The original study excluded consideration of logs as a specific commodity, as it was believed earlier research had fully addressed the issues [28, 29, 30]. It became clear that this work was not well known, and when the issue re-surfaced, it was resolved by making that work more widely known. The research is significant, because it dealt successfully with a commodity that has a tendency to settle as the trip progresses, which means that the tiedowns progressively become looser. This was addressed by developing a tiedown system that effectively and continuously takes up slack in the tiedowns as the logs settle, so tension is maintained almost constant in the tiedown [28,

29, 21, 31]. This tiedown system was built from readily available truck air system components, which were familiar to motor carriers, and could be maintained in the field.

Other types of cargo may also settle or otherwise adjust their position by small amounts, perhaps not to the extent that happens with logs, but enough nevertheless to require that tiedowns should be re-tensioned from time to time [8]. The concept of a constant tension tiedown, with an ability to take up slack, is one that could be much more broadly applied to these other types of cargo. It has the potential to make cargo securement more reliable. No such devices are currently known to exist for general freight applications. It was not the mandate of this project to develop them, but there appear to be interesting possibilities if an anchor point could be integrated with an automatic tiedown tension device.

#### **5.7.5/ Safe Securement of Tiedowns**

While it was not part of the research, it became clear that there are different ways to attach tiedowns to a vehicle, and there are significantly different risks associated with different methods of attachment. It only takes about 2-3 cm (1 in) of slack in a tiedown to allow a grab hook attached (say) to the bottom of a stake pocket, or a flat hook attached to the lower flange of a side rail, to fall out. Any hook attached to a designated anchor point or chain should therefore be attached so that gravity holds it in place, and the hook cannot fall out if the tiedown becomes slack. If the vehicle has no designated anchor points, the choice is limited and the hook can only be attached to a part of the structure of the vehicle, like the lower flange of a side rail. Perhaps all vehicles should be provided not only with designated anchor points, but anchor points that provide for safe connection of tiedowns.

Most flatdeck semitrailers are equipped with stake pockets and rub rails, whereas few flatdeck straight vehicles seem to be so equipped. Rub rails serve to protect the side of the trailer from minor scrapes, probably mostly against fixed objects, and provide a place to secure tarps and other load coverings. When chain tiedowns are attached to anchor points on the side of the vehicle, in many cases they are looped outside the rub rail before the hook is attached. When webbing tiedowns are extended from the winch, they often also pass outside the rub rails, on one or both sides. First, rub rails are not a suitable anchor point for tiedowns securing a heavy article of cargo [13]. Second, passing tiedowns outside the rub rail exposes them needlessly to risk of damage, and ignores the purpose of the rub rail, which is to protect the side of the vehicle and the tiedowns. When a vehicle is equipped with a rub rail, or other equivalent side protection for tiedowns, this protection should be used. A recent accident study found that cargo separated from the vehicle when webbing tiedowns passing outside rub rails, or on the upper corner of the cargo, were severed as a result of friction burns when the vehicle rolled over [27]. The protection of the rub rail might avert some of these cases. Since rub rails can be used to protect tiedowns, it suggests that vehicles without rub rails should perhaps be so equipped.

### 5.7.6/ Standards and Procedures for Rating Tiedowns

The tiedown assembly is the central element for securement of most cargo that is not contained. There is a wide range of equipment manufactured to internal or industry standards, with production samples tested by the manufacturer from time to time. The rating of this equipment is not in question [3]. Most of it is marked by the manufacturer, either with a rating, or a code that corresponds to a rating. All such equipment should be manufactured, tested and marked to similar standards. It is appropriate for manufacturers and industry associations to develop standards and procedures in these areas. Government standards tend to reflect technology and design at the time the standard is written, and are difficult to change, so either to fall into disuse or simply inhibit progress. Manufacturers must adapt to new materials and technology, so have a much greater interest and ability to keep standards current.

There is some equipment on the market that is marked with a rating but may not have been produced from the proper materials, with the proper control over quality, or tested, so does not achieve its rating. Selling such equipment is presumably misrepresentation or fraud, and possibly subject to prosecution under consumer law, though there is no known case. Using it, with any suspicion that it may not be what it purports to be, could accrue considerable civil liability to the user if it is a factor in a serious accident.

### 5.7.7/ Tiedown Ratings

Tiedown ratings are now being expressed in pounds and kilograms, using a conversion that approximates the exact conversion of  $1 \text{ kg} = 2.2046 \text{ lb}$ . The metric unit equivalent to pounds force is the Newton (N), with  $1 \text{ lb} = 4.45 \text{ N}$ . Large forces are commonly expressed in kiloNewtons (kN), or thousands of Newtons. The kilogram is the unit of mass, equivalent to pounds mass. Tiedown working load limit ratings are derived from the force required to break the tiedown, which presumably means that the metric rating should be in Newtons or kiloNewtons, not kilograms. However, under a rule which states that the aggregate working load limit for all tiedowns should equal half the weight of the cargo [23], the ratings for a tiedown could be interpreted as meaning that a single tiedown rated at (say) 2,443 kg (5,000 lb) is allowed to secure cargo whose mass may be up to 4,886 kg (10,000 lb). This interpretation now effectively makes the rating depend on the rule, and not on the strength of the tiedown.

A compromise was adopted for the purpose of the technical reports of which this is a summary. To conform with current practice, a tiedown rating is expressed in kilograms, converted from its nominal Imperial rating in pounds force as stated above. However, tiedown tensions arising from tests are expressed in kiloNewtons (kN), to remain technically correct. If it is desired to assess results, then tiedown tension results in kiloNewtons should be divided by 0.00981 to achieve a value that may be compared to a rating expressed in kilograms.

## 5.8/ Blocking and Other Woodwork

Wood, nailed or otherwise secured, is used as blocking, bracing, cleats, chocks, cribs, fillers, and spacers for cargo securement, and maybe in other ways, too. Each of these are distinct and different uses of wood, as defined in Chapter 2, but each is often generically referred to as blocking. There are only two areas for comment at this time.

First, the tests showed that the working load limit of typical 16 d (3.5 in) nails through a 5x10 cm (2x4 in) softwood timber is about 1.33 kN (300 lb). At this rate, it would take 42 nails to immobilize (say) an 11,340 kg (25,000 lb) article against an acceleration of 0.5 g, with no other restraint. It is simply not practical to expect that anyone would drive that number of nails more than once to provide securement just for one direction. Blocking, alone or augmented by cleats, only seems practical to provide a significant contribution to total securement for articles of modest weight. Alternatively, blocking can only provide a modest contribution to total securement of heavy articles. Finally, as blocking is constructed on-site with only the materials available, the outcome will likely not be as reliable as devices manufactured in a factory.

Where a filler is placed between an article and other articles or the structure of the vehicle, load is simply transferred along the filler, and any nails simply prevent the filler from buckling or popping out. The strength of the nail joint does not seem so critical in this case as it is for blocking. The issue that arises, where the filler bears against the structure of a vehicle, is what working load limit to assign to that structure. While there is probably modest resistance to loading in the centre of a van wall panel, there may be higher resistance if a 5x10 cm (2x4 in) timber is laid along the base of a wall to distribute filler loads, as it is working against the shear connection between the lower sill and the floor beams. Similar issues arise with respect to trailer headboards.

## 5.9/ Friction

Friction is the principal factor that keeps cargo from shifting in transit [7]. It is also clear that friction is not reliable. The cargo may be frozen or oily, or the deck may be covered with ice or dirt, or may be oily. There is in general no control of vehicle deck or cargo surface characteristics, so no control of cargo and vehicle deck interface conditions. Whether the interface is controlled or not, vibration of the vehicle always affects friction characteristics while the vehicle is in motion [4, 5]. The recent Australian cargo securement guide recognizes the role of friction in cargo securement [25]. However, North American cargo securement requirements for highway transportation do not [1, 23, 24], though it is widely recognized for cargo packed in containers and trailers making an intermodal move by railroad [32]. Shippers and motor carriers who use means to improve the friction between cargo and vehicle deck, or between layers of cargo, get no credit for the securement it provides. It is clear that motor carriers who meet the tiedown requirements but do not use means to increase the friction have less actual securement than those adding friction, or controlling friction by covering the deck and cargo so that it does not become wet or icy. Cargo shipped without use of

additional friction, or subject to reduced friction, will be more prone to movement in transit.

The formal tests identified that there are combinations of vehicle deck and cargo materials that may result in low (under 0.2), moderate (0.2 to 0.5) and high (over 0.5) coefficients of friction. Dirt or water in the interface may increase or decrease the coefficients of friction, with the increase often occurring if one of the two surfaces is soft. Oil usually only decreases coefficients of friction. A high-friction interface like a rubber pad also usually only increases coefficients of friction [10].

Assume for the moment that friction may be considered reliable, and does not vary with vibration while the vehicle is in motion. If the securement requirement would require  $xg$ , and if the friction coefficient is  $f$ , then the remainder of the securement system need only provide  $(x-f)g$  of securement. If  $x=0.8$  and  $f=0.2$ , then the remainder of the securement system must provide  $0.6g$  of securement, which is substantial. However, if friction can be enhanced, so that  $f=0.5$ , then the remainder of the securement system need only provide  $0.3g$  of securement, which is half that required in the initial low friction case. It is clear from this little example that the need for other forms of securement can be reduced to the extent that the reliable contribution of friction can be increased.

The effect of vibration on the coefficient of sliding friction was also examined [5]. It was found that this coefficient varied roughly proportionally to the amplitude of vibration, with secondary effects from the cargo mass and interface characteristics, with the latter becoming significant at larger amplitudes as the cargo approached the point where it would start to hop from the deck. Using real data recorded from a real trailer on a rough section of typical road, it was found that the coefficient of sliding friction was below 75% of the static (i.e. no vibration) value for 25% of the time.

Vehicle deck vibration occurs if the road surface is not exactly flat. This arises from continuous roughness in the road surface, which may accumulate with time, patches of ice that may accrete to road surfaces in northern climes during winter, and discrete roadway flaws like misaligned expansion or construction joints, potholes, and other local surface failures. The magnitude of response depends on the magnitude of the roadway roughness, vehicle speed, and the dynamic characteristics of the vehicle. In general terms, response increases linearly with roughness, exponentially with speed, inversely proportionally to vehicle weight, and inversely proportionally to suspension damping. This means, for a given bump, vibration increases as the vehicle travels faster, and diminishes as the weight of cargo on the vehicle increases. It is not uncommon to observe axles of lightly loaded vehicles hop entirely off the ground at roadway joints, which clearly implies a brief period where the cargo may be subject to a vertical acceleration in excess of  $1g$ . Vehicle suspension damping at the time of manufacture typically is quite low, except for some specialized vehicles designed to minimize vibration-induced cargo damage, and is typically not well maintained.



If a vehicle is in a high vertical vibration environment while a high lateral or longitudinal acceleration is demanded, and the vertical vibration diminishes the coefficient of friction below the level of the external horizontal acceleration, the cargo will tend to shift. The principal issue is the relationship between vertical and horizontal acceleration, and particularly, the probability that high vertical acceleration will occur simultaneously with high longitudinal (braking) or lateral (turning) acceleration. High vertical acceleration occurs wherever there is a large deviation from a smooth road surface. These locations are fixed in the roadway system, gradually getting worse until alleviated by repair or rehabilitation. They may also occur at variable locations, in the case where lumps of ice accrete to the roadway surface. The need for an emergency brake application will occur at random on the highway system, but is more likely around those locations where stops must normally be made, like traffic signals and stop signs. High lateral accelerations occur on curves. The issue, then is to assess the combined probability of a high longitudinal or lateral acceleration with a severe vertical acceleration. This is not easy. However, the horizontal accelerations are of relatively long duration, up to maybe 10 s long, but vertical vibrations are cyclic, most commonly at the trailer heave frequency in the range 2-4 Hz. A discrete bump will create several cycles of vertical vibration, each lasting 0.25-0.5 s, and the cargo will tend to shift only during the period while the horizontal acceleration exceeds the difference between the static coefficient of friction and the vertical acceleration.

Since friction is the major factor in preventing cargo movement [7], the incidence of cargo movement would diminish if there would be a general increase in the coefficient of friction of vehicle decks, without changing any other securement requirement. Vehicle decks currently offered on the market provide quite a wide range of coefficient of friction. A deck of transverse steel rollers, commonly used for shipping building materials, evidently provides a very low effective coefficient of friction as often only a few of the rollers lock. The research showed that an aluminium deck provides a relatively high coefficient of friction for many types of cargo. There may be other deck materials with similar properties. Deck coatings applied during manufacture or subsequently, and wear, may change the inherent friction properties of the deck material, either to increase or decrease it.

It is conceivable that some motor carriers may need a deck having relatively low friction characteristics for some operational reasons. For all other purposes, the highest readily achievable coefficient of friction should be used. It would therefore be helpful for manufacturers to develop some procedure for rating the friction properties of vehicle decks, and to provide this information to prospective purchasers. Those that wished to purchase a deck having high frictional properties would then have the information on cost, weight and friction, and could use this in their selection. Those buying the cheapest may still end up with lower friction than might be preferred. If the coefficient of friction can be identified as low, due to design, manufacture, wear, ice, or other contamination, an objective level of securement will require more securement by other means. A procedure like this could lead to a trend that would increase the average friction of vehicle decks, pallets, skids, wrappings and other supplementary materials

and equipment used during transportation. Further, it could be enhanced by use of coatings, which may already be available or could be developed, that provide both high friction and resistance to scuffing.

#### **5.10/ Dunnage and Devices for Cargo or Tiedown Protection**

It was evident from several tests that a tiedown passing over or through an article of cargo can be tensioned initially to exert high forces on the corners of the cargo [8, 9]. Tests also showed that if the cargo should move, high forces can also arise [12]. In either case, if the tiedown was harder than the corner, the tiedown bit into the corner [8, 17, 18]. In one case, where corner protection was used, the corner protector was formed steel with a channel for the chain, and there was empty space between that channel and the cargo. The high corner forces simply crushed the steel shape [18]. Small sheet metal corner protectors made by the test staff simply fell out as the cargo moved. In both these cases, after the force was removed, the tiedowns were loose [18].

Motor carriers may elect, or shippers may require, that the cargo securement system include means to protect the cargo against damage in transit. The motor carrier may also use similar devices to protect webbing tiedowns from a hard or sharp corner. These devices act in concert with the cargo securement system, as noted above.

Current regulations are silent on use of corner protection devices. Since these clearly affect performance of the cargo securement system, they should not be ignored. If corner protection devices are to be effective, and not compromise the cargo securement system, they should conform fully to the edge, there should be no space under the device, they should be at least as hard as the tiedown, and should either be wide enough or channelled so that the device does not fall out as the cargo moves when a large external acceleration is applied.

#### **5.11/ Designing for Safety and Reliability**

If a system must be safe and reliable, it must be maintainable, and must be designed from the ground up to meet these objectives. It is often difficult to modify a system to achieve these outcomes once it has been built, and trying to do this usually results in some compromises in performance. Methods have been developed to design safe and reliable systems, and are used particularly where the consequences of component failure may be very costly. This covers not only the obvious, like nuclear power plants and military systems, but also things like production lines and delivery systems that must operate continuously to serve their customers.

There are several outcomes from design for safety and reliability. The system can simply be made so robust that it cannot fail. Multiple independent load paths can be provided, so that if one fails, others remain that can maintain the function, though perhaps at some reduced capacity. There are others, depending partly on the type of system. The fundamental principle in every case is to conduct an analysis of failure

modes and effects. This identifies the conditions under which each component of a system could fail, and whether a single occurrence could result in simultaneous failure of multiple components. It also examines the consequences of these failures. Systems are redesigned if the consequences of failure are sufficiently serious.

The procedures used in other industries are very complex, often using sophisticated statistical models to estimate and model outcomes of events with a very low probability of occurrence. This type of analysis is not required for cargo securement. What is required is that a simple failure modes and effects analysis should be conducted for each candidate securement system. The designer should not assume it will work as designed, but should assume that each component will fail at some time, and should ensure that the design mitigates the consequences of failure. The preferred system should be that with the greatest likelihood of safety and reliability.

### **5.12/ Cargo Shift**

Current regulations are written as a general requirement that cargo should not shift [1, 23, 24]. This is clearly a desirable objective. Cargo that remains in place on the vehicle is clearly not a hazard. If it shifts, it may become a hazard. However, a rigorous interpretation of this rule leads directly to the conclusion that cargo may only be immobilized. It would not allow securement by tiedowns, which are elastic and do not prevent cargo movement. Clearly, if no cargo movement is allowed, but an inspection finds significant cargo movement, there is no difficulty in laying a charge of inadequate cargo securement, and obtaining a conviction. Unfortunately, the laws of physics dictate that cargo will move if the external acceleration is sufficiently severe. The cargo may be adequately secured so the movement may still be "safe", or there may be a potentially hazardous situation, but the fact of movement still allows the charge to be laid. In practice, inspection staff exercise discretion. They may not charge when the cargo is clearly secured in accordance with requirements, appears "safe", and the movement is "small". They will certainly be more likely to charge if any of these conditions is not met.

The difficulty, as noted above, is that no shift means that cargo must be rigidly secured. Chain is elastic, and synthetic webbing is very elastic. From an engineering point of view, it is not possible to design a securement system using elastic tiedowns if cargo is allowed zero shift. It is concluded, therefore, that the possibility of shift must be recognized. However, since cargo shift is undesirable, it is necessary to ensure that conditions reduce the likelihood of cargo shift to a minimum.

## **6/ Principles for Cargo Securement**

The purpose of this section is to bring together the conclusions and recommendations from all the foregoing into some clear language statements that can serve as the basis for a new cargo securement standard.

### **Regarding cargo offered for transportation :**

- 1/ Cargo offered for transportation must have sufficient structural integrity that it can withstand the forces of stacking, securement and transportation, up to the design limits of the cargo securement system.
- 2/ Freight is often packaged for transportation by the shipper, and may be loaded by the shipper, too. The respective roles and responsibilities of the shipper, motor carrier, and other intermediaries involved in transportation of cargo, need to be clarified.

### **Regarding levels of securement :**

- 3/ There should be an objective level of resistance to external acceleration that any cargo securement system should meet.
- 4/ No component of a cargo securement system should exceed its working load limit under any condition possible on a highway, short of a crash.

### **Regarding choice of securement method :**

- 5/ Cargo should preferably be fully contained in a vehicle having sufficient strength to contain it.
- 6/ If there is not sufficient cargo for it to be fully contained, preferably it should be partially contained against the walls of the vehicle, with the separate parts immobilized to prevent longitudinal movement and tipping.
- 7/ If cargo cannot be contained using the vehicle walls, it should preferably be immobilized.
- 8/ If cargo cannot be immobilized, it must be secured.
- 9/ Some means of cargo securement may contribute to more than one of these requirements, and may contribute to both longitudinal and lateral securement.
- 10/ Different choices may be made for securement against longitudinal and lateral acceleration.

- 11/ A failure modes and effects analysis should be conducted for each candidate securement system, and the preferred approach among a group requiring comparable effort should be that offering the greatest reliability, or least risk.
- 12/ Preferred methods of securement should provide redundancy so that the cargo remains secure if there is a single failure in the securement system.
- 13/ Any method of securement where a single event or failure will result in the cargo being free should have more stringent requirements than if there is redundancy.

**Regarding anchor points :**

- 14/ Vehicles that can carry heavy articles of cargo require anchor points designated for securement of that cargo.
- 15/ All anchor points should be provided with a load capacity rating.
- 16/ The possible directions of loading should be considered in developing the load capacity rating of anchor points.
- 17/ The manufacturer of an anchor point is in the best position to specify its load capacity rating and intended use. Manufacturers should be involved in developing anchor point standards and consensus ratings of existing equipment.
- 18/ A systematic method should be developed to evaluate when a damaged anchor point should be repaired or replaced.
- 19/ Anchor points should be designed so that a hook attached to the anchor point will not fall out if the tiedown becomes slack.

**Regarding tiedowns :**

- 20/ Tiedowns may serve either to resist applied forces, or increase friction between the cargo and the vehicle deck.
- 21/ The purpose and relative effectiveness of different means of using tiedowns should be clearly spelled out.
- 22/ Tiedowns are currently central to cargo securement, yet are not fully reliable. If greater diligence with other means of cargo securement can be encouraged, it may be possible to increase the actual level of securement even if there were no change in tiedown requirements.
- 23/ The current requirement that the aggregate working load limit of all tiedowns should exceed half the weight of the article being secured may be adequate for

general commodities secured by transverse tiedowns, but other cases could require different tiedown capacity depending on the other securement provided or available.

- 24/ The hook on a tiedown should not be attached so that it could fall out if the tiedown became slack. It should always be attached so that gravity or a positive lock holds it in place.
- 25/ A tension device that can take up slack in the tiedown and maintain tension as cargo settles would significantly improve the reliability of tiedowns.
- 26/ Where a vehicle is equipped with a rub rail, the tiedown should be passed inside the rub rail on both sides of the vehicle, to make use of the protection offered.
- 27/ Since rub rails serve to protect the tiedowns, consideration should be given to a requirement that all vehicles with tiedowns have such protection.
- 28/ Manufacturers should rate and mark all tiedown equipment with a working load limit.
- 29/ Manufacturers should clarify the meaning of tiedown ratings.

**Regarding devices for protection of cargo or tiedowns :**

- 30/ Corner protection devices and dunnage affect the performance of the cargo securement system. Only devices that do not compromise cargo securement should be used.
- 31/ Corner protection devices should :
  - a/ conform fully to the edge of the cargo;
  - b/ have no space under the device;
  - c/ be at least as hard as the tiedown; and
  - d/ either be wide enough, or channelled, so that the device does not fall out if the cargo shifts and the tiedown slips along the edge of the cargo.

**Regarding blocking :**

- 32/ Blocking is only suitable to provide a substantial part of the securement for an article of modest weight, or a modest part of the securement for a heavy article.
- 33/ The use of fillers depends upon the strength of those parts of vehicles to which they might transfer loads.

**Regarding friction :**

- 34/ The role that high friction coefficients play in inhibiting cargo movement should be formally recognized in the proposed standard, to encourage development and use of high friction.
- 35/ Manufacturers should develop and offer trailer decks with specified high coefficients of friction.
- 36/ Cargo handling equipment and materials, like pallets, skids and wraps that are also used during transportation, should be designed with high coefficients of friction on both surfaces.
- 37/ Rubber mats, and any other materials with equivalent friction properties, appear to increase the coefficient of static friction over 0.5 (considered high) for many typical combinations of cargo and deck, and their use should be encouraged.
- 38/ No matter how high the level of friction, it remains inherently unreliable, and should never be considered as the sole means of cargo securement.
- 39/ If friction is evidently low, then it should be compensated by a requirement for greater amount of securement provided by other means.
- 40/ Probabilistic approaches can be used to determine a friction level that provides any required minimum level of risk.

**Regarding large metal coils :**

- 41/ Large metal coils are incompatible with flatdeck trailers, and should preferably be transported on custom-designed trailers or in custom-designed compartments that provide proper longitudinal and lateral securement.
- 42/ Hardwood blocks should always be used with bunks to form a cradle which prevents the blocks from popping out under extreme loading conditions.
- 43/ Blocks should be as high as possible, with the minimum chamfer necessary, and should be placed as far apart as possible, so that the coil sits as deeply in the well as possible, without touching the deck.
- 44/ The cradle should preferably be immobilized so that it cannot slide on the deck
- 45/ The coil should preferably be immobilized so that it cannot slide along the blocks.
- 46/ If the cradle or coil are not immobilized, then means should be used to increase the coefficient of friction at the cradle/deck and coil/block interfaces.

- 47/ When symmetric chain tiedowns are placed through the eye of a coil with its eye lateral on the vehicle, the chain angle should not exceed 45 deg to the horizontal.
- 48/ Where an odd number of tiedowns is used, the last (odd) tiedown should be placed to resist the force of deceleration of the vehicle.
- 49/ For a coil with its eye longitudinal on the vehicle, chain securement angles should be kept as low as possible and should never be higher than 65 deg with respect to the horizontal line.
- 50/ The initial tension in a chain tiedown should not exceed 20% of it's working load limit.
- 51/ There are cases where the crossed chain arrangement is significantly poorer than the straight through arrangement, so the latter is preferred.
- 52/ Any desired level of lateral and longitudinal resistance can be achieved by appropriate combination of cradle dimensions, friction and chain tiedowns.
- 53/ Placing the cradle so that the coil has its eye laterally on the vehicle should, in general, provide the most reliable securement.
- 54/ Webbing tiedowns are generally too elastic for use, even over the top of a coil.
- 55/ Special measures should be taken to avoid surfaces becoming contaminated with oil, and if this arises, or a oil-soaked coil is being transported, a likely reduced level of friction resistance should be compensated by an increase in resistance provided by other sources.





## 7/ Conclusions

Cargo securement practices vary widely, between and within different types of cargo. Variations occur by personal preference of drivers, and through motor carrier and shipper initiatives and procedures. Much of this practice meets current requirements, and some exceeds it by a wide margin. Where current practice already provides the performance that the new standard will require, it should be quite satisfactory under that standard. The new standard may not affect those who deliberately do not meet current regulations. Between these, there is a range of marginal practice. The principal gains in safety should be achieved in this area.

The research findings laid out above, common sense, and the best of current practice together provide a basis for a new standard that could eliminate the marginal practice. To achieve this, it will be necessary to resist arguments advanced by some motor carriers and shippers to maintain the marginal practice. These may be based on cost-effectiveness and equipment flexibility, supported by the "satisfactory" experience of many thousands of shipments. This is fundamentally flawed. Severe external accelerations occur quite infrequently, so marginal (or even no) cargo securement practice would be expected to be "successful" almost all the time.

The objective that all cargo should be safely secured before it is transported will only be realized if the proposed standard requires that only proper equipment and procedures are used. In most cases, if the motor carrier has the proper equipment, it should take no longer to achieve an objective level of cargo securement than it takes to secure it anyhow.



## References

- [1] National Safety Code for Motor Carriers, Standard 10, "Security of Loads Standards", Canadian Council of Motor Transport Administrators, 1988, ISBN 0-921795-01-7.
- [2] "New Challenges, New Opportunities, New Requirements for Motor Carrier Load Securement", Report of Task Force on Load Security to CCMTA Standing Committee on Compliance and Regulatory Affairs, November 1992.
- [3] 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.
- [4] Gillespie T.D., "Engineering Analysis of Cargo Restraint on Commercial Highway Trucks", University of Michigan Transportation Research Institute, Report UMTRI-87-28, August 1987.
- [5] Rakheja S., Sauve P. and Juras D., "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, 1997.
- [6] Heidersdorf E. and Hay E., "Slippage Tests with Anti-skid Mats", North American Load Security Research Project Report 3, Canadian Association of Motor Transport Administrators, 1997.
- [7] Hay E., Williams W. and Heidersdorf E., "Dressed Lumber Tiedown Tests", North American Load Security Research Project Report 4, Canadian Council of Motor Transport Administrators, 1997.
- [8] Mercer W.R.J. and Billing J.R., "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, 1997.
- [9] Mercer W.R.J. and Billing J.R., "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, 1997.
- [10] Billing J.R. and Lam C.P., "Friction Coefficients between Typical Cargo and Truck Decks", North American Load Security Research Project Report 7, Canadian Council of Motor Transport Administrators, 1997.

- [11] Mercer W.R.J. and Billing J.R., "Load Capacity of Nailed Wood Blocking", North American Load Security Research Project Report 8, Canadian Council of Motor Transport Administrators, 1997.
- [12] Billing J.R., "Effect of Cargo Movement on Tension in Tiedowns", North American Load Security Research Project Report 9, Canadian Council of Motor Transport Administrators, 1997.
- [13] 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, 1997.
- [14] Mercer W.R.J., "Tests on Methods of Securement for Thick Metal Plate", North American Load Security Research Project Report 11, Canadian Council of Motor Transport Administrators, 1997.
- [15] Mercer W.R.J. and Billing J.R., "Tests on Methods of Securement for Large Boulders", North American Load Security Research Project Report 12, Canadian Council of Motor Transport Administrators, 1997.
- [16] Mercer W.R.J., "Bending Strength of Trailer Stakes", North American Load Security Research Project Report 13, Canadian Council of Motor Transport Administrators, 1997.
- [17] Mercer W.R.J., "Effect of Tiedowns on Wood Blocks Used as Dunnage", North American Load Security Research Project Report 14, Canadian Council of Motor Transport Administrators, 1997.
- [18] Billing J.R. and Lam C.P. , "Tests on Methods of Securement for Large Metal Coils", North American Load Security Research Project Report 15, Canadian Council of Motor Transport Administrators, 1997.
- [19] Mercer W.R.J. and Billing J.R., "Tests on Methods of Securement for ISO Containers", North American Load Security Research Project Report 16, Canadian Council of Motor Transport Administrators, 1997.
- [20] Grandbois J., "Assessing a Securement Method for the Transportation of Heavy Machinery Using a Combination of Highway Vehicles", CAMTech Consultants Inc Report, Ministère des Transports du Québec, 1997.
- [21] Desrosiers G., "Evaluation of Common Tiedown Systems for Securing 1.22 metre Long Logs Placed Across the Bed of a Vehicle During Transport", Ministère des Transports du Québec, Quebec City, February 1994.

- [22] Klusmeyer L.F., Gray A.W., Bishop J.S., Van Schoiack M., Woods J.M. and Mahmoud W.M., "An In-service Evaluation of the Reliability, Maintainability and Durability of Antilock Braking Systems (ABS) for Heavy Truck Tractors", National Highway Traffic Safety Administration, U.S. Department of Transportation, Report DOT HS 807846, March 1992.
- [23] Federal Motor Carrier Safety Regulations, "Protection Against Falling or Shifting cargo", 49 CFR 393.100, Federal Highway Administration, U.S. Department of Transportation.
- [24] "Loading Regulations", Title 13, Subchapter 7, California Highway Patrol.
- [25] "Load Restraint Guide", Federal Office of Road Safety, Department of Transport, Australian Government Publishing Service, Canberra, Australia, 1994.
- [26] Billing J.R., "Aggregate Truck Load Shift Experiment", Ontario Ministry of Transportation, Transportation Technology and Energy Branch, Report CV-90-01, February 1990.
- [27] Hildebrand E.D. and Wilson F.R., "The Development and Intermediate Findings of a Level III Heavy Truck Collision Study", Paper 971502, Transportation Research Board Annual meeting, Washington D.C., January 1997.
- [28] Franklin G.S., "Testing of Methods to Secure 8' Wood on a Tractor-Trailer Haul Unit", Forest Engineering Research Institute of Canada, Montreal, Report TR-60, January 1985.
- [29] Franklin G.S., "Load Security on Tractor-Trailer Haul Units with 8-foot, 16-foot and Tree-length Wood", Forest Engineering Research Institute of Canada, Montreal, Report SR-55, November 1988.
- [30] Lavoie J-M., "Securing Systems for Truck Loads of Tree Lengths", Forest Engineering Research Institute of Canada, Montreal, Technical Note TN-41, February 1981.
- [31] Hart D, "Auto-Tensioning Wrapper Improves Load Retention on Butts-Forward Log Hauling", Forest Engineering Research Institute of Canada, Vancouver, Equipment Note, February 1995.
- [32] "Intermodal Loading Guide for Products in Closed Trailers and Containers", Circular No. 43-C, Pamphlet No. 45, BOE Pamphlet No. 6C, Association of American Railroads, Washington D.C., 1995.









## North American Load Security Research Project Reports

- [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] Rakheja S., Sauvé P. and Juras D., "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 Hay E., "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., Williams W. and Heidersdorf E., "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 Billing J.R., "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 Billing J.R., "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 Lam C.P., "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 Billing J.R., "Load Capacity of Nailed Wood Blocking", North American Load Security Research Project, Report 8, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.
- [9] Billing J.R. and Lam C.P., "Effect of Cargo Movement on Tension in Tiedowns", North American Load Security Research Project, Report 9, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.
- [10] 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.

- [11] Mercer W.R.J. and Billing J.R., "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 Billing J.R., "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 Billing J.R., "Bending Strength of Trailer Stakes", North American Load Security Research Project, Report 13, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.
- [14] Mercer W.R.J. and Billing J.R., "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, 1997.
- [15] Billing J.R. and Lam C.P., "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 Billing J.R., "Tests on Methods of Securement for ISO Containers", North American Load Security Research Project, Report 16, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.
- [17] Billing J.R. and Leung D.K.W., "Analysis of Heavy Truck Cargo Anchor Points", North American Load Security Research Project, Report 17, Canadian Council of Motor Transport Administrators, Ottawa, Ontario, 1997.
- [18] 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.
- 
- [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.
-