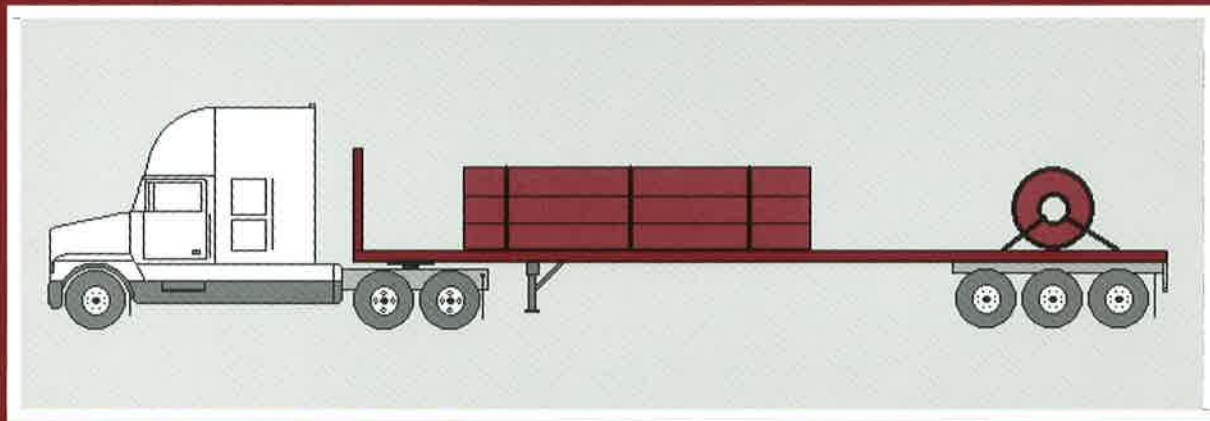


CCMTA Load Security Research Project

Report # 16

TESTS ON METHODS OF SECUREMENT FOR ISO CONTAINERS



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

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Report # 16

TESTS ON METHODS OF SECUREMENT FOR ISO CONTAINERS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

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October 1998

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Conseil canadien des administrateurs en transport motorisé

ISBN 0-921795-44-0

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North American Cargo Securement Standard

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

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

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Abstract

A series of tests were conducted to determine the forces that arise in the tiedowns securing a 12.19 m (40 ft) ISO container to a flatdeck semitrailer when the semitrailer was driven up a ramp that simulates a curb.

Only modest increases in tiedown tension were detected, well within the working load limit of the tiedowns. These arose principally from the difference in torsional stiffness between the trailer and the container.

Recommendations are made for securement of containers for transportation on the highway.

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.

Preliminary work identified a number of commodities that are known to be difficult to secure on trucks, and an ISO container on a flatdeck semitrailer was one of these. The general issues of securing box-like rigid articles by tiedowns were covered by other parts of the project, and this work only examines the effect on securement systems of driving the rear wheels of the trailer over a curb, an event known to have been a factor in some accidents where containers fell off trailers.

A 12.19 m (40 ft) container was secured to a test trailer, and the trailer was backed up a two-stage ramp so that the left rear wheels of the trailer were elevated above ground. This induced torsion (twisting) of the trailer and container, equivalent to it being driven over a curb. Transducers measured the displacement of the container relative to the trailer, and tension in the tiedowns. The test did not address horizontal loading or movement of the container on the truck deck, nor did it address impact loading. Horizontal motion of the container was curtailed by four twist lock devices that held the container in place on the trailer tested. Such devices protrude above the floor of the trailer into openings on the underside of the container, and restrict horizontal motion of the container, while allowing it vertical motion at the twist lock connector point.

Only modest movements of the container occurred, and the tiedown tensions were well within the working load limit of the tiedown whether the tiedown was chain or webbing. When the container was secured directly to the bed by a transducer system, the highest force noted was only 2.92 kN (656 lb). This arose due to the difference in torsional stiffness between the trailer and the container.

A container should only be transported if at least four vertical posts designed to engage twist locks are resting completely on the vehicle, and these are used to immobilize and secure the container. It is recommended that a container should preferably be transported on a chassis designed for that purpose.

If it is to be transported on other equipment, the container should be constrained from longitudinal and lateral movement by means as effective as the pedestals of twist locks. If the container is not so immobilized, it should be secured using a chain tiedown at each corner.

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

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, composed of one representative of each of the funding partners, and chaired by Mr. M. Schmidt of Federal Highway Administration, Albany, New York. Sean McAlister provided administrative support from CCMTA.

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

1/ Introduction

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

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

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

Containers are often carried on flatdeck trailers, and there are known to have been a number of cases where a container has slid off a trailer. The general issues of securing box-like rigid articles by tiedowns are covered by other parts of the project, so this work only examines the effect on securement systems of driving the rear wheels of the trailer over a curb, an event known to have been a factor in some of these accidents. The tests examine the effectiveness of various configurations of tiedown in securing a container when the trailer is subjected to a torsional displacement, such as would occur when it climbs a curb. The work was outlined in Section 13.7 of the project proposal [1].

2/ Test Program

2.1/ Objectives

The objectives of this test were to determine :

- 1/ The relative displacements and tiedown tensions due to trailer torsion;
- 2/ The restraining capabilities of various tiedown methods; and
- 3/ The forces required to hold a container to the truck deck.

2.2/ Scope

The test was conducted using a 12.19 m (40 ft) long ISO steel container, mounted on a flatdeck semitrailer.

The container was tested with each of the following tiedown arrangements :

- 1/ Unsecured;
- 2/ Secured by a twist lock, illustrated in Figure 1, at each corner;
- 3/ Secured by a tension transducer at each corner;
- 4/ Secured by four webbing tiedowns over the top of the container, as shown in Figure 2;
- 5/ Secured by four chain tiedowns, with two placed diagonally on each side of the container, as shown in Figure 3;
- 6/ Secured by four chain tiedowns, with two placed diagonally across each end of the container, as shown in Figure 4;
- 7/ Secured with two chains, one at each end through holes in the posts at the corners of the container frame, and attached and tensioned to the trailer frame, by two methods as shown in Figures 5 and Figure 6; and
- 8/ Secured by twist locks at the rear, with the front free or secured with a single webbing tiedown.

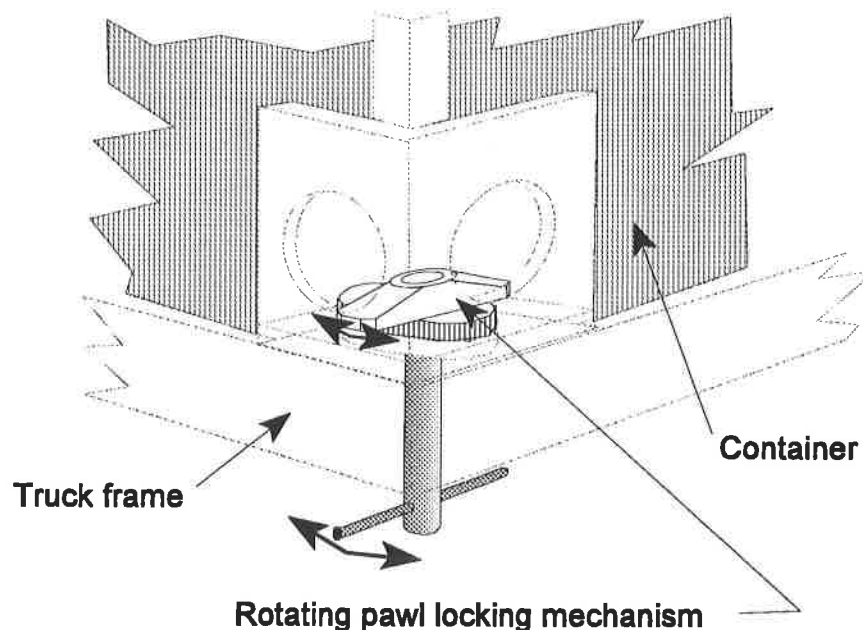


Figure 1/ Twist Lock Mechanism

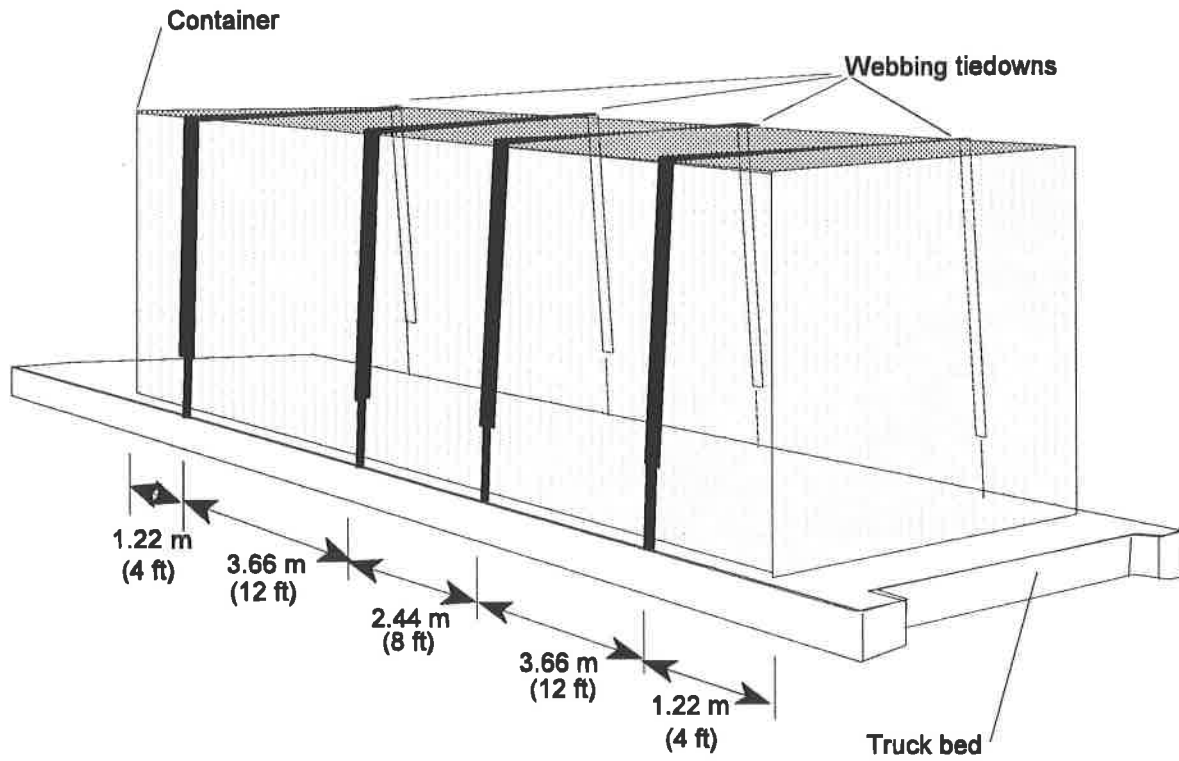


Figure 2/ Container Secured With Four Webbing Tiedowns

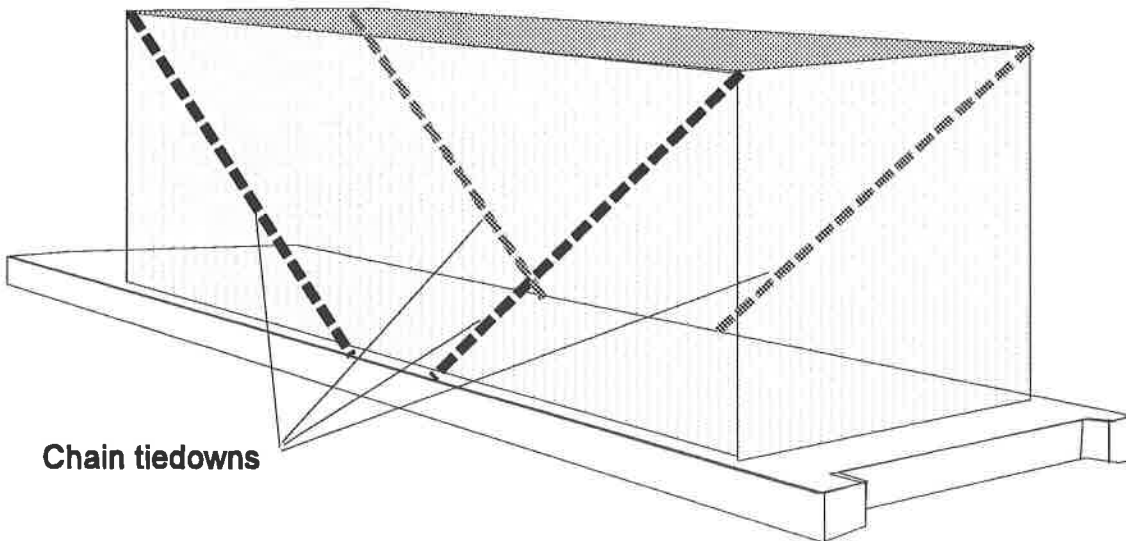


Figure 3/ Container Secured with Two Diagonal Chains on Each Side

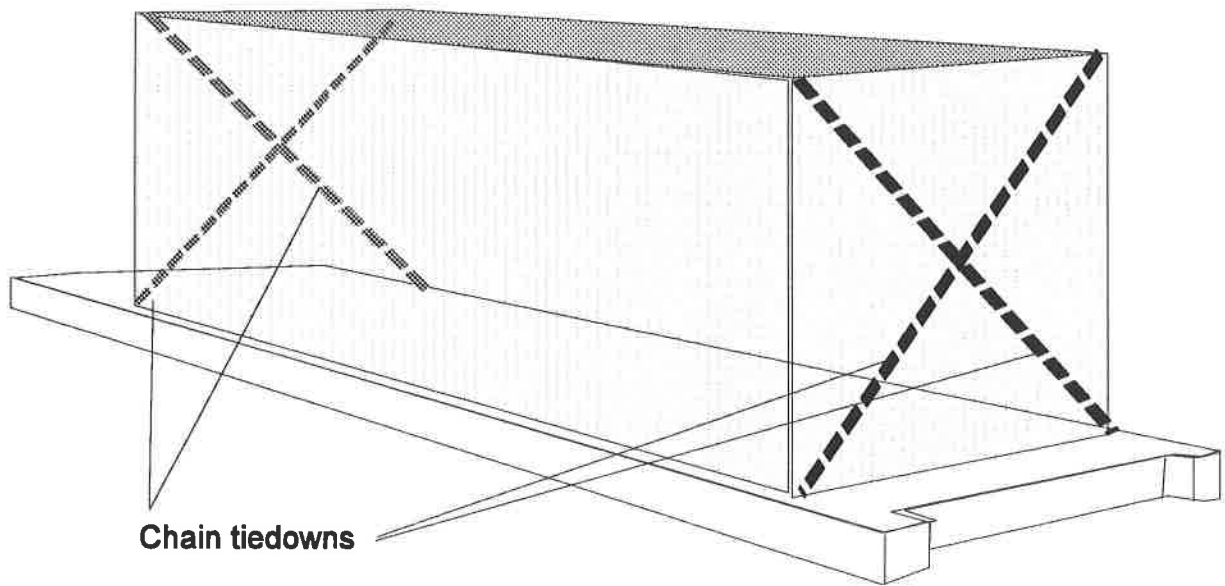


Figure 4/ Container Secured with Two Crossed Chains at Each End

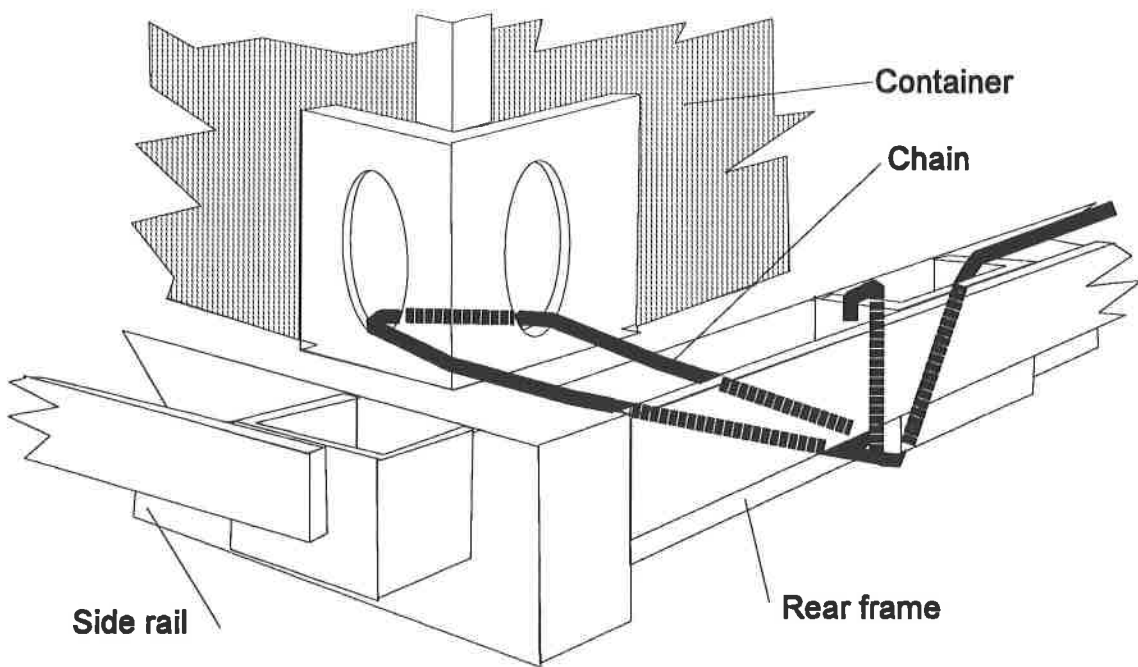


Figure 5/ Chain Securement Method a

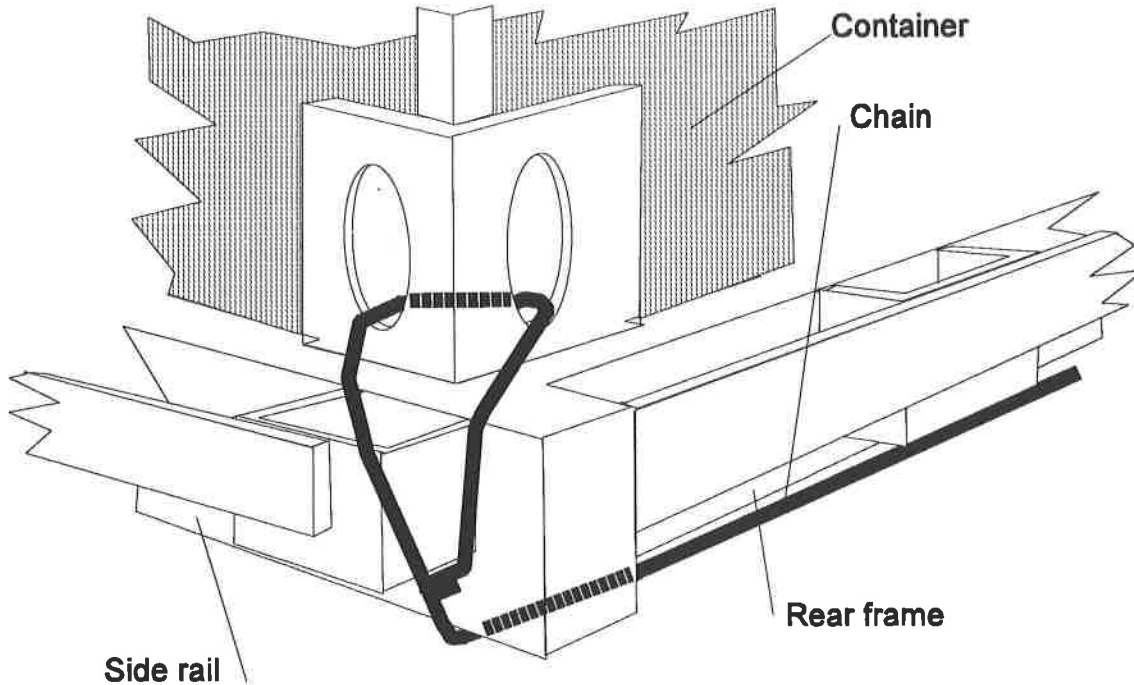


Figure 6/ Chain Securement Method b

3/ Procedures

3.1/ Test Apparatus

The test was conducted using a 12.19 m (40 ft) long ISO steel container, 2.44 m (8 ft) wide and 2.59 m (8 ft 6 in) high, with a load rating of 30.48 t (67,200 lb). The empty container was mounted on a 13.7 m (45 ft) long semitrailer, 2.44 m (8 ft) wide. The trailer was a configuration common in eastern Canada, with a 1.83 m (72 in) spread tandem axle at the rear of the trailer and a single liftable axle 3.05 m (120 in) ahead of it. The trailer was originally built as a flatdeck, but four container twist lock devices had been added inside its side rails for carriage of containers. The action of a typical twist lock was illustrated in Figure 1.

The container was secured to the truck with its twist locks, or by 5/16 in grade 7 chain with a working load limit (WLL) of 20.9 kN (4,700 lb), or 7.5 cm (3 in) synthetic webbing with a WLL of 22.2 kN (5,000 lb).

In each test the semitrailer was backed onto a ramp, placed behind the left wheels of the trailer tandem axle. The ramp was designed with two stages to create two progressive torsional steps for the trailer. Each stage was long enough to take both axles of the tandem axle group. The ramp dimensions are illustrated in Figure 7.

Backing up the ramp induced torsion in the trailer frame, as seen in Figure 8, and caused a reaction at the tiedown points as a result of dissimilar torsional stiffness of the trailer and container. This test represents a trailer mounting a curb and inducing forces in the tiedowns as a consequence of torsion of the trailer and container. A typical curb is about 17.8 cm (7 in) high.

3.2/ Instrumentation and Data Capture

The separation of each corner of the container from the deck of the trailer was measured with a linear variable differential transducer (LVDT), as shown in Figure 9. Where tiedowns were used, the tension was measured using three links of chain, with the middle link strain gauged with a four-arm bridge to measure tension. This is seen in Figure 10. The rise and run characteristic of the ramp was measured, and vehicle travel distance was measured with a pull cord transducer mounted on a tripod and stretched to the front of the tractor. Accelerometers were placed at the trailer front and rear to measure trailer roll angle, as seen in Figure 11. A general configuration sketch with roll orientation is shown in Figure 12. Data from these instruments was captured into a PC-based data acquisition system at a sample rate of 50 Hz per channel.

3.3/ Test Procedure

The vehicle started initially with the left rear wheels of the trailer just short of the ramp. Prior to a run, the container was secured in the specified manner. Any chain or webbing tiedown was initially tensioned between 4.45 kN (1,000 lb) and 5.34 kN (1,200 lb). The corner displacement transducers, vehicle movement recorder, roll angle accelerometers and tension transducers were zeroed, and a calibration sequence was recorded. Data recording was initiated and the vehicle reversed onto the ramp, as seen in Figure 8. The pull cord transducer had inadequate length for the entire ramp, so when both rear wheels were completely on the first stage of the ramp, the vehicle stopped and data capture was stopped while the transducer was moved up to the vehicle. Data capture resumed, and the vehicle then backed onto the second stage and stopped when both wheels were completely on the plateau. It paused briefly, then the procedure was reversed as the vehicle drove forward off the ramp.

The data in the PC were saved to a file on the hard disk, under a file name that completely described the test conditions. The data were retrieved, the calibrations were examined, adjusted if necessary, and a quick look assessed whether the data looked reasonable. If there was any question, the run was repeated, and sometimes adjustments were made to test conditions or fittings to ensure consistent and repeatable data. The file was saved again, and a backup was 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.

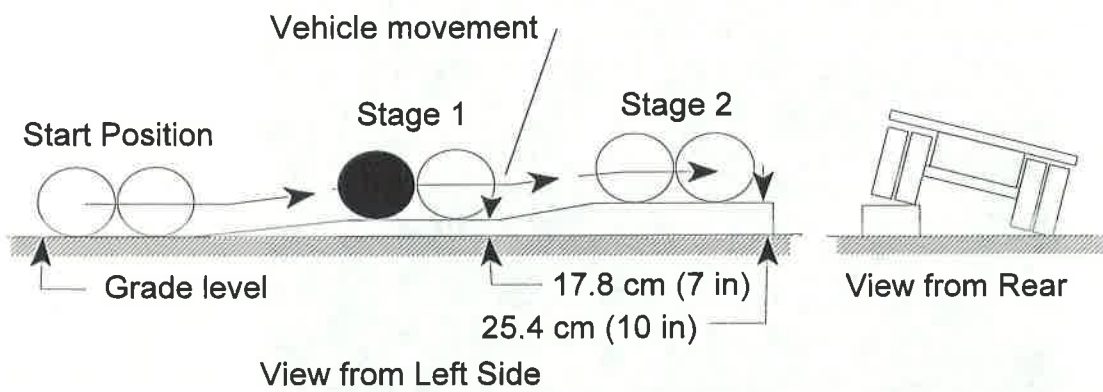


Figure 7/ Test Ramp

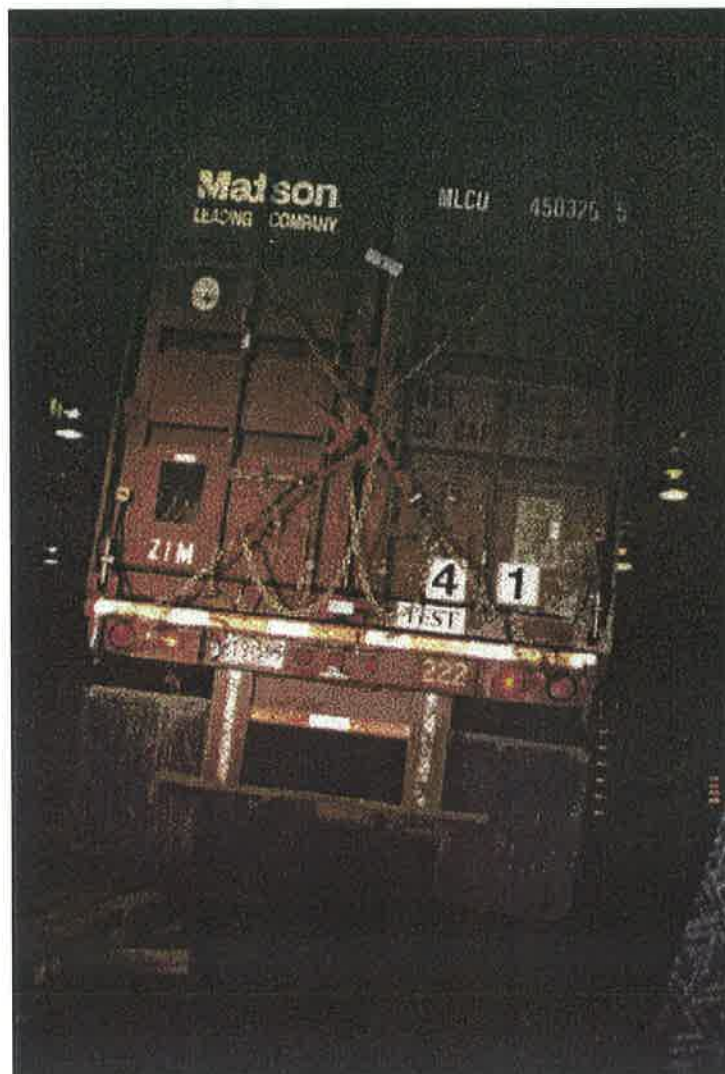


Figure 8/ Vehicle Backing Up Ramp



Figure 9/ Linear Variable Differential Transducer

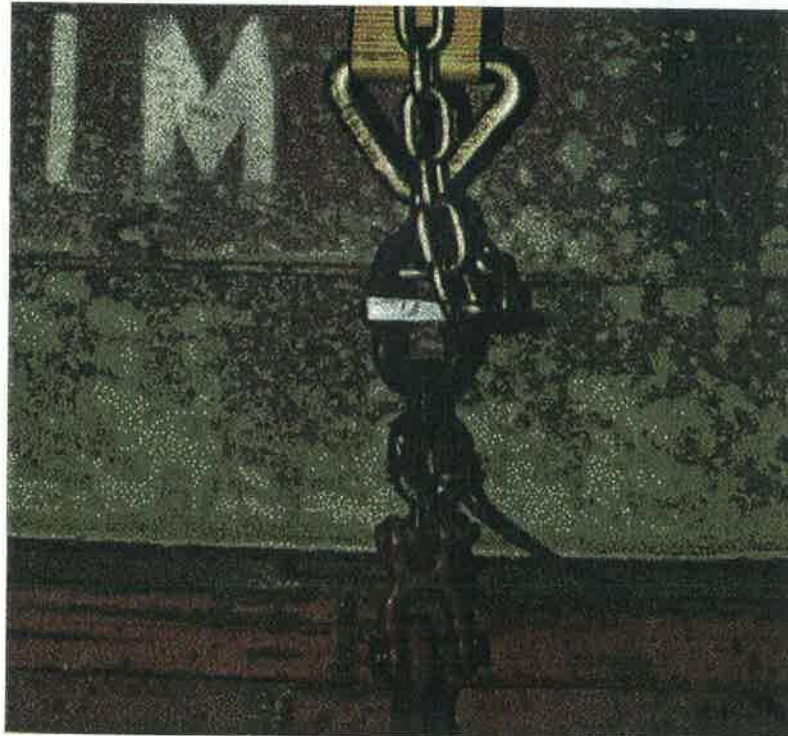


Figure 10/ Tension Transducer

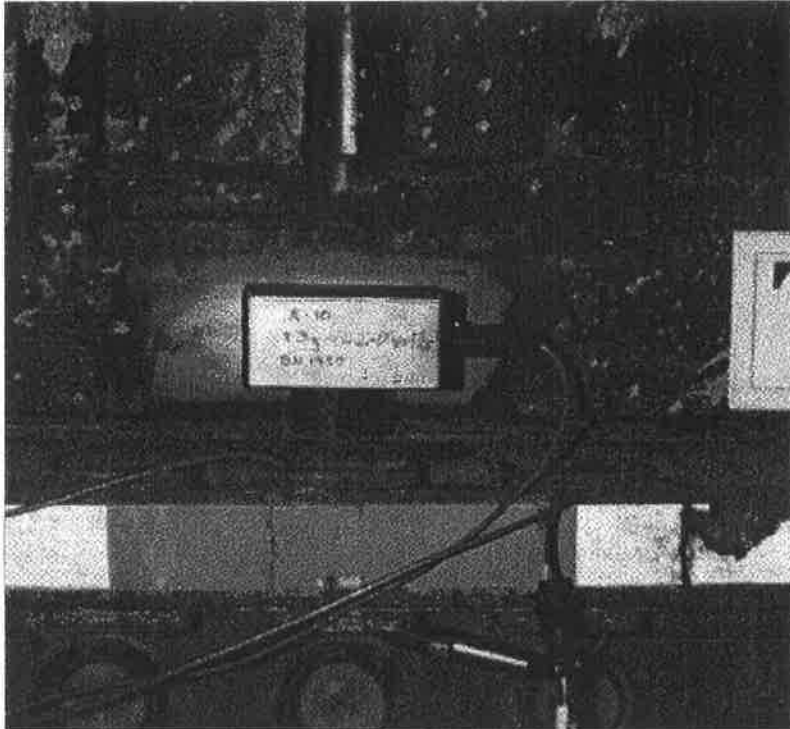


Figure 11/ Accelerometer/Roll Angle Transducer

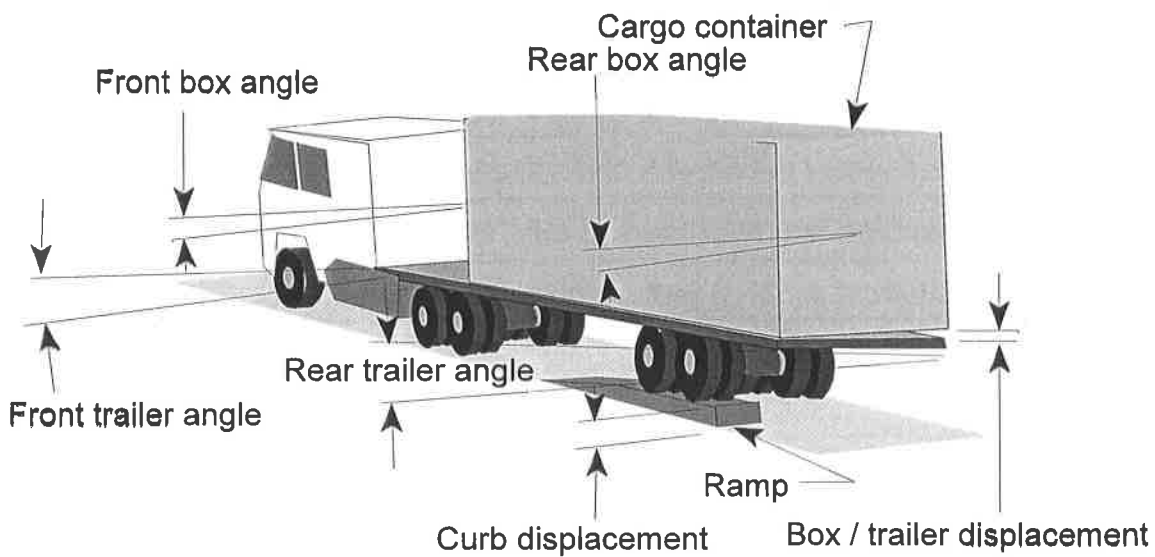


Figure 12/ General Configuration, Displacement and Roll Angle Orientation

3.4/ Data Processing

The data from each run was simply calibrated and de-trended in a specialized test data processing program written at MTO. Traces of LVDT, tiedown tension and distance travelled were examined to determine the characteristics of responses. Peak values were extracted manually, entered in a spreadsheet program, and were summarized in tables and graphical form for this report.

3.5/ Test Matrix

The matrix of test conditions is summarized in Table 1.

Table 1/ Test Conditions

Test	Condition
1	Container unsecured
2	Container secured with twist locks only, one at each corner
3	Container connected at four corners with force transducers
4	Container secured with four webbing tiedowns, as shown in Figure 2
5	Container secured with angled chains on each side, as shown in Figure 3
6	Container secured with crossed chains at each end, as shown in Figure 4
7	Container connected to bed with chain at each end, as shown in Figure 5
8	Container connected to bed with chain at each end, as shown in Figure 6
9	Container secured with twist locks at rear, front free
10	As 9, but with front secured with a single webbing tiedown

4/ Results

When the left rear corner of the trailer was raised by the ramp, the left rear corner of the container was raised by it, and the container rolled, essentially as a rigid body, about its lower right-hand edge. Because the container was much more stiff in torsion than the trailer, its base tended to remain planar, so its left front corner tended to separate from the deck, unless it was secured. Separation of the left front corner of the container from the deck was therefore taken as the reference criterion. Table 2 presents this for four baseline tests, which establish the relative torsional stiffness of the trailer and container. It shows that left front corner separation ranged from 0.37 cm (0.15 in) when the container was secured to the deck with transducers, to 4.32 cm (1.70 in) when there was no restraint at all. The twist lock allowed a vertical movement of 1.04 cm (0.41 in) at the left front corner, which is within the 2.54 cm (1.00 in) allowed by regulation [2], under the curious condition of 0.5 g vertical acceleration, which is insufficient to cause lift-off. The container could not move longitudinally or laterally, since the twist lock receptacles on the container sat over a pedestal.

In test condition 3, all four corners of the container were secured by force transducers. Table 3 shows the incremental force in each transducer for both stages of the ramp. The only significant one is at the left front corner, and it represents the difference in

Table 2/ Left Front Corner Separation of Container for Baseline Tests

Stage	Left front corner separation (cm) by test condition			
	1 Unsecured	2 Twist Locks	3 Transducers	9 Rear secured
Stage 1, 17.8 cm	2.19	0.87	0.37	0.53
Stage 2, 25.4 cm	4.32	1.04	0.37	4.08

Table 3/ Transducer Forces for Test Condition 3

Stage	Transducer location			
	Front left	Front right	Rear left	Rear right
Stage 1, 17.8 cm	0.45 kN (101 lb)	-0.48 kN (-107 lb)	0.08 kN (18 lb)	0.08 kN (18 lb)
Stage 2, 25.4 cm	2.92 kN (656 lb)	-0.53 kN (-118 lb)	0.12 kN (27 lb)	0.27 kN (61 lb)

torsional stiffness of the container and trailer. Table 3 shows that the maximum force was only 2.92 kN (656 lb). This would be the maximum vertical force expected of any vertical tiedown, regardless of the tiedown type, since the force transducer was probably stiffer than any tiedown, so generated the maximum container torsion. This force is small compared to the working load limit of any tiedown that would be used to secure a container.

Figure 13 shows the corner separations and tiedown tensions for test condition 4, when the container was secured with four transverse webbing tiedowns, as illustrated in Figure 2. Figure 13 shows that the left front corner of the container separated as the trailer climbed the second stage, with a momentary maximum separation of 2.80 cm (1.10 in). There was a minor coincidental increase in tension for the left front tiedown, but essentially no change in tension in any of the other tiedowns, on either side.

For test condition 5, the container was secured with four diagonal chain tiedowns on the sides, as illustrated in Figure 3. The results are summarized in Table 4. This arrangement of tiedowns would be expected to be relatively effective in resisting longitudinal motion, but did allow 1.83 cm (0.74 in) separation at the left front corner of the container. The chain tensions on the left-hand side tended to slacken, whereas those on the right tended to increase, though the increase was modest, no more than 1.52 kN (342 lb).

For test condition 6, the container was secured with two diagonal chain tiedowns at each end, as illustrated in Figure 4. The results are summarized in Table 5. This arrangement of tiedowns would be expected to be relatively effective in resisting lateral motion, and did constrain the container to a small left front corner separation of only

**Table 4/ Tiedown Tensions and Left Front Corner Separation
Test Condition 5, Diagonal Chains at Sides**

Stage	Tiedown tension				Left Front Corner separation
	Front Left	Front Right	Rear Left	Rear Right	
Start	5.09 kN (1146 lb)	5.58 kN (1255 lb)	5.28 kN (1188 lb)	5.27 kN (1184 lb)	0.00 cm (0.00 in)
Stage 1 17.8 cm	4.16 kN (937 lb)	6.66 kN (1497 lb)	4.21 kN (946 lb)	6.28 kN (1412 lb)	0.09 cm (0.09 in)
Stage 2 25.4 cm	5.78 kN (1299 lb)	7.10 kN (1597 lb)	5.04 kN (1134 lb)	6.67 kN (1499 lb)	1.83 cm (0.74 in)

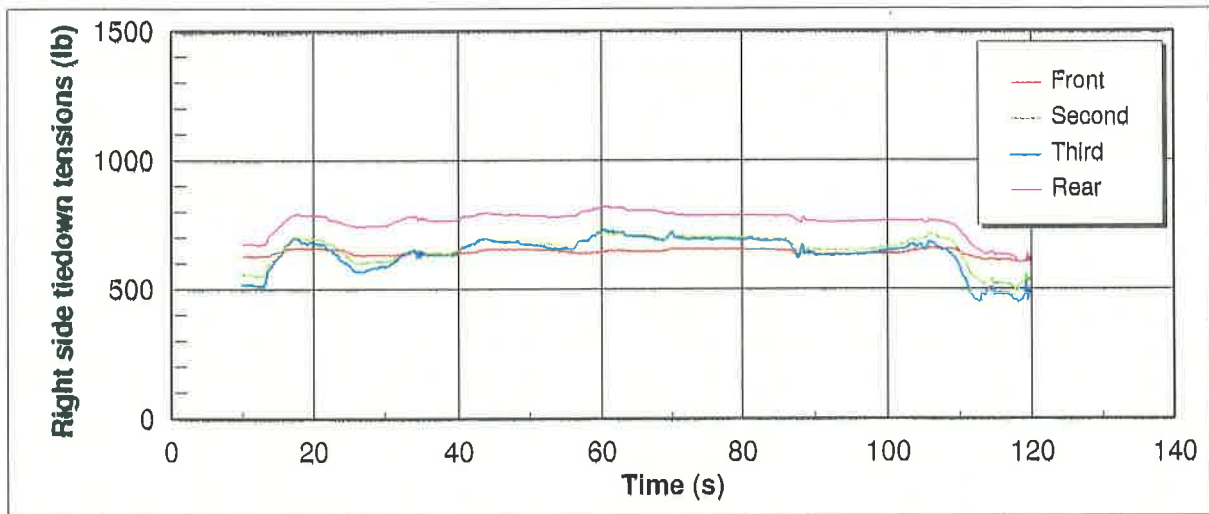
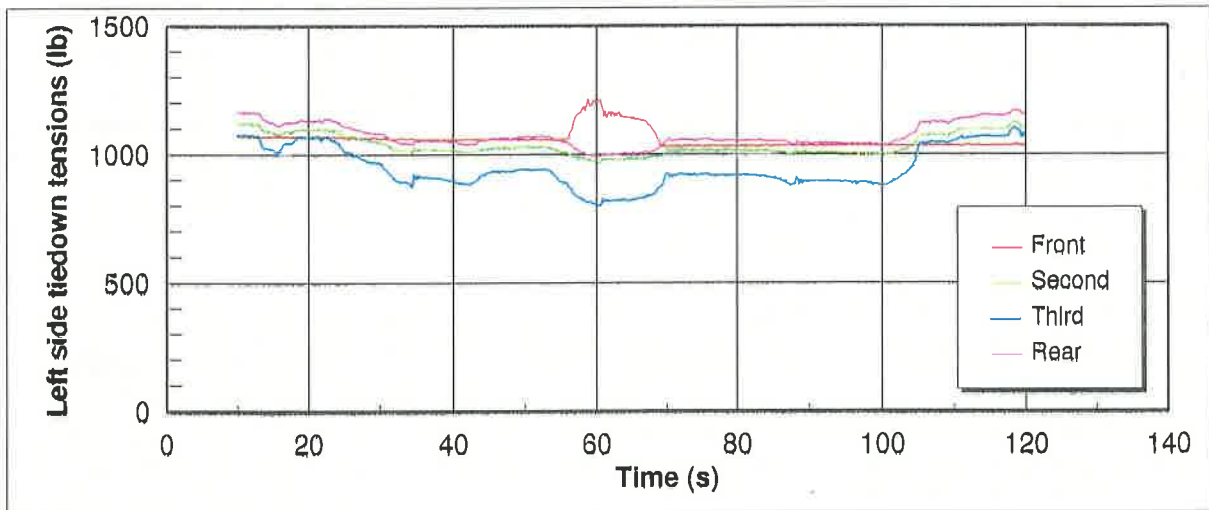
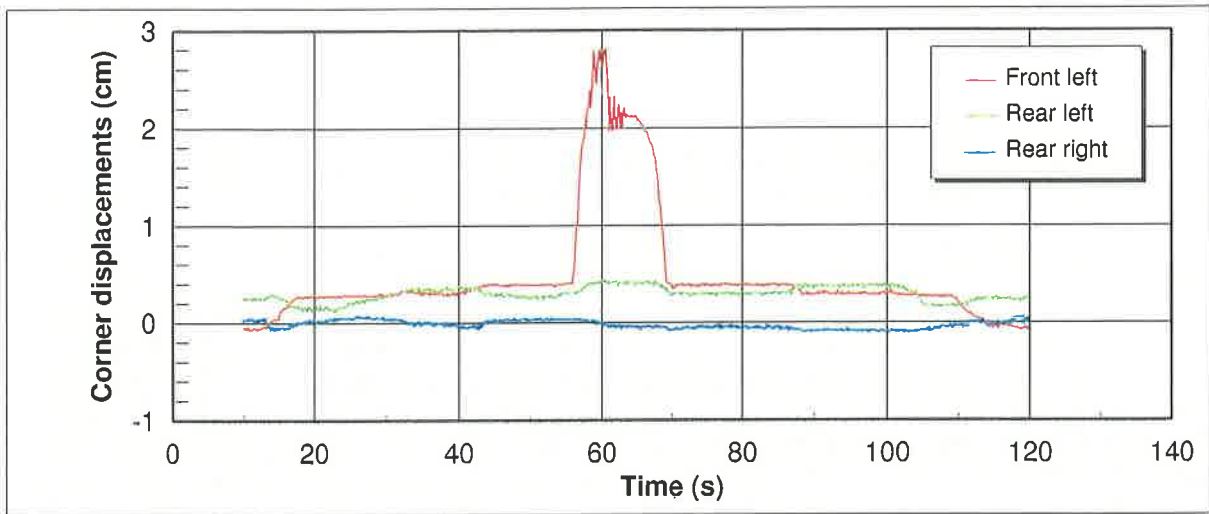


Figure 13/ Typical run, condition 4, four 3 inch webbing tiedowns

0.19 cm (0.07 in) separation. The chain tensions from the bottom right to top left at each end tended to slacken, whereas those from the bottom left to top right tended to increase, though the increase was modest, only 1.62 kN (363 lb).

**Table 5/ Tiedown Tensions and Left Front Corner Separation
Test Condition 6, Crossed Chains at Ends**

Stage	Tiedown tension				Left Front Corner separation
	Front Bottom lhs to top rhs	Front Bottom rhs to top rhs	Rear Bottom lhs to top rhs	Rear Bottom rhs to top lhs	
Start	5.22 kN (1174 lb)	5.10 kN (1147 lb)	5.69 kN (1279 lb)	5.32 kN (1197 lb)	0.00 cm (0.00 in)
Stage 1 17.8 cm	5.58 kN (1254 lb)	4.68 kN (1053 lb)	4.79 kN (1078 lb)	6.19 kN (1391 lb)	0.02 cm (0.01 in)
Stage 2 25.4 cm	6.84 kN (1537 lb)	4.52 kN (1016 lb)	4.54 kN (1021 lb)	6.40 kN (1438 lb)	0.19 cm (0.07 in)

The results for the two chain tiedowns through the corner posts of the container are shown in Table 6. The tiedowns were not instrumented in this test, due to lack of space to insert transducers, and because friction between the chain and vehicle structure would have been unavoidable. Only the separation of the left front corner of the container from the deck was monitored. Each case displayed very little separation.

**Table 6/ Left Front Corner Separation for Test Conditions 7 and 8 (cm)
Chains through Container Corner Posts**

Stage	Test condition 7	Test condition 8
Start	0.00 cm (0.00 in)	0.00 cm (0.00 in)
Stage 1 17.8 cm	0.03 cm (0.01 in)	0.03 cm (0.01 in)
Stage 2 25.4 cm	0.04 cm (0.02 in)	0.47 cm (0.19 in)

In order to demonstrate a worst case for a webbing tiedown, the rear of the container was secured with twist locks and the front of the container was secured with a single transverse webbing tiedown. This fixed the rear of the container to the trailer deck and allowed the free front end to display the maximum separation as represented by the difference in torsional stiffness of the trailer and container. The single webbing tiedown would be forced to absorb all of the tension requirement to hold the container. The tension in the webbing would therefore be the maximum tension achievable for a webbing tiedown given the specific trailer input. The results are shown in Table 7. The maximum separation of the left front corner of the container was 1.83 cm (0.76 in), and the corresponding increase in tiedown tension was 0.81 kN (184 lb), a near insignificant amount.

**Table 7/ Tiedown Tensions and Left Front Corner Separation
Test Condition 10, Webbing Tiedown at Front, Rear Secured with Twist Locks**

Stage	Left Tension	Right Tension	Left Front Separation
Start	4.55 kN (1022 lb)	2.69 kN (605 lb)	0.00 cm (0.00 in)
Stage 1 17.8 cm	4.30 kN (967 lb)	2.86 kN (642 lb)	0.09 cm (0.09 in)
Stage 2 25.4 cm	5.36 kN (1206 lb)	2.91 kN (654 lb)	1.83 cm (0.74 in)

The left front corner separation is compared for all test conditions in Figure 14. If the four baseline tests are excluded, test condition 5, diagonal side chains, allowed the greatest left front corner separation. All others actually allowed less than twist locks at all four corners, but this was simply due to the free play in the twist lock, which provides positive securement against movement in all directions.

The maximum tension achieved in the tiedown is shown summarized in Figure 15. It can be seen that the diagonal side chains reacted with the greatest tension, followed by the crossed end chains. None of the cases tested caused a significant increase in tiedown tension.

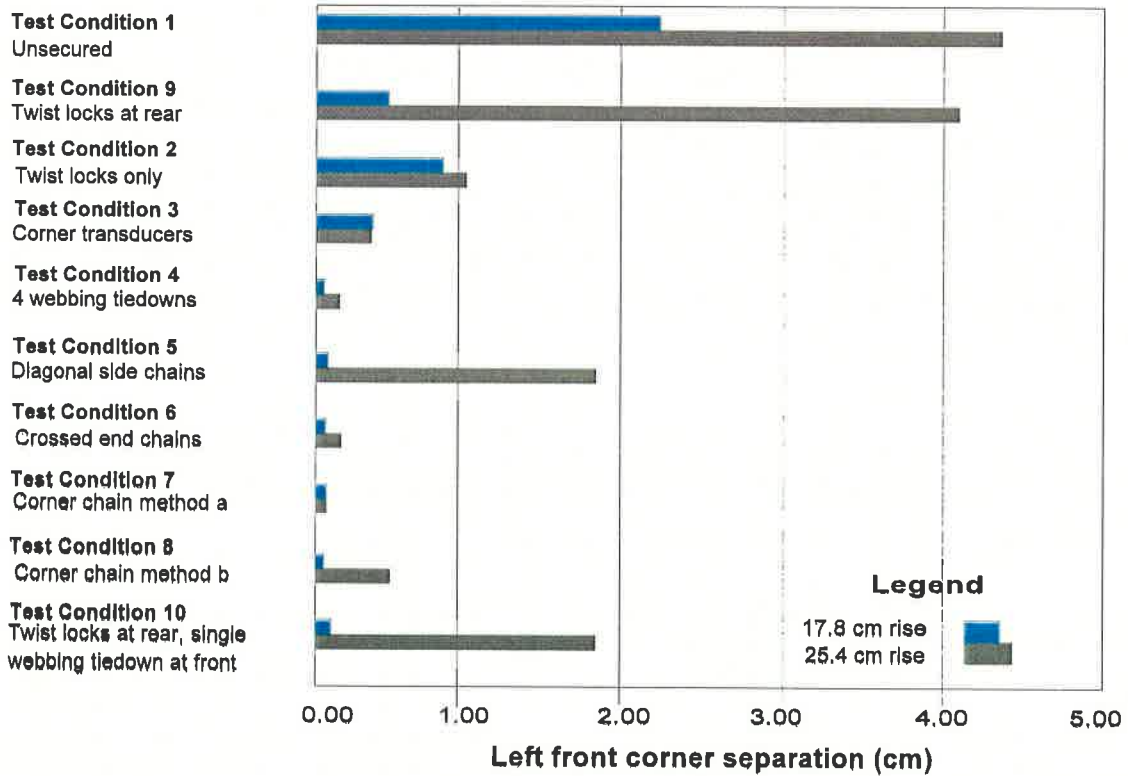


Figure 14/ Summary of Container Left Front Corner Separation

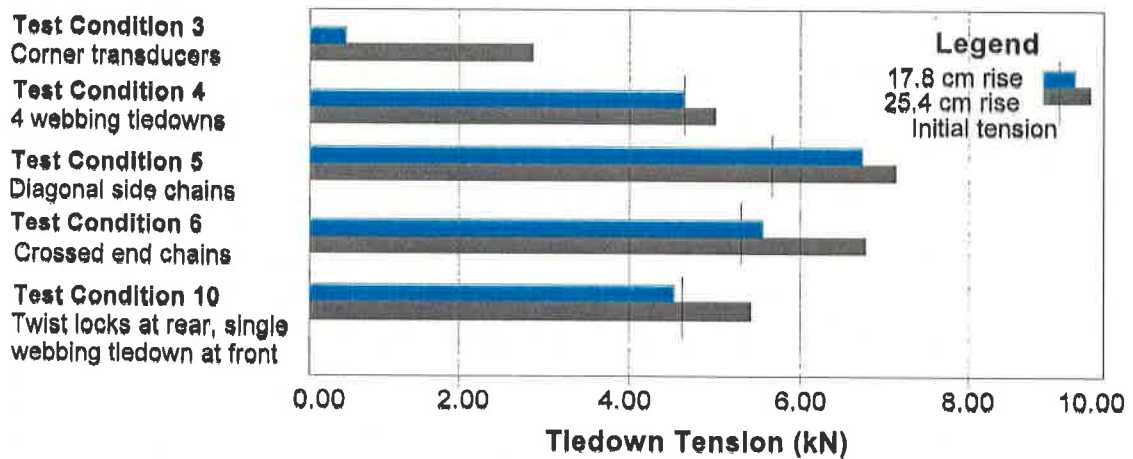


Figure 15/ Summary of Maximum Tiedown Tensions

5/ Discussion

This test series does not address the entire spectrum of issues of securement of a container on a flatdeck trailer. Those issues relating to the securement of a rigid box-like article of cargo by transverse tiedowns have been dealt with separately [3]. These tests only address the effect of a semitrailer mounting a curb, and the effect this may have on tiedown tension. This addresses one known mode where containers have slid off flatdeck semitrailers.

The displacement caused by suspension deflection when the rear wheels of the trailer mount a curb induces a torsion into the trailer that is transmitted to the container. The relationship depends on the arrangement and stiffness of the tiedowns. A maximum curb height of 25.4 cm (10 in) resulted in only minor change in tiedown tension. It appears that when the trailer mounts a curb, the resulting deformation should not bring any tiedown close to its working load limit, let alone be likely to cause it to fail.

The trailer tested was equipped with twist locks. Each lock enters an aperture at the bottom of a corner post on the container, and only allows the container to move in the horizontal plane to the extent that there is free play and clearance. When the test personnel had to move the container a small amount to align and orient it, it was moved relatively easily and left the impression that it would move as readily when transported on the road. Unless provision was made to restrict horizontal motion, the container could slide significantly. As noted from other work, a transverse tiedown over the container provides no initial resistance either to longitudinal or lateral movement [3]. It is in fact friction that keeps cargo that is secured only by transverse tiedowns from shifting [4].

The pedestals of the twist locks on the test trailer effectively immobilized the container, preventing it from moving longitudinally or laterally. The twist lock itself simply serves to secure the container, once it is positioned over the pedestal. The pedestals are part of the structure of the trailer, and are strong enough to resist forces arising from longitudinal or lateral acceleration, which are related to the weight of the container. The twist lock itself needs only to be strong enough to resist the upward force due to the difference in torsional stiffness of the container and the trailer. This series of tests demonstrated that these forces are quite modest. They are also independent of the weight of the container, depending only on the difference in torsional stiffness of container and trailer. The trailer used was a design common in eastern Canada, and had larger frame rails than the majority of flatdecks used in North America, so would have been stiffer in torsion than them. However, even if the incremental tiedown tensions due to mounting such a curb are doubled or tripled, still the outcome is far below the working load limit of tiedowns that are typically used to secure containers.

A container placed on the ground is actually designed to rest on its corner posts. These serve as short legs, which keep the bottom side of the container clear of the ground. If a container is secured on a flatdeck by transverse tiedowns, and the container moves,

one of the corner posts can slide off the side of the trailer, unless there is some means to prevent such movement. The tiedowns will have little effect in preventing this movement, and, if it is sufficiently aggressive, it could result in tiedown failure. If provision is made to arrest lateral motion, in a device that is as effective as the pedestal of the twist lock, then the tiedowns charged with holding the container down to the deck need only be strong enough to resist the difference in trailer and container torsion, just like the twist locks.

If the trailer deck has a pronounced upward curvature, so that the container does not rest squarely on the four corner posts, the container may tend to pitch like a teeter-totter, and may also tend to yaw if its contents are not symmetrically disposed within it. This is clearly an inappropriate situation, and should not be countenanced. Similarly, if a container overhangs past the end of the trailer so that it does not have corner posts at each end placed firmly on the deck and providing support to the container, it cannot be restrained by tiedowns alone, since tiedowns do not provide effective restraint. Some containers longer than 12.19 m (40 ft) have interior posts as well as corner posts. In this case, as long as posts at each end of the container, whether interior or corner, rest firmly on the deck of the trailer and support the container, then it can be secured.

6/ Conclusions

A test was conducted to assess the effect on systems for securing an ISO container to a flatbed trailer when the trailer was driven up a ramp to heights of 17.8 and 25.4 cm (7 and 10 in), which represents the trailer mounting a curb.

The pedestal of a conventional twist lock device for securing containers serves to immobilize the container. The twist lock merely holds the container down once it is in place, and needs only be strong enough to resist forces arising from the difference in torsional stiffness of the trailer and container.

Only modest increases in tiedown tension were found for a number of different applications of tiedowns to secure the container. It would not be expected that such a manoeuvre would result in failure of a tiedown.

Each of the securement arrangements tested provides little immediate resistance to either longitudinal or lateral movement of the container. Any of them is best used to supplement other means that immobilize the container. A container cannot be properly secured unless it is supported only by four corner posts, two at each end, that rest firmly on the deck of the trailer.

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 [4].

7/ Recommendations

It is recommended that :

- 1/ A container should not be transported unless it has at least four vertical posts designed to engage twist locks resting completely on the vehicle, including two towards the rear of the container, and these are used to immobilize and secure the container.
- 2/ An ISO (or other) container should preferably be transported only on a chassis that is compatible with the container, and designed to provide proper securement for it.
- 3/ If a container is transported on other equipment, the container should be immobilized so that it cannot move longitudinally or laterally.
- 4/ If the container is not immobilized so that it cannot move longitudinally or laterally, then it should be secured using a chain tiedown at each corner.

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