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REVISION OF THE CODE OF SAFE PRACTICE FOR SHIPS CARRYING TIMBER DECK CARGOES

Complementary tests and summary on timber uprights

Submitted by Finland

SUMMARY

Executive summary:	This document contains complementary studies on the strength of uprights holding timber deck cargoes, carried out in order to aid the Revision of the Code of Safe Practice for Ships Carrying Timber Deck Cargoes. The study is made by Philippe Chanfreau, The Maritime Academy of Åland University of Applied Sciences, Finland.
Strategic direction:	5.2
High-level action:	5.2.3
Planned output:	5.2.3.8
Action to be taken:	Paragraph 6
Related documents:	DSC 12/14; DSC 13/11, DSC 13/WP.3, DSC 13/INF.5; DSC 14/10, DSC 14/INF.4, DSC 14/INF.5 and DSC 15/7

Introduction

1 The Sub-Committee, at its twelfth session, considered document DSC 12/14 (Sweden), which provided a framework and a schedule for the revision of resolution A.715(17) on the Code of Safe Practice for Ships Carrying Timber Deck Cargoes, and agreed that this is an important topic and that Sweden had provided a useful way forward.

2 The Maritime Academy of Åland University of Applied Sciences, Finland, is participating in the revision of the Code concentrating on the task of determining formulas for the required strengths of uprights holding timber deck cargoes.

3 With reference to document DSC 15/7, a report on complementary studies especially concerning the effect of lashings on the strength of uprights holding timber deck cargoes for the Revision of the Code of Safe Practice for Ships Carrying Timber Deck Cargoes is annexed to this document.

Findings

4 Based on test results, it is suggested to slightly revise some of the formulas for dimensions of cargo securing arrangements in the Draft Revised Code of Safe Practice for Ships Carrying Timber Deck Cargoes, as amended in document DSC 15/7.

5 It has further been demonstrated in the annexed report that the formulas for dimensions of uprights may be moved into a separate appendix concerning advanced calculations of uprights and be replaced by simplified tables based on standard cargo and loading configurations.

Action requested of the Sub-Committee

6 The Sub-Committee is invited to note the information provided.

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ANNEX

Complementary Model Tests and Summary on Timber Uprights

Research report as part of the TIMRA project and within the framework of the IMO Timber Deck Code

11 June 2010

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Summary and overview

I Overview of tests

The Åland Maritime Academy has conducted model tests with timber deck cargoes during 2008-2010. Full scale tests have also been performed. The aim is to find quantitative rules for the design strength of uprights holding timber deck cargoes. The performed tests are briefly described below. Formulas have been derived based on the behaviour and measurements observed in the tests and on basic physical theory.

The present report is a complementary addition to the reports included in DSC 14/INF.4, and DSC 14/INF.5 mentioned below. In this report more refined equipment and methods are used for the complementary tests, that have been focused on the influence of lashings on the required strength of uprights.

Full scale tests
Tests in full scale were performed by Mariterm AB in Sundsvall Sweden in February 2008. During a four day period a variety of tests were performed ranging from different tests with round timber to ones with packaged timber, including friction and racking strength tests. These full scale tests were thoroughly reviewed in the report by Mariterm in DSC 14/INF.4, submitted by Sweden
(see http://www.mariterm.se/TIMRA/TIMRA_Practical_Tests_with_Timber_Cargoes.pdf.)

Model tests and derivation of formulas
Starting from the experience from the full scale tests in Sundsvall, model setups were mounted in the facilities of the Maritime Academy in Mariehamn, Åland Islands. These results and the results from the Sundsvall full scale tests serve as a basis for the theoretical derivation of formulas. This is thoroughly reviewed in DSC 14/INF.5 submitted by Finland http://www.ha.ax/files/forskarrapport_chanfreau.pdf or
http://www.mariterm.se/TIMRA/TIMRA_Reports.html and in the present report.

Model tests with round timber
A long range of inclination tests with round timber has been performed. A set of two design formulas for the strength of uprights were derived which mathematically describe the behaviour of a stow of logs in variable conditions. The first formula ("the base formula") gives a constant value regardless of the transverse acceleration up to a certain point and is based on the **static** behaviour of logs in a stow. The second formula ("the main formula") gives a value that rises with the transverse acceleration and includes also the **dynamic** behaviour of logs when the stow is exerted to forces. In simple words: the Base formula gives the required strength for minor accelerations while the Main formula gives the strength for the greater accelerations that might occur on long voyages with a possibility of rough weather. The above-mentioned formulas have been reviewed and adjusted this year.

Auxiliary tests with round timber
The derivation of the above formulas uses observations done in other tests such as friction tests and force distribution tests. These are also described in DSC 14/INF.5 and in this report.

Round timber with lashings
In the present report a range of tests were made investigating to what extent lashings relieve the pressure from the log cargo on the uprights. Tests with top-over lashings and with hog lashings were made with variable pretensions and with stows of different sizes. Proposed rules for the reduction of the design formulas due to the influence of lashings are included in this report.

Model tests with packaged sawn timber
The problem with timber packages was attacked from three different viewpoints. Although the three behaviours: sliding, tipping and deforming of packages can happen simultaneously the three were separated into different studies. Each study resulted in a different design formula. It is thought that the one formula that in each set of circumstances gives the highest value would be the one to apply.

Auxiliary tests with packaged timber
The following auxiliary tests were made, in brief: Friction tests, force distribution tests and racking strength tests (testing the tendency for the packages to deform) under a variety of circumstances. These are thoroughly described in DSC 14/INF.5.

II Overview of proposed formulas and results

With regard to the results from the tests described in this report, it is suggested to revise some of the formulas in chapter 6 of the *Draft Code of Safe Practice for Ships Carrying Timber Deck Cargoes*, as amended to the report from the Correspondence Group, DSC 15/7/XX. Suggestions for the revision of these formulas are given below.

It is further suggested that the formulas covering the design of uprights in sections 6.5.38 through 6.5.41 can be moved to a separate appendix and that the formulas in these sections are replaced by tables based on standard cargo and loading configurations, as described below.

The denotations used in the formulas in this report are explained in chapter 6.2.

II.1 Racking strength of Timber Packages

The racking strength of the bottom timber package may be calculated using the following formula, taking into account also the effect of the weight of packages in upper tiers:

$$RS_q = RS + \mu_i * (q-1) * m_p$$

Where:

q	*is the number of packages in the stack including the bottom one,*
RS_q	*is the racking strength of the bottom package with q packages in the stack,*
RS	*is the initial racking strength of the package without any other ones on top of it,*
μ_i	*is the inner friction coefficient of the bottom package, and*
m_p	*is the average mass of one package.*

Furthermore, it has been concluded that the racking strength of packages should be defined per meter instead of per package, since packages may vary in length.

Based on the above formula and by assuming that the internal friction for the wood to wood contact within the stow is at least $\mu_i = 0.5$, the following suggestions for replacement formulas in the Draft Code have been obtained:

6.5.11 $n_p \cdot L \cdot RS \geq m_a \cdot (a_t - 0.5) + PW_a + PS_a$

6.5.17 $n_p \cdot L \cdot RS + n \cdot CS \cdot \cos\alpha \geq m_a \cdot (a_t - 0.5) + PW_a + PS_a$

6.5.26 $n_p \cdot L \cdot RS \geq m_a \cdot (a_t - 0.5) + PW_a + PS_a$

II.2 Strength of Uprights Supporting Timber Packages

The tests performed have shown that the bending moment in uprights holding packaged sawn timber may be calculated using the following formulas, considering **1 Tipping, 2 Sliding and 3 Racking** of the packages (as found in section 6.5.39 of the Draft Code):

(1)
$$CM_{bending1} = \frac{m}{n_p \cdot k \cdot N} \cdot \left(a_t \cdot \frac{H}{2} - g_0 \cdot \frac{b}{2} \right) \cdot \frac{1-(1-f_i)^{n_p}}{f_i}$$

where: $f_i = \mu_{internal} \cdot \frac{2b}{H}$

(2)
$$CM_{bending2} = \frac{H}{2 \cdot k \cdot N} \cdot m \cdot (a_t - \mu_{internal} \cdot g_0) \cdot \frac{q-1}{2q}$$

(3)
$$CM_{bending3} = \frac{H}{k \cdot N} \cdot \left(m \cdot a_t - (n_p - 4)(q-2) \cdot L \cdot RS \right) \cdot \frac{(q-1)}{2q}$$

[Formula (2) in this form was suggested already in document DSC14/INF.5. and is now suggested to replace the corresponding formula in 6.5.39 of the Draft Code. There were two alternatives for formula (3). It is now suggested that only the present one above is chosen.]
And the final strength of the uprights is chosen by taking the maximum value from the above formulas:

$$M_{bending} \geq 1.35 \cdot \max\left(CM_{bending1},\ CM_{bending2},\ CM_{bending3} \right)$$

By choosing standard values for typical cargo configurations it is possible to produce simplified tables that can be used instead of the formulas in the Draft Code, and the formulas can be moved to a separate appendix for advance calculation of uprights. The following tables have kindly been calculated by Sven Sökjer-Petersen of MariTerm AB.

For typical sturdy packages, this would produce the following table for required bending resistance in uprights:

Height [m]	**Transverse Acceleration** $[m/s^2]$						
	3.0	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**
2					26	70	115
3		22	70	118	165	213	378
4	124	237	350	463	576	689	953
5	458	679	900	1120	1341	1562	1927
6	1040	1421	1803	2184	2565	2946	3405
7	1934	2539	3144	3748	4353	4958	5563
8	3202	4104	5007	5909	6812	7714	8617
9	4907	6192	7477	8761	10046	11331	12615

Required bending resistance in cm^3 on uprights supporting packages of sawn wood.

The values in the table above are based on the following parameters for the timber packages:

- Height of each package = 0.6 meter
- Width of each package = 1.0 meter
- Length of each package = 4.5 meter
- Racking strength, RS = 7 kN/meter
- Friction between packages = 0.5
- Density of the cargo = 0.5 ton /m^3
- Weight increase due to water absorption = 10%
- It has been assumed that the width of the deck cargo is 4.5 times its height

For weaker packages, this would produce the following table for required bending resistance in uprights:

Height [m]	**Transverse Acceleration** [m/s^2]						
	3.0	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**
2	3	32	61	90	118	147	176
3	524	660	797	934	1071	1207	1344
4	724	1095	1466	1837	2208	2579	2950
5	725	1304	2084	2864	3644	4423	5203
6	1645	2248	2982	4393	5804	7215	8626
7	3055	4011	4966	7200	9512	11824	14136

Required bending resistance in cm^3 on uprights supporting packages of sawn wood.

The values in the table above are based on the following parameters for the timber packages:

- Height of each package = 1.1 meter
- Width of each package = 1.0 meter
- Length of each package = 4.5 meter
- Racking strength, RS = 3.5 kN/meter
- Friction between packages = 0.3 (with plastic covers)
- Density of the cargo = 0.5 ton /m^3
- Weight increase due to water absorption = 10%
- It has been assumed that the width of the deck cargo is 4.5 times its height

The values in the tables above are based on two uprights supporting each stow of packages. It has further been demonstrated that if hog lashings are used and properly tightened, the values in the table above may be divided by a factor of $k = 1.8$.

II.3 Strength of uprights supporting round wood

With regard to the tests performed over the last year, it is suggested to slightly revise the formulas for uprights for round wood which are found in section 6.5.38 of the Draft Code as described below:

The **base** formula should read:

$$CM_{bending1} = 0.1 \cdot \frac{H^2}{k \cdot B \cdot N} \cdot m \cdot g_0$$

Since refined tests have shown that the centre of forces on the uprights for a stow of logs subject to a transverse acceleration force is found to be no higher than 33% of the height of the stow, the **main** formula should read:

$$CM_{bending\,2} = \frac{H}{3 \cdot k \cdot N} \cdot \left(m \cdot \left(a_t - 0.6 \cdot \mu_{static} \cdot g_0\right) + PW + PS\right)$$

The tests with **hog lashings** have shown that, provided they are properly tensioned, the k-factor may be taken as 1.8.

Furthermore, in typical cases as a simplified suggestion, **top-over lashings** applied in accordance with sections 5.1 or 6.5.30 – 6.5.32 in the Draft Code, the bending moment of the uprights may be reduced by 4 %. If **wiggle-wires** are used, the bending moment may be reduced by an additional 8 %.

By choosing standard values for typical cargo configurations it is possible to produce simplified tables that can be used instead of the formulas in the Draft Code, and the formulas can be moved to a separate appendix for advance calculation of uprights. The following table has kindly been calculated by Sven Sökjer-Petersen of MariTerm AB.

Height [m]	**Transverse Acceleration** [m/s^2]							
	3.0	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**
2	107	150	193	235	278	321	363	406
3	330	474	618	762	906	1050	1194	1338
4	756	1097	1438	1780	2121	2462	2803	3144
5	1452	2118	2785	3451	4118	4784	5451	6117
6	2486	3638	4790	5941	7093	8245	9396	10548
7	3926	5755	7584	9413	11242	13070	14899	
8	5840	8570	11300	14030	16759			

Required bending resistance in cm^3 on uprights supporting round wood.

The values in the table above are based on the following parameters for the timber packages:

- Length of logs = 4.5 meter
- Static friction between logs = 0.5
- Density of the cargo = 1 ton /m^3
- Stowage factor: 2.0 m^3 space / m^3 cargo
- Weight increase due to water absorption = 10%
- It has been assumed that the width of the deck cargo is 4.5 times its height

The values in the tables above are based on two uprights supporting each stow of logs. It has further been demonstrated that if hog lashings are used and properly tightened, the values in the table above may be divided by a factor of 1.8.

II.4 Additional results and observations in the tests

- The centre of forces on the uprights for a stow of logs subject to a transverse acceleration force is found to be no higher than 33% of the height of the stow.

- The tests show throughout that the degree of pretension in the complementary lashings is decisive for the lashings to relieve the pressure on the uprights. A lashing wire, ever so strong, doesn't do any good if it isn't tightened properly.
- Top-over lashings always loose tension when the cargo is subject to acceleration forces.
- The tension in a hog lashing typically slightly increases when the cargo is subject to acceleration forces. However, the elongation of the lashing due to elasticity would in most real cases be much greater than the deflection of the stanchion and thus the initial tension of a hog-lashing is far more important than its strength.
- The mere presence of intermediate hog-lashings within the stow does not have any effect. They have to be tightened to reduce the stress on the upright.

1. Introduction

1.1 Preamble

The *Maritime Academy* of *Åland University of Applied Sciences* is participating in the TIMRA-project in cooperation with MariTerm AB under the leadership and coordination of the Swedish Maritime Administration in the preparation of the revision of the IMO *Code of Safe Practice for Ships carrying Timber Deck Cargoes*.

The Maritime Academy is concentrating on the task of determining formulas for the required strengths of uprights holding timber deck cargoes.

Within the TIMRA project practical tests in full scale were performed with typical timber deck cargoes in order to investigate their behaviour and characteristics. Tests were performed with both round wood and square sawn timber packages in February 2008 at SCA Transforrest's facilities in Sundsvall, Sweden. See separate report http://www.mariterm.se/TIMRA/TIMRA_Practical_Tests_with_Timber_Cargoes.pdf.

The Maritime Academy managed model tests simulating timber deck cargoes during the spring months of 2008, -09 and -10. The tests were performed in the Åland University of Applied Sciences's facilities in Mariehamn, Åland Islands. These results and the results from the Sundsvall full scale tests in February 2008 serve as a basis for the theoretical derivation of formulas.

The first report about this subsection of the Timra project was presented in IMO DSC 14 in September 2009. It was included in document DSC 14/INF.5 submitted by Finland. This research report is a complementary addition to the above-mentioned one.

The present report contains some additional similar tests as in the former report with more refined methods and enhanced equipment, and further investigations into especially how lashings can relieve the pressure on the uprights. This report concentrates mainly on round wood deck cargoes but also contains an overview of the results of the research conducted within this project by the Åland Maritime Academy.

Sven Sökjer-Petersen has participated in this report by kindly contributing with some calculations and advice.

2. Test setup and methods

2.1 The test setup

The experiments were generally performed through inclination tests. The effect of an inclination is similar to the effect of a transversal acceleration. This is discussed in subsection 3.1.

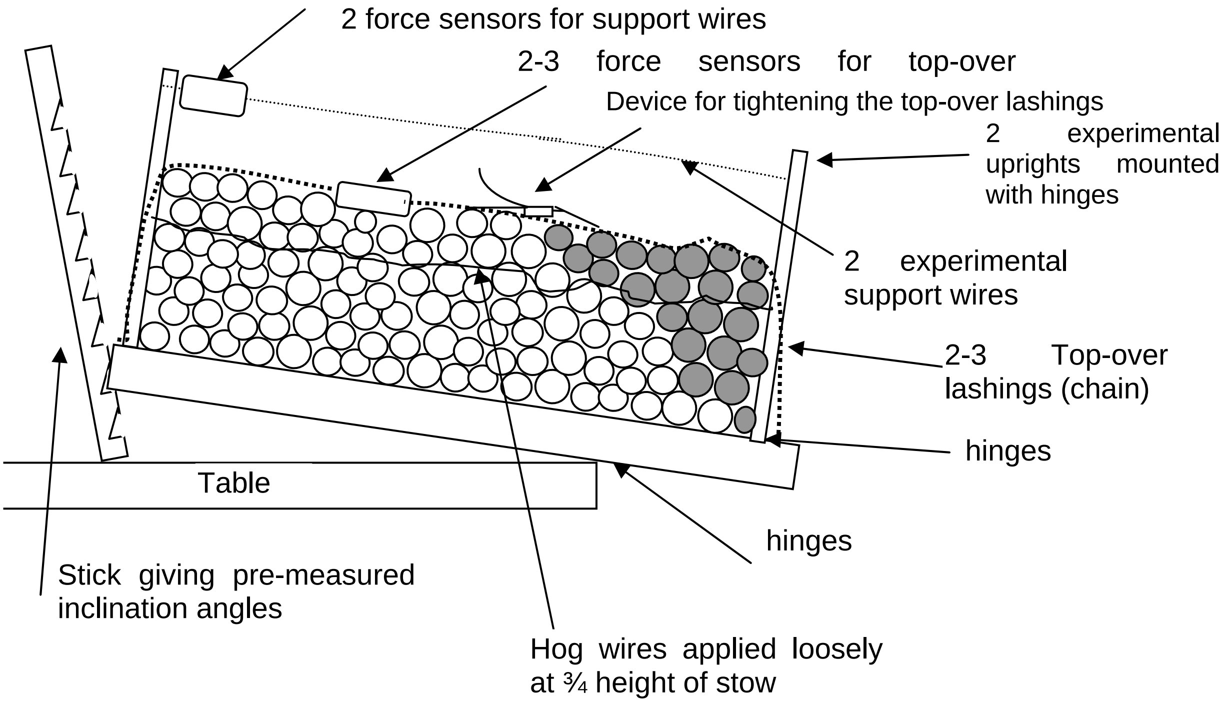


Figure 2.1. *Simplified description of the test setup with model logs*

2.2 Enhanced equipment

Since the report of 2009 the test setup has been enhanced. High resolution force sensors are used in combination with a data logger GLX of the make Pasco. The data is collected from the sensors into the GLX and is then transferred to a computer spreadsheet. A rotary motion sensor was also tried out to continuously register the current inclination angle. But it did not give reliable figures in the long run in this setup, so a wooden stick with notches was used. The test surface was raised stepwise and rested momentarily on every subsequent notch. Each notch in the stick represented a premeasured inclination angle.

More model logs were prepared since last year and a typical test stow now contains spruce model logs of length 40-50 cm and diameter 1-4 cm. The stow is typically 76 cm wide and the height varies between 30 to 46 cm. the weight varies between 35 and 61 kg. These measures are then converted into meters and tons and kN in corresponding real cases using scales like 1:10 or 1:20.

Figure 2.2. *(a) The GLX-data logger, (b) Two force sensors attached to top-over lashings and (c) two force sensors measuring the tension in the support wires and a rotary motion sensor.*

As support wires special fishing line ("fire line") was used. This was almost unstretchable: less than 0.2 % with a pulling force of 50N. As top-over lashings, 1.5 mm chain was used. The chain stretched 0.5 % with a pulling force of 50N. Some synthetic cord was used in both ends of the chain so as to create an elasticity of about 1.5-2 % which should correspond to the behavior of a real case steel wire.

2.3 Model log stows

There were three different model stows of logs used in the tests. All stows were 7.6 dm wide, but the height and the weight varied.

- The 53 kg stow consisted of mostly spruce logs and some shorter deciduous ones. The height was 4 dm.
- The 61 kg stow was put together with about 60 % spruce, 30 % deciduous logs and the rest were round pieces of plained wood from the lumber yard. The height was 4.6 dm.
- The 35 kg stow consisted of purely spruce logs – even the thickest ones of those were removed. The remaining logs had a length between 4.3 and 5.0 dm and diameters from 0.1 to 0.4 dm and they formed a stow with height 3.0 dm. This stow is more proportionate and the most realistic in that respect.

Table 4.1 shows which configuration was used in every specific test run.

Figure 2.3. *(a) the 53 kg stow (test run 31), (b) the 61 kg stow (test run 65) and the (c) 35 kg stow (test run 95).*

2.4 The test procedures

Procedure I was used up to run 75.
Between each test run the uprights were fixed in upright position by means of an extra pair of strings. The stow was not reloaded, but merely loosen up so as to neutralize the settling in the previous run. In tests 60-72 the support wires were each time set at an initial tension of totally 10N.

Procedure II was used starting from run 76. The procedure was as follows:

A. The test uprights were blocked in vertical position, by means of a piece of board and a rubber band.
B. The logs were reloaded.

C. The test support wires were only lightly tightened to almost horizontal position.
D. The setup was shaken.
E. The blockings were removed.
F. If the top-over-lashings or hog lashings on top were to be set, these were set at this stage.
G. The test inclination and measurements started.

The loose tension that is initially created when straightening the support wires (at C. while the uprights are blocked) is subtracted from all subsequent values. This can be motivated with the fact that the initial tension is needed to keep the line straight in horizontal position including lifting the adjustment device, and is not part of what actually is meant to be measured, i.e. the logs acting on the uprights.

3. Definitions

3.1 The relation between inclination angle and transverse acceleration

The two cases: (a) a horizontal acceleration force and (b) the component of the gravitation force acting on a box, are compared (see figure 4.3).

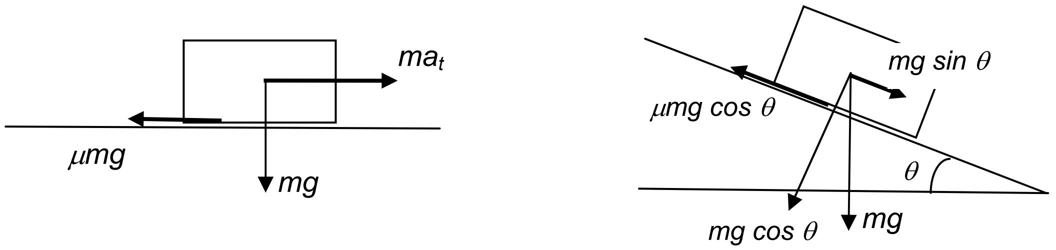


Figure 3.1. *(a) A box subject to an acceleration force* ma_t*. (b) A box on an inclined plane.*

The resulting forces in the two cases are: a) $R_a = ma_t - \mu mg$ and b) $R_b = mg \sin \theta - \mu mg \cos \theta$. Solving the equation $R_a = R_b$ with respect to a_t gives $ma_t = \mu mg + mg \sin \theta - \mu mg \cos \theta$ and finally:

$$a_t = g (\sin \theta + \mu(1 - \cos \theta))$$

So the transverse acceleration will be simulated through inclination tests and calculated using the above formula. This is a simplified version of the one presented in reference 6.

3.2 The scales used

In all the experiments in last year's report and the tests up to run 75 the model tests were conducted in the scale 1:10. Using the 35 kg stow the scale was changed to 1:20.
For example the above measures (sub-section 2.3) in the scale 1:10 would give log lengths of 4.3 m to 5.0 m, diameters of 0.1 to 0.4 m and a total weight of 35.0 ton.
A scale of 1:20 would give log lengths of 8.6 to 10.0 m, diameters of 0.2 to 0.8 m and a total weight of 280 ton. The model would represent a real stow of height 6.0 m and width 15.2 m. A lashing pretension of 27 kN in real life would correspond to a 8000^{th}, that is about 3.5 N in the model.

4. List of Model Tests

The following model tests within the Timra project have been made in the Maritime Academy

Test number or period	**Test purpose**	**Where to find the text** (section numbers refer to DSC 14/INF.5)	**Remarks**
2009	Friction tests to determine the friction coefficient between logs and the test surface.	Subsection 2.2.2	
2008	Angles of repose	2.2.3	
FD1-3; 2009	Force distribution	2.2.4 and this report 6.3	
2009; 2010	Inclination tests to determine design formulas for round timber. Resulting in two formulas.	2.3-2.4 and this report	
2009	Tests with sawn timber packages	Section 3.	
2009	Friction tests packages-surface	3.1.2	
2009	Inclination tests to investigate packages tipping (model 1)	3.2	
2009	Inclination tests to investigate packages sliding (model 2)	3.3	
2009	Force distribution test for sliding packages	3.3.2	
2009	Racking strength tests	3.4.3	
2009	Racking strength for super positioned packages	3.4.4	
2009	Inclination tests for model 3, deformable packages	3.4.5-3.4.6	

Test number	**Test purpose**	**Height of stow**	**Weight of stow**	(section numbers refer to this report)	**Remarks**
FD 2-3	Force distribution tests		31kg; 48 kg	5.1	
1 -16	Preliminary tests				Problems with sensors
21-26		4 dm	53 kg	5.3	With old digital dynamometer
27-33	Chain top-over lashings	4 dm	53 kg	5.3	With dynamometers and force sensors
41-58	Chain top-over lashings	4,6 dm	61 kg	5.3	
60	Chain top-over lashings	4,6 dm	61 kg		Slightly crowned top
61-69	Intermediate hog lashing	4,6 dm	61 kg	5.4.2	
70-72	hog lashing removed	4,6 dm	61 kg	5.4.2	
73-75	Tests with top-over lashings	3 dm	35 kg	5.2, 5.3	Stowe always collapses at 50^{o}. t-o-lashings set to 3*3,5N. Scale 1:20,
76-80	Tests without lashings	3 dm	35 kg	5.2	Procedure 2 to start tests.
81-94	Tests with top-over lashings	3 dm	35 kg	5.2, 5.3	Pretension 3*3,5N, 3*7 N, 3*13 N, 3*27 N
95-102	Tests with hog lashings	3 dm	35 kg	5.4.1	Pretension 2*2N, 2*3,5N, 2*7N

Tables 4.1 *The top table refers mainly to the report in DSC 14/INF.5. The tests in the bottom part are performed in 2010 and used in this report.*

5. Performed tests and results this year

5.1 Force distribution tests with a stow of logs

In the report of DSC 14/INF.5 a force distribution test ("FD-1") was made for a stow of logs against the uprights. The center of forces was estimated to 45% of the height of the stow. That test had some weak points. Later two more tests were made, FD-2 and FD-3, this time using somewhat enhanced equipment. FD-2 was conducted with a stow of 31.1 kg and FD-3 with a stow of 47.8 kg.

Essentially the method was the same: between the uprights and the logs a piece of plywood and a rectangular piece of stiff foam-rubber were placed. The logs touching the foam were in the later tests a number of identical pieces of round wood from the lumber yard. These are called "contact logs". Behind the contact logs were the actual stow pressing on the contact logs that in turn were pressing into the foam. At each inclination angle the advancement of each contact log was measured at both of its ends. The contact logs were numbered from 1 to 12 (from down up).

incl angle	contact log number												side
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	of log
17	99	97	98	99	100	100	100	99	98	100	100	100	W
	99	97	98	99	100	100	100	99	98	100	100	100	E
20	99	97	97	99	100	100	100	99	99	100	100	100	W
	99	99	99	98	101	98	97	99	98	100	100	100	E
25	97	98	96	98	100	100	99	99	100	100	100	100	W
	98	98	98	98	100	100	98	98	99	100	100	100	E
32	92	90	92	96	97	100	96	99	99	98	100	100	W
	92	92	95	97	97	99	96	99	99	100	99	100	E
37	88	88	91	95	95	99	96	99	99	97	100	100	W
	91	92	94	95	97	98	95	99	98	100	100	100	E
41	77	82	85	96	96	98	98	99	98	96	100	100	W
	77	80	85	95	95	95	94	97	97	100	99	100	E

***Table 5.1.** The numbers show the thickness of the foam (mm) at both ends of each contact log in test FD-2.*

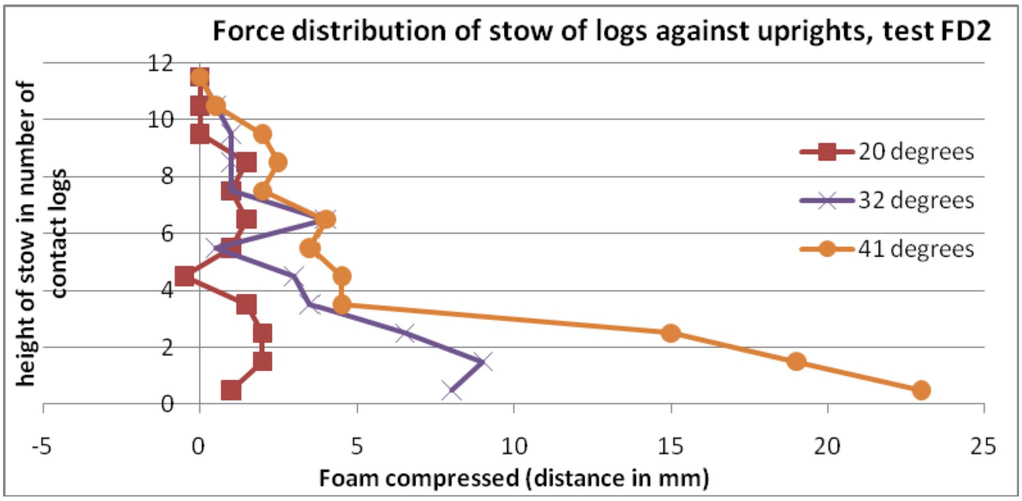


***Figure 5.1** shows how much each contact log has compressed the foam. The graphs show the force distribution for three selected inclination angles.*

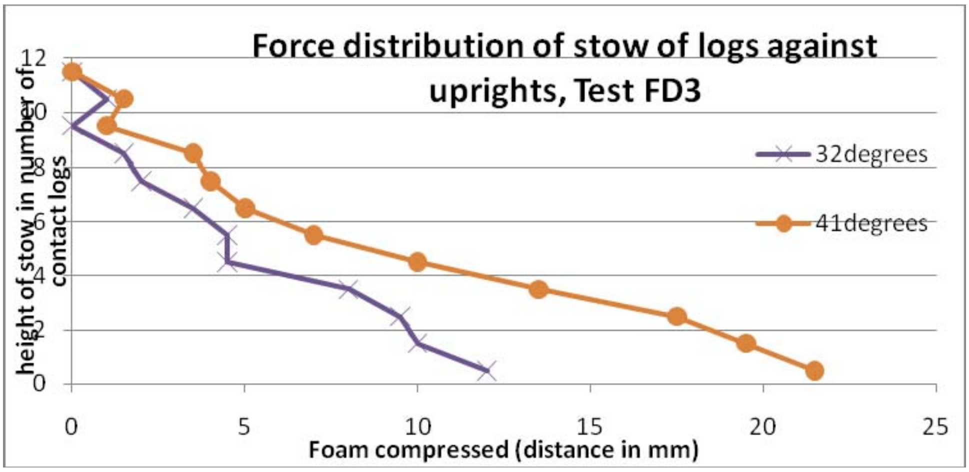


***Figure 5.2** shows the force distribution for two inclination angles in test FD3.*

a)

incl.angle (degrees)	height of Center of forces in logs	in %	moving average
17	3,8	32 %	
20	4,3	36 %	32 %
25	3,4	28 %	30 %
32	3,1	26 %	27 %
37	3,1	26 %	25 %
41	2,7	23 %	

b)

incl.angle (degrees)	Height of Center of forces in logs	in %
32	3,2	26,4 %
41	3,2	26,6 %

***Table 5.2** (a) shows the calculated height of the center of forces in the force distributions in test FD2, and (b) the center of forces in test FD3.*

The centers of the force distributions are then calculated taking into account that contact log number 1 touches at the height ½ of a log, number two at 1½ of a log and so on. The calculated centers vary a lot but if the resulting series, in FD-2 column three, is smoothened out with a moving average, see *Table 5.2a*, an interesting relationship is revealed that seems to imply that the center of forces moves downwards with increasing inclination angle, i.e. increasing acceleration. However, this will not be investigated further in this context. It is simply deduced out of these figures that it should be safe to conclude that the center of forces is no higher than 33% of the height of the log cargo. This differs from the result in the former report, where 45% of the height of the cargo was proposed. The setup was different then with some weak points and the result was interpreted with a safe high value. These experiments are conducted with more elaborated method and equipment and the result 33% is verified through a better fit with the experimental graphs.

5.2 Revision of the design formulas for logs.

The graph of the formulas set up for round wood in DSC14/INF5 is displayed in the diagram 5.4. The "base coefficient" of the base formula is lowered from 0.12 to 0.10 and the coefficient in the main formula that reflects the height of the center of forces is lowered from 0.45 to 0.33 according to subsection 5.1.

The new versions of the formulas are as follows:

The base formula:

$$M_b = 0.1 \cdot \frac{H^2}{B \cdot k \cdot N} \cdot mg_0 \qquad (5.1)$$

The main formula:

$$M_b = \frac{0.33 \cdot H}{k \cdot N} \cdot m \cdot \left(a_t - \mu \cdot g_0\right) \qquad (5.2)$$

Out of which the one that gives the higher value should be used.

The used symbols are described in section 6.2.

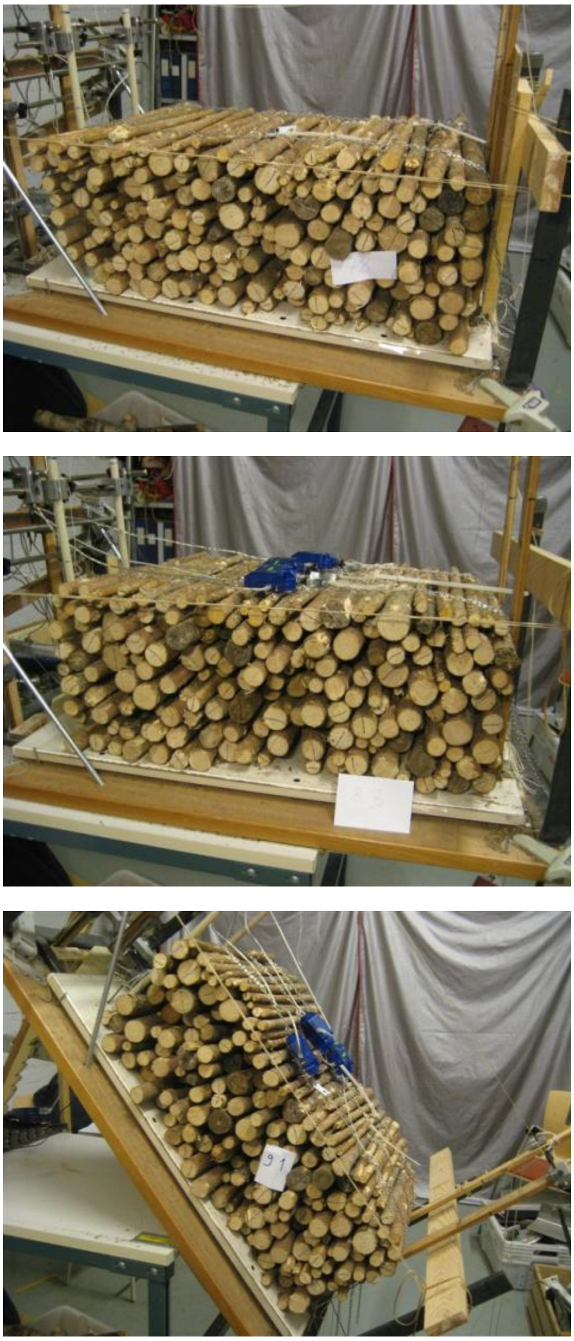


Figure 5.3. *(a) The 35 kg stow loaded with procedure II. (b) Blockings removed and top-over lashings tightened. (c) Inclination test 91 under way.*

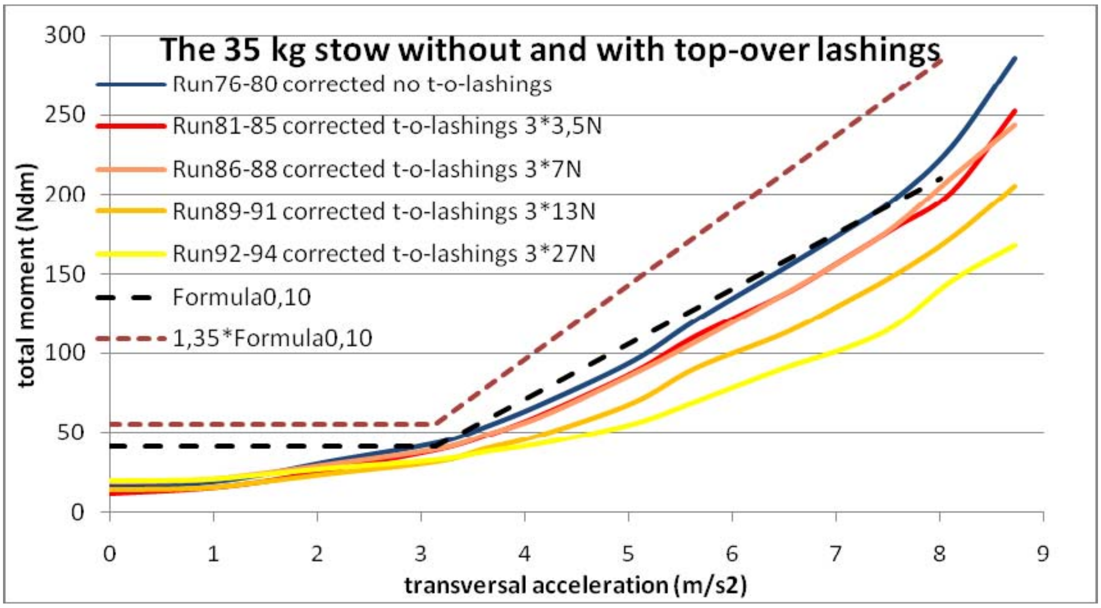


***Figure 5.4**. The adjusted design formula graphs are plotted together with graphs of tests without and with top-over lashings with variable pretension.*

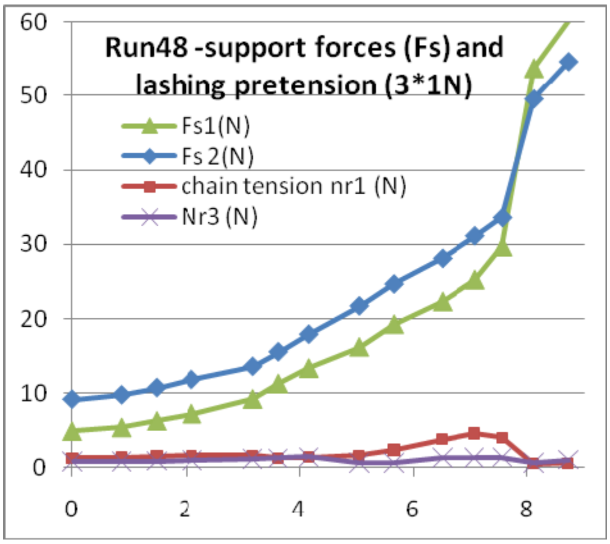
5.3 Investigating the effect of top-over-lashings on a stow of logs

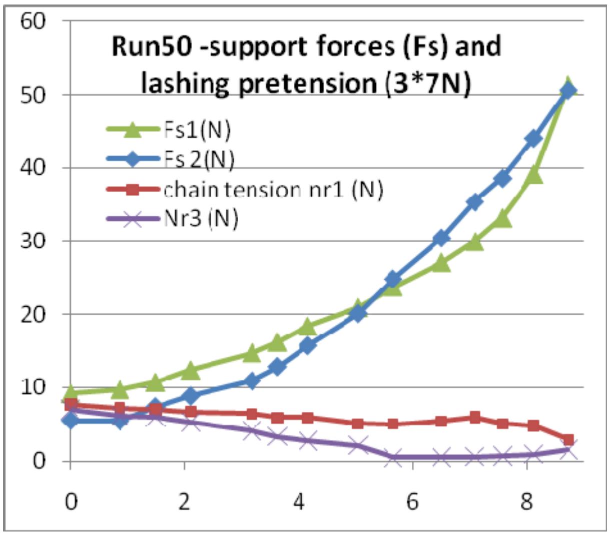
In the experiments in 2008-09 no actual model lashings were applied. The experimental support wires that relied the lower uprights through dynamometers to the upper uprights generally ran on top of the log stow and served as a kind of hog lashings. In this subsection and in the experiments performed during the spring months of 2010 model top-over lashings were applied and the experimental support wires were placed at a certain height in order not to interfere with the dynamics of the stow but purely measure the pressure against the uprights. The aim of this subsection is to determine to what extent top-over lashings applied in various ways can relieve the pressure on the uprights.
Force sensors were placed to determine the pretension of the top-over lashings and also to be able to follow the change of tension with growing inclination angles.
Three model stows were used when investigating top-over lashings (see sub-section 2.3 and *table 4.1*):

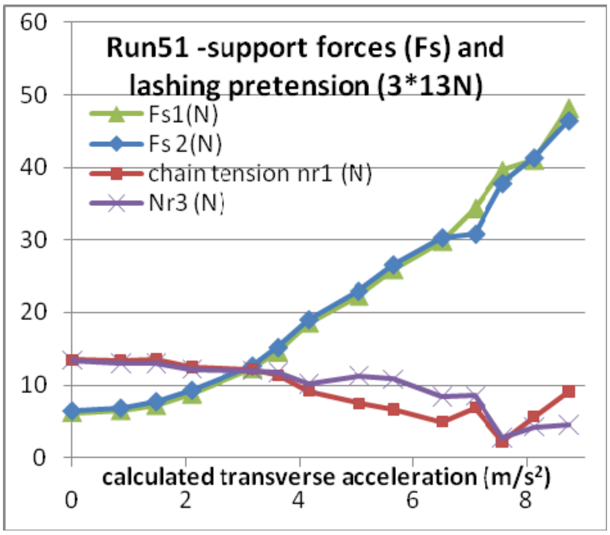
- the 53 kg stow (test runs 24 to 33),
- the 61 kg stow (test runs 41 to 58) , see *figures 5.5* and *5.6*
- the 35 kg stow (test runs 81 to 94), see *figure 5.4*

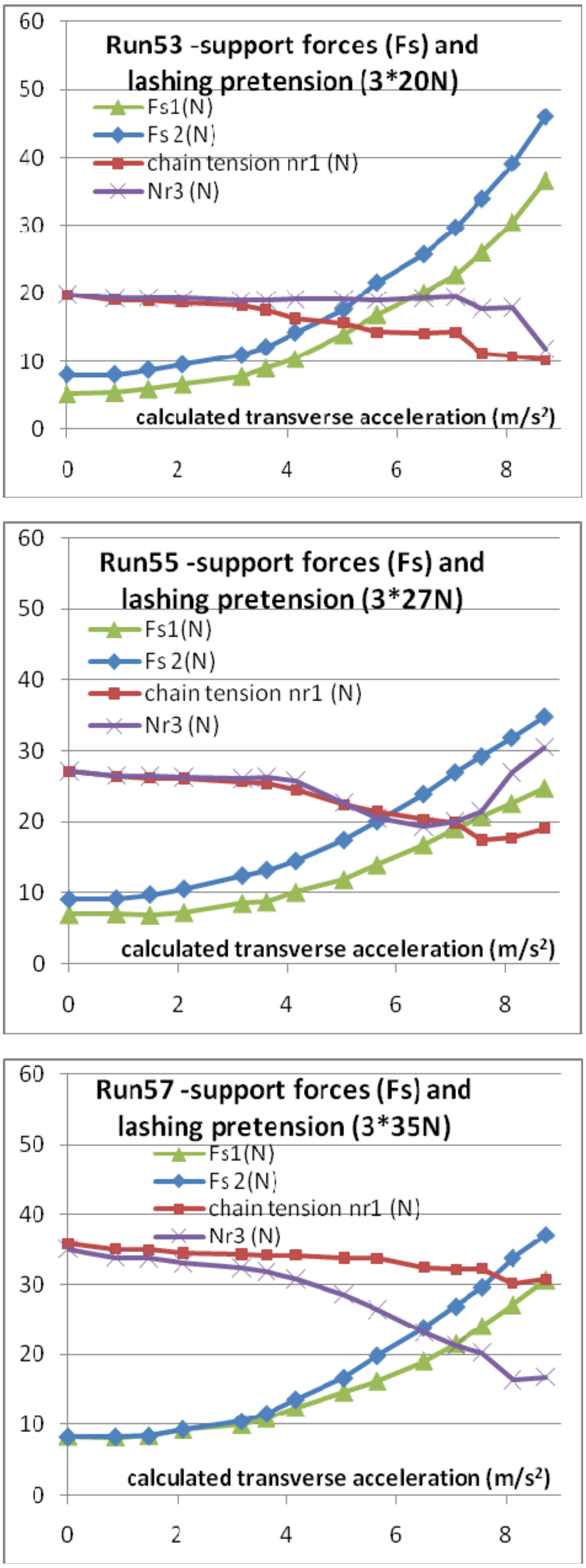
In *figures 5.5a-f)* a selected set of test runs is displayed. There were three top-over lashings. Each of those was set to the same pretension in the beginning of each test. The evolvement of the tension of two of them during the experiment is recorded and displayed. Likewise, the two upright support forces (F_{s1} and F_{s2}) are displayed.
A large number of similar tests were performed. In *figure 5.6* each graph is the mean of 2-3 tests with identical lashing pretension.

Roughly, as expected, the F_s-curves lower as the lashing pretension increases, which means the uprights are more and more relieved the more the pretension of the lashings is tight. The graphs do not come in perfect order, though. Particularly when the pretension 27 N is exceeded the result doesn't improve. It seems as an excessive pretension at some point suddenly deforms the stow from rectangular to more circular and thereby the lashing tension decreases again. And for small pretensions the graphs are more or less the same. But in general the tendency is clear. In *figure 5.4* the same tendency can be seen with the 35 kg stow.









Figures 5.5. *The graphs show the horizontal support forces (Fs1 and Fs2) holding back the uprights and the tension in two of the three top-over lashings as they change when the calculated transversal acceleration changes. Tests performed with the 61 kg stow.*

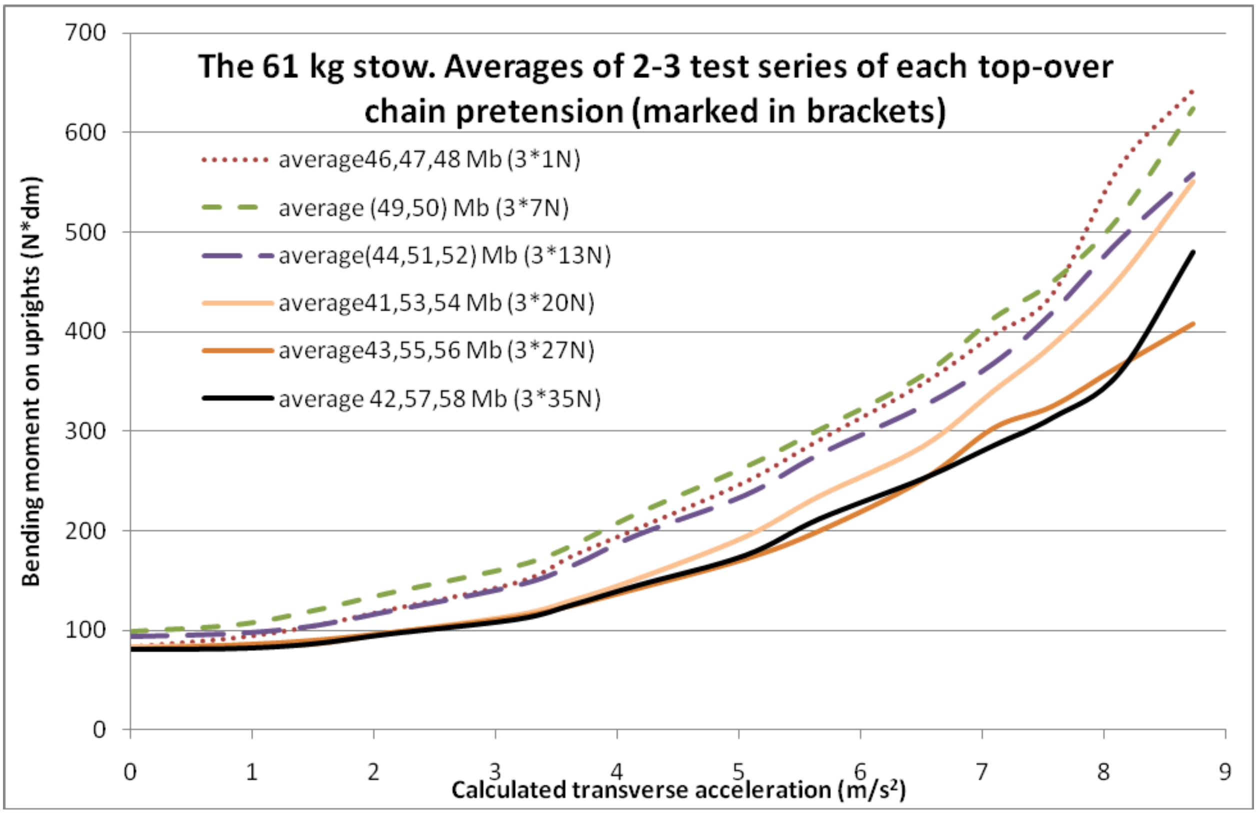


Figure 5.6. *The diagram shows how top-over lashings ease the pressure against the uprights in tests with the 61 kg stow.*

Looking for a rule

A way to look for a rule that describes how the required bending moment of the uprights is dependent on the top-over lashings is the following. It is assumed that the possibility of reduction in required bending moment is mainly dependent of the lashing pretension and the cargo weight. The 35 kg stow is especially investigated. All set pretensions in test runs number 81-94 are converted into how many percent these are in relation to the cargo weight, see table 5.3 below.

Cargo weight	350 N	Top-Over Lashing Pretensions			
		3*3,5N	3*7N	3*13N	3*27N
Lashing Pretension in relation to Cargo Weight:		3,0 %	6,0 %	11,1 %	23 %

Table 5.3

For every given acceleration in each case of lashing pretension the reduction in bending moment compared to having no lashings is calculated. For small and for large accelerations the results are very jumpy. Apparently they depend also on other factors. But the middle range of accelerations, roughly from $4\ m/s^2$ to $7\ m/s^2$, displays an interesting regularity. This is shown in the diagram in figure 5.7. Each graph represents a particular acceleration. To each graph a least-square trend line through the origin is fitted. The slope of these trend lines is about *1.9*. A corresponding investigation into tests with the 61 kg stow resulted in a slope of about *1.7*. Apparently the height of the cargo plays a role. If the lower value is chosen this would mean that the following formula could be proposed:

$$\Delta CM_{bending} = 1.7 \cdot \frac{PT_{Htot}}{mg} \tag{5.3}$$

Where $\Delta CM_{bending}$ is the reduction (in %) of the bending moment compared to having no top-over lashings. PT_{Htot} is the sum of the top-over pretensions for that cargo.

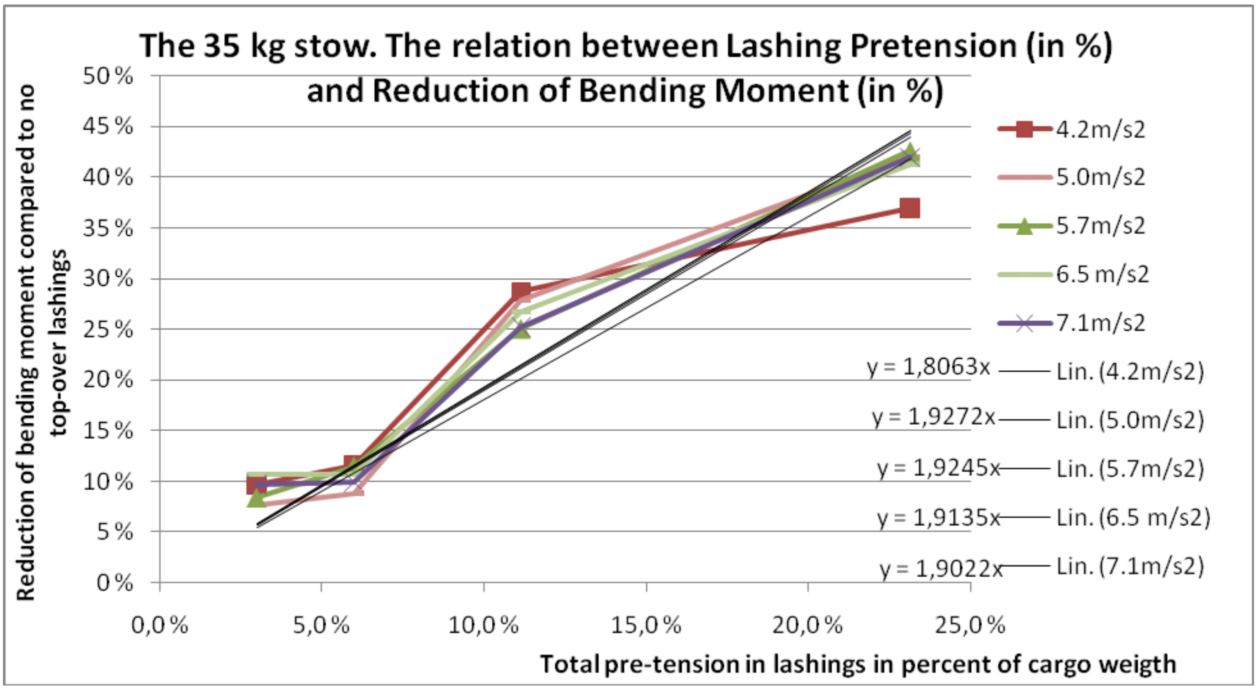


Figure 5.7.

In the Draft Code, as amended to DSC 15/7/XX as well as in the present Timber Deck Cargo Code, it is suggested to use a longitudinal separation of top-over lashings of 3.0 meters for cargoes up to 4 meters heights and 1.5 meter separation for heights above 4 meters. The horizontal part of the lashing should be tensioned to 27 kN.

When wiggle wirers are used, it is harder to know the exact pre-tension but it is assumed that they are more effectively tightened than ordinary top-over lashings.

In the Draft Code, three example calculations are given in Appendix B for three vessels carrying round wood deck cargo. The cargo weights and the lashing properties for these three examples are listed in the table below, as well as the reduction of bending moment in the uprights that formula (5.3) would allowed for considering top-over lashings in accordance with above.

	Vessel 1	**Vessel 2**	**Vessel 3**
Deadweight	28 400 ton	16 600 ton	6 000 ton
Weight of deck cargo	10 500 ton	3 000 ton	1 500 ton
Height of deck cargo	7 m	3.7 m	3.1 m
Length of deck cargo	110 m	80 m	65 m
Spacing of lashings	1.5 m	3.0 m	3.0 m
Number of top-over lashings	73 pcs	27 pcs	22 pcs
Pre-tension in lashings	27 kN	27 kN	27 kN
Reduction in bending moment	**3.2 %**	**4.2 %**	**6.9 %**

Thus it is suggested to allow for 4% reduction of required bending resistance in the uprights if top-over lashings have been applied in accordance with the code and an additional 8 % if wiggle wirers have been used. The above percentages have been calculated in the numerical examples below.

Numerical examples

Refering to the *Draft – Timber Deck Code Annex 1 B.5 Example Calculation – Uprights for Round Wood*, corresponding numerical examples will be presented concerning reductions to upright bending moments due to applied top-over lashings.

Example B.5.1, a 28 400 DWT Vessel:
m = 10 500 ton, mass of the section to be secured in ton.
L = 110 m, length of deck cargo to be secured
H = 7 m, height of deck cargo
110/1.5 = 73 pcs of top-over lashings, since H > 4 m.
27 kN = standard recommendation for top-over lashing pretension.

Then the above formula (5.3) will result in:

$$\Delta CM_{bending} = 1.7 \cdot \frac{PT_{Htot}}{mg} = 1.7 \cdot \frac{73 \cdot 27kN}{10500t \cdot 9.81m/s^2} = 0.033$$

Which means that the calculated bending moment for an upright may be lowered by about 3.2 % or multiplied by a factor 0.968.

Example B.5.2, a 16 600 DWT Vessel:
m = 3000 ton, L = 80 m, H = 3.7 m
80/3 = 27 pcs of top-over lashings, since H <= 4 m.

Then the formula (5.3) will result in:

$$\Delta CM_{bending} = 1.7 \cdot \frac{PT_{Htot}}{mg} = 1.7 \cdot \frac{27 \cdot 27kN}{3000t \cdot 9.81m/s^2} = 0.042$$

Which means that the calculated bending moment for an upright may be lowered by about 4.2% or multiplied by a factor 0.958.

Example B.5.3, a 6 000 DWT Vessel:
m = 1500 ton, L = 65 m, H = 3.1 m
65/3 = 22 pcs of top-over lashings, since H <= 4 m.

Then the above formula will result in:

$$\Delta CM_{bending} = 1.7 \cdot \frac{PT_{Htot}}{mg} = 1.7 \cdot \frac{22 \cdot 27kN}{1500t \cdot 9.81m/s^2} = 0.069$$

Which means that the calculated bending moment for an upright may be lowered by about 6.9 % or multiplied by a factor 0.931.

Results

- As can be seen in *figures 5.5* that the tension in the top-over lashings typically stays at the pretension value or decreases with increasing transverse acceleration, whatever the initial pretension is.
- It has clearly been demonstrated that the greater pretension used, the greater reduction is achieved of moments in the uprights.
- The required bending moment of the uprights can be reduced as a function of the pretension of the top-over lashings using *formula (5.3).*

5.4 Testing with hog wires

The basic idea with hog-lashings is to divert some of the tension in the upright on the low side to the upright on t high side. Under optimal conditions, the hog-lashings would distribute the tension evenly between the stanchions on each side, thereby reducing the required bending resistance in the uprights by 50%.

5.4.1 Hog wires on top of the stow

The hog wires were placed right on top of the stow. The stow was loaded following procedure II described in subsection 2.4. A typical test with hog wires is displayed in figure 5.9. Starting on the negative side of the graph: The support wires were given a basic tension in order to hang fairly horizontal (at " -2"). At "-1" the blockings are removed and the pressure from the logs is registered without hindrance by a greater moment. Then (at $a_t = 0$) the hog wires were given a small pretension of about 2N each, the combined hog wire moment became 2 * 2 N * 3 dm = 12 Ndm. The tension in the support wires were immediately seen to decrease.

Figure 5.8.

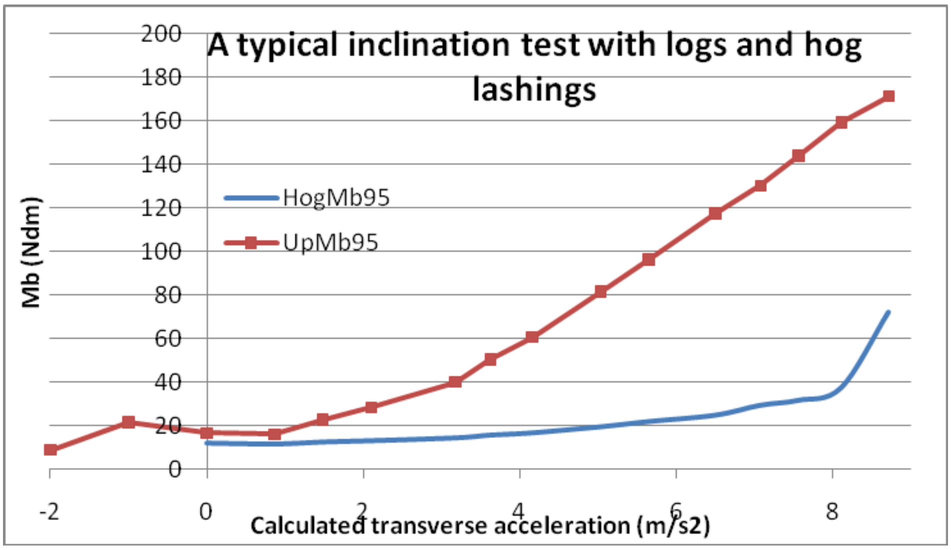


Figure 5.9. *Test 95 displayed with a graph showing the bending moment in the uprights and another one showing the bending moment of the hog wires.*

As the experiment proceeds the tension in the hog wires slowly rises and the moment in the uprights also rises. In this particular test there is a sudden shift in the stow at about 50 degrees of inclination, which is registered by a raise in the hog lashing graph. Obviously it is important to pay due attention to the hog wire strength when lashing.

Then a number of tests with increasing pretension in the hog lashings are performed. The pretensions vary from 2N to 3.5N and 7 N with three test runs of each. The resulting upright graphs are displayed in *figure 5.10*.

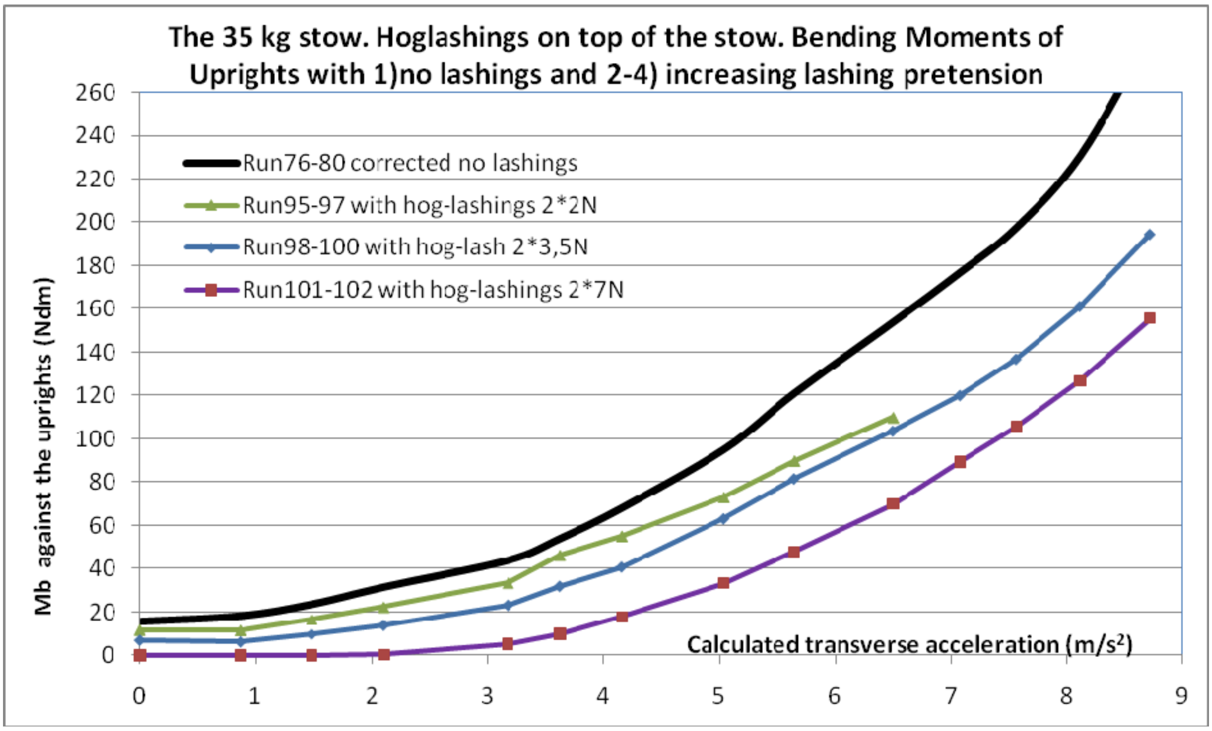
In *figure 5.10 a)* the uppermost graph shows the bending moment of the uprights without any lashings at growing calculated acceleration. The lower graphs show the same stow with hog-lashings: first with two lashings with pretension 3.5 N each and the bottom graph with pretension 7.0 N each. At any rate it is clear that hog lashings make a difference, it is also very clear that the degree of pretension (and remaining tension for that matter) in the lashings makes a huge difference in lowering the pressure on the uprights. With every increase in hog lashing pretension the required bending moment of the uprights gets lower. This shows with a lower graph each time.

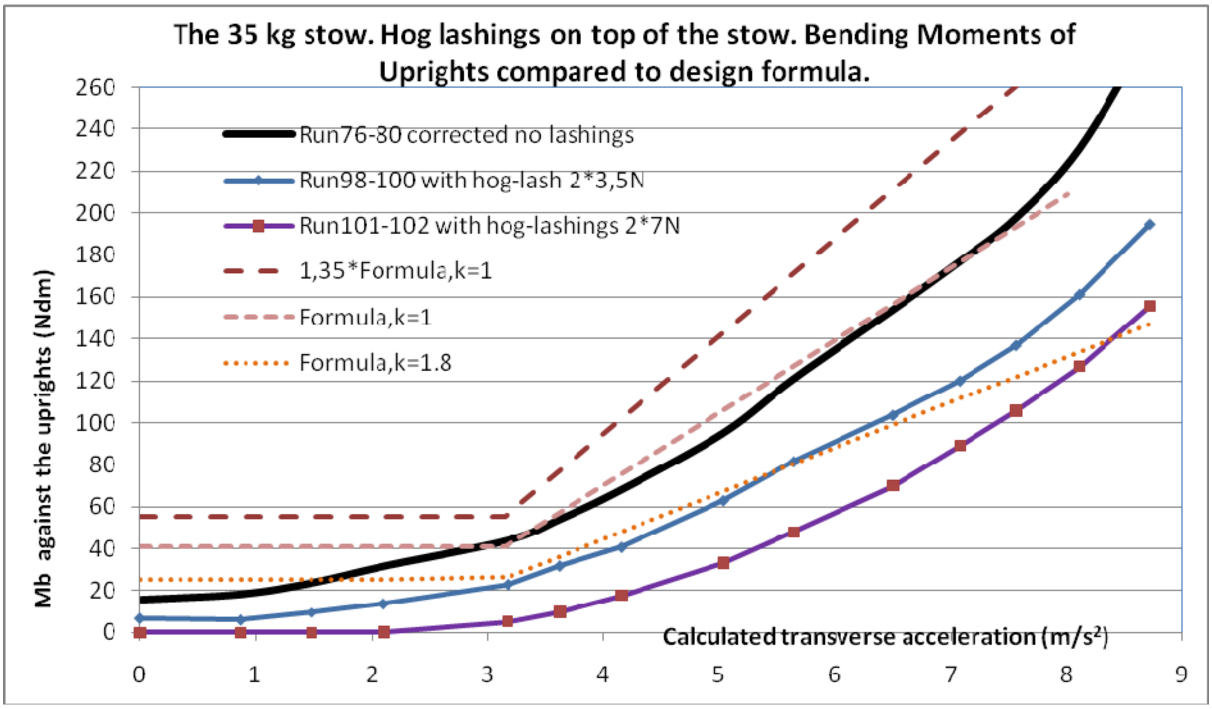
How does the design formula fit in to this? In *figure 5.10 b)* the design formula for two different values of the "hog lashing coefficient" *k* is plotted. The design formula graph with *k = 1* follows closely the "no lashing graph". It is suggested that if hog lashings are used, and that they are used properly, the value of *k* can be raised to *1.8*. The corresponding graph is plotted.

The test situation can be translated into a real situation by using the scale 1: 20 (see sub-section 3.2). The logs would be 10 m long and the stow would weight 280 ton. Three to four hog lashings with pretension 27 kN each would be required. They would be set on top of the stow at a height of 6 m. Translating this back to the model means that three to four hog lashings with pretension 3.5 N would be adequate. Thus a total of 10.5 to 14.0 N. This means that the "2*7N-graph" would be the closest. The diagram shows that the design formula with *k = 1.8* covers that graph sufficiently well. It must be stressed however that using *k =1.8* in the formula implies a disciplined and regular retightening of lashings. Otherwise a lower value of *k* could be chosen.

Results

The tests show that the pretension of the hog lashing is of decisive importance.
The design formula graph can be lowered when hog lashings are used. The "hog lashing coefficient" *k* can be raised depending on the pretension of the hog wires. The tests show that a maximum of about k = 1.8 can be used provided the pretension is sufficient.





Figures 5.10. *(a) The first diagram shows how the pressure on the uprights (here taken as the bending moment) decreases with hog lashings – and especially with increased tension in the hog lashings. (b) the second diagram includes three versions of the design formula.*

5.4.2 Intermediate hog-lashings in a stow of logs

In this test strong plastic fishing lines were used as "hog wires". In the following they are simply referred to as hog wires. A continuous hog wire was laid loosely at about ¾ height of the stow. There were no padeyes in the uprights. The wire was simply attached in one left side upright, then laid across and around the opposite upright and across again diagonally to the opposite right side upright and so on and ending attached to the upright it started from roughly describing an "angular number eight".

Figure 5.11. *(a), (b) The intermediate hog lashings were laid at roughly ¾ of the height (c), (d) The top layers of logs were reloaded, top-over lashings set and experiments started.*

A number of tests were performed with the hog wires in place and with the hog wires removed. The three top-over lashings were mounted in each test. Two sets of tests were performed: the pretension of the top-over lashings in those sets of tests was set to 27 N and to 13 N respectively. In all these tests the hog wire was left laid inside the stow the same way as described above. The stow was not reloaded. Between each test the logs are pushed back and slightly lifted up so as to recreate the same situation again. And then the pretension was set the same way each time. The 61 kg stow was used (see subsection 2.3)

The resulting graphs show that there was no significant difference in the pressure against the uprights whether the hog wires were there or not. This doesn't prove that intermediate hog wires are without importance. As mentioned above they were laid "really loose" and just round each upright – not through any padeyes. So the wires were probably too loose and could have moved vertically with the stove. Anyway the tests show that the mere presence of wires between the logs doesn't seem to have any effect. The experiment with intermediate hog lashings was not repeated due to lack of time and difficulties to attach force sensors to the wires inside the stow.

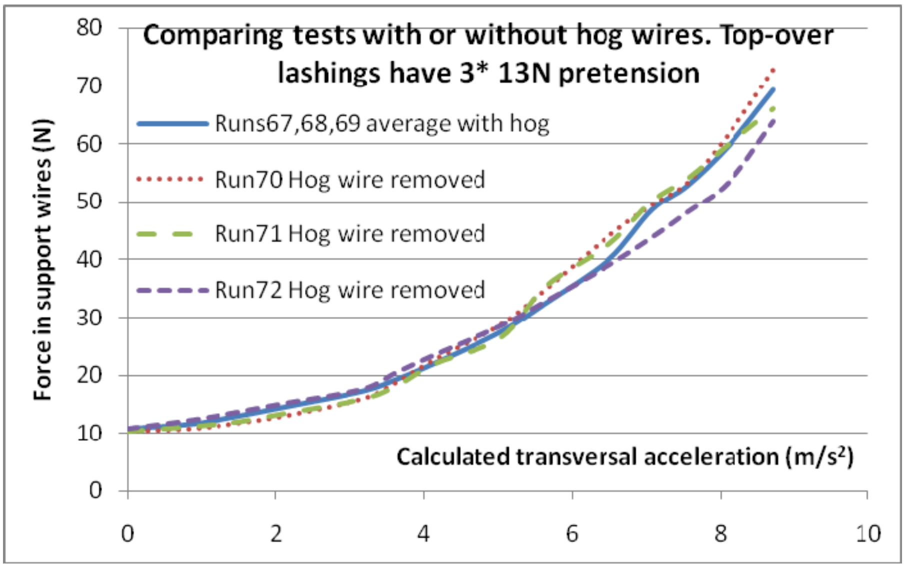


Figure 5.12. *Out of five successful runs (number 64, 66-69) with hog lashings the lowest and the highest are omitted and the average of the three middle ones is plotted.The graph of tree runs 70-72 without hog lashings are also plotted.*

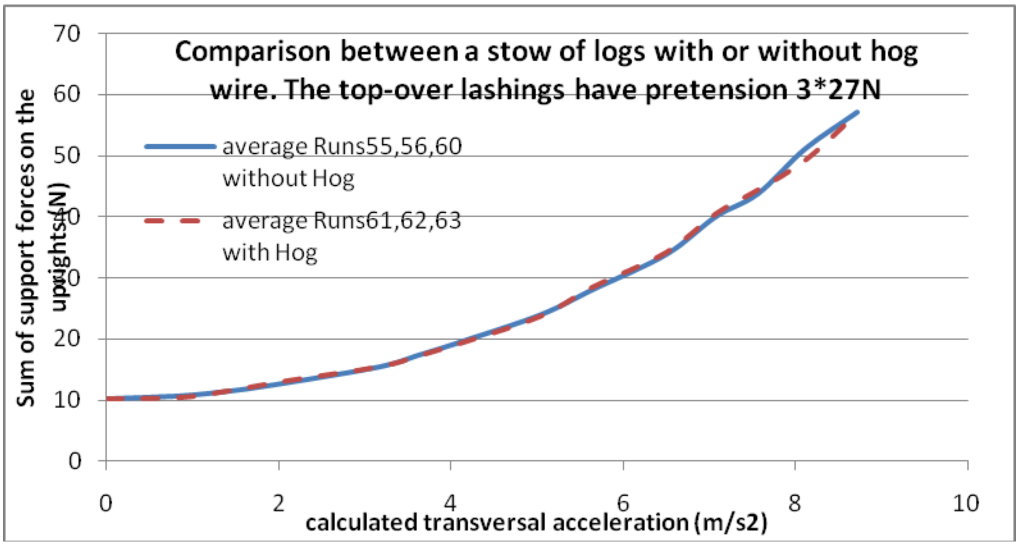


Figure 5.13.

Results

Here again the right pretension of the wires is crucial in order to get a useful reduction to the required strength of the uprights. In these tests the intermediate hog lashing was obviously laid too loose and no difference compared to the case without lashing was observed. The mere presence of wires inside the stow did not have any effect.

6. References and acknowledgements

6.1 References

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5. Sjöfartsverkets författningssamling SJÖFS 2003:14.

6. CEN/TC 168/WG 6: Practical inclination test for determination of the efficiency of cargo securing arrangements.

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6.2 Denotations

The denotations used in the formulas in the formulae in this report are listed below:

a_t = *Largest transverse acceleration at the centre of gravity of the deck cargo in the forward or aft end of the stow in* m/s^2
B = *Transverse width of deck cargo in meter*
b = *Width of each individual stack of packages*
CS = *Calculated strength of lashing in kN*
f_R = *Reduction factor for accelerations due to expected sea state*
g_0 = *Gravity acceleration* $9.81\ m/s^2$
H = *Height of deck cargo in meter*
H_M = *Maximum significant wave height*
h = *Height above deck at which hoglashings are attached to the uprights in meter*
k = *Factor for considering hog lashings;*
$k = 1$ *if no hog lashings are used*
$k = 1.8$ *if hog lashings are used*
L = *Length of the deck cargo or section to be secured in meter*
L_L = *Length of each lashing in meter*
$M_{bending}$ = *Design bending moment on uprights in kNm*
MSL = *Maximum Securing Load in kN of cargo securing devices*
m = *Mass of the deck cargo or section to be secured in tonnes, including absorbed water and possible icing*
N = *Number of uprights supporting the considered section on each side*
n = *Number of lashings*
n_b = *Number of bottom blocking devices per side of the deck cargo*
n_p = *Number of stacks of packages abreast in each row*
PS = *Pressure from unavoidable sea sloshing in kN based on 1 kN per* m^2 *exposed area, see CSS Annex 13*

PT_V = *Pretension in the vertical part of the lashings in kN*
PT_H = *Pretension in the horizontal part of the lashings in kN*
PW = *Wind pressure in kN based on 1 kN per m^2 wind exposed area,*
q = *Number of layers of timber packages*
RS = *Racking Strength per meter in kN.*
α = *Angle between the hatch cover top plating and the lashings in degrees*
δ = *Small transverse movement of deck cargo in meter due to elasticity of lashing arrangement*
ε = *Elasticity factor for lashing equipment, taken as fraction of elongation experienced at the load of MSL for the lashing.*
$\mu_{dynamic}$ = *Dynamic coefficient of friction between the timber deck cargo and the ship's deck / hatch cover and considered to be 70% of the static friction value.*
$\mu_{internal}$ = *Coefficient of dynamic friction found internally between the packages of sawn wood*
μ_{static} = *Static coefficient of friction between the timber deck cargo and the ship's deck / hatch cover*

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