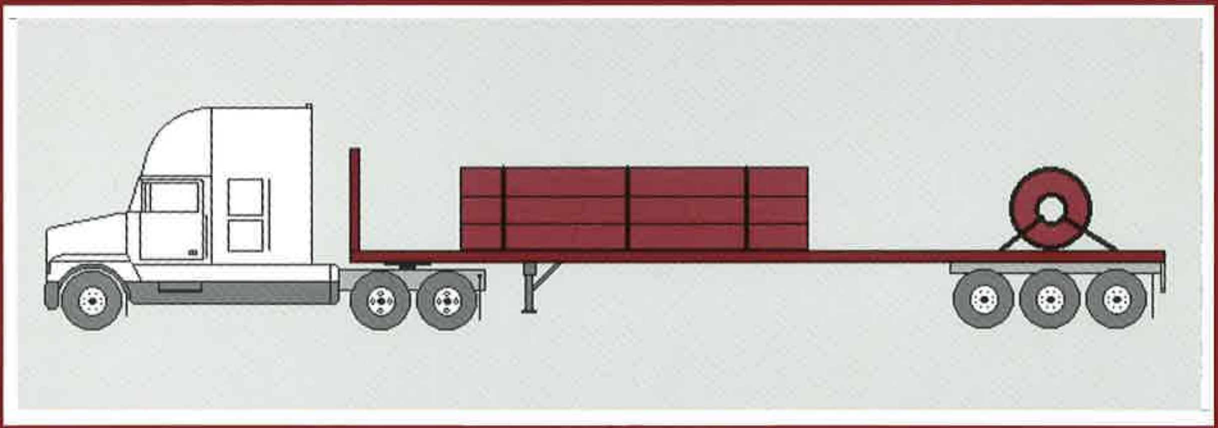
CCMTA Load Security Research Project

Report # 6

EFFECT OF BINDER TYPE AND CHAIN LENGTH ON TENSION IN CHAIN TIEDOWNS



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

CCMTA Load Security Research Project

Report # 6

EFFECT OF BINDER TYPE AND CHAIN LENGTH ON TENSION IN CHAIN TIEDOWNS

Prepared for

Canadian Council of Motor Transport Administrators
Load Security Research Management Committee

By

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North American Cargo Securement Standard

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

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

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Abstract

A test was conducted to determine the tension that could be applied to a tiedown chain with the use of a load binder. Three binder types were used on three different chain types and lengths, 1/4, 5/16 and 3/8 in each at 1, 3 and 6 meter lengths. Each binder was tested at three different set points to determine their general operating range. To enhance the mechanical advantage and simulate an industry practice, the binders were tensioned with a 0.61 m (24 in) pipe .

The lever type binders could produce tensions in excess of the working load limit of the chain when the pipe was used. The ratchet binder could be tensioned to very high loads with a conscious effort by the user. For fixed set-points, as the chain length increased, the tension decreased. For fixed set points, the larger type chain produced higher tensions than the smaller type chain. It was concluded that with the use of a pipe to augment the mechanical advantage of the binder that the working load limit of the chain could easily be exceeded and without it, it was not likely to be exceeded.

Executive Summary

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

This preliminary work identified that the ability to develop tension in tiedowns was potentially a critical factor in cargo securement. A series of tests were defined to examine the effect of binder type, binder set point, chain size and chain length on the tension that the binder could produce in a chain. The work reported here addresses these issues through this series of tests, outlined in Section 8.2 of the project proposal.

A binder applies tension to a chain by shortening the length of the binder, causing the chain to elongate and produce a tension. Different types of binder produce displacement in different ways. The use of a 0.61 m (24 in) pipe placed over the lever of the binder allowed the operator to tension chains near their working load limit.

When the chain was lengthened, the maximum uniform tension decreased at similar binder set points. The larger cross section chains developed higher tensions at identical set points. The lever binders could not be set to fail the chain. The ratchet binder could produce chain tension significantly higher than the lever binder. When lever type binders were used with a 0.61 m (24 in) pipe the resulting tension in the chain reached the working load limit of that chain and in some cases higher. When used in the manner prescribed by the manufacturer, without the assistance of a lever extender such as a pipe, then lever type binders would not allow typical chains such as 1/4 to 3/8" to become tensioned above their working load limit unless the operator used excessive force. If he (she) was able to sustain a high load throughout the rotation of the lever then the tension would increase but this is unlikely due to the location and orientation of most lever type tiedowns. It would be expected that an above average strength operator would produce non-excessive loads without such assistance.

The ratchet type binder was capable of exerting loads near the working load limit when operated by a person familiar with its mechanical advantage and capabilities. The ratchet binder tested could significantly over-tension a chain by excessive ratcheting.

It is recommended that lever binders should be secured only by the operators own strength. Devices should not be used to enhance the binder's mechanical advantage. Ratchet binders should be used with care, also without lever extenders. When long chain spans are used, the chain should not be allowed to twist, or snag on obstructions or corners. Care should be taken to match the binder with its prescribed chain size.

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

Acknowledgments

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

The project was funded jointly by the following :

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

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

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.

The initial tension developed by a load binder in a chain tiedown may have a significant influence on cargo securement. If insufficient tension is developed, the cargo may be prone to movement. Alternatively, if the initial tension is too high, the tiedowns may crush or cut into the cargo, or protection provided for the cargo. Further, if a high vehicle deceleration causes the cargo to move, with less margin between the initial tension and the ultimate strength of the tiedown, there will be more likelihood of a broken tiedown, which could result in loss of cargo. Consideration of these issues resulted in this series of tests, which examine the tension created in the span of a chain tiedown by application of a typical load binder. The test examines the effect of binder type, application variances, chain size and chain span length. The work reported here was outlined in Section 8.2 of the project proposal [1].

2/ Test Program

2.1/ Objective

The objective of this test was to examine the effect that binder type, binder initial set point, chain size and chain length have on the initial tension produced by tightening a chain with a binder.

2.2/ Scope

Three types of load binder were used :

1/ a lever lock load binder;
2/ a lever lock spring loaded load binder; and
3/ a ratchet load binder.

Three set-points were used for each binder. The initial set point was chosen using a 1 m long chain span with a nominal initial tension of 1.33 kN (300 lb), sufficient to ensure the chain was not slack. For the lever action binders, the set point was that point where the operator could just lock the lever, and for the ratchet binder, it was that point where the operator could just apply 540 deg of rotation to the lever arm. Two equally spaced less demanding set points were arbitrarily selected for each binder.

Three sizes and types of chain in common use were tested.

Three chain span lengths were tested:

1/ 1 m (39.5 in);
2/ 3 m (118.5 in); and
3/ 6 m (237.0 in).

3/ Procedures

3.1/ Test Apparatus

A special test rig was designed and constructed for these tests, as shown in Figure 1. The test rig consisted of a frame, about 7.3 m (24 ft) long. It was provided with three anchor points which allowed a test chain to be installed at lengths of 1, 3 and 6 m. A load cell and the test load binder were installed in series with the chain, and the test rig had a second anchor point to which the binder was attached.

Three types of load binder were used, as illustrated in Figure 2 :

1/ a Lebus model L-150 size 7-1 lever action, lever lock load binder, with a working load limit (WLL) of 2,449 kg (5,400 lb) and a minimum ultimate strength of 8,618 kg (19,000 lb);
2/ a Lebus model L-150 size 7-12 lever action, lever lock, spring loaded load binder, with a WLL of 2,449 kg (5,400 lb) and a minimum ultimate strength of 7,257 kg (16,000 lb); and
3/ a Lebus model L-140 size R-A ratchet load binder, with a WLL of 4,173 kg (9,200 lb) and a minimum ultimate strength of 14,969 kg (33,000 lb).

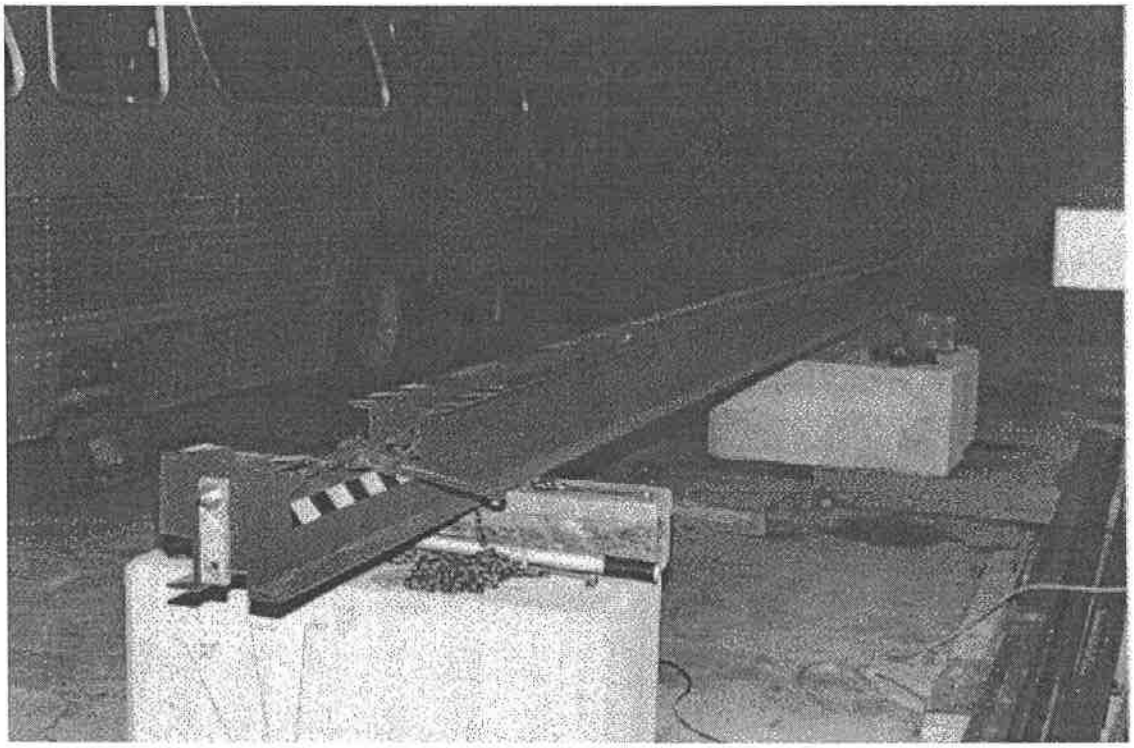

Figure 1/ View of Test Rig

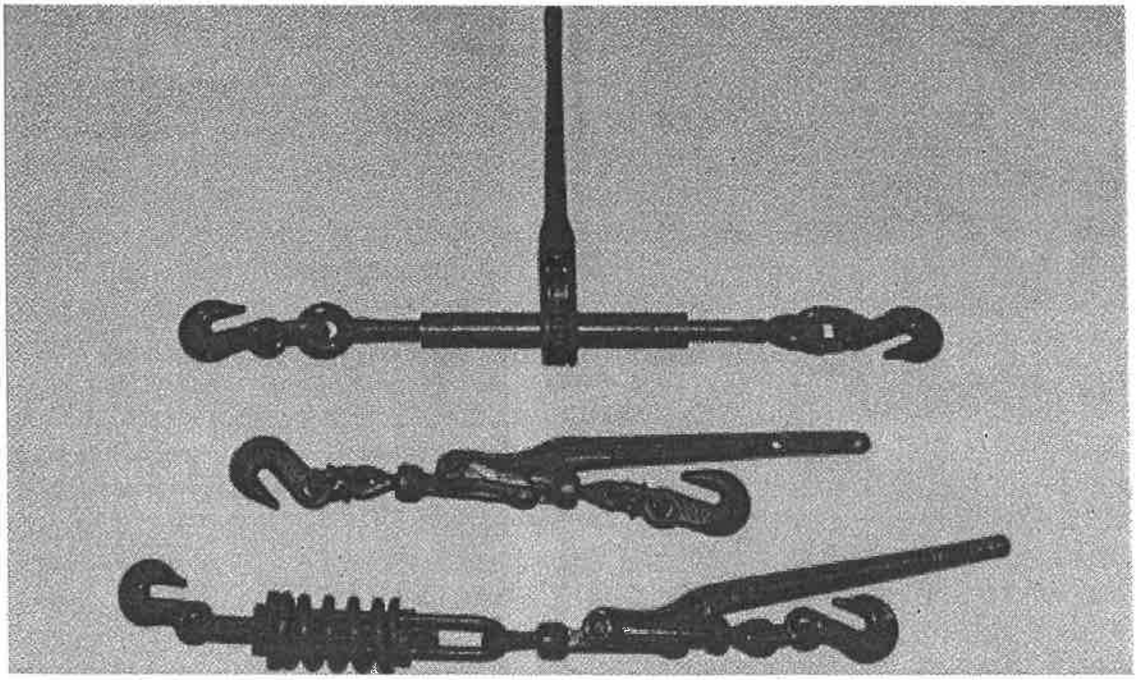

Figure 2/ Ratchet, Lever and Lever Spring Binders

The operation of a lever binder and its displacement are shown in Figure 3, and operation of a ratchet binder is shown in Figure 4. All three binders were tensioned by using a 0.61 m (24 in) pipe placed over the lever arm. This reflects common industry practice, although the manufacturer of the binders specifically recommends against it.

Three types of chain were tested:

1/ 1/4 in Crosby Spectrum 4, with a working load limit (WLL) of 1,179 kg (2,600 lb), and a minimum ultimate strength three times the WLL;
2/ 5/16 in Crosby Spectrum 8, with a WLL of 2,018 kg (4,450 lb), and a minimum ultimate strength four times the WLL; and
3/ 3/8 in Crosby Spectrum 4, with a WLL of 2,449 kg (5,400 lb), and a minimum ultimate strength three times the WLL.

3.2/ Instrumentation and Data Capture

A Strainsert Model SJ-F8 Type H load sensing stud, rated at 66.7 kN (15,000 lb), was attached to the chain through spherical joints that eliminated transfer of moments and torsion to measure tension in the chain, as shown in Figure 5. Data from this instrument were captured into a PC-based data acquisition system at a sample rate of 100 Hz, which provided adequate definition to measure tension characteristics of the chain.

3.3/ Test Procedure

Before the test program began, a series of experiments were conducted to determine some standard set points for the binders. The lever binder and load cell were installed in the test rig, and attached to the 3/8" chain, the strongest, set at its shortest length of 1 m. The position of the binder was adjusted until the operator of the binder could just lock the binder mechanism using the added leverage of a 0.61 m (24 in) pipe placed over the lever arm of the binder, from an initial chain tension of 1.33 kN (300 lb). The manufacturer of the binder recommends that no additional leverage be used when locking a lever binder. It is, however, common practice amongst truckers, so was used in this test to produce close to a "real world worst case" tension in the chain. When this point was located, it was recorded on a template as set point #1. Two other arbitrary set points were also recorded on the template, set point #1 plus 13 degrees and set point #1 plus 25 degrees. These three set points gave chain extensions of 39.7, 22.2 and 9.5 mm (1.563, 0.875 and 0.375 in) respectively. A similar experiment was conducted for the lever spring binder, and set points #2 and #3 were 15 and 30 deg beyond set point #1 respectively. These set points were also recorded on the template. The template and set point angles are illustrated in Figure 6. The mechanism for applying load to the ratchet binder is different, so the template was not used. Set point #1 for the ratchet was set arbitrarily at 540deg (1 1/2 turns) of the lever arm, set point #2 was 360 degrees (1 turn), and set point #3 was 180 degrees (1/2 turn). These three set points gave chain extensions of 9.5, 6.4 and 3.2 mm (0.375, 0.250 and 0.125 in) respectively.

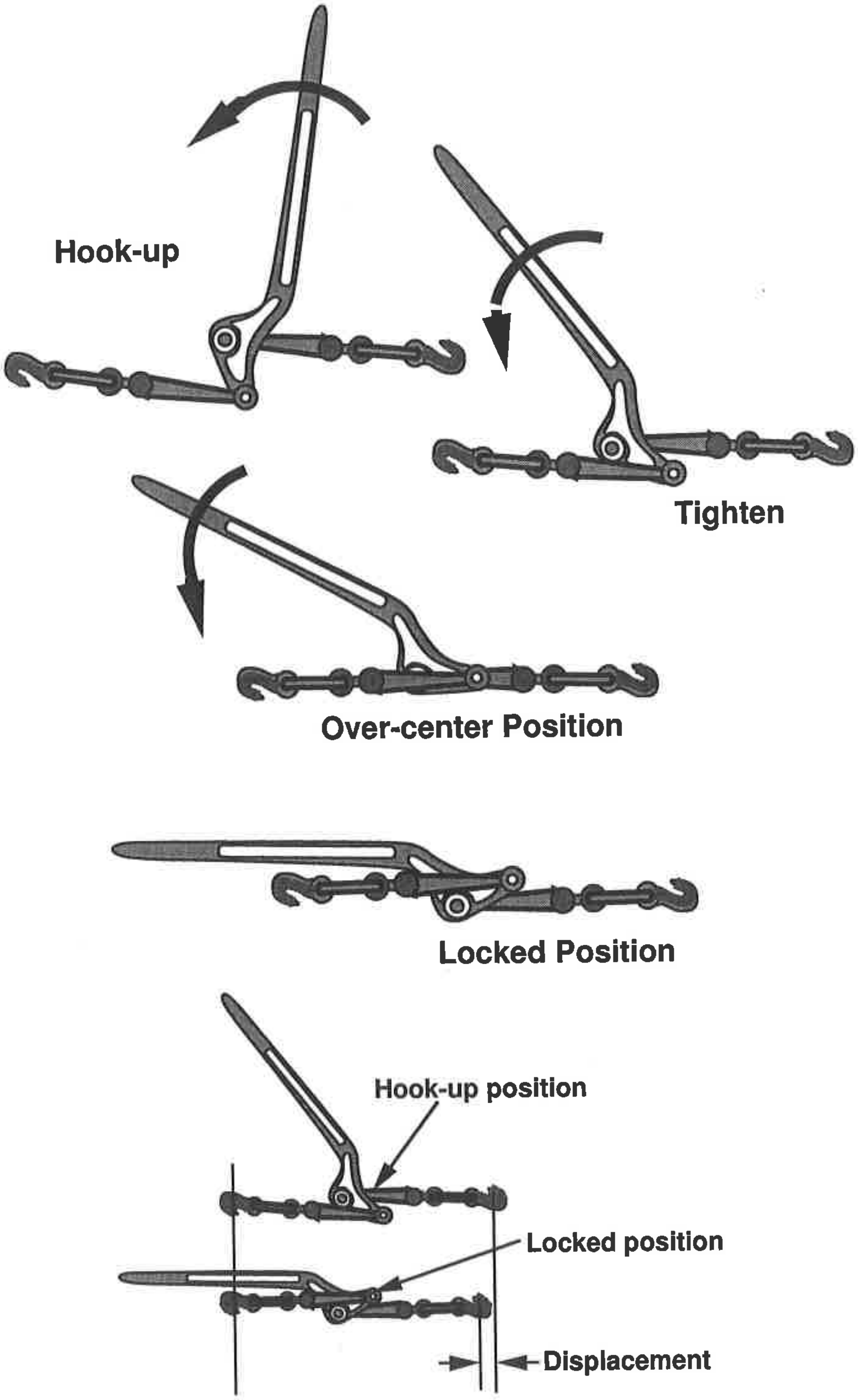

Figure 3/ Operation of Lever Load Binder

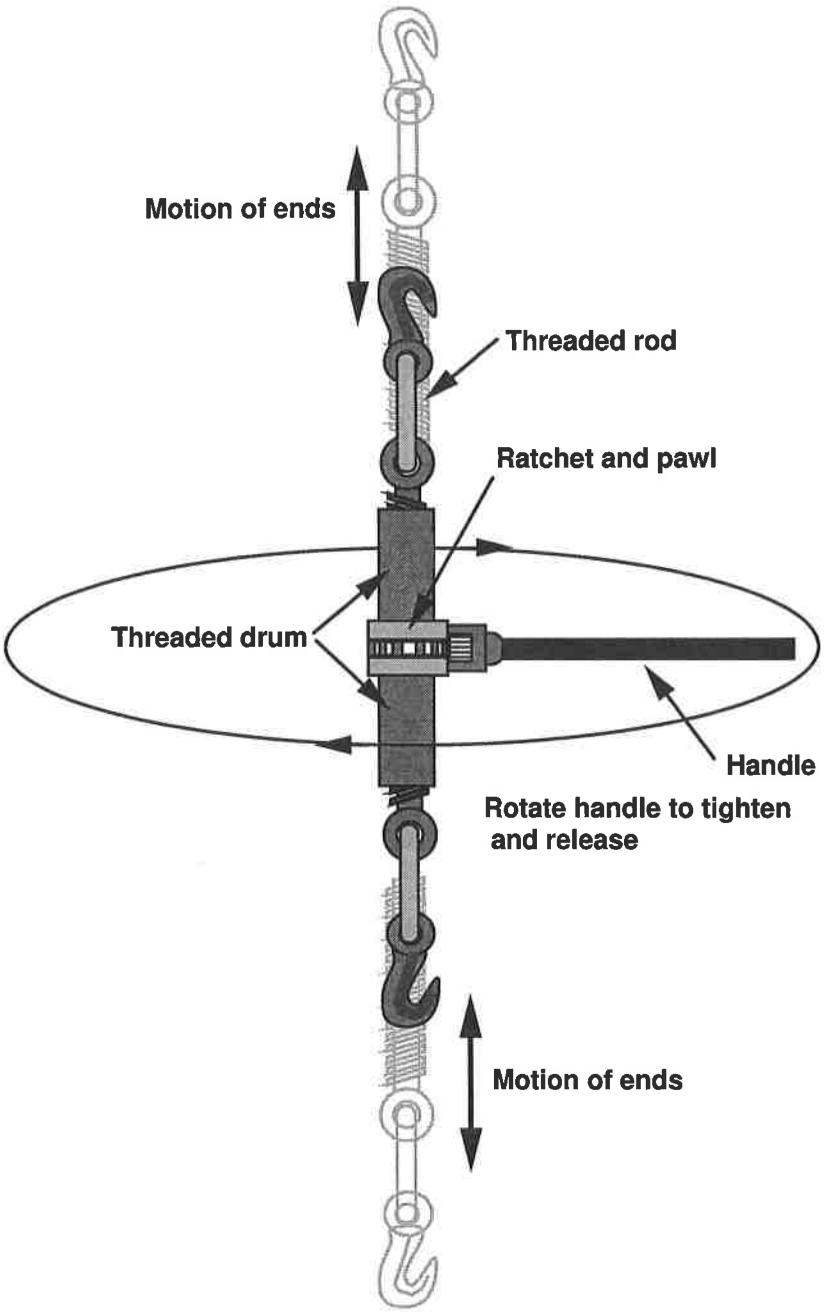

Figure 4/ Operation of Ratchet Load Binder

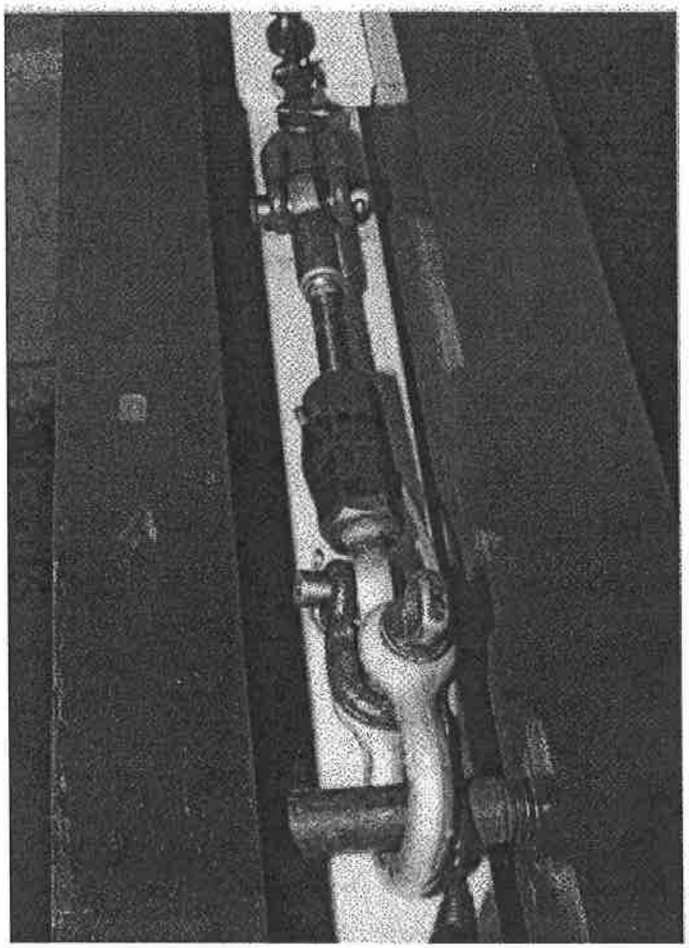

Figure 5/ Load Cell

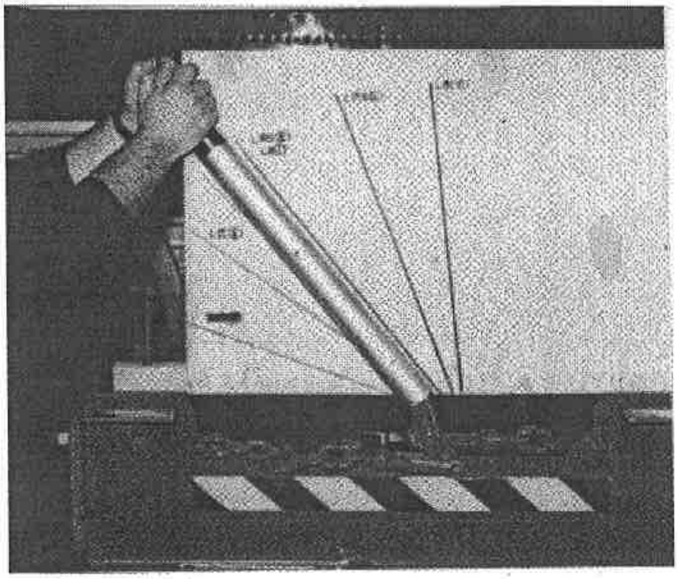

Figure 6/ Set Point Template with Lever Binder and Pipe

For the two lever binders, set point #1 imparted a load in the chain based on the maximum force that could be applied by the operator on the binde, whereas for the ratchet binder, it imparted a load that offered moderately high resistance to motion of the ratchet jackscrew.

For any particular test, the binder, chain and load cell were mounted in the test rig, and the load cell was connected to the data acquisition system. The load cell output was zeroed, data acquisition was started and a system calibration was applied and recorded, followed by a few seconds of zero data. Data acquisition was then suspended. The chain length was now adjusted so that the chain could be tensioned to 1.33 kN (300 lb) at the desired binder set point. When all was ready, data acquisition was resumed and a force was applied to the binder to bring it to the locked position, as shown in Figures 7 and 8 for the lever binder, and Figure 9 for the ratchet binder. After holding the locked position for about ten seconds, the binder was released. Data acquisition was stopped when the chain was slack.

After each test, the data in the PC were saved to a file on the hard disk. The file was retrieved, and the calibrations were examined and adjusted if necessary. A quick look at the data was taken to ensure that the results were reasonable. If there was any question, the run was repeated, and sometimes adjustments were made to test conditions to ensure consistent and repeatable data. The file was then 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. Color 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 from each run was simply calibrated and de-trended in a specialized test data processing program written at MTO. Peak and steady chain tension values were extracted manually, entered in a spreadsheet program, and were summarized in tables and graphical form for this report.

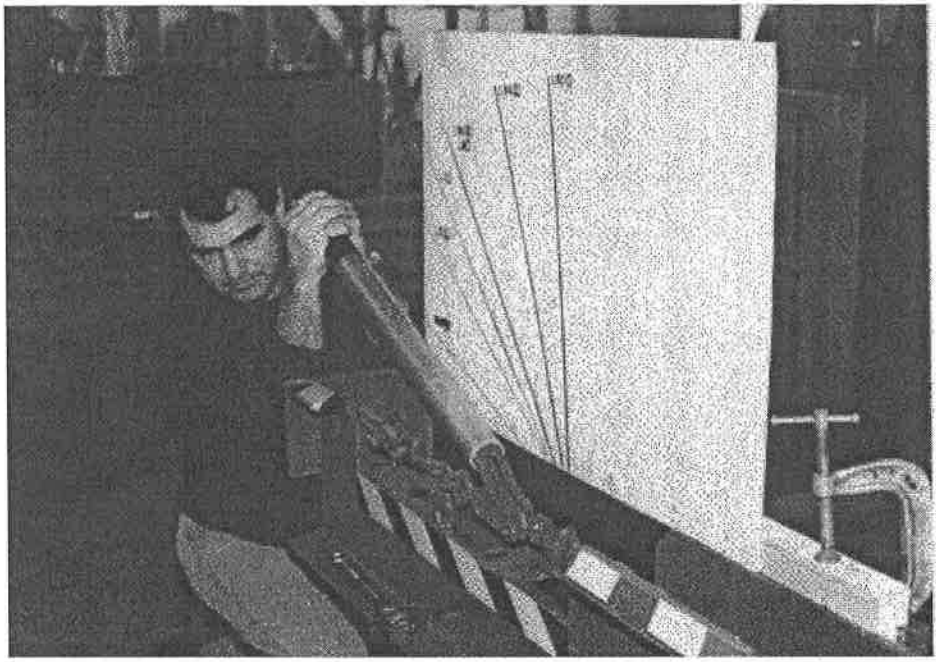

Figure 7/ Tightening a Lever Binder to Achieve Lock

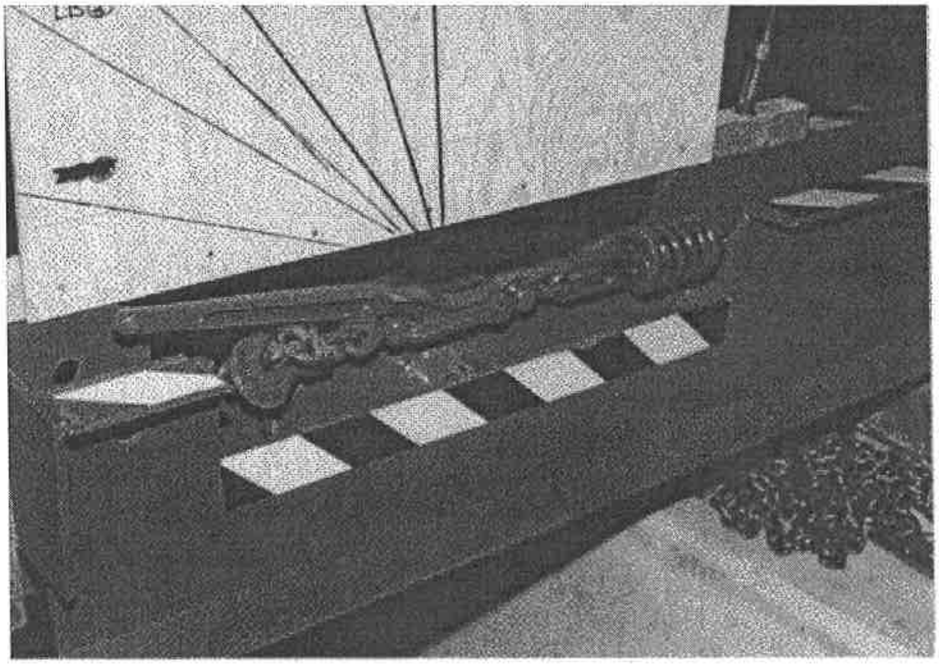

Figure 8/ Lever Spring Binder, Shown Locked

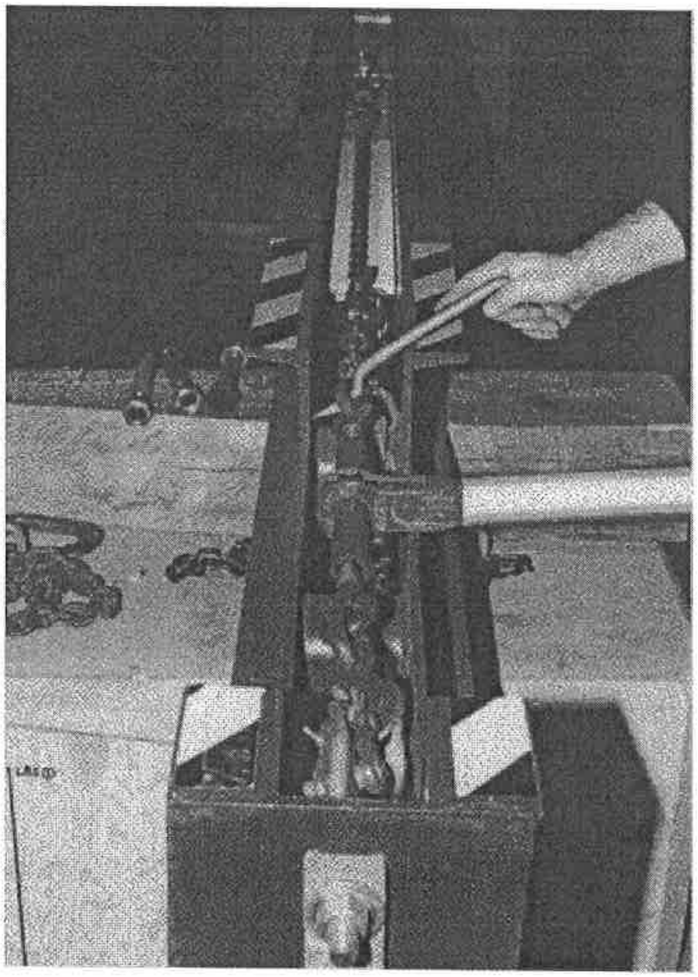

Figure 9/ Ratchet Binder, Shown Locked

3.5/ Test Matrix

The scope identified three binders, three binder set points, three chains and three chain lengths, for a total of 81 combinations. The 27 combinations for one binder are presented in Table 1.

Table 1/ Test Matrix for each binder

Case	Binder set point	Chain			Chain span		
		1/4 in	5/16 in	3/8 in	1 m	3 m	6 m
1(a)	1	X			X		
1(b)	2	X			X		
1(c)	3	X			X		
2(a)	1	X				X	
2(b)	2	X				X	
2(c)	3	X				X	
3(a)	1	X					X
3(b)	2	X					X
3(c)	3	X					X
4(a)	1		X		X		
4(b)	2		X		X		
4(c)	3		X		X		
5(a)	1		X			X	
5(b)	2		X			X	
5(c)	3		X			X	
6(a)	1		X				X
6(b)	2		X				X
6(c)	3		X				X
7(a)	1			X	X		
7(b)	2			X	X		
7(c)	3			X	X		
8(a)	1			X		X	
8(b)	2			X		X	
8(c)	3			X		X	
9(a)	1			X			X
9(b)	2			X			X
9(c)	3			X			X

4/ Results

Figure 10 superimposes the characteristic change in chain tension when a lever binder and a ratchet binder tighten a 1/4 in chain 1 m long. A spike occurs as a the lever mechanism passes the over-center position to lock. The tension then becomes uniform in the locked position. When the lever is released, there is a smaller spike as the lever reverses past the over-center position. This characteristic is shared by both types of lever binder. The ratchet binder, with its proportional loading mechanism, increased the tension in steps, with each sweep of the lever. There was sometimes a small spike at the beginning of a step, but this was due to the operator's handling of the binder during tightening. It must be restrained to prevent the entire mechanism from rotating, and these restraining forces induce a slightly higher tension in the chain.

Figure 11 illustrates the change in chain tension when a lever binder tightens a 1/4 in chain 1 m long, with results for the three different set points superimposed.

The peak tensions recorded in the chain for each set point and each binder are presented in Tables 2, 3 and 4, and the steady tensions are presented in Tables 4, 5 and 6. These results are summarized graphically in Figure 12. As the chain was lengthened, the maximum peak and maximum uniform tension decreased at similar set points, as shown in Figure 13. Larger chains developed higher tensions at identical set points, as shown in Figure 14.

5/ Analysis and Discussion

The use of the 0.61 m (24 in) pipe to extend the lever of a lever binder allowed the operator to induce higher chain tensions than if the lever alone was used. Even with use of this pipe, the lever binders could not induce sufficient tension to fail the chain with the strength of the operator. However, the ratchet binder could be tightened significantly in excess of the working load limit of any of the chains. At set point #1, the operator encountered resistance to ratchet screw rotation, but could have continued to apply more load. The forces encountered in the assembly were such that further tightening of the ratchet would have not been advisable. The working load limit of the ratchet binder used was slightly less than double that of the lever binders, and although there was little doubt that the ratchet binder would survive the test, the chain could be seriously overloaded.

The ratchet binder had the potential to achieve the highest tension in a chain, primarily due to its theoretical mechanical advantage of approximately 650 with the 0.61 m (24 in) pipe. The effective mechanical advantage of the ratchet was somewhat lower than 650 due to the friction in the ratchet spool and double screw threads. The lever binder had a nominal mechanical advantage of approximately 10, that increases as the lever is rotated towards the locked position. The inherent friction in the lever binder is substantially less because it is a second class lever with two freely rotating fulcrums.

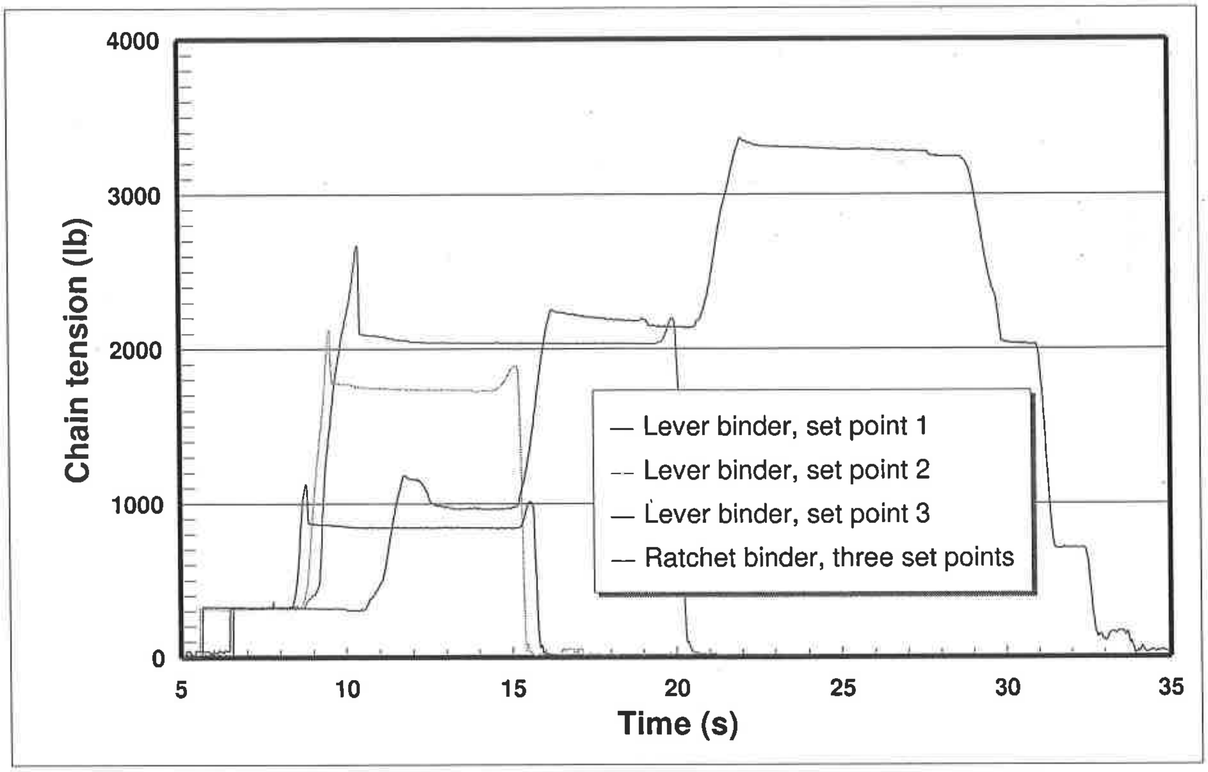

Figure 10/ Tension in 1 m Long 1/4 in Chain, Three Set Points, Lever and Ratchet Binders

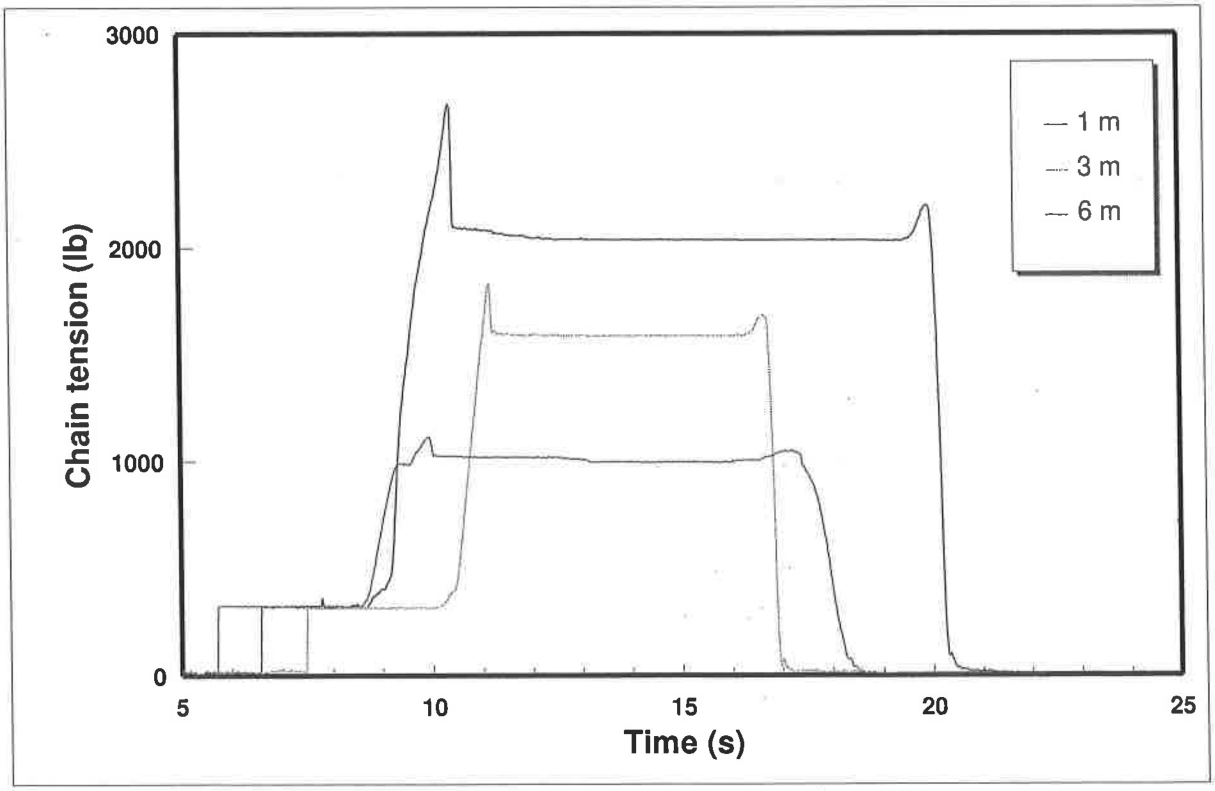

Figure 11/ Tension Developed in 1/4 in Chains of Different Lengths for Set Point 1

Table 2/ Peak tension for 1/4 in grade 4 chain with 1,179 kg (2,600 lb) WLL

Binder	Set point #1			Set point #2			Set point #3		
	Chain length			Chain length			Chain length		
	1 m	3 m	6 m	1 m	3 m	6 m	1 m	3 m	6 m
Lever	2668	1838	1116	2125	1403	912	1124	825	576
Lever spring	3900	2521	2023	2019	1713	1369	1082	909	788
Ratchet	3363	2000	1240	2257	1339	928	1181	901	637

Table 3/ Peak tension for 5/16 in grade 8 chain with 2,018 kg (4,450 lb) WLL

Binder	Set point #1			Set point #2			Set point #3		
	Chain length			Chain length			Chain length		
	1 m	3 m	6 m	1 m	3 m	6 m	1 m	3 m	6 m
Lever	4474	2321	1351	3186	1592	1037	1524	950	678
Lever spring	3280	2619	2192	1917	1724	1422	984	878	848
Ratchet	5554	2797	1777	3605	1838	1309	1788	1056	833

Table 4/ Peak tension for 3/8 in grade 4 chain with 2,449 kg (5,400 lb) WLL

Binder	Set point #1			Set point #2			Set point #3		
	Chain length			Chain length			Chain length		
	1 m	3 m	6 m	1 m	3 m	6 m	1 m	3 m	6 m
Lever	4285	2745	2020	3445	2178	1566	1747	1180	792
Lever spring	5414	3065	2612	2008	1943	1687	1105	1015	894
Ratchet	6000	3485	2483	4432	2347	1747	2370	1260	1030

Table 5/ Constant tension for 1/4 in grade 4 chain with 1,179 kg (2,600 lb) WLL

Binder	Set point #1			Set point #2			Set point #3		
	Chain length			Chain length			Chain length		
	1 m	3 m	6 m	1 m	3 m	6 m	1 m	3 m	6 m
Lever	2038	1320	999	1732	1275	780	841	667	470
Lever spring	3669	2446	1966	1906	1638	1317	1007	867	739
Ratchet	3242	1925	1240	2136	1240	909	793	667	599

Table 6/ Constant tension for 5/16 in grade 8 chain with 2,018 kg (4,450 lb) WLL

Binder	Set point #1			Set point #2			Set point #3		
	Chain length			Chain length			Chain length		
	1 m	3 m	6 m	1 m	3 m	6 m	1 m	3 m	6 m
Lever	4050	2144	1260	2778	1407	946	1128	780	565
Lever spring	3016	2517	2144	1807	1645	1384	931	837	825
Ratchet	5478	2782	1762	3537	1826	1282	1698	1014	810

Table 7/ Constant tension for 3/8 in grade 4 chain with 2,449 kg (5,400 lb) WLL

Binder	Set point #1			Set point #2			Set point #3		
	Chain length			Chain length			Chain length		
	1 m	3 m	6 m	1 m	3 m	6 m	1 m	3 m	6 m
Lever	3685	2460	1815	2778	1902	1327	1082	931	667
Lever spring	4945	2895	2536	1868	1838	1626	1010	901	863
Ratchet	5740	3390	3390	4224	2250	1725	2190	1128	1030

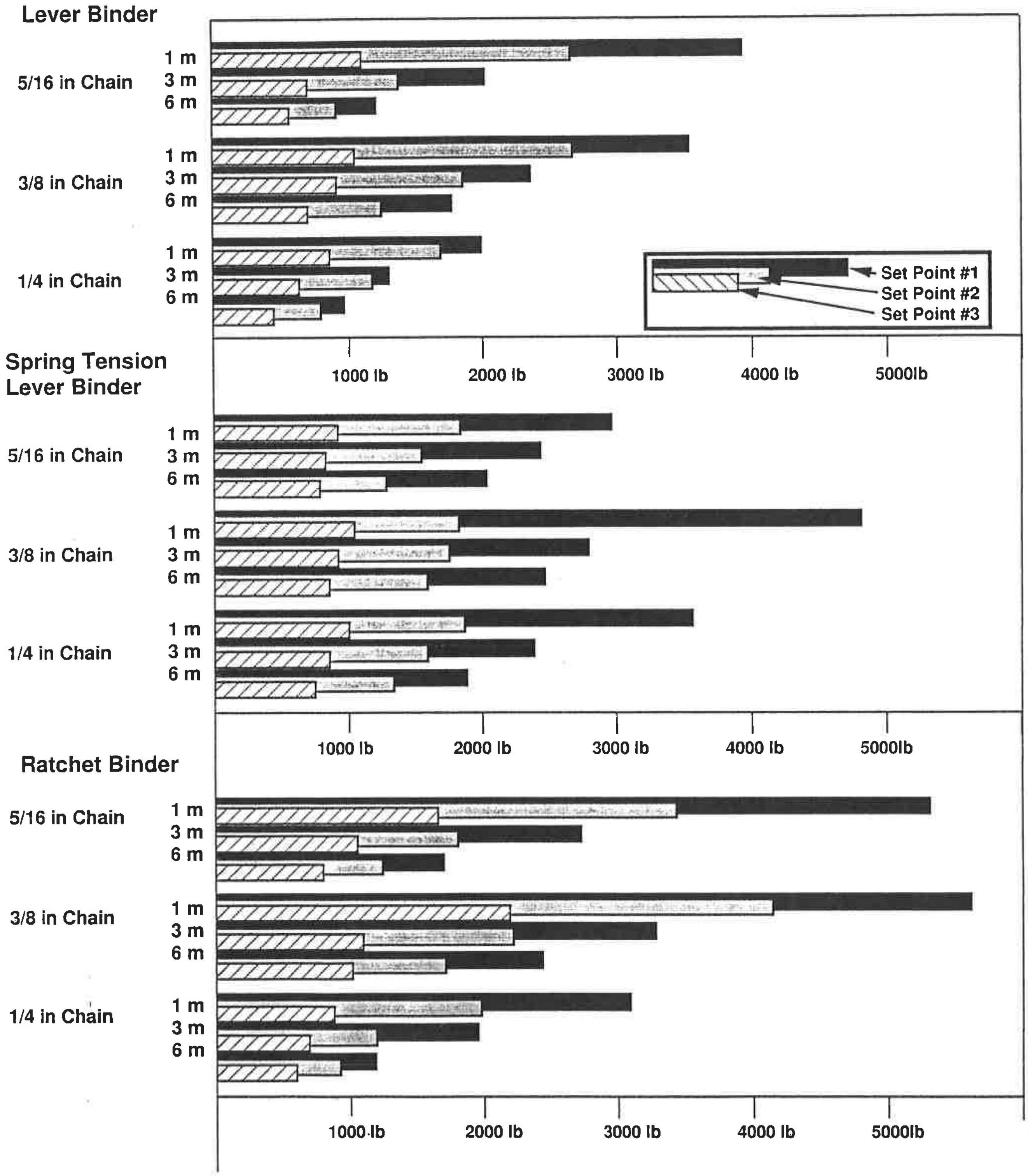

Figure 12/ Comparison of Tension Force, 3 Chains / 3 Binders / 3 Lengths and 3 Set Points.

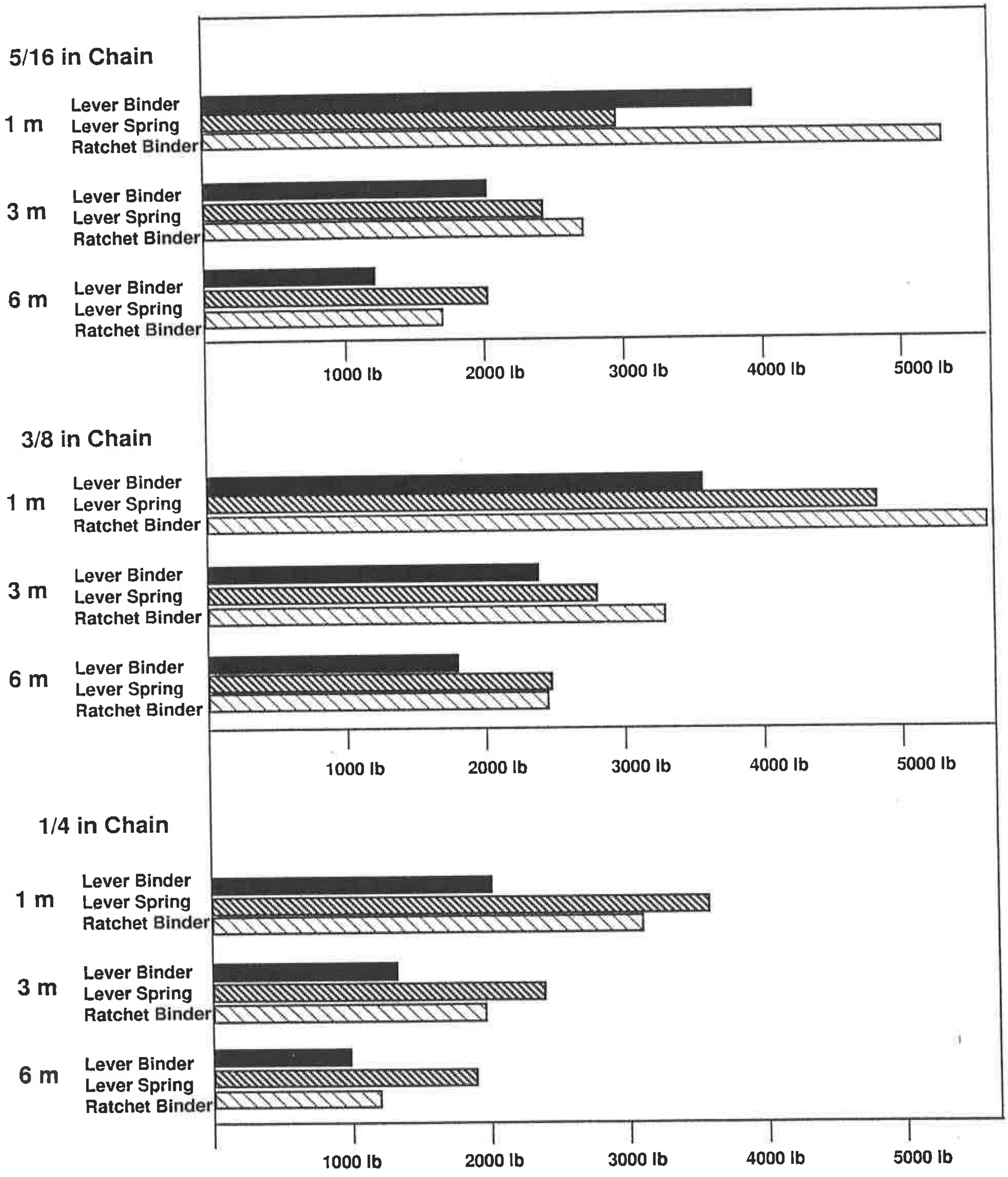

Figure 13/ Effect of Chain Length on Tension
(Set Point #1)

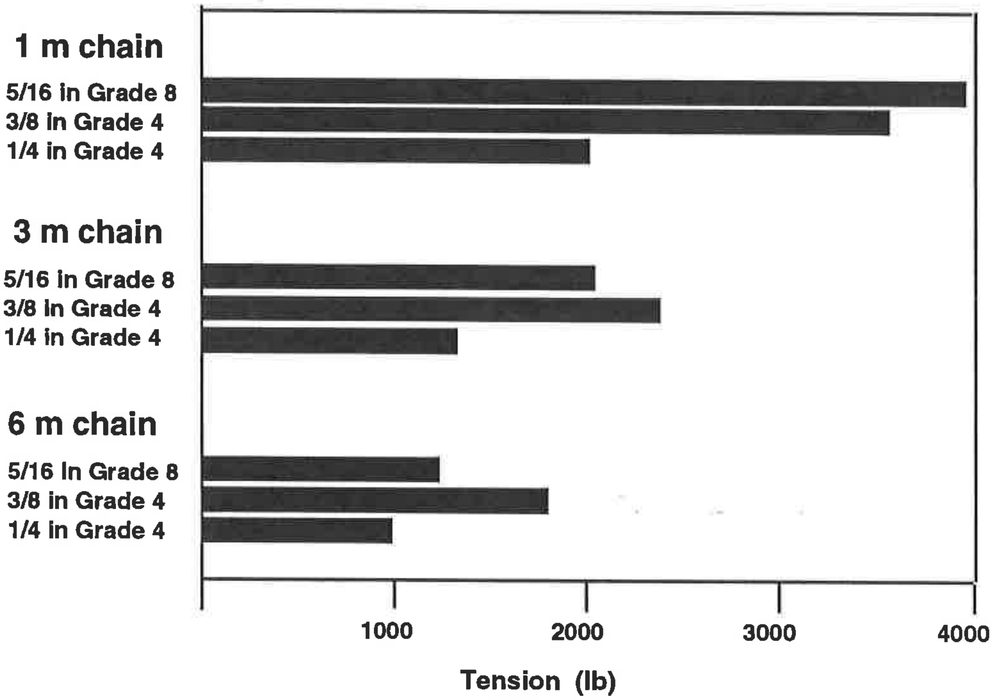

Figure 14/ Effect of Chain Size/Type on Tension (Set Point #1, Lever Binder)

The chain length significantly influenced its resulting tension, for a given binder set point, as shown in Figure 12. Assuming that the chain behaves like an extension spring, in its elastic range, lengthening it would lower its spring constant. Because of the shape of chain links and their contact on adjacent links, the overall chain characteristic was expected to be slightly different than an extension spring. This is due to high point loads at the contact point of two radii at the link connection, flattening of burrs and forge flashing, possible lack of link uniformity, and non-linear displacements due to shape and eccentric forces at the link.

The chain size influenced the resulting tension for a given set point and length. The larger link diameter chain (3/8 in) produced higher tension in most cases with 5/16" chain next and lastly 1/4" chain. The differences varied between approximately 8.9 kN (2,000 lb) for a short (1 m) chain span to approximately 3.34 kN (750 lb) for a 6 m chain span. The effect of chain size and type is shown in Figure 14.

6/ Conclusions

A chain assembly was tested with three different types of load binder to determine the tension that can be generated through typical usage. Each binder type was used to impart a load from three different set-points with the assistance of a 0.61 m (24 in) pipe placed over the lever arm. Three different chain lengths, 1, 3, and 6 m and three different chain sizes, 1/4, 5/16, and 3/8 in were used.

When lever type binders were used in conjunction with a 0.61 m (24 in) pipe the resulting tension in the chain can reach the working load limit of that chain and in some cases slightly higher. The lever binder had the potential to tension the test chains well beyond the working load limit. The length of the chain was found to be a significant influence on the resulting tension for fixed set points.

A lever binder cannot tension a chain above its working load limit unless the operator uses excessive force. This is usually done using a pipe to extend the lever, a practice not recommended by the manufacturer. The mechanical advantage of the lever binders tested was about 7, so could produce a tension of 9.3 kN (2,100 lb) by bearing all the weight of a 136 kg (300 lb) operator on the lever. The location and orientation of most lever binders on trucks make this unlikely. However, the test operator was able to produce tensions near the chain's working load limit using a pipe to double the mechanical advantage.

The ratchet type binder exerted reasonable loads when operated by personnel who were familiar with its mechanical advantage and capabilities. Such operation could produce tensions at or near working load limits of the test chains. The ratchet binder tested could significantly over-tension a chain by excessive ratcheting.

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

7/ Recommendations

It is recommended that lever type binders not be used with devices intended to enhance their mechanical advantage and should be secured by use of the operators strength only. Ratchet type binders should only be used with due care, without assistive devices and with a knowledge of chain and cargo tiedown requirements.

It would be very desirable for some simple means to be developed for operators to estimate the actual tension imparted to a chain.

When long span chains are used with a single binder care should to taken to ensure that there are no snags, hang-ups, or kinks in the chain that would lead to premature loss of tension.

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