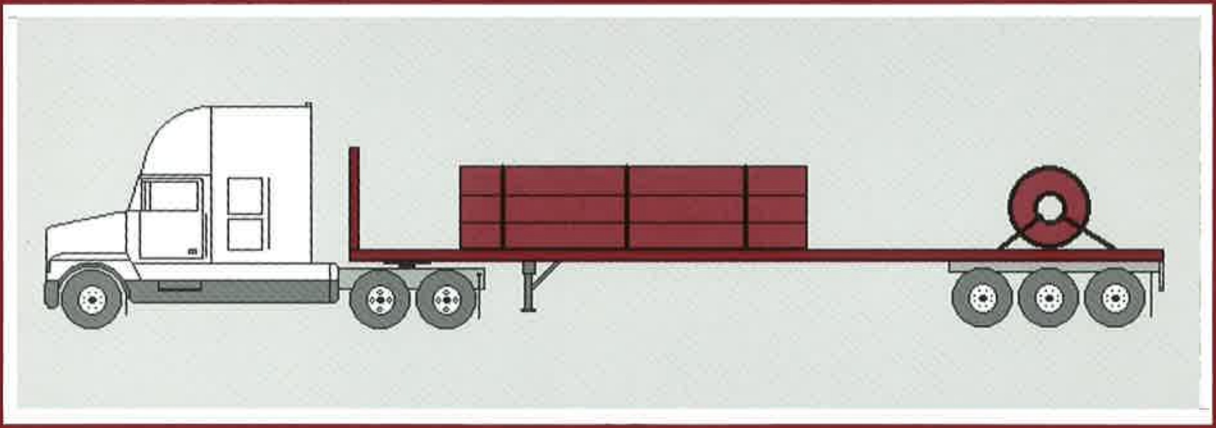
CCMTA Load Security Research Project

Report # 12

TESTS ON METHODS OF SECUREMENT FOR LARGE BOULDERS



CCMTA • CCATM

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

CCMTA Load Security Research Project

Report # 12

TESTS ON METHODS OF SECUREMENT FOR LARGE BOULDERS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

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

October 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.

ISBN 0-921795-40-8

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

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

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

North American Cargo Securement Standard

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

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

Table of Contents

Abstract

A series of tests were conducted to assess the effectiveness of various methods of securement of large boulders. The tests examined different shapes of boulder, unsecured, or secured in one of four different ways, for different tiedown tensions, and subject to either longitudinal or lateral external acceleration.

Unsecured boulders would roll or slide at accelerations in the range 0.42 to 0.65 g. All tiedowns at all tensions successfully restrained all boulders against lateral acceleration. A single transverse tiedown of chain or webbing was adequate securement for those boulders that did not have a tendency to roll. A more sophisticated securement system is required for these, and nailed wood blocking in combination with crossed chain tiedowns was found satisfactory. Other approaches may provide equivalent securement.

Recommendations are made for securement of large boulders on heavy trucks.

Executive Summary

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

The proposal identified a number of types of cargo whose characteristics make them difficult to secure. This included large boulders. The series of tests reported here address the effect of different securement methods on the tendency of large boulders to roll or slide on a truck deck. It is outlined in Section 13.4 of the project proposal.

Three boulders were tested, one rectangular shape, one generally round, and one rectangular with rounded corners. A boulder was placed on a tilt bed constructed for these tests, secured as necessary, and the bed was tilted to 46 deg, equivalent to an external acceleration of 0.72 g for rolling or 1.04 g for sliding. Tests were conducted with the boulder unsecured, or secured with one transverse chain or webbing tiedown, or with crossed chains, alone or with wood blocking. Two tiedown tensions were used. Tiedowns were oriented to represent longitudinal and lateral acceleration of a truck. Instrumentation measured tiedown tensions, boulder movement, and tilt angle, and each test run was videotaped.

Unsecured boulders would roll or slide at accelerations in the range 0.42 to 0.65 g. A single transverse chain or webbing tiedown at nominal initial tension of 0.44 kN (100 lb) did not always prevent lateral motion, but always contained the boulder once movement occurred, and also contained it 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 1.76 kN (400 lb), the boulder was held motionless up to 0.88 g. No boulder moved up to 1.04 g when crossed chains and blocking were used.

Rounded boulders tended to slide or roll at a lower acceleration than boulders with flat or irregular surfaces. A single transverse tiedown did not provide sufficient restraint against longitudinal acceleration, so a more sophisticated securement system is needed that provides at least three well-separated points of contact for the boulder to prevent it from rolling. The crossed chain tiedown used in conjunction with blocking was successful in this regard. A rounded tapered boulder oriented with its fat end in the direction of the acceleration slid out from under the tiedowns, but the tiedowns were able to arrest it when it was turned around. The natural shape of a boulder should be used to form a wedge, with its point facing forward on the truck.

Recommendations are made for securement of boulders.

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

Acknowledgments

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

The project was funded jointly by the following :

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

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

The work was conducted additionally by Norm Carlton, Gary Giles, Bill Stephenson and Mike Wolkowicz of Strategic Vehicle Technology Office of MTO.

Some of the tiedown equipment used in these tests was donated for the project by Kinedyne Canada Ltd.

1/ Introduction

Heavy truck cargo securement is a matter of public safety, subject to a body of industry practice and government regulation. Regulations are broadly similar across North America's many jurisdictions, but there are also some significant differences. When the Canadian Council of Motor Transport Administrators (CCMTA) came to revise a cargo securement standard for Canada's National Safety Code, a lack of understanding of the technical basis for existing regulations made it impossible to resolve differences between them, and a number of research needs were identified. Ontario Ministry of Transportation prepared a draft proposal for this research that was widely circulated for review through governments and industry. The proposal was revised and became the work statement for the North American Load Security Research Project [1]. It has three objectives :

- To determine how parts of cargo securement systems contribute to the overall capacity of those systems;
- To demonstrate the adequacy of parts, and the overall capacity, of cargo securement systems; and
- To develop principles, based on sound engineering analysis, that could contribute to an international standard for cargo securement for heavy trucks.

The goal is to supplement existing practice with these research findings, and to develop uniform North America-wide standards for cargo securement and inspection.

There are a number of types of cargo that are not a typical cuboid shape, so are difficult to secure on flatdeck trailers. A number such were identified during the development of the project, and large boulders was one of these. Boulders are often secured by chains, webbing, blocking, or combinations thereof. The purpose of this test was to determine the propensity of various shapes of boulder to move, roll or slide, both unsecured, and while secured using common methods. The work was outlined in Section 13.4 of the project proposal [1].

2/ Test Program

2.1/ Objective

The objectives of this test are to determine :

1/ The acceleration required to cause motion of an unsecured boulder;
2/ The relative effectiveness of different tiedowns, tiedown methods, and their tensions on boulder securement;
3/ The effect of boulder shape on securement; and
4/ The mechanics of boulder dislodgement and arrest.

2.2/ Scope

The tests were conducted using three boulders of different shapes, described below.

All boulders were tested in the following manners:

1/ Unsecured;
2/ Secured with a single transverse tiedown;
3/ Secured with two diagonal tiedowns; and
4/ Restrained with a 5x10 cm (2x4 in) spruce blocking nailed to the deck, and secured with two diagonal tiedowns.

The tiedowns used were:

1/ 7.5 cm (3 in) synthetic webbing with a working load limit (WLL) of 1,814 kg (4,000 lb); and
2/ 9.5 mm (0.375 in) grade 4 chain with a WLL of 2,449 kg (5,400 lb).

Tests were conducted for two initial tensions in the tiedowns:

1/ A nominal tension of 0.44 kN (100 lb), equivalent to a "loose" tiedown; and
2/ 10% of the working load limit of the tiedown, or 1.78 kN (400 lb) for webbing, and 2.40 kN (540 lb) for chain.

Tests represented the effects of longitudinal deceleration due to braking, and lateral acceleration due to turning.

3/ Procedures

3.1/ Test Apparatus

The tests were conducted using three boulders of different shapes :

1/ Boulder #1, shown in Figure 1, an irregularly round river bed boulder weighing 632 kg (1,390 lb);
2/ Boulder #2, shown in Figure 2, a somewhat oval shaped river bed boulder weighing 791 kg (1,740 lb); and
3/ Boulder #3, and shown in Figure 3, a rectangular block of quarried limestone weighing 770 kg (1,695 lb).

It was not possible to apply a controlled, consistent force at the centre of gravity of each boulder in the same manner, because the rounded boulders tended to tip as they were pulled. The force due to an external acceleration was therefore simulated by tilting the surface on which the boulder was placed, using gravity to create an acceleration from

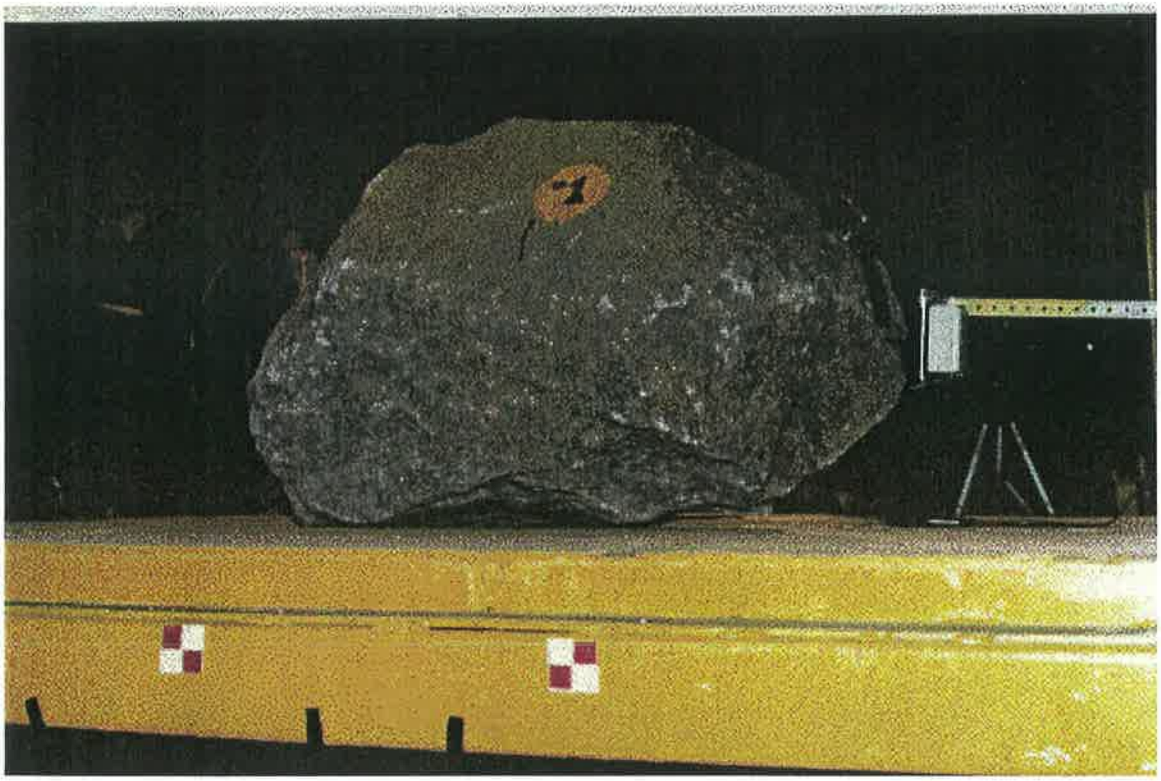


Figure 1/ Boulder #1

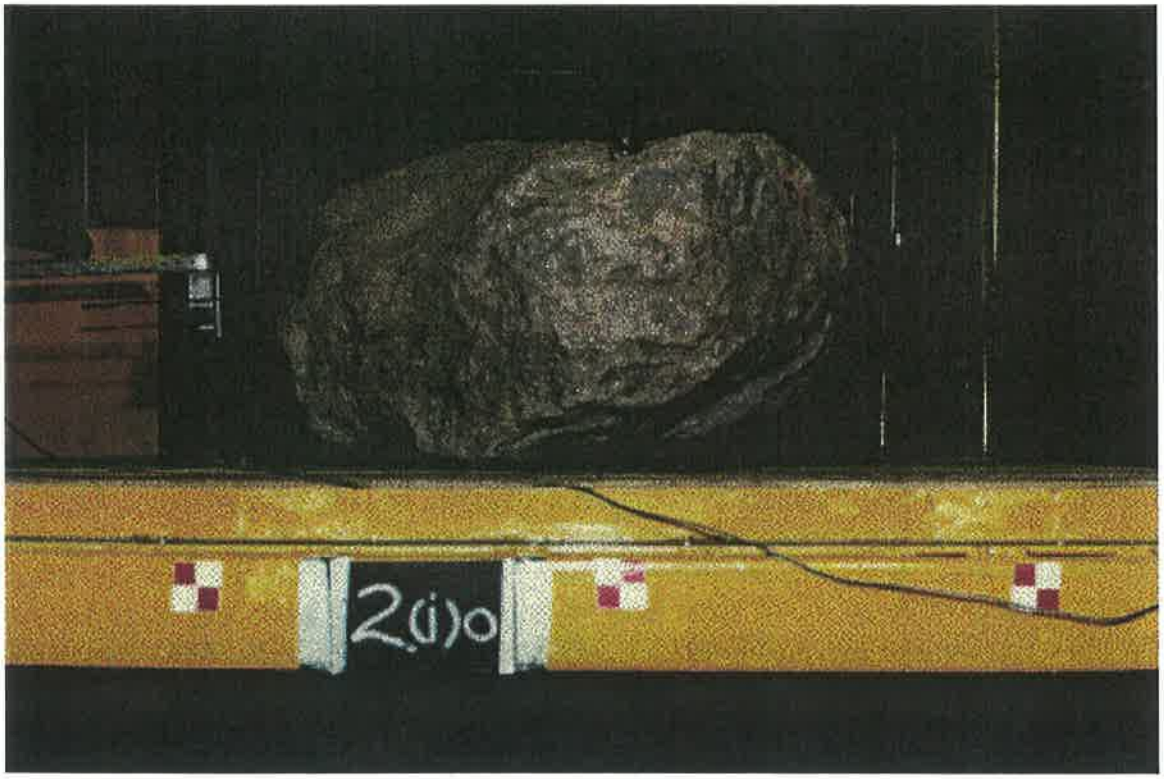


Figure 2/ Boulder #2

Figure 3/ Boulder #3

the lateral component of the boulder weight. The sine of the tilt angle represents the applied external acceleration at which a boulder would roll away, expressed in units of g, the acceleration due to gravity. The tangent of the tilt angle represents the applied external acceleration at which a boulder would slide away. Since the applied acceleration is a simulated force, it cannot be related to individual tiedown tensions, which are absolute values. The initial tension and resulting tiedown loads were used as a guide to assess a boulder's ability to slide or roll while under load. This test demonstrates the relative motions of the boulders for given external accelerations under various tiedown scenarios.

A tilt table, shown in Figure 4, was constructed from a surplus MTO maintenance truck. The dump box was modified with a hardwood deck, the sides were cut away for access, and control limiters were installed to produce a smooth, steady tilt from horizontal to 46 deg. This represents an external acceleration of 0.72 g for rolling, and 1.04 g for sliding. An arresting barrier was constructed from old tires secured to the tailgate at the lower end of the tilt deck. This was able to capture any boulder that escaped its securement without damage to the table or ancillary equipment. The tilt platform was fitted with removable anchor brackets such that tiedowns could be connected on any of the four sides. Since boulders are commonly secured with a transverse tiedown, tilt with a transverse tiedown represented longitudinal deceleration due to braking, and tilt with a longitudinal tiedown represented lateral acceleration such as from driving in a curve. This is illustrated in Figure 5.

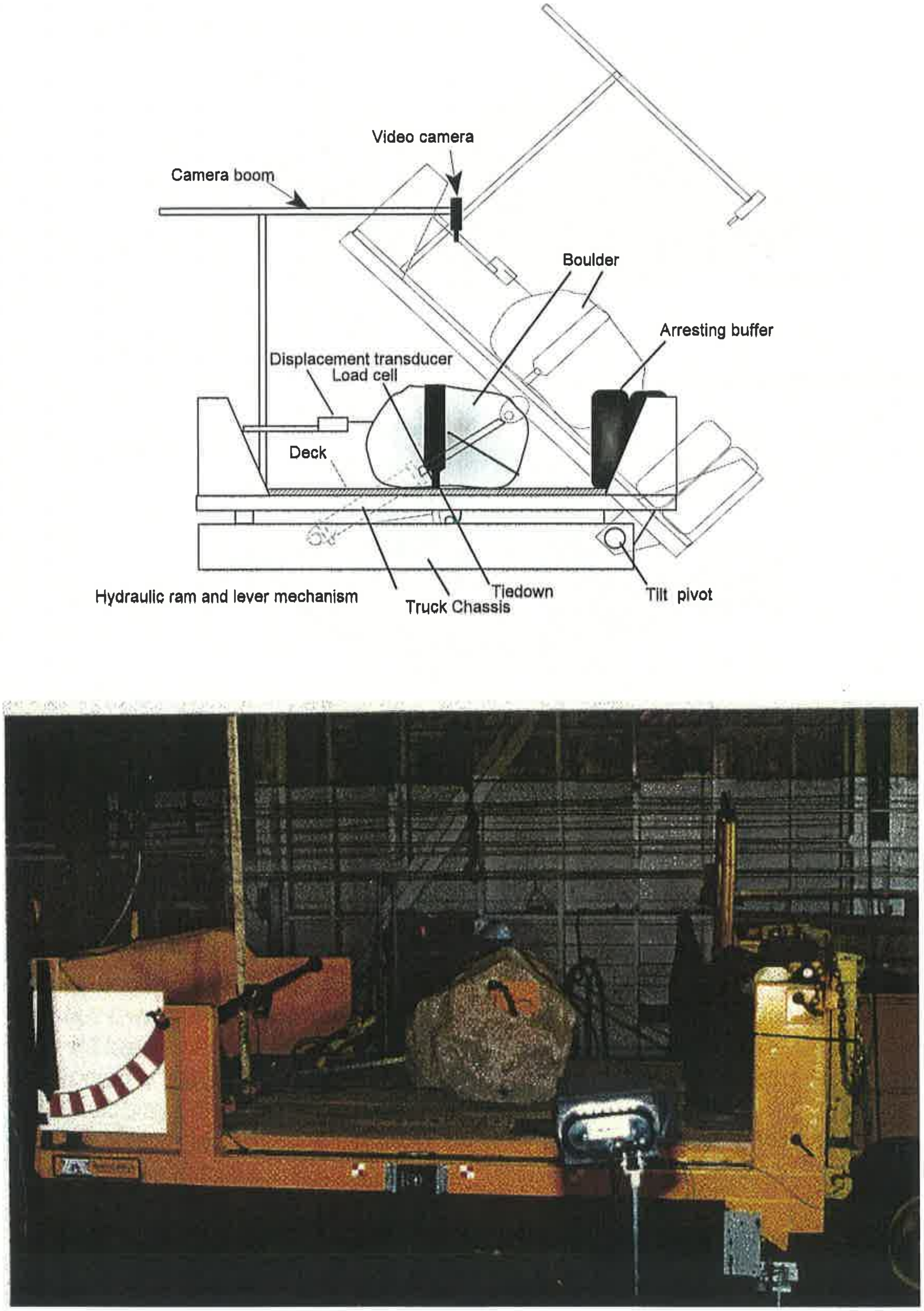


Figure 4/ Tilt Table

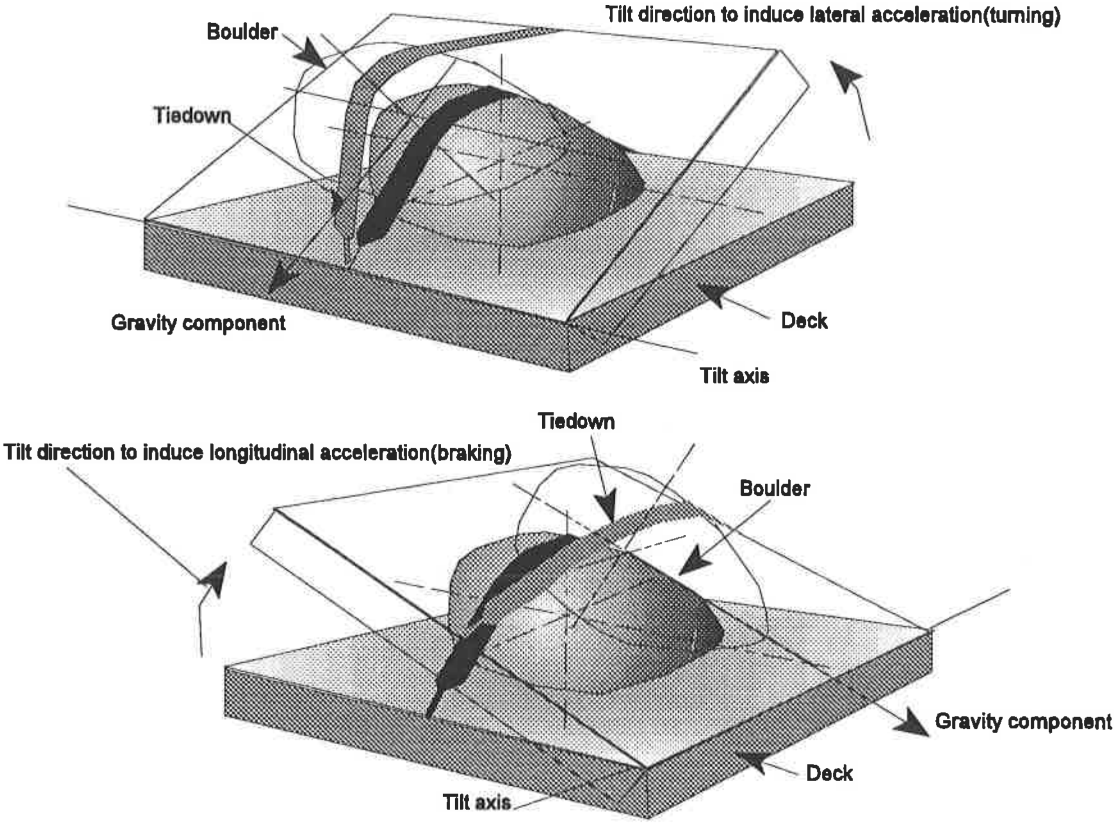


Figure 5/ Tilt Directions for Braking and Turning Accelerations

3.2/ Instrumentation and Data Capture

A mechanical device was developed for this test that transformed the tangent of the tilt angle of the deck into a linear motion, which was then measured using a pull-cord transducer. This device is shown in Figure 6. A second pull-cord transducer was modified with a reverse push rod assembly to measure motion of the boulder on the outstroke. It was attached to the bed with the rod contacting the boulder. Each tiedown was secured to the truck deck with a three link piece of chain, where the middle link was strain gauged with a four-arm bridge. These links were individually calibrated, and served as load cells.

Data from these instruments was captured into a PC-based data acquisition system at a sample rate of 50 Hz per channel. This sample rate provided adequate definition to measure forces in the tiedowns and identify first movement of the boulder. Two video cameras were also used as part of data capture. A mini camera was mounted on a boom overlooking the boulder, as illustrated in Figure 4, and the second camera was focussed on a digital readout of the tangent of the tilt angle. Its image was inset in the

Figure 6/ Tilt Angle Tangent Device

screen image from the overhead camera, which provided a direct visual readout of the equivalent external acceleration at which a boulder moved.

3.3/ Test Procedure

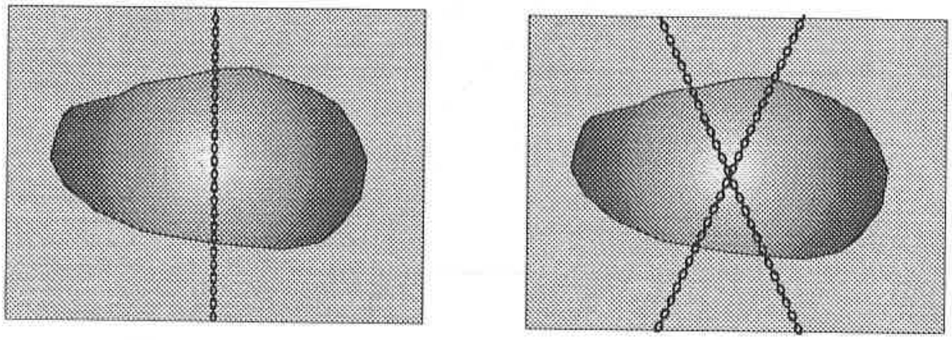
All three boulders were prepared in the same way prior to any testing. Each was drilled and an eye was anchored on its top surface to facilitate lifting. It was then weighed. The boulder was visually examined and oriented to determine a stable resting position, and an assessment was made of the locations of its longitudinal and lateral axes. The axes were marked, and the boulder was numbered. The deck was marked with reference lines to facilitate consistent positioning and alignment of the boulders.

Tests were conducted with the longest axis of the boulder, when sitting in stable position on the bed, on the longitudinal centre-line of the tilt bed. Where the boulder was tapered, the nominal orientation placed the larger end toward the low end of the tilt table, in the direction that motion was expected. This provided a "worst case" condition, where the boulder could slide out from under the tiedowns. If this happened, then the test was repeated with the boulder facing the opposite way to ensure that the break-out motion was directly related to the profile of the boulder and not necessarily the tiedown tension.

Four levels of securement were examined:

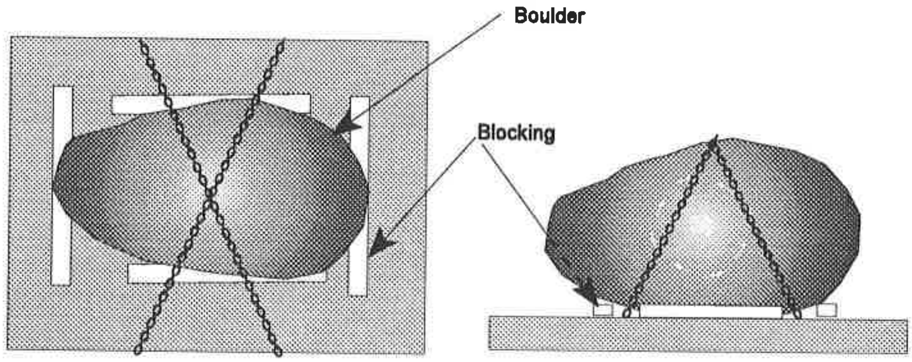
1/ Unsecured;
2/ Secured with a single transverse tiedown;
3/ Secured with two diagonal tiedowns; and
4/ Restrained with a 5x10 cm (2x4 in) spruce block nailed to the deck, and secured with two diagonal tiedowns.

The last three of these are illustrated in Figure 7. The tiedowns were initially tensioned



Single chain or webbing

Crossed chains



Plan View

Elevation

Crossed chains and blocking

Figure 7/ Boulder Tiedown Methods

either nominally, to approximately 0.44 kN (100 lb), or to 10% of the working load limit of the tiedown, approximately 1.96 kN (450 lb). Two tiedowns were used, chain and webbing, each with a load cell at each end.

For each test, a boulder was placed on the tilt table and aligned with the proper mark on the deck. The appropriate tiedown method was installed, and the load cells were wired into the data acquisition system. The tiedowns were tensioned until all the load cells were within approximately 0.25 kN (50 lb) of the target value. The displacement transducer was aligned with the tilt table centre-line, preloaded against the boulder, and secured to the bed. The arresting barrier was adjusted to ensure that the boulder would be captured. Transducers and other measuring devices were reset to zero, data capture was enabled, an instrumentation calibration sequence was recorded, video cameras were turned on, and the tilting sequence was initiated.

The deck was tilted until relative motion was detected between the boulder and the deck. If a sequence of motions or interactions between the boulder, tiedown and deck were detected, the tilting was allowed to continue until the sequence terminated, culminating either with motion of the boulder arrested by the tiedowns, or with the boulder sliding or rolling down the bed into the arrest barrier. At that point, tilting stopped, data and video capture were turned off, and the tilt table was lowered. The data in the PC were saved to a file on the hard disk, under a file name that completely described the test conditions. The data were retrieved, the calibrations were examined, and adjusted if necessary, and a quick look assessed whether the data looked reasonable. If there was any question, the run was repeated, and sometimes adjustments were made to test conditions or fittings to ensure consistent and repeatable data. The file was saved again, and a backup file was also saved immediately on a floppy disk.

Samples of equipment and test activity were recorded on video tape. Colour still photographs and slides were taken of the tests, instrumentation and test activity. A detailed log of test activities and observations was maintained.

3.4/ Data Processing

The data was read into a specialized test data processing program written at MTO, the data channels were de-trended, and graphs of instrumentation outputs were plotted against time and tangent of tilt angle for each run. These were compared with the video recording for the corresponding run, and a judgement was made of the point at which the boulder began to move. The equivalent external acceleration, and outcomes of boulder movement, were summarized in a spreadsheet of results.

3.5/ Test Matrix

The scope identified three boulders, four securement methods, two tiedowns, two tiedown tensions and two tilt directions, for a total of 32 combinations per boulder.

Because it was not possible to use two crossed webbing tiedowns, and there were no variations in tiedown type or tension when a boulder was unsecured, these were reduced to the 18 combinations shown in Table 1, for each of the boulders. In addition, a small number of additional cases of interest were tested, as shown in Table 2.

Table 1/ Test Matrix, for Any Boulder

Case	Tilt Direction		Tiedown				
	Lat.	Long.	Single, Chain	Crossed Chains	Crossed Chains, Blocked	Single, Webbing	None
(a)	X		Nominal				
(b)	X		10% WLL				
(c)	X			Nominal			
(d)	X			10% WLL			
(e)	X				Nominal		
(f)	X				10% WLL		
(g)	X					Nominal	
(h)	X					10% WLL	
(i)	X						X
(j)		X	Nominal				
(k)		X	10% WLL				
(l)		X		Nominal			
(m)		X		10% WLL			
(n)		X			Nominal		
(o)		X			10% WLL		
(p)		X				Nominal	
(q)		X				10% WLL	
(r)		X					X

Table 2/ Specific Cases of Interest for Boulders #1 and #2

Case	Tilt Direction		Boulder		Tiedown Type and Situation
	Lat.	Long.	1	2	
A-1		X	X		Crossed chains at zero tension
A-2		X		X	Fat end at top, single chain at nominal tension
A-3		X		X	Fat end at top, single chain at 10% WLL
A-4		X		X	Fat end at top, webbing at nominal tension
A-5		X		X	Fat end at top, webbing at 10% WLL

4/ Results

4.1/ Unsecured Boulders

Most boulders shifted and rolled slightly at low accelerations. These movements were not considered to be significant, and were therefore disregarded. The acceleration at which the boulder moved significantly is assumed to be the acceleration of the onset of instability. The boulders rolled, slid, or moved in a combination of these, and crashed into the arrester barrier at the bottom of the tilt table.

Initial tests were conducted to determine the longitudinal and lateral acceleration that caused motion of an unsecured boulder. The results are summarized in Figure 8. The acceleration for the boulder that rolled is presented as the sine of the tilt angle, whereas those for sliding are presented as the tangent of the tilt angle, and represent the acceleration necessary to overcome friction. This differs from the way results werer presented in other tilt tests conducted in this project [2].

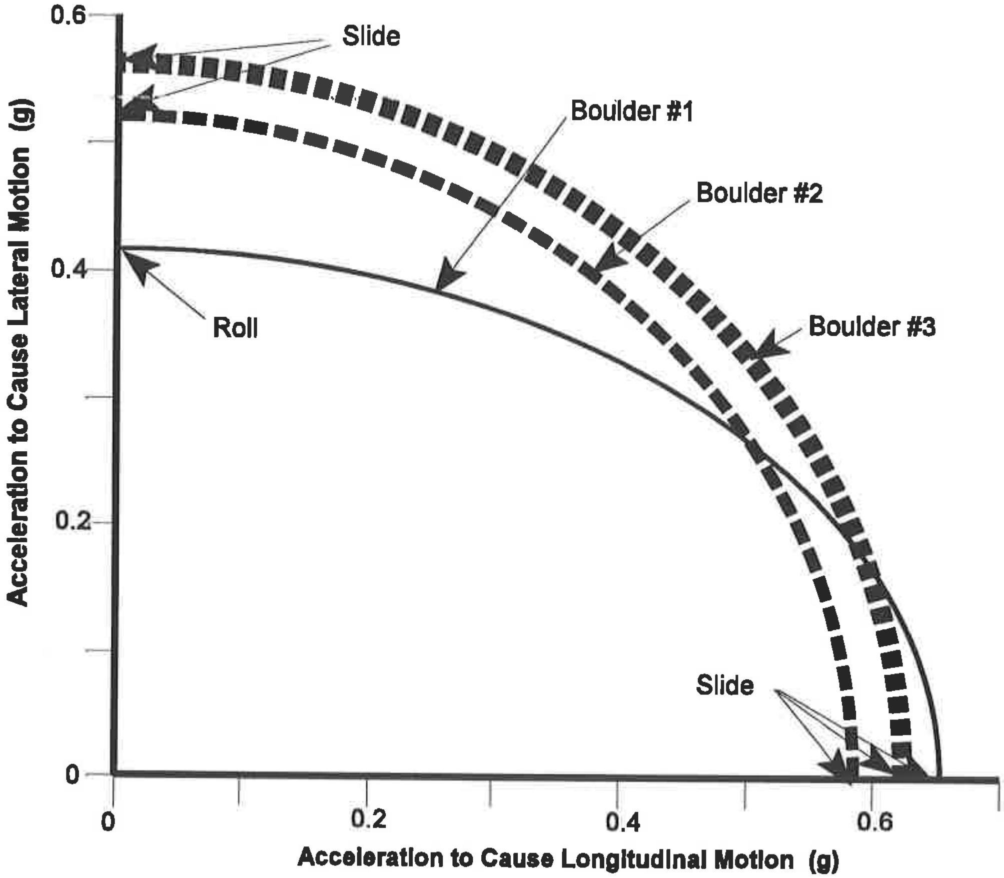


Figure 8/ Acceleration to Cause Motion of Unsecured Boulders

4.2/ Secured Boulders

Figure 9 illustrates test data with responses from two tilt tests for boulder #1. The upper graph shows that the unsecured boulder slid away at an external acceleration of about 0.70 g. The middle graph shows that the same boulder suddenly moved about 14 cm (5.5 in) at an external acceleration of about 0.80 g before the single transverse chain tiedown arrested its movement. Finally, the lower graph shows that the tension in each side of the tiedown started at the nominal value of about 0.44 kN (100 lb), rose sharply to about 16 kN (3,500 lb) as it arrested the motion of the boulder, and settled at about 7.5 kN (1,700 lb) while the deck tilt continued to 46 deg, with the boulder now held.

Each boulder was subjected to a tilt in both lateral and longitudinal directions. Tables 3 and 4 summarize the results, and Figures 10, 11 and 12 combine these results with those of the preceding section, in graphical form. Again, the acceleration for a boulder that rolled is presented as the sine of the tilt angle, whereas those for sliding are presented as the tangent of the tilt angle, and represent the acceleration necessary to overcome friction. The grey bar at the top of each set represents the baseline acceleration for movement when the boulder was not secured. The cyan bars show the equivalent external acceleration required to cause each boulder to move in a significant manner, either rolling or sliding, regardless of whether it was subsequently restrained by the tiedowns. The yellow bars are those cases where there was no movement of the boulder.

The force applied to a boulder by tilting the deck simulates the force that would arise from an external acceleration, but it does so at the expense of the force normal to the deck. As a consequence, if a boulder slides during this test, the tiedown tensions required to arrest it cannot be related directly to those that would be required under the corresponding real-life situation. However, the initial tensions, and the final tension after a boulder moved were used as a guide to assess the consequences of boulder movement. When the boulder slid or rolled a small amount, the tiedown tension increased no more than 45% of tiedown working load limit. For larger movement, over about 8 cm (3 in), the boulder reached a higher sliding speed and the tiedown tensions approached the working load limit due to a significant impact while arresting boulder motion when the initial tiedown tension was low. At higher initial tiedown tension, there was little or no boulder movement, and final tensions were lower. The increases in tiedown tension occurred as a result of extension of the tiedown produced by boulder sliding and rolling. In all cases the resulting tensions were less than the tiedown working load limit, and did not appear to be a threat to tiedown integrity.

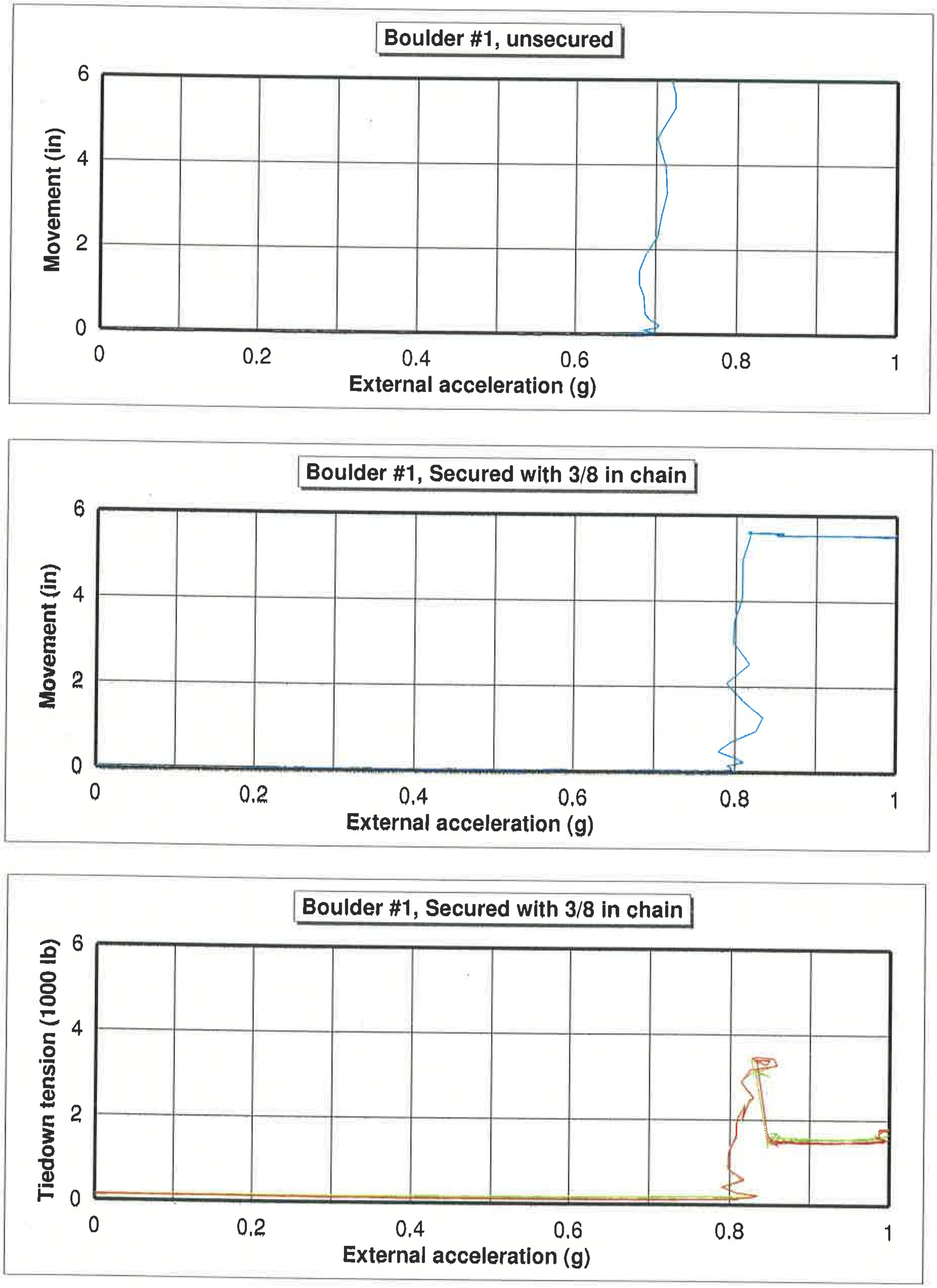


Figure 9/ Typical responses

Table 3/ Observations from Lateral Loading Tests on Three Boulders

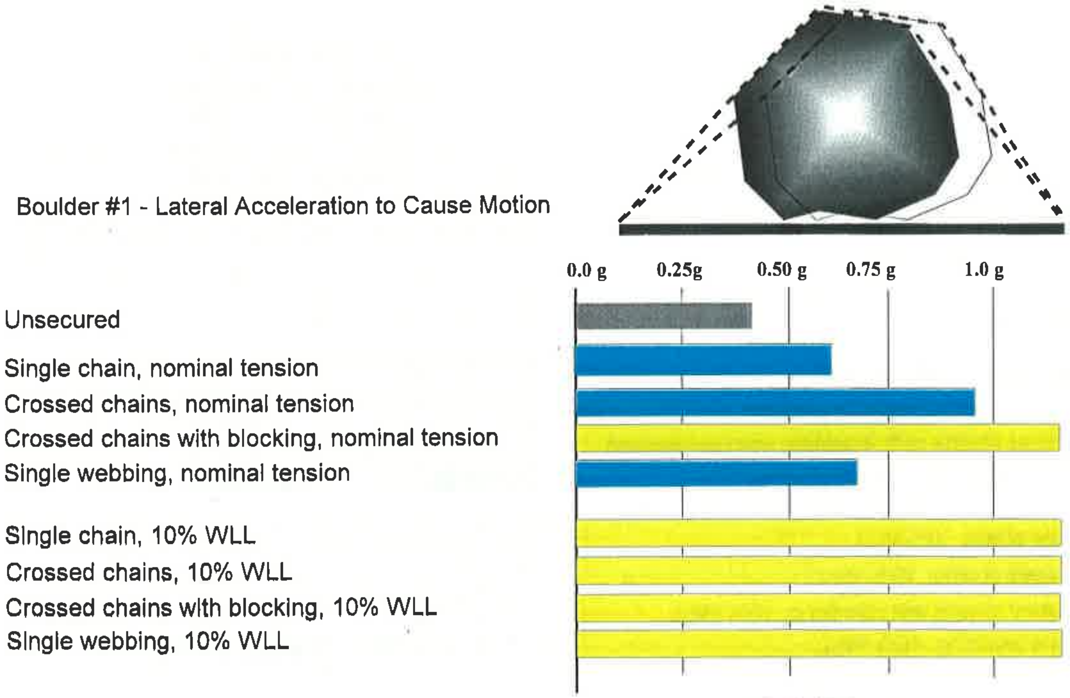
Case	Boulder	Tiedown and Tension (L/H)	Boulder Contained	Observations
1(a)	1	Single chain (L)	Yes	Slight roll at 0.60 g, contained by tiedown
1(b)	1	Single chain (H)	**Yes**	**No Movement**
1(c)	1	Crossed chains (L)	Yes	Slight roll and slide at 0.91 g, contained by tiedown
1(d)	1	Crossed chains (H)	**Yes**	**No Movement**
1(e)	1	Crossed chains, blocking (L)	**Yes**	**No Movement**
1(f)	1	Crossed chains, blocking (H)	**Yes**	**No Movement**
1(g)	1	Webbing (L)	Yes	Rolled and slid 20 cm at 0.64 g , contained by tiedown
1(h)	1	Webbing (H)	**Yes**	**No Movement**
2(a)	2	Single chain (L)	**Yes**	**No Movement**
2(b)	2	Single chain (H)	**Yes**	**No Movement**
2(c)	2	Crossed chains (L)	**Yes**	**No Movement**
2(d)	2	Crossed chains (H)	**Yes**	**No Movement**
2(e)	2	Crossed chains, blocking (L)	**Yes**	**No Movement**
2(f)	2	Crossed chains, blocking (H)	**Yes**	**No Movement**
2(g)	2	Webbing (L)	Yes	Slide at 0.80 g, contained by tiedown
2(h)	2	Webbing (H)	Yes	Slide at 0.88 g, contained by tiedown
3(a)	3	Single chain (L)	Yes	Slide at 0.73 g, contained by tiedown
3(b)	3	Single chain (H)	**Yes**	**No Movement**
3(c)	3	Crossed chains (L)	Yes	Slide at 0.90 g, contained by tiedown
3(d)	3	Crossed chains (H)	**Yes**	**No Movement**
3(e)	3	Crossed chains, blocking (L)	**Yes**	**No Movement**
3(f)	3	Crossed chains, blocking (H)	**Yes**	**No Movement**
3(g)	3	Webbing (L)	Yes	Slide at 0.87 g, contained by tiedown
3(h)	3	Webbing (H)	**Yes**	**No Movement**

Table 4/ Observations from Longitudinal Loading Tests on Three Boulders

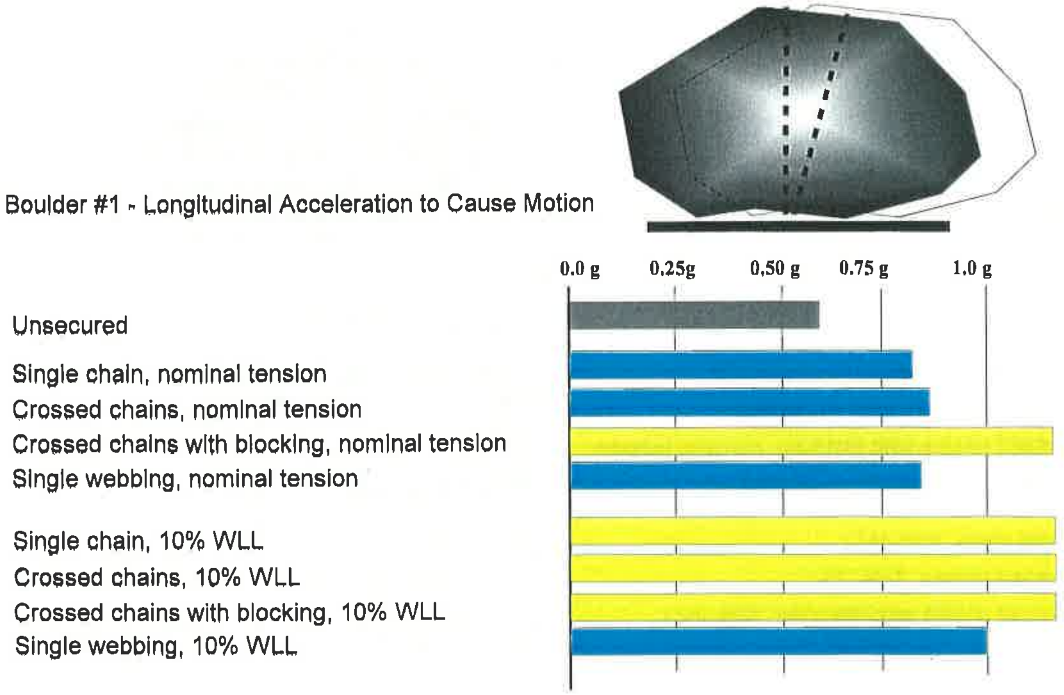
Shaded areas denotes cases where tiedown could not contain boulder

Case	Boulder	Tiedown and Tension (L/H)	Boulder Contained	Observations
1(j)	1	Single chain (L)	Yes	Slid at 0.84 g , contained by tiedown
1(k)	1	Single chain (H)	**Yes**	**No Movement**
1(l)	1	Crossed chains (L)	Yes	Slid at 0.88 g, contained by tiedown
1(m)	1	Crossed chains (H)	**Yes**	**No Movement**
1(n)	1	Crossed chains, blocking (L)	**Yes**	**No Movement**
1(o)	1	Crossed chains, blocking (H)	**Yes**	**No Movement**
1(p)	1	Webbing (L)	Yes	Slid at 0.86 g, contained by tiedown
1(q)	1	Webbing (H)	Yes	Slid at 1.0 g, contained by tiedown
2(j)	2	Single chain (L)	**No**	**Slid free from tiedown at 0.88 g**
2(k)	2	Single chain (H)	**Yes**	**No Movement**
2(l)	2	Crossed chains (L)	**No**	**Slid free from tiedown at 0.93 g**
2(m)	2	Crossed chains (H)	**Yes**	**No Movement**
2(n)	2	Crossed chains, blocking (L)	**Yes**	**No Movement**
2(o)	2	Crossed chains, blocking (H)	**Yes**	**No Movement**
2(p)	2	Webbing (L)	**No**	**Slid free from tiedown at 0.77 g**
2(q)	2	Webbing (H)	**Yes**	**No Movement**
3(j)	3	Single chain (L)	Yes	Slid at 0.71 g, contained by tiedown
3(k)	3	Single chain (H)	Yes	Slid at 0.89 g, contained by tiedown
3(l)	3	Crossed chains (L)	**Yes**	**No Movement**
3(m)	3	Crossed chains (H)	**Yes**	**No Movement**
3(n)	3	Crossed chains, blocking (L)	**Yes**	**No Movement**
3(o)	3	Crossed chains, blocking (H)	**Yes**	**No Movement**
3(p)	3	Webbing (L)	Yes	Slid at 0.81 g, contained by tiedown
3(q)	3	Webbing (H)	Yes	Slid at 0.92 g, contained by tiedown

Note: Tests 2(j) and 2(p) were repeated with the boulder facing the opposite direction. In both cases the boulder slid, at 0.64 and 0.74 g respectively, and was contained by the tiedown.

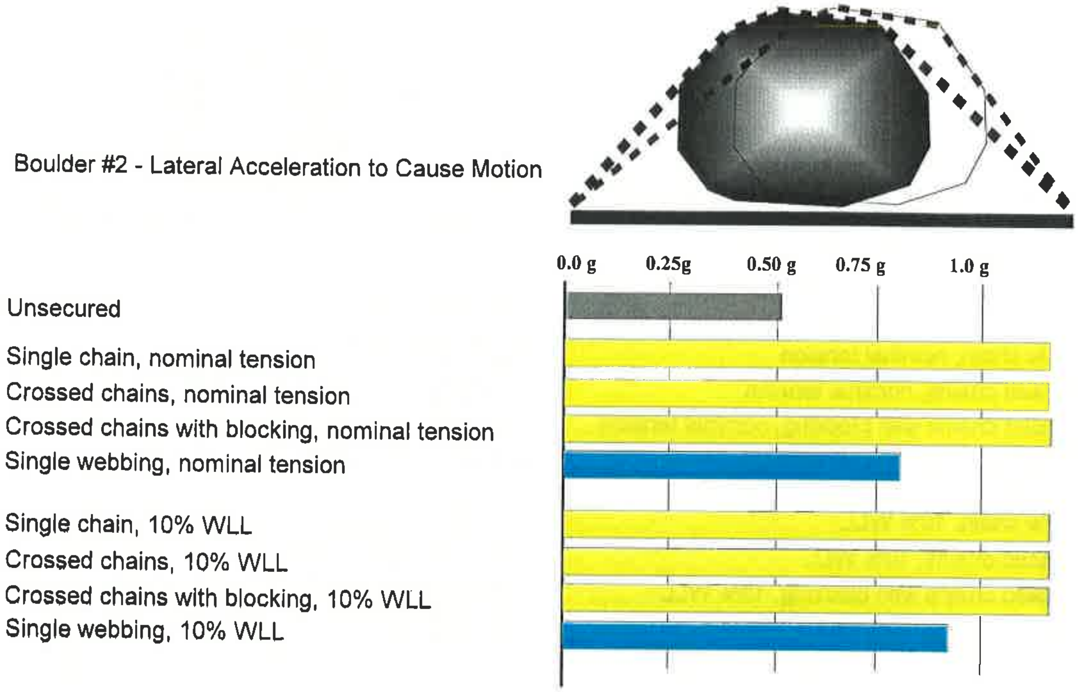


Boulder #1 - Lateral Acceleration to Cause Motion



Boulder #1 - Longitudinal Acceleration to Cause Motion

Figure 10/ Accelerations to Cause Motion for Boulder #1


Boulder #2 - Lateral Acceleration to Cause Motion

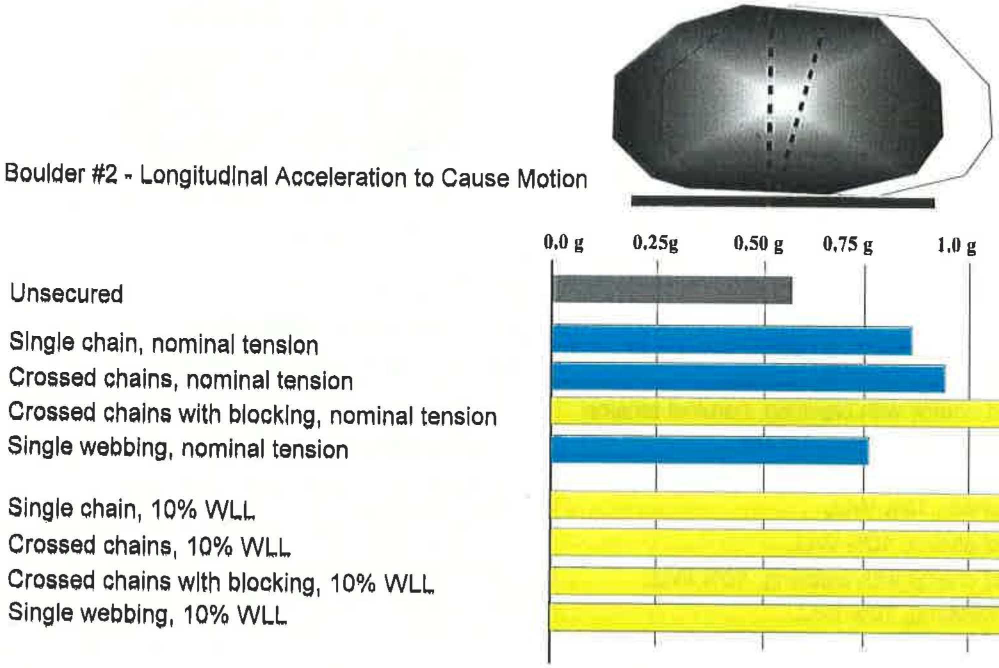
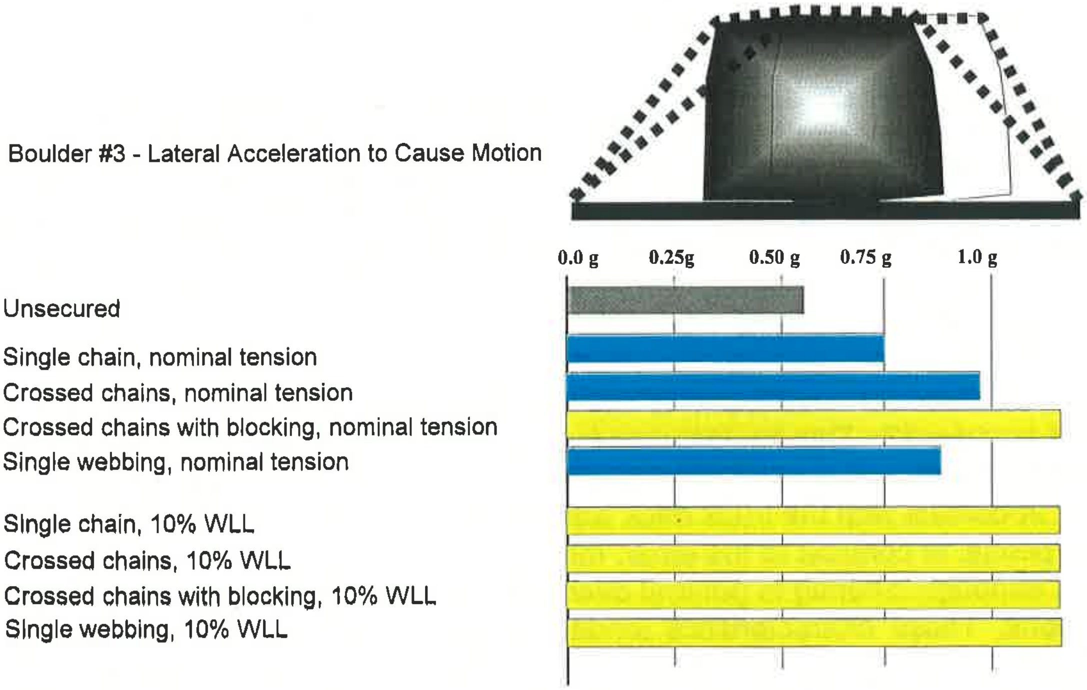

Boulder #2 - Longitudinal Acceleration to Cause Motion

Figure 11/ Accelerations to Cause Motion for Boulder #2


Boulder #3 - Lateral Acceleration to Cause Motion

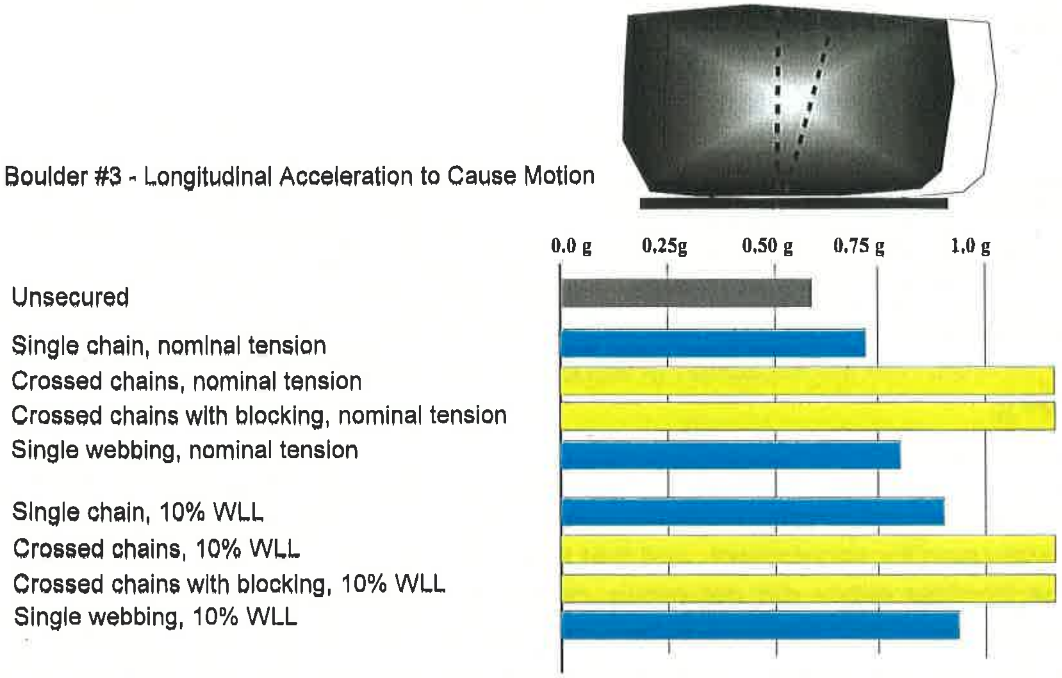

Boulder #3 - Longitudinal Acceleration to Cause Motion

Figure 12/ Accelerations to Cause Motion for Boulder #3

5/ Discussion

5.1/ Effect of Using/Not Using a Tiedown

When no tiedown was used, the boulders slid or rolled away between 0.42 and 0.65 g, and struck the arrester barrier. In 94.4% of the cases with tiedowns, the boulders either did not move, or were successfully restrained by the tiedowns and motion was arrested. In the cases where the boulder slipped out of the tiedowns, a minimum of 0.77 g was required to initiate motion. All these occurred for boulder #2.

5.2/ Effect of Boulder Shape

The only boulder that was found to slip out from under the tiedowns was the oval, rounded boulder #2. This boulder was found to have the lowest coefficient of friction in the slide mode and tended to slide and roll during an upset. The portion of this boulder in contact with the truck deck was a smooth, rounded surface, contacting at several points, in contrast to the other, more irregular shaped boulders. Boulders #1 and #3, although differing in general overall shape, had sharper corners, ridges and protrusions. These characteristics tended to increase point loading on the deck, sometimes indenting into the deck and causing scoring when moved. These characteristics increased the coefficient of friction of these boulders compared to boulder #2.

5.3/ Effect of Force Direction

In all cases of the equivalent of a lateral acceleration secured by transverse tiedowns on a truck, the boulder either did not move, or the tiedowns were able arrest the motion. There were no cases where the boulder slid or rolled out of the tiedown. There was some motion at nominal tiedown tensions where single tiedowns were used, but this occurred at 0.73 g and higher, and all such motions were soon contained. In all cases of higher tension, with the exception of webbing on boulder #2, there was no movement up to 1.04 g.

In three cases of the equivalent of a longitudinal acceleration, boulder #2 slid out from under the tiedown and crashed into the arrester barrier. This only occurred when one tiedown was used for securement, and that tiedown was at nominal tension. In all other cases the boulder either did not move, or the friction between the tiedown and the boulder was greater than the friction between the boulder and the floor resulting in the boulder shifting, tightening the tiedown and arresting further motion. Unlike the case of lateral acceleration, arrest of the boulder in this mode requires that boulder/tiedown friction be considered. For lateral acceleration, boulder and tiedown geometry is the most significant factor, and should still arrest boulder motion because of the orientation of the tiedown and its anchor points on the deck, even if friction between the tiedown and boulder was much less than its actual value.

5.4/ Effect of Tiedown Tension

When all cases of nominal tiedown tension were examined, with the exception of crossed chains and blocking which allowed no movement, the acceleration to cause initial movement ranged from 0.77 to 0.93 g. When the same tiedowns were tightened to 10% of WLL, in all but two cases there was no movement at all, and in those other two cases, movement was initiated at 0.88 g or greater and was successfully arrested by the tiedowns.

5.5/ Effect of Tiedown Method

The tests involving crossed chains with blocking allowed no motion of the boulders up to the maximum of 1.0 g, for all cases in both directions examined. In most cases, the single chain and single webbing gave rather similar restraint, with initial motion occurring at accelerations ranging upwards from 0.75 g.

5.6/ Effect of Boulder Shape and Orientation

Where a boulder was tapered or had a cross-sectional area getting progressively larger toward one end then that end was normally positioned toward the direction that motion was expected. In the three cases when the boulder slid out from under the tiedowns, an identical test was performed with the boulder facing the opposite way. In all these cases, the subsequent test was successful in arresting motion.

Orientation of the boulder such that any motion in the direction of an expected acceleration would cause the tiedown to tighten ensures that the boulder will be restrained, up to the tensile limits of the tiedown. This method of tiedown utilizes not only the friction available from the boulder weight, and tiedown force contribution to that weight, but also the captive property of the tiedown around the girth of the boulder producing a self energizing or "noose" effect. It is equivalent to creating a wedge.

6/ Conclusions

A series of tests were conducted to evaluate methods of securement for transportation of large boulders. The tests used boulders which ranged from a relatively rounded natural stone from a river bed to a block of quarried limestone.

Without securement, the boulders would roll or slide at accelerations in the range 0.42 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 a longitudinal acceleration, as the boulder tends to roll if it lacks at least three well-separated points of contact with the ground. It requires a more sophisticated securement system, which provides these points of contact in a manner that effectively prevents it from rolling. The crossed chain tiedown used in conjunction with blocking was successful in this regard. Other securement systems may be able to immobilize such boulders in a similar manner.

When the rounded tapered boulder was oriented with its fat end in the direction of the acceleration, it slid from under the tiedowns. However, the tiedowns were able to arrest motion of the boulder when it was turned around. 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.

This report presents technical results from just one task in this project. The results may be limited by the scope of this task, but are placed in context in the summary report [3].

7/ Recommendations

It is recommended that:

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/ Any 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.

4/ Crossed chain tiedowns provide greater securement than transverse tiedowns.

5/ Any boulder that has a tendency to roll requires special care, and must have that tendency constrained. A crib, formed from 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.

References

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

[2] 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.

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

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.