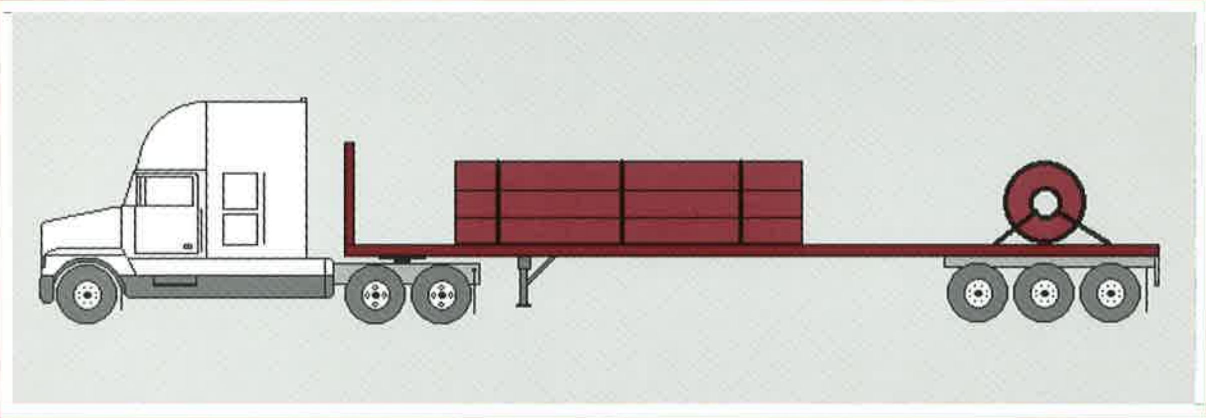
CCMTA Load Security Research Project

Report # 8

LOAD CAPACITY OF NAILED WOOD BLOCKING



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

CCMTA Load Security Research Project

Report # 8

LOAD CAPACITY OF NAILED WOOD BLOCKING

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 series of tests were conducted to determine the forces required to cause dislodgement of wood blocking nailed to a truck deck. The tests examined different nailing methods and nail sizes.

The results show that nails driven perpendicular to the deck provide greater resistance than nails driven at an angle. While hardwood decks offered greater resistance than softwood decks, the species of block was not very significant. Results correlated well with limited data offered by standards for intermodal shipments of the Association of American Railroads.

Recommendations are made that blocking should be considered as part of the cargo securement system.

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 securement properties of nailed wood blocking were largely unknown. The work reported here is outlined in Section 9.2 and 9.3 of the project proposal. It is a series of tests to determine the effects of various nailing techniques and nail sizes on the force required to dislodge wood blocks nailed to a truck deck.

A test machine was designed and built to apply a force to a wood block nailed to a deck on the machine, with means to record the force and displacement associated with dislodgement. Hardwood and softwood blocks were used, for four nailing methods and five nail sizes. Deck materials examined were pine and oak, with grain either parallel or perpendicular to the direction of force.

It was found that nailed joints with the nail driven perpendicular through the block into the deck were stronger than other nailing methods. The hardwood deck offered significantly greater resistance than the softwood deck. The species of block had little effect on the resistance. It was found that pushes with the grain perpendicular to the line of force offered greater resistance to dislodgement than pushes parallel to the line of force.

Analysis of the mechanics of joint failure revealed that when the nail must bend significantly to allow extraction, without significantly damaging the deck nail hole, then the dislodgement forces are high. Too much bending, however, damages the nail hole to the point that nail extraction from the deck is relatively easy. The optimal joint has the nail at right angles to the surface, which allows a compromise of bending and nail hole distortion. The results correlated well with limited data from the Association of American Railroads, "Intermodal Loading Guide for Products in Closed Trailers and Containers" for specific nailed connections.

Recommendations for the safe and adequate use of nailed blocks were generated from the data and conclusions, and a recommended Working Load Limit for nailed blocking was proposed.

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.

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.

Wood blocks are often nailed to the deck of a truck against cargo to prevent movement of the cargo on the deck. While nailed wood blocking is widely used by carriers, it is not given credit by all jurisdictions for the securement it provides. Nailed wood blocking is prescribed by railroads for intermodal uses, and some tables of working load limits are published [2]. The capacity of various methods of nailing wood blocking, and of various sizes of nail, were not widely known. This series of tests was undertaken to determine the forces required to dislodge nailed wood blocking, and to understand the characteristics of the process of dislodgement, for different nailing methods and nail sizes. The work reported here is outlined in Sections 9.2 and 9.3 of the project proposal [1].

2/ Test Program

2.1/ Objectives

The objectives of this series of tests were to :

1/ Determine how nailing method affects the force required to dislodge nailed wood blocking from a truck deck;
2/ Determine how nail size affects the force required to dislodge nailed wood

blocking;
3/ Determine the effect of block and deck material on dislodgement force; and
4/ Understand the mechanics of dislodgement.

2.2/ Scope

All tests were conducted on two truck deck materials :

1/ Oak; and
2/ Pine.

For the nailing method tests, three block materials were used :

1/ Pine;
2/ Maple; and
3/ Spruce.

Four nailing methods were used :

1/ Toenailing at the front of the blocking, on the side away from the applied force;
2/ Toenailing at the rear of the blocking;
3/ Double toenailing, both front and rear; and
4/ An unsecured block with nails driven perpendicularly through a 5x10 cm (2x4 in) back-up block.

These are shown in Figure 1. All nailing method tests were conducted with 8.90 cm (3.5 in) common steel nails. The majority of nailing method tests were conducted with the deck material grain parallel to the applied force, with a more limited range of tests with the grain normal to the force.

The nail size tests were conducted using 10x10 cm (4x4 in) pressure-treated spruce blocks notched along two sides to produce an "L" shaped section with a leg width of 4.5 cm (1.75 in). The effect of grain was taken out of consideration by placing the blocking on strips of 14 gauge steel. The blocking was nailed straight through, perpendicular to the deck, as if it were a standard 5x10 cm (2x4 in) block while allowing for the high push position.

The following steel nails were tested :

1/ 6.35 cm (2.5 in) uncoated common;
2/ 8.90 cm (3.5 in) uncoated common;
3/ 8.90 cm (3.5 in) spiral galvanized;
4/ 12.7 cm (5 in) uncoated common; and
5/ 15.2 cm (6 in) uncoated common.

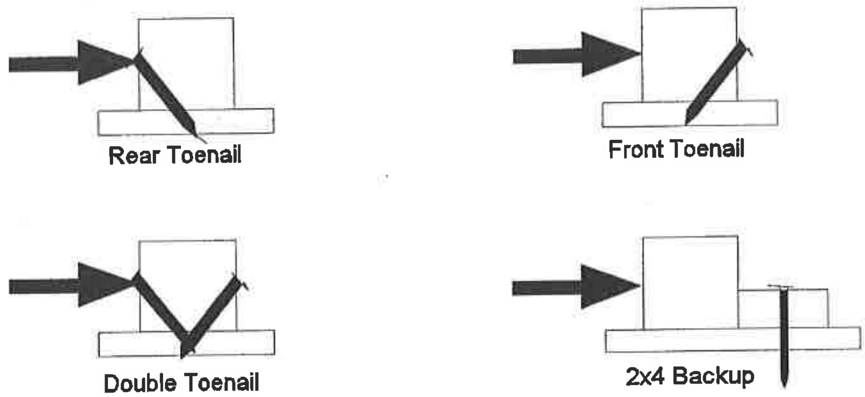


Figure 1/ Block Nailing Techniques
Arrow indicates force direction

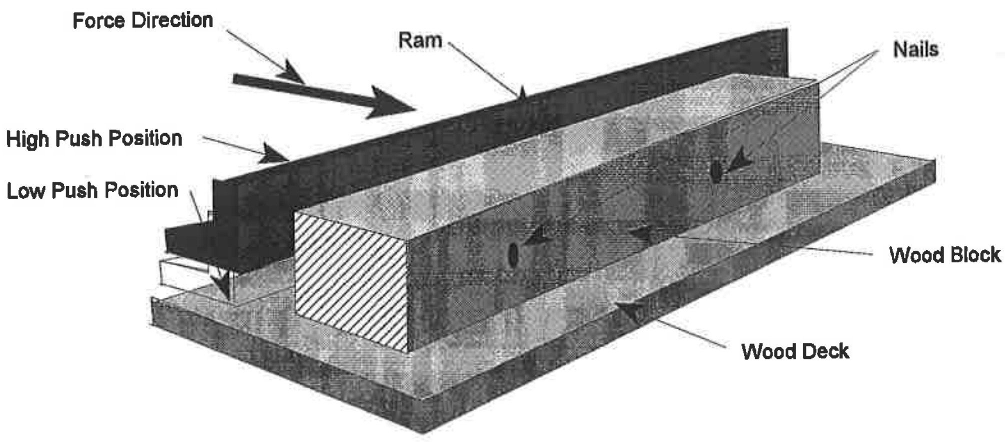


Figure 2/ Arrangement of Ram for Nailed Wood Blocking Tests

3/ Procedures

3.1/ Test Apparatus

The tests were conducted with a test machine built specially for this purpose. This provided a platform on which a piece of truck deck material could be mounted. A pneumatic actuator with a stroke of 20.3 cm (8 in) and a maximum force of 13.4 kN (3,000 lb) carried a ram, and was arranged to push the ram horizontally over and parallel to the deck surface. The ram was adjustable, such that its lowermost point could be 2.5 cm (1 in) or 7.5 cm (3 in) above the deck, as shown in Figure 2. The ram was instrumented to measure the force applied to the block, and the displacement of the ram. General views of the machine are shown in Figure 3.

3.2/ Instrumentation and Data Capture

A Strainsert model CPA-0.75 clevis pin load sensor, rated at 26 kN (6,000 lb), was used to measure the force at the ram face. A Unimeasure model P510-20 pull cord transducer was attached to the bed, and its cord was attached to the ram to measure forward motion of the ram. Data from these two instruments was captured into a PC-based data acquisition system at a sample rate of 200 Hz per channel. This sample rate provided adequate definition to measure force and displacement characteristics of the block.

3.3/ Test Procedures

For a series of tests of nailing method, the deck material was placed on the bed of the test machine, and bolted into place. The ram face was moved forward approximately 2.5 cm (1 in) from its retracted position, and the sample block was placed against it. The block was nailed into place, if possible, otherwise the deck material was removed from the test machine, the block was nailed , and the deck was re-installed. Hardwood blocks were pre-drilled for the nail, to avoid risk of splitting the block as the nail was driven home. New nails were used for each test. The ram was then retracted to its original position, instrumentation was zeroed, the data acquisition system was started, and a three point calibration (zero, half-scale and full-scale) was recorded, followed by at least three seconds of zero data. Data acquisition was then stopped, and the ram was brought out until it just made contact with the block. Data acquisition was re-started, the actuator was energised, and after the ram dislodged the block from the bed, the test was complete and the data acquisition was stopped.

For a series of tests of nail size, the deck material was placed on the bed of the test machine, and bolted into place. Several slats of 14 gauge steel banding 2.5x20 cm (1x8 in) were laid on the deck parallel to the push direction, to reduce the friction and focus on the forces to deform and extract the nail. The ram face was moved forward approximately 2.5 cm (1 in) and the sample block is placed against it, on the slats, and nailed into place. Thereafter, the procedure followed that described above.

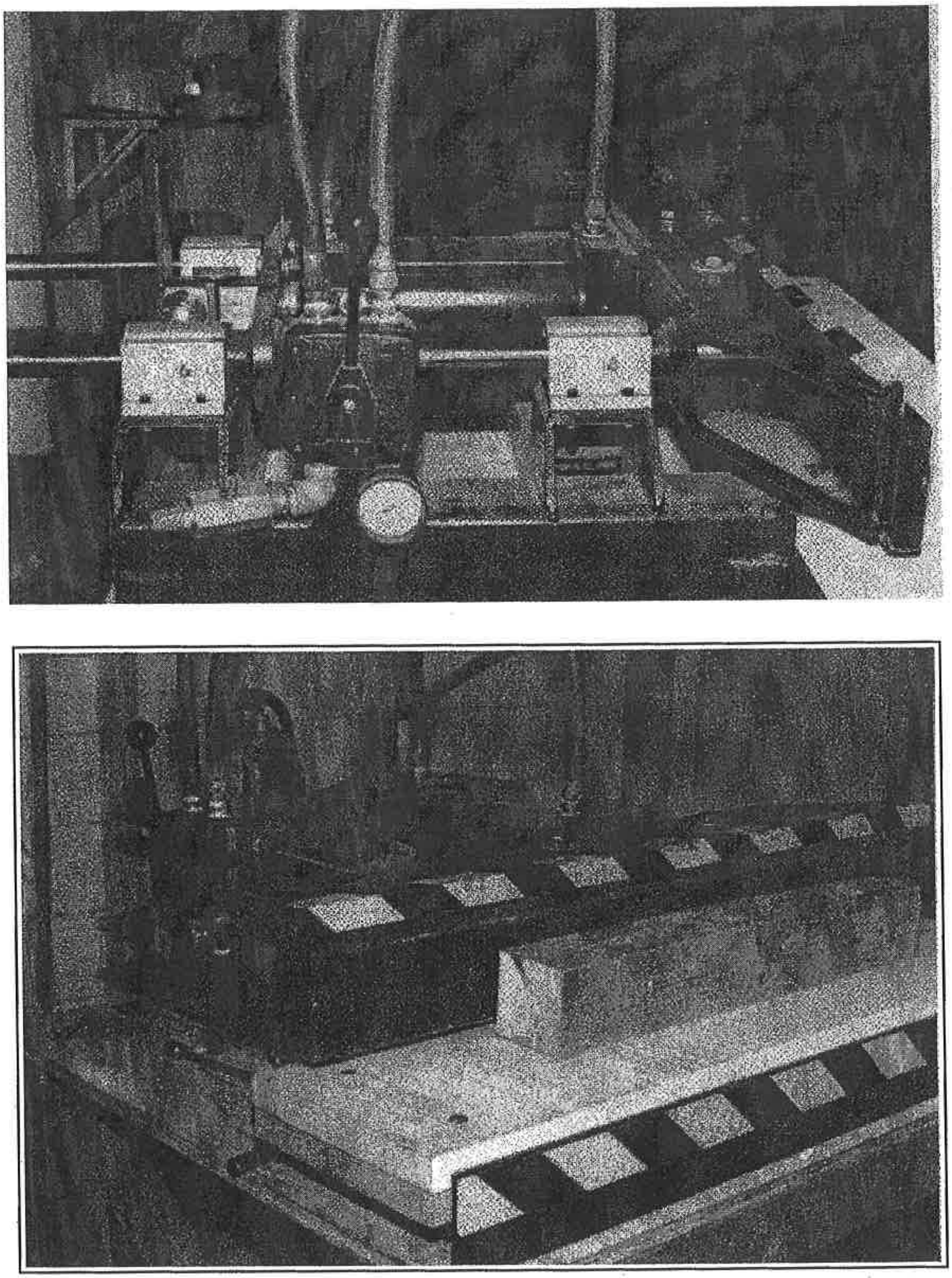


Figure 3/ Nailed Wood Blocking Test Machine

Planed wood and new nails were used for all tests. All contact surfaces were clean, smooth and dry.

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, including and notes and sketches on the manner and characteristic of dislodgement.

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, and a file was produced that could be read in by a spreadsheet program. This was used to determine peak values and energy distributions, and the results were accumulated in a summary file, where average values were computed and graphical summaries of the results were prepared.

3.5/ Test Matrix

The scope for the nail method test identified two deck materials, three block materials, four nailing methods, two grain directions and two ram heights. The scope for the nail size test identified two bed materials, one block material, five nail types and two ram heights. Combinations were selected that eliminated those conditions judged unlikely to occur in daily practice. The combinations included in the two phases of the test are shown in Tables 1 and 2, below.

Table 1/ Test Matrix for Nailing Methods

Run	Bed	Block	Rear Toenail	Front Toenail	Double Toenail	2X4 Backup	Grain	Push
1(a)	Oak	Pine	X				Par	Low
1(b)	Oak	Pine	X				Par	High
1(c)	Oak	Pine		X			Par	Low
1(d)	Oak	Pine		X			Par	High
1(e)	Oak	Pine			X		Par	Low
1(f)	Oak	Pine			X		Par	High
1(g)	Oak	Pine				X	Par	Low
1(h)	Oak	Pine				X	Par	High
2(a)	Oak	Maple	X				Par	Low
2(b)	Oak	Maple	X				Par	High
2(c)	Oak	Maple		X			Par	Low
2(d)	Oak	Maple		X			Par	High
2(e)	Oak	Maple			X		Par	Low
2(f)	Oak	Maple			X		Par	High
3(a)	Oak	Spruce	X				Par	Low
3(b)	Oak	Spruce	X				Par	High
3(c)	Oak	Spruce		X			Par	Low
3(d)	Oak	Spruce		X			Par	High
3(e)	Oak	Spruce			X		Par	Low
3(f)	Oak	Spruce			X		Par	High
4(a)	Pine	Pine	X				Par	Low
4(b)	Pine	Pine	X				Par	High
4(c)	Pine	Pine		X			Par	Low
4(d)	Pine	Pine		X			Par	High
4(e)	Pine	Pine			X		Par	Low

Table 1/ Test Matrix for Nailing Methods

Run	Bed	Block	Rear Toenail	Front Toenail	Double Toenail	2X4 Backup	Grain	Push
4(f)	Pine	Pine			X		Par	High
4(g)	Pine	Pine				X	Par	Low
4(h)	Pine	Pine				X	Par	High
5(a)	Pine	Maple	X				Par	Low
5(b)	Pine	Maple	X				Par	High
5(c)	Pine	Maple		X			Par	Low
5(d)	Pine	Maple		X			Par	High
5(e)	Pine	Maple			X		Par	Low
5(f)	Pine	Maple			X		Par	High
6(a)	Pine	Spruce	X				Par	Low
6(b)	Pine	Spruce	X				Par	High
6(c)	Pine	Spruce		X			Par	Low
6(d)	Pine	Spruce		X			Par	High
6(e)	Pine	Spruce			X		Par	Low
6(f)	Pine	Spruce			X		Par	High
7(a)	Oak	Maple	X				Perp	Low
7(b)	Oak	Maple	X				Perp	High
7(c)	Oak	Maple		X			Perp	Low
7(d)	Oak	Maple		X			Perp	High
7(e)	Oak	Maple			X		Perp	Low
7(f)	Oak	Maple			X		Perp	High
7(g)	Oak	Maple				X	Perp	Low
7(h)	Oak	Maple				X	Perp	High

Table 2/ Test Matrix for Nail Size

Run	Bed	Nail Type and Size	Quantity Used	Push
1(a)	Oak	6.35 cm (2.5 in) common	1	Low
1(b)	Oak	6.35 cm (2.5 in) common	1	High
1(c)	Oak	6.35 cm (2.5 in) common	2	Low
1(d)	Oak	6.35 cm (2.5 in) common	2	High
1(e)	Oak	6.35 cm (2.5 in) common	3	Low
1(f)	Oak	6.35 cm (2.5 in) common	3	High
2(a)	Oak	8.90 cm (3.5 in) common	1	Low
2(b)	Oak	8.90 cm (3.5 in) common	1	High
2(c)	Oak	8.90 cm (3.5 in) common	2	Low
2(d)	Oak	8.90 cm (3.5 in) common	2	High
2(e)	Oak	8.90 cm (3.5 in) common	3	Low
2(f)	Oak	8.90 cm (3.5 in) common	3	High
3(a)	Oak	8.90 cm (3.5 in) spiral	1	Low
3(b)	Oak	8.90 cm (3.5 in) spiral	1	High
3(c)	Oak	8.90 cm (3.5 in) spiral	2	Low
3(d)	Oak	8.90 cm (3.5 in) spiral	2	High
3(e)	Oak	8.90 cm (3.5 in) spiral	3	Low
3(f)	Oak	8.90 cm (3.5 in) spiral	3	High
4(a)	Oak	12.7 cm (5 in) common	1	Low
4(b)	Oak	12.7 cm (5 in) common	1	High
4(c)	Oak	12.7 cm (5 in) common	2	Low
4(d)	Oak	12.7 cm (5 in) common	2	High
5(a)	Oak	15.2 cm (6 in) common	1	Low
5(b)	Oak	15.2 cm (6 in) common	1	High

Table 2/ Test Matrix for Nail Size

Run	Bed	Nail Type and Size	Quantity Used	Push
6(a)	Pine	6.35 cm (2.5 in) common	1	Low
6(b)	Pine	6.35 cm (2.5 in) common	1	High
6(c)	Pine	6.35 cm (2.5 in) common	2	Low
6(d)	Pine	6.35 cm (2.5 in) common	2	High
6(e)	Pine	6.35 cm (2.5 in) common	3	Low
6(f)	Pine	6.35 cm (2.5 in) common	3	High
7(a)	Pine	8.90 cm (3.5 in) common	1	Low
7(b)	Pine	8.90 cm (3.5 in) common	1	High
7(c)	Pine	8.90 cm (3.5 in) common	2	Low
7(d)	Pine	8.90 cm (3.5 in) common	2	High
7(e)	Pine	8.90 cm (3.5 in) common	3	Low
7(f)	Pine	8.90 cm (3.5 in) common	3	High
8(a)	Pine	8.90 cm (3.5 in) spiral	1	Low
8(b)	Pine	8.90 cm (3.5 in) spiral	1	High
8(c)	Pine	8.90 cm (3.5 in) spiral	2	Low
8(d)	Pine	8.90 cm (3.5 in) spiral	2	High
8(e)	Pine	8.90 cm (3.5 in) spiral	3	Low
8(f)	Pine	8.90 cm (3.5 in) spiral	3	High
9(a)	Pine	12.7 cm (5 in) common	1	Low
9(b)	Pine	12.7 cm (5 in) common	1	High
9(c)	Pine	12.7 cm (5 in) common	2	Low
9(d)	Pine	12.7 cm (5 in) common	2	High
10(a)	Pine	15.2 cm (6 in) common	1	Low
10(b)	Pine	15.2 cm (6 in) common	1	High

4/ Results and Observations

4.1/ Effect of Nailing Method

Figure 4 shows the force-displacement plots for low and high pushes, which result in failure modes described as roll/shear and roll/tumble respectively. With a low push, the nails tend to bend, and while the block rolls somewhat, the resistance of the nails tends to result in a shear-type failure mode. In contrast, with a high push, the block simply rolls and withdraws the nail with relatively little bending. This figure shows that the roll tumble mode has a slightly longer displacement, because the higher roll angle of the block requires greater ram travel prior to nail extraction. It also shows that the high push encounters greater resistance, as the nail bends while it is being extracted.

Figure 5 shows example force-displacement plots for the four nailing methods, for a low push on pine blocks on an oak deck. In all tests, joint failure was considered to have occurred when the ram load cell force dropped to zero. The area under any of these curves represents the energy consumed during dislodgement, and serves as an indicator of the resistance of the joint. This figure shows that front toenailing has a lower resistance, and is also dislodged much more quickly, than any of the other methods, as the push simply withdraws the nail from the deck. In contrast, the push against the rear toenail bends the nail, and the wood at the interface splits and deforms during the nail pull-out process, so the joint stays intact longer and requires greater force to dislodge. Double toenailing provides resistance close to that of front and rear toenailing combined. The backup block has slightly lower resistance than double toenailing, but maintains a relatively high resistance for a longer duration of push.

Figure 6 summarizes the force to dislodge the block for each nailing method, averaged over all deck and block materials and both push heights. It provides a ranking of the methods used to nail the block. The unsecured square block backed by the 5x10 cm (2x4 in) block clearly provided greater resistance than the other nailing methods. The double toenail method was next strongest, and somewhat less than the sum of individual front and rear toenailing. This was because each nail compromised the pull-out characteristic of the other, and allowed a smoother withdrawal of the front toenail. Front toenailing, the easiest method to use because work space more likely to be available on the outer sides of the cargo, was the weakest of the four nailing methods tested. This is because the force only needs to extract the nail. The other three nailing methods all required the force to cause the nails to bend, in addition to extracting them from the deck, and this bending also usually caused the wood to splinter.

The area under any of the curves shown in Figure 4 or 5 is a measure of the energy consumed to dislodge the block. Figure 7 shows the energy consumed to dislodge the block, averaged over all deck and block materials and both push heights. This results in a similar ranking to that shown in Figure 6, and the block with 5x10 cm (2x4 in) backup required the greatest amount of energy to dislodge.

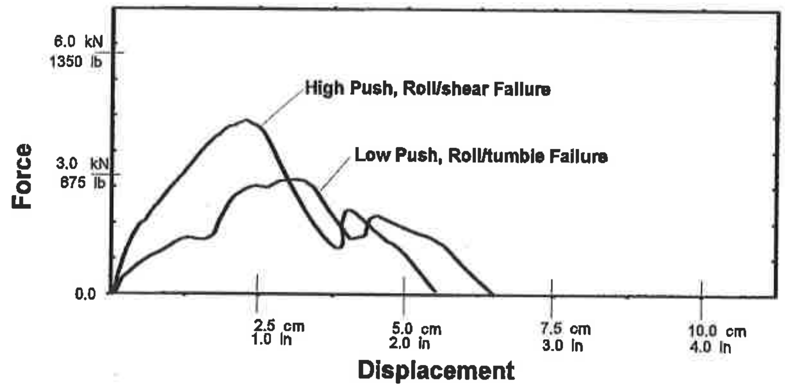


Figure 4/ Comparison of Responses for Low and High Pushes Spruce Block on Oak Deck

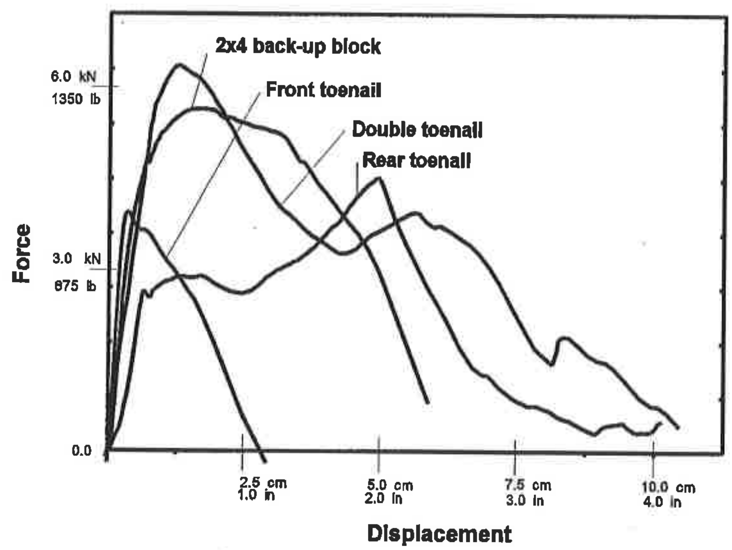


Figure 5/ Comparison of Responses for Four Nailing Methods Low Pushes on Pine Block on Oak Deck

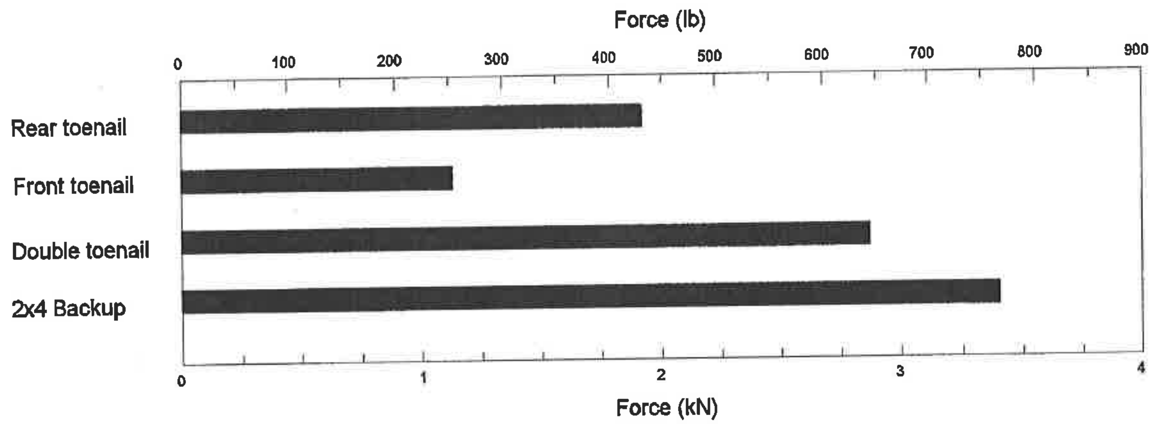


Figure 6/ Effect of Nailing Method on Force to Dislodge Block

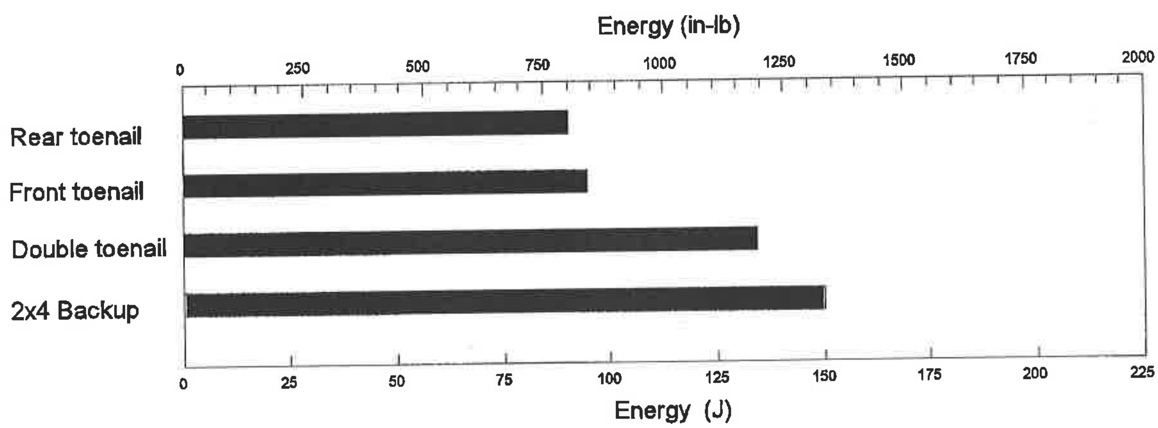


Figure 7/ Effect of Nailing Method on Energy Consumed to Dislodge Block

4.2/ Effect of Block and Deck Material

The forces and energies required to dislodge the various blocks from each deck are shown in Figures 8 and 9 respectively. The softer wood blocks such as pine and spruce required generally less force to cause dislodgement on the soft pine deck than maple, as seen in the upper family of bars in Figure 8. The energy required was similar for all three block materials on a pine deck, indicating that the softer wood blocks held the nail for greater displacements than the maple, partly because the nail head was pulled into the wood. The maple block had greater resistance to nail head pull-through, so could only rely on the resistive forces at the nail-deck interface. The force and energy to dislodge were similar for all block materials on the oak deck, and about 50 % higher than on the pine deck. So, with a hard deck material, the hardness of the blocking seems to be unimportant.

4.3/ Effect of Grain Orientation

The forces required to dislodge a maple block on an oak deck are shown in Figure 10, for pushes parallel and perpendicular to the deck grain. The force required to dislodge with a push perpendicular to the grain was almost 50% higher than a push parallel to the grain. When the push is perpendicular to the deck grain, the block tends to roll and its lower front corner can get wedged in the grain, adding to the resistance provided by the nails. Depending on the relative hardness of the block and deck, either the edge fibres of the block or the grain fibres of the deck fail, and the block then pushes out very quickly. This gave rise to a rather irregular force time history, with a pronounced peak.

4.4/ Effect of Nail Size and Mode of Extraction

The low push, 2.5 cm (1 in) above the deck, resulted in the block rolling a small amount and bending the nail a large amount. This was termed the roll/shear mode of dislodgement. The high push, 7.5 cm (3 in) above the deck, resulted in the block tending to roll significantly, with little bending of the nail as it is essentially levered out. This was termed the roll/tumble mode of dislodgement. These modes of dislodgement are shown in Figure 11.

The forces required to dislodge the blocks for the five types of nail tested are shown in Figure 12. The force to extract the nails was approximately proportional to the nail diameter and not length, since all samples were embedded into the deck a similar amount. This is supported by other empirical data [3]. Both common and spiral 8.75 cm (3.5 in) nails had similar force and energy characteristics, and in most cases the forces in roll/tumble and roll/shear modes were reasonably similar, too. The exception was the 15 cm (6 in) nail. This larger diameter nail was able to resist the forces tending to cause bending, so the higher forces at the wood-nail interface cause splitting and separation of the wood near the deck surface.

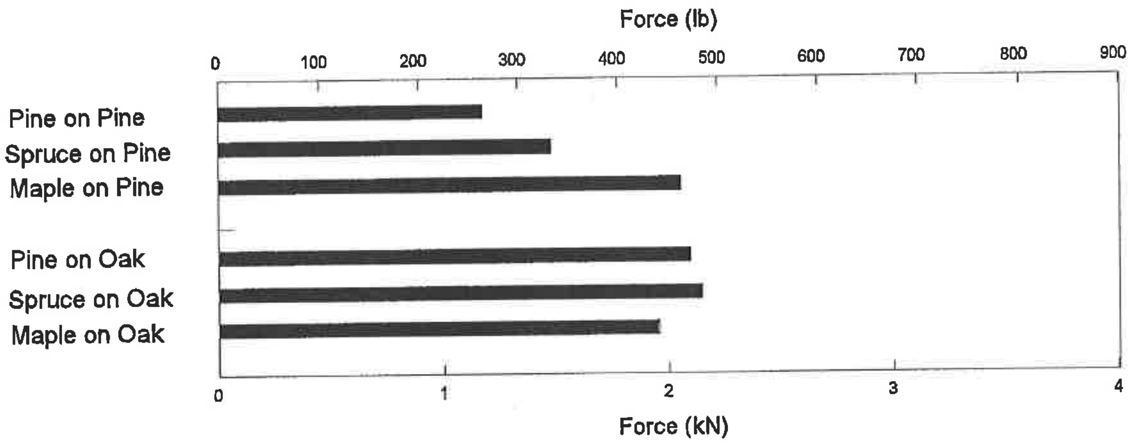


Figure 8/ Effect of Block and Deck Material on Force to Dislodge Block

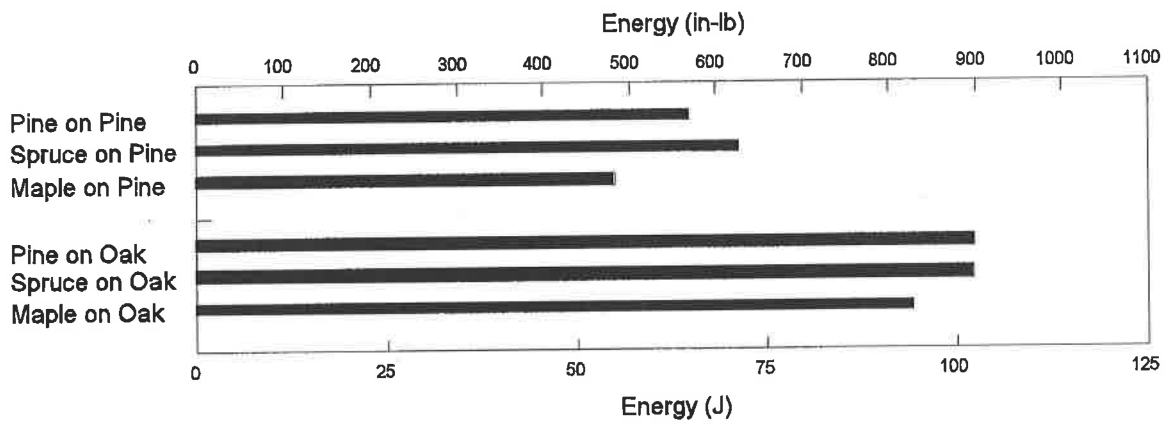


Figure 9/ Effect of Block and Deck Material on Energy to Dislodge Block

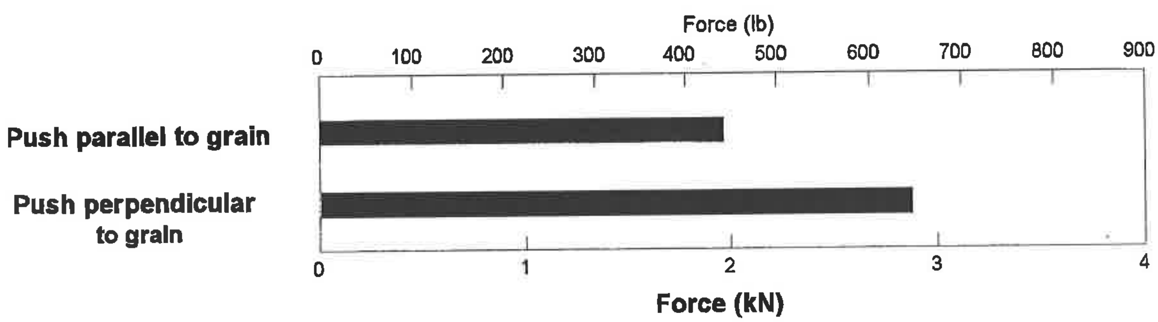


Figure 10/ Effect of Grain on Force to Dislodge Maple Block on Oak Deck

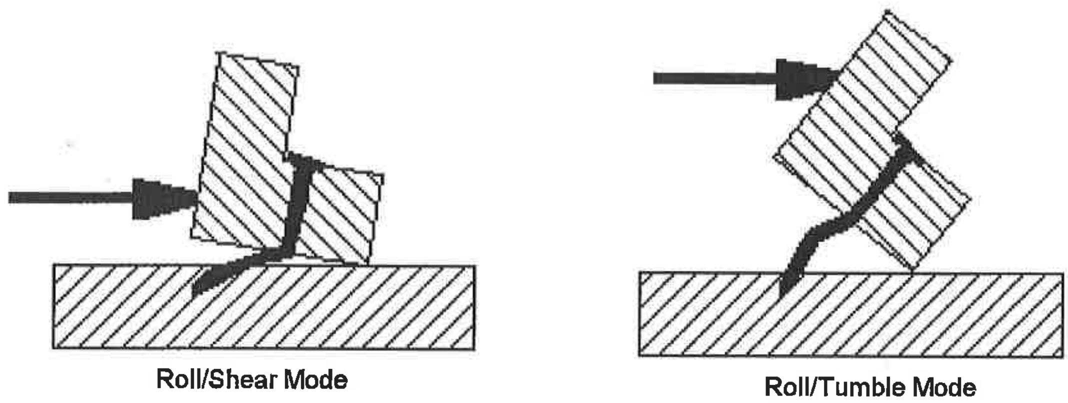


Figure 11/ Modes of Nail Extraction and Block Dislodgement

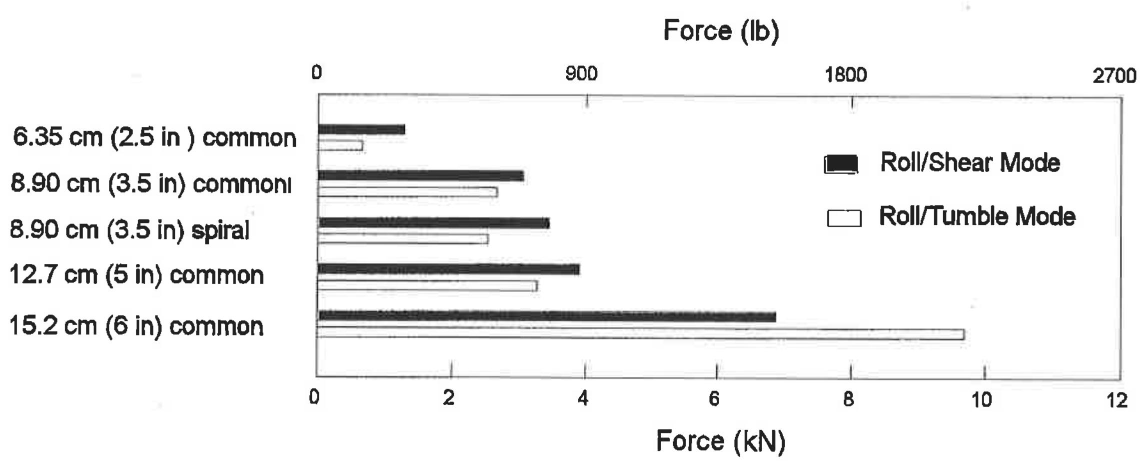


Figure 12/ Effect of Nail Size on Force to Dislodge Block

4.5/ Effect of Nail Size and Deck Material

The effect of nail size on forces to dislodge the blocks is compared for oak and pine decks in Figure 13. The forces were from 25% higher for the larger nails to 150% higher for the smaller nails for an oak deck than for a pine deck. This was because local damage of the deck material in the vicinity of the nail hole reduced the frictional pull-out force and influenced the bending response of the nail.

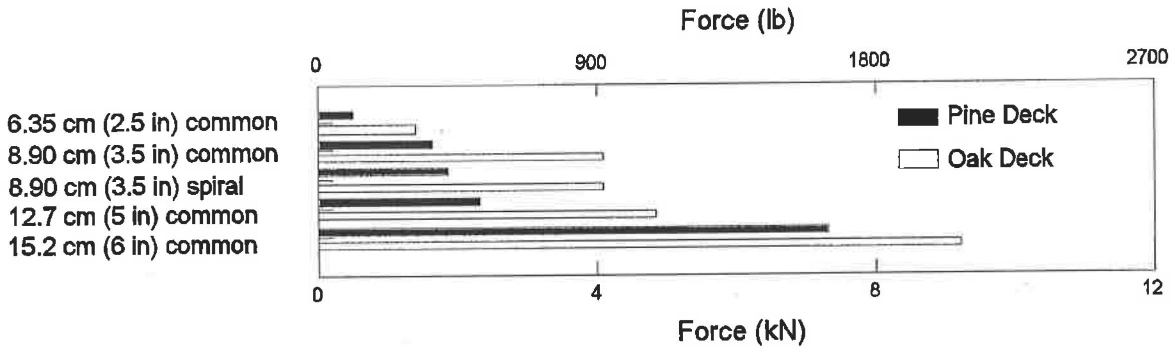


Figure 13/ Effect of Nail Size and Deck Material on Force to Dislodge Block

5/ Analysis and Discussion

5.1/ Review of Results

It became obvious from the tests that three mechanisms combined to resist the force applied by the ram to a nailed block :

1/ Friction between the block and deck;
2/ Friction of the nail in the deck; and
3/ Bending of the nail.

The contributions of these three mechanisms provide the resistance to dislodgement of the nailed block. Each mechanism influences the other and may compromise its ability to resist.

For a low push 2.5 cm (1 in) above the deck, from the initial contact to approximately 3 cm (1.2 in) into the push, the block appeared to be in contact with the bed. After that point, it was usually possible to see underneath the block, so clearly friction between the block and deck was no longer present. The bending nail damaged the wood in the vicinity of the hole thereby reducing the pressure between the nail and the hole, and the resulting deformation of the wood allowed an increase in nail bending radii and hence reduced bending stresses. In all tests the following were found to happen :

1/ Shearing motion by the nail, at the interface of the two woods, caused local deformation (rounding) of the wood at the surfaces adjacent the nail.
2/ Bending of the nail was initiated at the interface, usually a double bend with two anchored "ends" causing an "S" shape in the nail. This was due to the slide constraint imposed by the two plane surfaces involved. Such bending served to deform and splinter the wood even further.
3/ As lateral displacement continued to occur, the wood deformation (rounding) ceased as compressive forces in the wood reached a maximum. The nail then was stressed as to cause extraction from both wood components. The block component resisted because of the nail head. The deck therefore accepted the pull through of the nail thereby causing further bending of the nail and abrasive damage to the hole and sliding surfaces.

In the 7.5 cm (3 in) high push, the block would tend to roll and tumble to produce a lever that extracted the nail, initially with little bending, but when sufficient length of the nail was exposed, motion of the block tended to cause bending of the nail.

A short series of tests was conducted to determine the direct pull-out force required to extract each nail tested. The pull-out force acts along the nail, and perpendicular to the deck surface. The results are presented in Table 3.

Table 3/ Forces Required for Direct Extraction of Nails from Two Decks

Nail Size and Type	Diameter mm (in)	Pull -Out Force in kN (lb)	
		Pine Deck	Oak Deck
6.35 cm (2.5 in) common	3.4 (0.1325)	0.707 (159)	1.526 (343)
8.90 cm (3.5 in) common	4.1 (0.1600)	2.567 (577)	6.312 (1419)
8.90 cm (3.5 in) spiral	3.7 (0.1435)	2.082 (468)	4.893 (1100)
12.7 cm (5 in) common	5.9 (0.2335)	3.127 (703)	7.161 (1610)
15.2 cm (6 in) common	7.0 (0.2770)	5.124 (1152)	15.991 (3595)

Empirical data suggests that the resistance of a nail to direct withdrawal from a piece of wood is proportional to the product of the diameter of the nail and the depth of penetration of the nail into the wood, as well as various properties of the wood [3]. This works quite well for the middle three nails, less well for the first and last.

The foregoing discussion relates principally to cases where nails are driven through the block and into the deck perpendicular to the deck. The effects observed can be extended to nails driven at angles, such as the toenail joints shown in Figure 1. The ranking of these various joints, from test data, is shown in Figure 14. The data indicate that where nail bending is at a minimum, such as the front toenail application, the force is resisted almost entirely by nail/wood friction. In the situations where the nail is required to deform in order for it to be extracted, the force profile is somewhat modified and becomes a combination of nail/wood friction and bending. Neither situation acts in a pure sense, since the onset of bending deforms the wood and loosens the nail and the loose nail then becomes a poor fulcrum for bending. The result being a dislodgement force less than the least of the bending or pull-out forces. Where aggravated or accentuated states of bending exist, such as the rear toenail and double toenail joint, the dislodgement force is seen to increase.

The resistance of a nailed block to dislodgement is also related to the height above the deck at which it is pushed. Larger heights tend to initiate tumbling, and a rapid "clean" extraction of the nail, with the block dislodging and the cargo riding on top of it. Figure 15 contrasts the sequence of dislodgement for the two pushes on a front toenailed block. The low push results in almost a shear dislodgement, and the high push shows a roll or tumble effect. Neither imposes significant nail bending. The force to pull out the nail is somewhat lessened from a 90 degree pull out. In the rear toenailed block, the higher push initiated tumbling. There was greater evidence of nail bending and deck damage. This is shown in Figure 16.

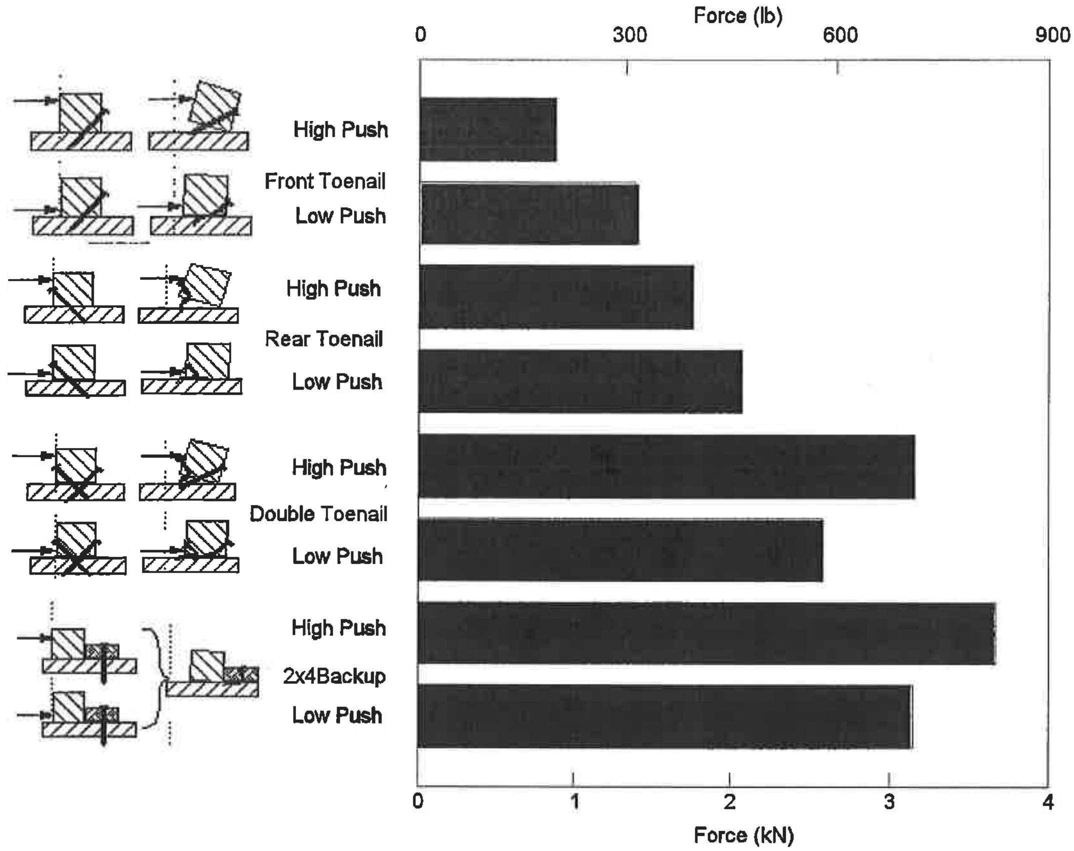
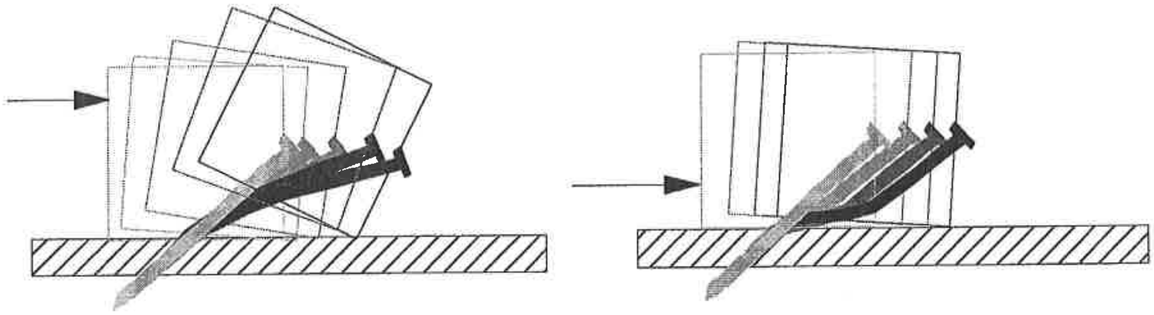
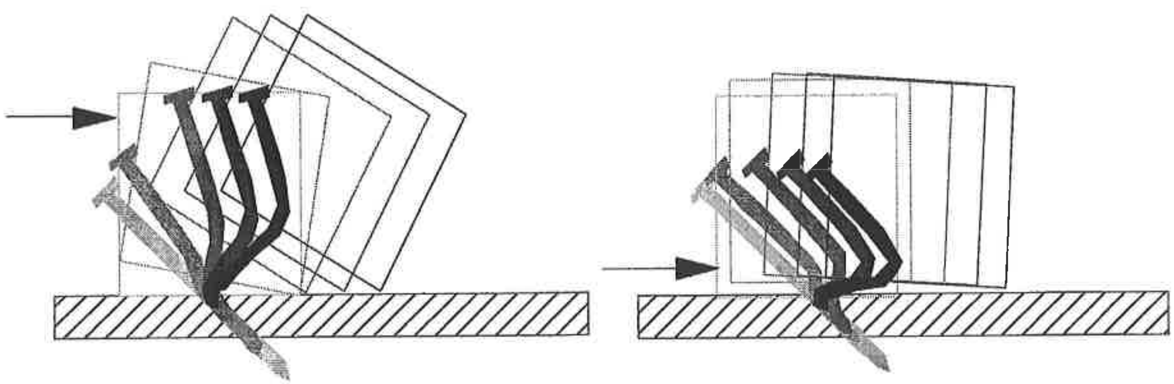


Figure 14/ Failure Forces for Various Nailing Methods and Push Heights



High Push **Low Push**

Figure 15/ Failure Modes of Front Toenail Blocking



High Push **Low Push**

Figure 16/ Failure Modes of Rear Toenail Blocking

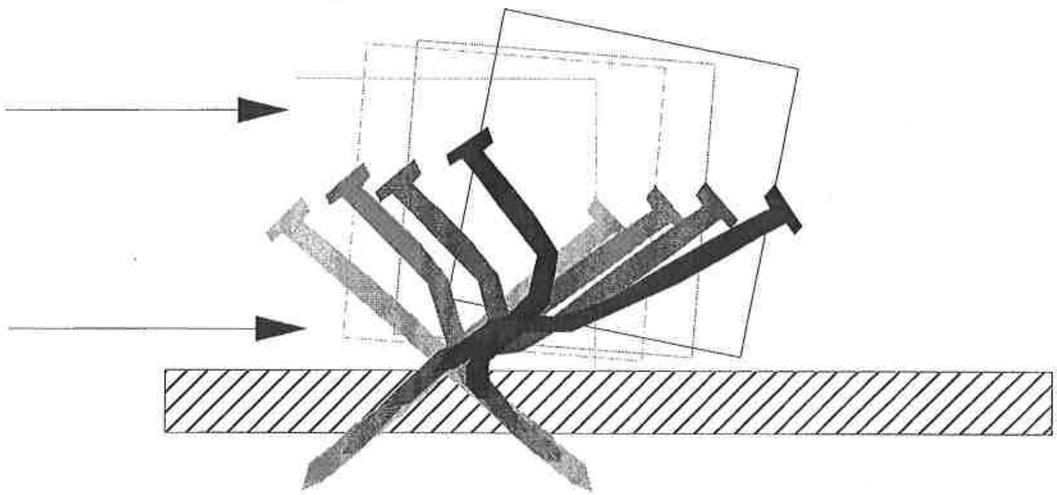


Figure 17/ Failure Mode of Double Toenail Blocking

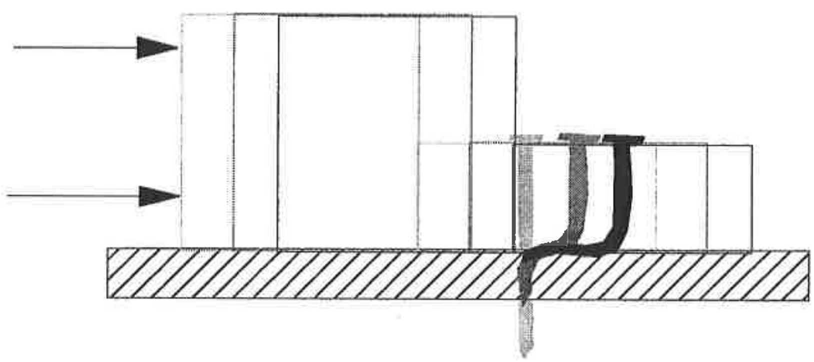


Figure 18/ Failure Mode of 2x4 Backup Blocking

With double toenailing, little roll was experienced with either a low or a high push, because the use of two nails at these angles tended to inhibit the tendency to roll. It produced a lifting motion with slight roll. This effect tended to cause scoring and surface splintering to the deck and caused the block to splinter in some cases. The double toenail dislodgement sequence is illustrated in Figure 17.

When the 10x10 cm (4x4 in) block was backed by a 5x10 cm (2x4 in) block, with the latter nailed directly to the deck, there was no tumbling effect at all, regardless of high or low push. The larger block simply acted as an adapter and caused an almost pure shear dislodgement, as shown in Figure 18. There was some compromise in that the deck hole was distorted and scored upon nail extraction. Because of an almost pure shear motion, both surfaces reacted parallel to each other and this form of blocking provided the greatest resistance.

in both double toenail and back-up block methods, the physical evidence difference between a low and high push was minor. A slight increase in force for the high push was attributed to a slight, almost imperceptible tilt of the 10x10 cm (4x4 in) block that may have caused a higher friction reaction on the deck.

When a gap exists between a nailed block and the cargo, and that cargo moves, then the load on the block becomes an impact load and the dislodgement energy, rather than force, would be the focus. In the majority of cases examined, the force ranking of a joint was similar its energy ranking, which would produce a similar strength ranking for cargo impacting the blocks.

5.2/ Comparison with Other Data

Applicable test data was compared to guidelines issued by The Association of American Railroads (AAR) for Securement, Nails and Nailing [2]. The test is defined as lateral resistance of nails when nailed through 5 cm (2 in) thick floor blocking and into 3.18 cm (1.25 in) hardwood trailer floor. The load is applied at 90 deg to the nail shank. The nails compared were 8d 6.35 cm (2.5 in) common, and 16d 8.90 cm (3.5 in) common, as shown in Table 4.

Table 4/ Comparison of AAR [3] and MTO Data

Nail Type	AAR [3] Guide kN (lb)	MTO test kN (lb)
8d 6.35 cm (2.5 in) common	1.53 kN (344 lb)	1.44 kN (323 lb)
16d 8.90 cm (3.5 in) common	4.25 kN (956 lb)	4.10 kN (920 lb)

5.3/ Working Load Limits for Nailed Wood Blocking

By reducing the MTO data to AAR [3] format, adding the toenail methods, and projecting, Table 5 results for common nails nailed through a 5 cm (2 in) thick block into a 3.18 cm (1.25 in) thick hardwood (oak) trailer floor.

Table 5/ Ultimate Strength of Nailed Wood Blocks

Nailing Method	Nail Size			
	8d-6.35cm (2.5 in)	16d-8.90cm (3.5 in)	40d-12.7cm (5 in)	60d-15.2cm (6 in)
Common Through per AAR [3] table	**1.44 (323)**	**4.10 (920)**	**7.28 (1637)**	**9.24 (2077)**
Front Toenailed	0.40 (91)	**1.16 (260)**	2.06 (463)	2.61 (587)
Rear Toenailed	0.54 (122)	**1.53 (347)**	2.74 (617)	3.48 (783)
Bold numbers indicate actual data, normal font indicate projected data. First number is force in kN, second is force in lb.				

Taking the data from Table 5, and assuming the same common 3:1 ratio between ultimate strength and working load limit as used in other areas of cargo securement, results in the proposed working load limits shown per nail in Table 6 for nailed wood blocking, assuming there is at least 3.18 cm (1.25 in) penetration into a hardwood deck:

Table 6/ Proposed Working Load Limits for Nailed Wood Blocking

Nail Size	Perpendicular to deck		At angle (>30 deg) to deck	
8d-6.35 cm-2.5 in common	0.5 kN	115 lb	0.15 kN	35 lb
16d-8.90 cm-3.5 in common	1.4 kN	315 lb	0.40 kN	90 lb
40d-12.7 cm-5.0 in common	2.5 kN	560 lb	0.70 kN	160 lb
60d-15.2 cm-6.0 in common	3.1 kN	700 lb	0.90 kN	200 lb

5.4/ Discussion

This series of tests has examined a number of parameters involved in nailed wood blocking. For practical purposes, common hardwood truck decks are about 38 mm (1.5 in) thick, and the most readily available blocking material is the common softwood stud with nominal dimensions of 5x10 cm (2x4 in), but actually about 38 mm (1.5 in) thick. The nails most commonly used on these studs are 7.62 or 8.90 cm (3.0 or 3.5 in) long, common or spiral. It would be more expensive to use longer nails, and the longer the nail, the more likely it will be driven into something beneath the deck. Recognizing that common materials will most likely be used for blocking, if blocking is required to provide the entire resistance (say) to an emergency braking over 0.6 g, it is clear from Table 6 that the number of nails quickly becomes prohibitive as the weight of the article of cargo increases. Building blocking and driving nails is hard work, so it is reasonable to expect that the more nails that might be required, the lower the likelihood that the full number will actually be used. If nailed wood blocking is used repeatedly on the same trailer, the deck will rapidly become full of holes in those areas where the blocking is nailed, and its life may be dramatically shortened. It is concluded, therefore, that nailed wood blocking may not be practical on a daily basis, nor for heavy articles of cargo.

It appears few regulations recognize the securement that nailed wood blocking can provide. It is regulated for railroad shipments [2]. It is known to be widely used, particularly for some heavy commodities like metal ingots that do not filla dry van. It is clear from other parts of this project that probably the single most important part of cargo securement is to ensure that the cargo is immobilized. Nailed wood blocking does this. If it is desirable to immobilize cargo, then appropriate credit should be given for any means that accomplishes that end, and nailed wood blocking is one.

6/ Conclusions

A series of tests have been conducted to determine the resistance to dislodgement of wood blocks nailed to a truck deck. These addressed various nailing methods, nail sizes, and species of block and deck.

Blocks secured with nails driven perpendicular to the deck surface were at least 200% stronger in resistive force than those with nails at 45 degrees in a front toenail mode, 75% stronger than those at 45 degrees in the rear toenail mode, and 15% stronger than those double toenailed. Block hardness did not significantly affect the resistance to dislodgement. Deck hardness significantly increased dislodgement force.

When nails were used in such a manner that block dislodgement required significant bending of the nail, the joint was found to be stronger than if the nail were allowed to pull-out directly.

The results compared well with limited other data.

Nailed wood blocking can be an effective way to immobilize some types of cargo.

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

The following recommendations for nailed wood blocking emerge from this work:

1/ The preferred nailing method is straight through the block, perpendicular to the deck, such that at least 3.18 cm (1.25 in) of the nail penetrates the deck.

2/ If toenailing must be used, then rear toenailing should be used. Front toenailing is not recommended.

3/ Nails need only be long enough to provide 3.18 cm (1.25 in) penetration into the deck.

4/ Only new nails should be used on each application.

5/ Blocking should be placed right against the cargo, with no clearance.

6/ If it is not possible to secure the blocking that is in direct contact with the cargo, then back-up blocking should be employed, secured in the manner described in recommendation (1).

7/ Blocking should be placed on all sides of the cargo.

8/ Only solid, substantial, and clean areas of deck should be used for affixing blocking.

9/ Every nail should be driven, without bending, until its head contacts the block.

10/ Splintered blocks should be discarded and damaged deck boards replaced.

11/ The proposed standard should recognize that blocking helps immobilize cargo, so should provide values for nail resistance. It should also recognize that blocking is only practical for articles of cargo of moderate weight.

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