# Practical Tests with Timber Deck Cargoes

*Tests performed in Sundsvall, Sweden,*
*between February 5th and 7th 2008*
*as part of the TIMRA-project*

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# Summary and Conclusions

The national project TIMRA has been started in Sweden with the purpose of preparing a draft code to be presented for the *International Correspondence Group on the Revision of the Timber Deck code*.

As part of this project, practical tests have been performed with typical timber deck cargoes in order to investigate their behaviour and characteristics. Tests have been performed with both round wood and square sawn timber packages during 5th through 7th February 2008 at SCA Transforrest's facilities in Sundsvall, Sweden.

Several different types of tests were conducted and their purpose and execution as well as the results and conclusions from them are presented below.

## Determination of friction coefficients

Coefficients of static friction were established for both timber packages and round wood through inclination tests, in which the timber was placed on different surfaces which were prepared in different ways in order to simulate both summer and winter conditions. The platform upon which the timber was loaded was then inclined until the cargoes slid.

Based on these tests, it is recommended that the following friction factors are used as input for a list of friction values in the new *Code of Safe Practice for Ships Carrying Timber Deck Cargoes*:

| Cargo type, material combination | Condition | Static coefficient of friction |
|---|---|---|
| Sawn timber – Plywood | Dry | 0.50 |
| Sawn timber – Plywood | Snowy | 0.25 |
| Sawn timber – Painted Steel | Dry | 0.45 |
| Sawn timber – Painted Steel | Snowy | 0.05 |
| Sawn timber – Plastic Hood | Dry | 0.40 |
| Sawn timber – Plastic Hood | Snowy | 0.25 |
| Log (Round wood) – Painted steel sheet | Wet | 0.38 |
| Log (Round wood) – Plywood | Wet | 0.62 |
| Log (Round wood) – Log | Wet | 0.78 |

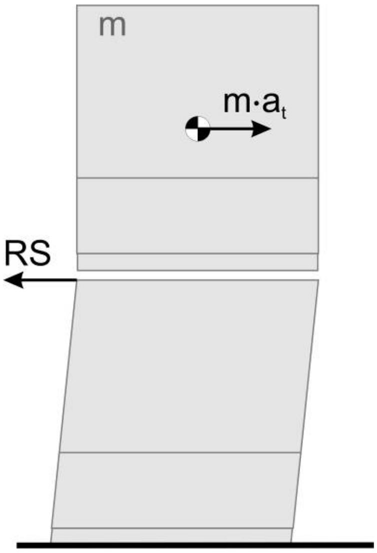
Since the values for the round wood timber are only based on one single inclination test each and since no tests for neither dry nor snowy and icy conditions were performed, it is strongly suggested that any friction value inserted into the new *Code of Safe Practice for Ships Carrying Timber Deck Cargoes* is based also on other studies.

## Racking strength of timber packages

A method for determining the racking strength of packages of square sawn timber was tried out with satisfactory results. The method is simply to measure the deformation of packages as a function of a pulling force applied parallel to the top of the package.

The big differences in racking strength observed between the four tested packages, despite their similar dimensions and bundling techniques, demonstrates the need for adopting some method for determining the racking strength of packages.

The result of the tests performed within this project shows that the method used may be a good indicator of the packages capacity for carrying other packages when the cargo is exerted to great horizontal forces. The method is, as such a test method must be, simple to carry out and requires a minimum of equipment. When performing tests in order to determine racking strength, the angle between the lashing and the platform should not be greater than 30°, since it is the lateral force that is of particular interest.



As a result of the trial, it is suggested that the racking strength, RS, of a timber package is taken as the force that produces a deformation at the top of the package equal to 10% of the package's width or maximum 100 mm.

The racking strength of timber packages determines their capacity of carrying other packages on top of them without collapsing. For packages not supported by uprights or other means, the racking strength, *RS*, must be equal to or greater than the mass force, $m \cdot a_t$, that the top packages are exerted to:

$$RS \geq m \cdot a_t$$

## Tests with loop lashed timber packages

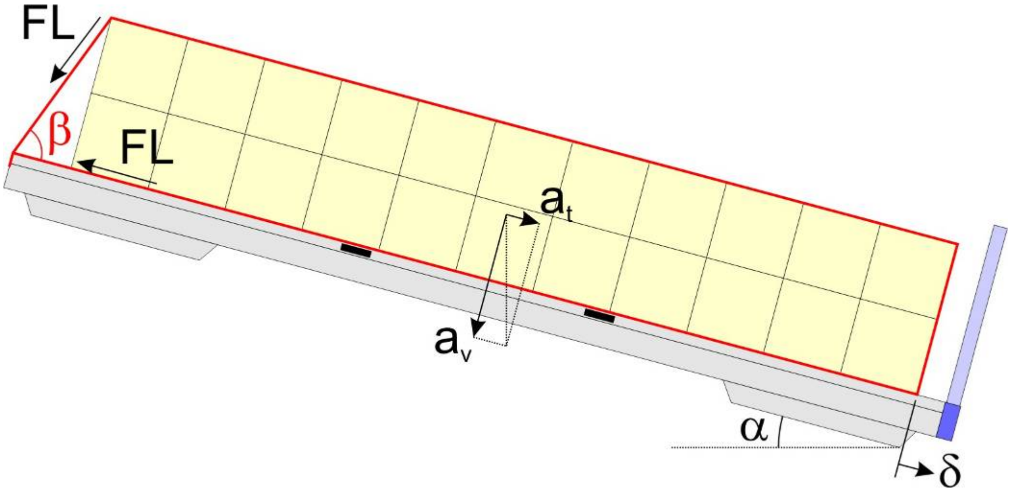
Inclination tests with twenty timber packages, representing a stow of deck cargo containing two layers with ten packages each, were performed with both chain and web lashing equipment.

It has been shown that the lashing forces and dislocation for loop lashed timber packages may be fairly accurately determined by the formulas below, at least at large accelerations:

$$FL = \frac{m \cdot (a_t - \mu_{static} \cdot 0.7 \cdot a_v)}{2 \cdot (1 + \cos\beta + \sin\beta \cdot \mu_{static} \cdot 0.7)}$$

$$\delta = L \cdot \frac{(FL - PT_V)}{MSL} \cdot \varepsilon$$

$$MSL_{req} = FL \cdot 1.35$$



*where:*

$m$ = *Mass of cargo section in ton*
$a_t$ = *Transverse acceleration*
$a_v$ = *Vertical acceleration*
$\mu_{static}$ = *Coefficient of static friction between the cargo and the platform:*
$\beta$ = *Angle between the horizontal plane and the vertical parts of the lashings*
$L$ = *Length of lashing*
$PT_V$ = *Pretension in the vertical parts of the lashings in ton*
$MSL$ = *Maximum Securing Load for the lashings in ton*
$MSL_{req}$ = *Calculated required MSL for lashings in ton*
$\varepsilon$ = *Elasticity factor for lashing equipment, taken as fraction of elongation experienced at the load of MSL for the lashing.*

The dramatic movement of the cargo within the lashings observed during the tests clearly demonstrates the need for using fastening devices on the lashings that does not allow them to loosen should they become slack.

It also clearly indicates the need for taking cargo movement due to flexibility of the securing arrangement into account when considering vessel stability.

The tests have also shown that for protection of the cargo and for minimisation of cargo dislocation, corner protectors between the lashings and the cargo is to be recommended.

## Tests with unsecured round wood stowed athwertships

Tests were carried out with a tire of logs loaded between the gables of a container flat, which were inclined transversely.

The tests showed that the logs are most likely to start sliding at the bottom against deck plating, at least on snowy and icy contact surfaces. This is also supported by the friction factors found in the tests with only a few logs on different surfaces.

*A container, handled by a fork lift, was used to prevent the logs from moving too far away from the container flat.*

*The logs started to move against the painted steel sheet at 30°.*

## Determination of required strength of uprights supporting longitudinally stowed round wood

In this test, 43 ton of round wood were stowed between uprights on a cassette to represent a tire stowed longitudinally on the deck of a vessel. The cassette was then inclined and the required support force was measured at the top of the uprights at the lower end of the cassette.

These tests showed that logs loaded longitudinally between uprights will shift and pack themselves towards the lower set of uprights and that the uprights on the high side will be left without support from the cargo, so that the bending moment produced by hog lashings will have to be taken up at the bottom of the upright. The shifting of the logs occurred suddenly, in steps, as the balance of forces between the logs was overcome and the friction against the deck turned from static to dynamic.

It is suggested that the following formula for calculating the bending moment produced by longitudinally stowed round wood can be used to determine the required strength of upright:

$$M_{bending} = max\left(\frac{1}{80} \cdot m \cdot H, \quad \frac{1}{6} \cdot m \cdot \left(a_t - \mu_{static} \cdot 0.7 \cdot a_v\right) \cdot H\right)$$

*where:*

$M_{bending}$ = *Bending moment in tonmeters, calculated by theoretic formulas proposed to be inserted in the new Code of Safe Practice for Ships Carrying Timber Deck Cargoes*
$F$ = *Measured force in each chain in ton*
$h$ = *Height of uprights in meters*
$m$ = *Mass of cargo section in ton*
$H$ = *Height of cargo stow in meters*
$a_t$ = *transverse acceleration in fractions of 1.0 g*
$a_v$ = *vertical acceleration in fractions of 1.0 g*
$\mu_{static}$ = *Coefficient of static friction between the cargo and the platform*

Furthermore, a safety factor of SF = 1.35 should be used to take account for uneven distribution of forces among the uprights.

# Contents

# 1 Preamble

As part of the TIMRA-project, MariTerm AB has on behalf of the Swedish Maritime Administration as well as the Swedish forest industries and ship owners, managed and supervised practical tests with timber deck cargoes, which were performed in order to aid the preparation of a draft for the revision of the IMO *Code of Safe Practice for Ships Carrying Timber Deck Cargoes*.

The tests were performed at the SCA Transforest's facilities in Sundsvall, Sweden, between the 5th and 7th February 2008. The cargo used in the tests was supplied by SCA. The testing equipment was prepared by the mechanical workshop of Rederi AB Transatlantic in Sundsvall. The lashing equipment used was provided by Forancra and Certex.

The purpose of the tests was foremost to establish practical test procedures for investigating the following timber deck cargo characteristics:

- Form stability of packed sawn timber
- Behaviour of different cargo securing arrangements, including flexibility and compression of the cargo
- Collapsing characteristics of tires of loosely stowed round wood
- Stress distribution produced over uprights

Furthermore, inclination tests were carried out in order to establish the coefficient of friction for different types of timber against different surfaces in different conditions.

The following tests were conducted:

**Tests with square sawn timber packages:**
- Friction tests with packages standing on different surfaces (February 5th)
- Tests of securing arrangements with different lashing equipment (February 5th)
- Tests of racking strength of packages (February 7th)

**Tests with round timber:**
- Friction tests with logs on different surfaces (February 7th)
- Test of required support force from uprights for longitudinally stowed round wood (February 6th)
- Tests of collapsing angle for logs stowed athwart ship (February 6th)

It is the intention to repeat some of these tests within the TIMRA-project with cargoes from other Swedish producers with timber having different dimensions and properties from those tested in Sundsvall. Furthermore, it is hoped that similar tests are conducted by other participants of the international correspondence group for the revision of the Timber Deck Code for verification and complementation of the Swedish results.

Video captions from the tests are available at the web site for the "*Correspondence Group on the Revision of the Code of Safe Practice for Ships Carrying Timber Deck Cargoes*":

http://www.mariterm.se/timra.html

## 2 Attendance

The following persons attended the tests:

| Name | Company | 2008-02-05 | 2008-02-06 | 2008-02-07 |
|---|---|---|---|---|
| Björn-Olof Ericsson | Högskolan Åland | x | x | x |
| Carl Axel Bouveng | Erik Thun AB |  | x |  |
| Claes-Göran Haraldsson | Rederi AB Transatlantic | x | x | x |
| Göran Hansson | RABT Verkstad | x | x | x |
| Lars-Erik Eriksson | SCA Sågverk Tunadal |  |  | x |
| Niclas Strömqvist | Södra Skogsägarna |  | x |  |
| Patrik Granstam | Sjöfartsverket |  | x |  |
| Per Floden | Erik Thun AB<br>(Vedén Engeneering) |  | x |  |
| Per Fransson | Österströms Rederi AB |  | x |  |
| Peter Andersson | MariTerm AB | x | x | x |
| Philippe Chanfrau | Högskolan Åland | x | x | x |
| Sven Sökjer-Petersen | MariTerm AB | x | x | x |
| Thomas Granberg | SCA Sundsvall | x | x | x |
| Ulf Höglund | Sundsvalls Hamn | x | x | x |

# 3 Test material and measuring devices

The cargo, the equipment and the measuring devices used in the tests are described below.

## *3.1 Cargo*

The behaviour and properties of both sawn timber packages and loosely stowed logs were studied in the tests. All cargoes were supplied by SCA and produced locally in Sundsvall.

### 3.1.1 Square sawn timber packages

Several packages with square sawn timber from spruce with different dimensions, bound together by either steel or plastic straps were used in the tests.

The weights of the packages varied between 1.5 and 2.5 ton. The lengths varied between 2.5 and 4.0 meters. All individual packages, however, contained timber of equal lengths.

The packages all had protective hoods, complying with Swedish work environmental regulations, meaning that they were produced in a material with enhanced friction compared to ordinary plastic covers.

The friction of the hoods has been tested in accordance with the Swedish Standard SS 92 35 15, meaning that the friction produced between the plastic cover and work boots is sufficient for preventing accidents like slips and falls.

### 3.1.2 Round wood

In the tests with round timber, pulp wood of different dimension and wood types were used, although the logs were predominately from coniferous tree. The diameters were ranging from approximately 10 to 50 cm. The lengths of the logs were approximately 3 meters.

The pulp wood had been stored outside and was covered with snow and ice. Additionally, snow was sprinkled in between the logs while loading them onto the test platforms.

## 3.2 Equipment

Two different platforms were used to facilitate the cargoes during the tests; a 40 foot cassette and a 20 foot container flat. Since both platforms had wooden flooring, painted steel sheets were used to replicate the contact surface between deck cargoes and the hatch covers of vessels. All of this equipment was prepared by the mechanical workshop of Transatlantic in Sundsvall.

In some of the tests the cargo was secured by different types of lashing equipment or supported by uprights.

### 3.2.1 Cassette

One of the platforms used was a 40 foot cassette with wooden flooring, normally used for transporting paper reels in RoRo vessels.

The cassette had been fitted with uprights in all four corners and extra lashing eyes on the short sides. Two of the uprights were removable. Moreover, two loose uprights were used to support a load of round wood. All six uprights were 2.5 meters high and produced from square cross section VKR steel profiles measuring 120 x 120 mm with a wall thickness of 5 mm.

Each upright had a weight of approximately 20 kg. The dimensions, and thereby the weight, of the uprights were purposely kept as small as possible for easier handling.

### 3.2.2 Container flat

The other platform used was a 20 foot container flat with fixed gables. An angle bar had been fitted along one side of the flat, serving as a bottom blocking device with a height of 50 mm.

The container flat had wooden flooring.

### 3.2.3 Steel sheets

In order to simulate the behaviour of cargoes on hatch covers on vessel decks, two painted steel sheets, measuring 1.2 x 2.5 meters were used. The steel sheets were laid underneath the cargo on top of both platforms and were placed either directly against the angle bar on the container flat or against the uprights on the cassette so that movement of the sheets was prevented.

### 3.2.4 Lashing equipment

Two sets of lashing equipment were used in the tests:

- *11 mm chain lashings with MBL 15 ton*
- *Web lashings with MBL =13.6 ton, especially designed for timber deck cargoes*

*(MBL = Minimum Break Load)*

The chain lashings were tensioned with a leverage tensioner supplemented by an extension handle. The web lashings were tensioned with the built in ratchet.

The lashing equipment was supplied by Forancra ABT and Certex.

*Chain lashing used in the tests*

*Web lashing used in the tests*

*Chain lashing in use*

*Web lashing being tensioned*

Wire lashing equipment was also made available for the tests but the test team decided to omit tests with wire since the behaviour of cargo secured with such equipment would probably be similar to that secured with web lashings, although the system would be less flexible. Shortage of time was also a contributing factor for the decision not to perform a test with wire lashings.

## 3.3 Measuring devices

Inclination angles were measured with an analogue bubble vial inclinometer of the make Tajima Slant 100 (see picture on the right).

Lashing forces were measured with two dynamometers, one of which was an analogue device with a maximum measuring capacity of 10 ton and the other a digital device with a maximum load of 12 ton (see pictures below).

*Analogue and digital dynamometer used in tests.*

# 4 Determination of friction coefficients

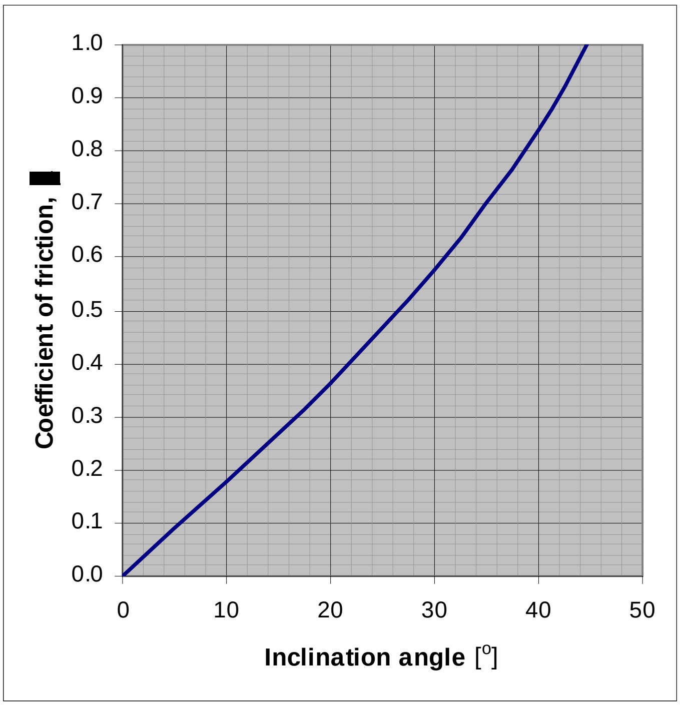
One way of determining coefficients of friction is to place the cargo on a platform and incline the platform until the cargo starts to slide. The static coefficient of friction is then calculated by the following formula:

$$\mu = \tan \alpha$$

*where:*

$\mu$ = *coefficient of friction*
$\alpha$ = *inclination angle*

In the diagram on the right the friction factor has been plotted against the inclination angle at which cargo starts to slide.



# 5 Acceleration model

The following formula, which has been incorporated in the cargo securing regulations of the Swedish Maritime Administration, can be used to calculate which static inclination angle that is required to simulate different combinations of horizontal and vertical accelerations for different coefficients of friction to obtain identical lashing forces in an inclination test as would appear in reality:

$$\alpha = 2 \cdot arctan\left[\frac{-1+\sqrt{1+\mu^2-\mu^2 \cdot a_v^2+2\cdot\mu\cdot a_v\cdot a_h-a_h^2}}{\mu+\mu\cdot a_v-a_h}\right], \quad \mu \neq \frac{a_h}{1+a_v}$$

$$\alpha = 2 \cdot arctan\left[\frac{a_h}{1+a_v}\right], \quad \mu = \frac{a_h}{1+a_v}$$

*where:*

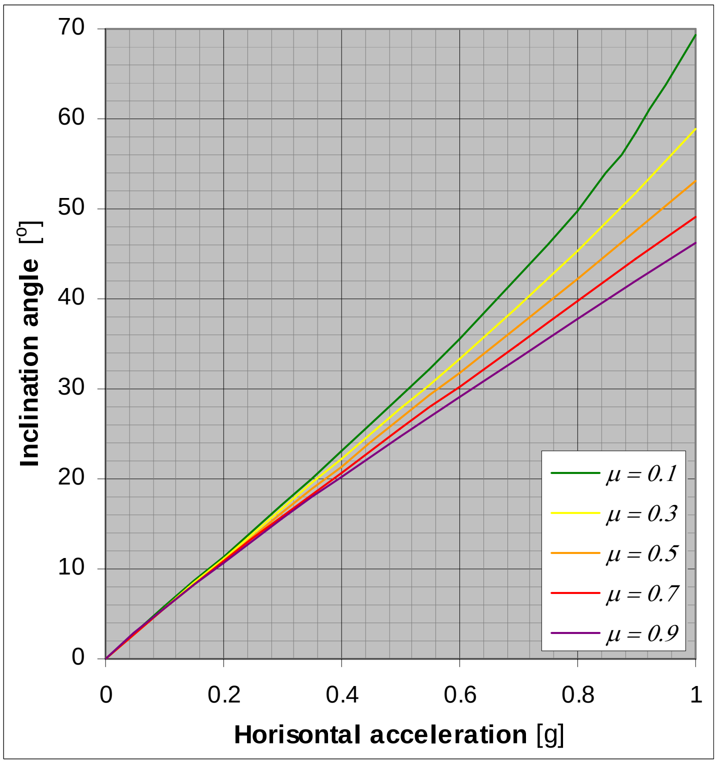
$\alpha$ = *Inclination angle*
$a_v$ = *vertical acceleration (expressed as part of g = 9.81 m/s²)*
$a_h$ = *horizontal acceleration (expressed as part of g = 9.81 m/s²)*
$\mu$ = *Coefficient of friction*

Similarly the following formula can be used to calculate the simulated horizontal acceleration at a given inclination angle as a function of the friction factor and the vertical acceleration:

$$a_h = \mu \cdot (a_v - cos\,\alpha) + sin\,\alpha$$

Following the methodology of Annex 13 in the Code of Safe Practice for Cargo Stowage and Securing, the vertical acceleration can be set equal to earth gravity, $a_v = 1.0\ g = 9.81\ m/s^2$, when considering the influence of transverse forces acting on cargoes onboard vessels.

In the diagram on the right, the inclination angle has been plotted as a function of the horizontal accelerations for different friction factors in accordance with the formulas above and given a vertical acceleration of 1 g.



For further information on how the formulas above have been derived, see Appendix A.

# 6 Tests with packaged sawn timber

The following tests were performed to investigate the properties and behaviour of square sawn timer in packages:

- Friction tests with packages loaded onto different surfaces
- Tests of securing arrangements with different lashing equipment
- Tests of racking strength of packages

## *6.1 Friction tests*

A package of sawn timber was placed on different surfaces on the 40 cassette, which was then inclined until the package started to slide, at which point the inclination angle was measured. From that angle the static coefficient of friction was determined by the use of the formula described in chapter 4 of this report.

*Inclination test with one package*

*Inclination test with two packages. The upper package is free to slide while the bottom one is blocked against the uprights.*

The following three different material contacts were tested:

- Sawn timber against plywood
- Sawn timber against painted steel
- Sawn timber against plastic hood (one package on top of the other)

When testing the friction between packages, i.e. the material contact between timber and the plastic hood, a second package was placed on top of the first one, which was placed directly against the uprights.

Throughout a first series of tests the cargo was placed on clean and dry surfaces that were kept free from frost, ice and snow. In a second series of tests, snow was sprinkled over the test surfaces.

During the tests, which were performed on February 5th, the weather was clear and the temperature slightly below 0 °C.

*Painted steel sheet used underneath the cargo to simulate the material contact between timber and the deck of a vessel.*

*Snow being sprinkled on top of the bottom package to obtained winter conditions.*

The properties of the timber packages used in the tests are given in the table below:

| **Package no.** | **Package dimensions L×H×B** [cm] | **Timber dimensions h×b** [mm] | **Weight** [ton] | **Quality** | **Straps** | **Battens** |
|---|---|---|---|---|---|---|
| 1 (Bottom) | 390×110×100 | 32×100 | 2.0 | Sawn | 3 pcs, steel | 2 pcs, underneath timber |
| 2 (Top) | 330×110×100 | 32×100 | 1.6 | Sawn | 3 pcs, steel | 2 pcs, underneath timber |

The packages were covered by a plastic hood from Storsäck Sverige AB, produced in a material with enhanced friction.

*Package 1*

*Package 2 being placed on top of package 1*

### 6.1.1 Results

| Material combination | Condition | Test no. | Inclination angle | Static coefficient of friction |
|---|---|---|---|---|
| Sawn timber – Fabric base laminate / plywood | Dry | 1 | 29.5° | 0.57 |
| | | 2 | 27.5° | 0.52 |
| | | 3 | 27.5° | 0.52 |
| | | | | |
| | Snowy | 1 | 18.0° | 0.32 |
| | | 2 | 16.0° | 0.29 |
| | | 3 | 16.0° | 0.29 |
| | | | | |
| Sawn timber – Painted Steel | Dry | 1 | 23.5° | 0.43 |
| | | 2 | 25.5° | 0.48 |
| | | 3 | 25.0° | 0.47 |
| | | | | |
| | Snowy* | 1 | 4.0° | 0.07 |
| | | 2 | 4.0° | 0.07 |
| | | | | |
| Sawn timber – Plastic Hood | Dry | 1 | 24.0° | 0.45 |
| | | 2 | 22.0° | 0.40 |
| | | 3 | 23.5° | 0.42 |
| | | | | |
| | Snowy | 1 | 16.0° | 0.29 |
| | | 2 | 16.0° | 0.29 |

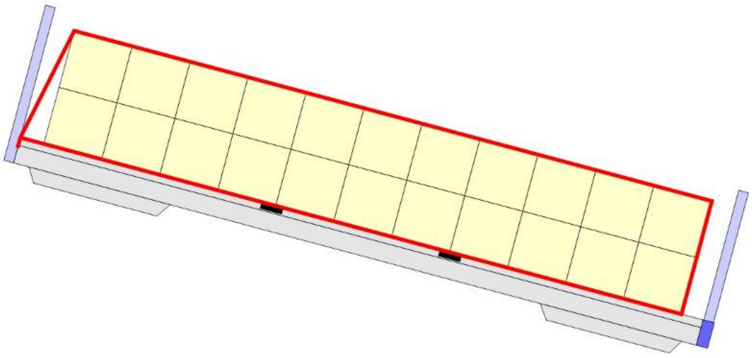
**A timber package weighing 2 tons placed on a snowy painted steel sheet could be moved by hand force.*

By taking the mean of all results for each combination and truncating the values to the nearest fraction of 5 /100, the following values on static friction factors were obtained:

| Material combination | Condition | Static coefficient of friction |
|---|---|---|
| Sawn timber – Plywood | Dry | 0.50 |
| | Snowy | 0.25 |
| | | |
| Sawn timber – Painted Steel | Dry | 0.45 |
| | Snowy | 0.05 |
| | | |
| Sawn timber – Plastic Hood | Dry | 0.40 |
| | Snowy | 0.25 |

## 6.2 Tests with lashing arrangements

In these tests 20 packages, weighing 43 tons together, were placed in two layers on the 40 foot cassette. The packages were secured with two loop lashings and the platform was then inclined to different angles. At each angle the tension in both the lower and the upper part of one of the two slings were measured with dynamometers.



*Setup for tests of lashing arrangement with two loop lashings.*

Since the 40 foot cassette was covered by ice and snow the static coefficient of friction between the battens of the packages in the bottom layer and the plywood of the cassette has, with guidance from the friction tests described in chapter 6.1, been established as $\mu_{static} = 0.25$.

Since loop lashings allow the cargo to move before they become tensioned to their full capacity, the strength of such arrangements should be dimensioned taking dynamic instead of static friction into account. A dynamic friction coefficient of $\mu_{dynami}c = 0.175$, taken as 70% of the static friction factor, has been used when evaluating the results from these tests.

*Preparation of platform prior to loading the timber.*

*Inclining of platform to different angles.*

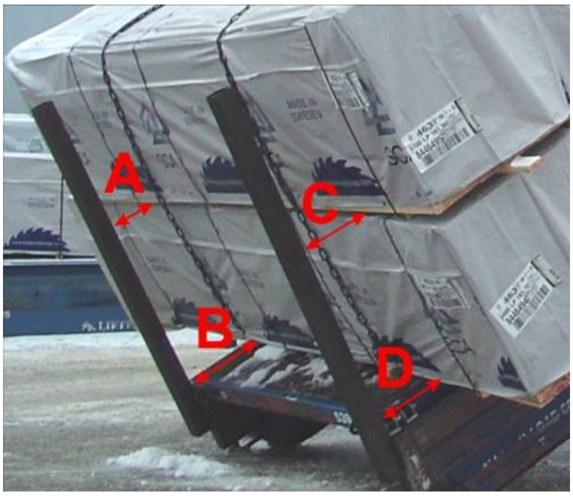
*Measuring of distances to the uprights at the lower end.*

*Measuring of distance and lashing forces at the high end.*

*Chain lashings.*

*Web lashings.*

To check the elasticity of the lashings and the compression of the cargo, the distances between the packages and the uprights on the cassette at several points were measured for each inclination angle. The locations of the measuring points are given in the figure below.



*Distances between the cargo and the uprights at the lower end.*

*Distance between the cargo and the end of the platform at the high end.*

The height above ground for the uppermost point on top of the cassette was also measured for the different inclination angles.

### 6.2.1 Results

In both the test with chain and web lashings, it was noted that the cargo moved in sudden steps, as the static friction was overcome and the cargo slid dynamically until the lashing forces were large enough to prevent further movement.

**Test with chain lashings**

The following lashing forces and distances were recorded during the test with chain lashings.

| **Angle** [°] | **Height** above ground [cm] | **Tension** [ton] | | **Distances** [cm] | | | | **Comments** |
|---|---|---|---|---|---|---|---|---|
| | | *lower part* | *upper part* | A | B | C | D | |
| 0 | 57 | 0.28 | 0.54 | 82 | 87 | 76 | 81 | |
| 18 | 363 | 4.60 | 2.94 | 52 | 63 | 43 | 54 | Major movement |
| 29 | 590 | 4.70 | 3.54 | 51 | 62 | 42 | 54 | |
| 36 | 706 | 9.10 | 5.48 | -* | - | - | - | Major movement |
| 0 | 57 | 1.60 | 1.43 | 52 | 63 | 41 | 52 | Moved back |

** The distances between the bottom packages and the uprights were not measured due to the risk of collapse of the loop lashings. After the test was finished, it was concluded that the package on the upper most end had moved 43 cm. Since it was visually observed that the packages compressed approximately 15 cm during the inclination tests and that they moved back some 10 cm during the lowering of the cassette, the maximum dislocation has been estimated to 40 cm.*

Although substantial movement of the cargo occurred, none of the packages collapsed.

It was noted that the chains had cut into the timber during the inclination test since no corner protections were used, as can be seen in the pictures below. Moreover, the link to which the shackle had been attached on one of the chains was deformed.

*Chain cutting through timber*

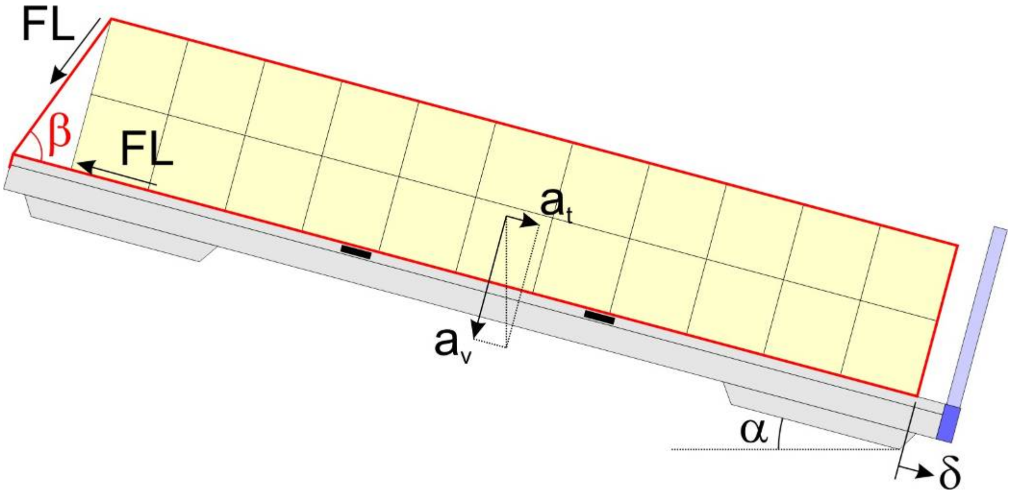
*Damaged link*

The lashing force, FL, and the dislocation, δ, which are presented in the table below, have been calculated by the use of the following formulas:

$$FL = \frac{m \cdot (a_t - \mu_{static} \cdot 0.7 \cdot a_v)}{2 \cdot (1 + \cos\beta + \sin\beta \cdot \mu_{static} \cdot 0.7)}$$

$$\delta = L \cdot \frac{(FL - PT_V)}{MSL} \cdot \varepsilon$$

$$MSL_{req} = FL \cdot 1.35$$



*where:*

$m$ = *Mass of cargo section in ton*
$a_t$ = *Transverse acceleration*
$a_v$ = *Vertical acceleration*
$\mu_{static}$ = *Coefficient of static friction between the cargo and the platform:*

$\mu_{static} = 0.25$ *for timber against plywood at snowy conditions*

$\beta$ = *Angle between the horizontal plane and the vertical parts of the lashings*
$L$ = *Length of lashing*
$PT_V$ = *Pretension in the vertical parts of the lashings in ton*
$MSL$ = *Maximum Securing Load for the lashings in ton*
$MSL_{req}$ = *Calculated required MSL for lashings in ton*
$\varepsilon$ = *Elasticity factor for lashing equipment, taken as fraction of elongation experienced at the load of MSL for the lashing:*

$\varepsilon = 0.020$ *for chain lashings*
$\varepsilon = 0.075$ *for web lashings*

| **Inclination angle, α** | **Accelerations** [g] | | **Measured dislocation at B** | **Calculated dislocation of cargo, δ** | **Measured max lashing force** [ton] | | **Calculated lashing force, FL** | **Calculated required MSL** |
|---|---|---|---|---|---|---|---|---|
| [°] | $a_t$ | $a_v$ | [cm] | [cm] | lower | upper | [ton] | [ton] |
| 18 | 0.31 | 0.95 | 24 | 8 | 4.6 | 2.9 | 2.1 | 2.9 |
| 29 | 0.48 | 0.87 | 25 | 28 | 4.7 | 3.5 | 4.9 | 6.7 |
| 36 | 0.59 | 0.81 | 40 | 40 | 9.1 | 5.4 | 6.6 | 8.9 |

In the diagram above, the vertical and transverse accelerations acting on the cargo have been calculated as functions of the inclination angle, α, by using the following formulas:

$$a_t = sin\alpha$$

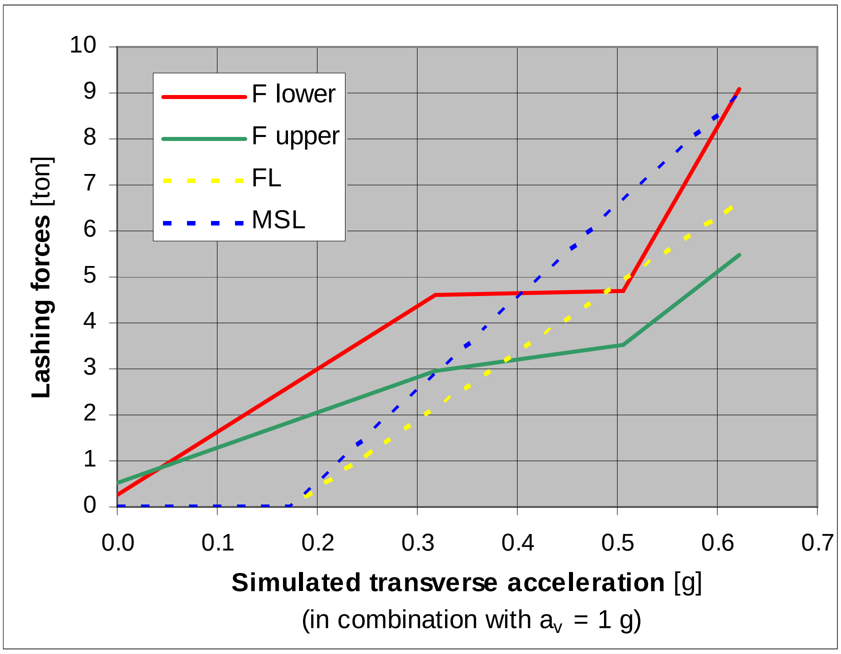
$$a_v = cos\alpha$$

With the help of the formulas presented in chapter 5, the lashing forces can alternatively be calculated based on a vertical acceleration $a_v = 1$ g and a simulated transverse acceleration taken as a function of the lashing angel and the coefficient of friction. In the diagram below, the two different set of accelerations are presented for each inclination angle.

| **Inclination angle, α** | **Real accelerations** [g] | | **Simulated transverse acceleration *** | **Calculated lashing force, FL **** | **Calculated required MSL **** |
|---|---|---|---|---|---|
| [°] | $a_t$ | $a_v$ | $a_v = 1\ g$ $\mu_{dynamic} = 0.175$ [ton] | [ton] | |
| 0 | 0 | 1.0 | 0 | | |
| 18 | 0.31 | 0.95 | 0.32 | 2.1 | 2.9 |
| 29 | 0.48 | 0.87 | 0.51 | 4.9 | 6.7 |
| 36 | 0.59 | 0.81 | 0.62 | 6.6 | 8.9 |

** The simulated transverse acceleration corresponding to each inclination angle in the table above has been determined by the diagram in chapter 5 of this report for a dynamic coefficient of friction* $\mu_{dynamic} = 0.175$ ($\mu_{dynamic} = \mu_{static} \cdot 0.7 = 0.25 \cdot 0.7$).

*** The formula for the loop lashing arrangement above will however give exactly the same calculated lashing force, FL, and required MSL, regardless of which set of accelerations that is used.*



*Comparison between measured and calculated lashing forces for chain lashings.*

A video caption from the test with chain lashings of timber packages is available for download at the web site for the "*Correspondence Group on the Revision of the Code of Safe Practice for Ships Carrying Timber Deck Cargoes*":

http://www.mariterm.se/timra.html

## Test with web lashings

The following lashing forces and distances were recorded during the test with web lashings:

| **Angle** [°] | **Height** above ground [cm] | **Tension** [ton] | | **Distances** [cm] | | | | | **Comments** |
|---|---|---|---|---|---|---|---|---|---|
| | | lower part | upper part | A | B | C | D | E | |
| 0 | 57 | 0.30 | 0.45 | 51 | 62 | 41 | 52 | 115 | |
| 14 | 300 | 1.80 | 1.44 | 27 | 40 | 15 | 27 | 118 | Major movement |
| 22 | 455 | 3.70 | 2.84 | 0* | 10 | 0 | 0 | 175 | Major movement |
| 0 | 57 | 0.90 | 0.72 | 27 | 38 | 20 | 28 | 144 | Moved back |

** At 22° degrees inclination the packages moved against the uprights at the lower end.*

The lashing force, FL, and the dislocation, δ, which are presented in the diagram below, have been calculated by the same formulas as was used for the chain lashings above.

| **Inclination angle** [°] | **Accelerations** [g] | | **Measured dislocation at B** [cm] | **Calculated dislocation of cargo, δ** [cm] | **Measured max lashing force** [ton] | | **Calculated lashing force, FL** [ton] | **Calculated required MSL** [ton] |
|---|---|---|---|---|---|---|---|---|
| | $a_t$ | $a_v$ | | | lower | upper | | |
| 16 | 0.24 | 0.97 | 22 | 3 | 1.8 | 1.4 | 1.00 | 1.3 |
| 27 | 0.37 | 0.93 | 52 | 61 | 3.7 | 2.8 | 2.93 | 4.0 |

In the diagram above, the vertical and transverse accelerations acting on the cargo have been calculated as functions of the inclination angle, α, by using the following formulas:

$$a_t = sin\alpha$$

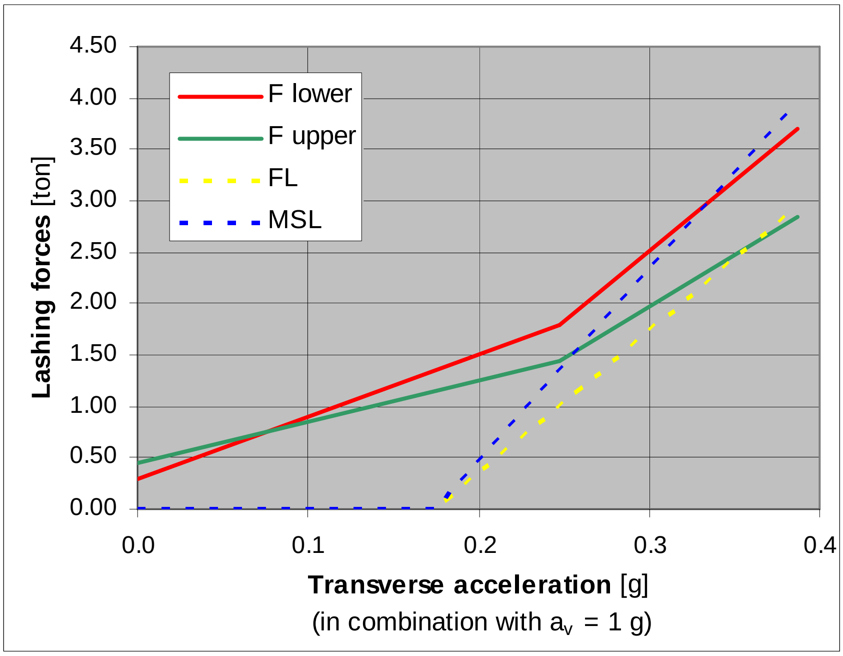
$$a_v = cos\alpha$$

With the help of the formulas presented in chapter 5, the lashing forces can alternatively be calculated based on a vertical acceleration $a_v = 1$ g and a simulated transverse acceleration taken as a function of the lashing angel and the coefficient of friction. In the diagram below, the two different set of accelerations are presented for each inclination angle.

| **Inclination angle** [°] | **Real accelerations** [g] | | **Simulated transverse acceleration** $a_v = 1\ g$ $\mu_{dynamic} = 0.175$ |
|---|---|---|---|
| | $a_t$ | $a_v$ | $a_t$ [g] * |
| 0 | 0 | 1.0 | 0 |
| 16 | 0.24 | 0.97 | 0.25 |
| 27 | 0.37 | 0.93 | 0.39 |

** The simulated transverse acceleration corresponding to each inclination angle in the table above has been determined by the diagram in chapter 5 of this report for a dynamic coefficient of friction* $\mu_{dynamic} = 0.175$ $(\mu_{dynamic} = \mu_{static} \cdot 0.7 = 0.25 \cdot 0.7)$.

The formula for the loop lashing arrangement above will however give exactly the same calculated lashing force, FL, regardless of which set of accelerations that is used.



*Comparison between measured and calculated lashing forces for web lashings.*

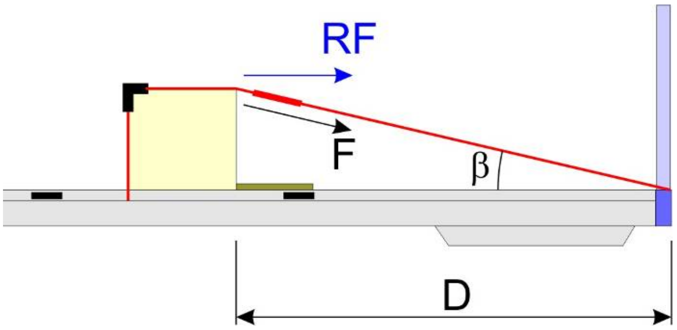
A video caption from the test with web lashings of timber packages is available for download at the web site for the "*Correspondence Group on the Revision of the Code of Safe Practice for Ships Carrying Timber Deck Cargoes*":

http://www.mariterm.se/timra.html

## 6.3 Test of racking strength

The racking strength of packages indicates their capacity of carrying other packages on top of them without collapsing, when the cargo is exerted to horizontal forces. The tests described below in this chapter were performed with the aim of establishing a procedure for determining the racking strength of packages.

In order to test the form stability of packages and the strength of different bundling techniques, four different packages bottom blocked and then subjected to a pulling force at the top, as illustrated in the figure below.



*F* = *Force in lashing*

*RF* = *Racking force parallel to the top of timber package*

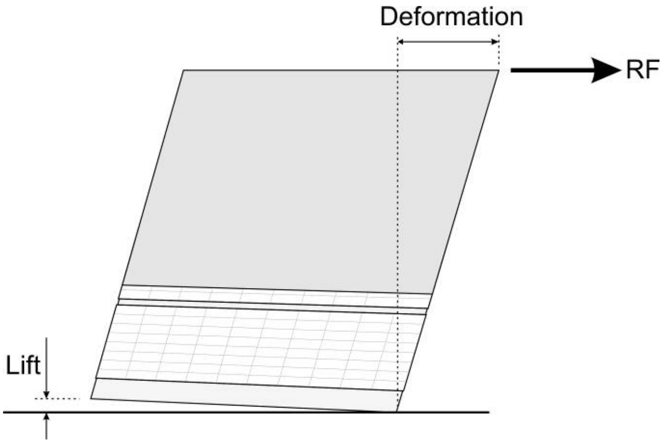
*β* = *Angle between lashing and platform*

*D* = *Distance between package and fitting for the lashing*

The racking force was produced by connecting two turnbuckles to chain lashings. The force produced was measured with the analogue dynamometer. The distance D was 3.03 meters in the tests.

*Pictures illustrating the assembly of chains used for producing the pulling force.*

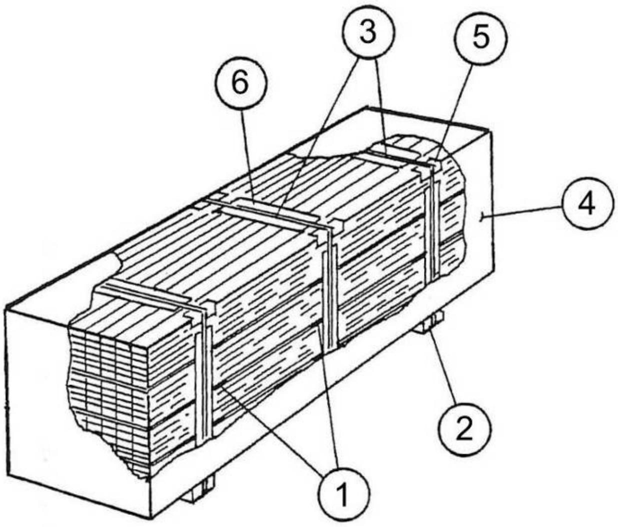
During the tests, the distance between the top of the packages and a reference point was measured in order to determine the deformation of the packages. Moreover, the lift produced between the bottom of the package and the platform at the back side was measured, both at maximum force and after the chains had been totally released.
The figure below shows which distances for package deformation that was measured during the tests.



The properties of the timber packages used in the tests are given in the table below:

| Package no. | Package dimensions L×H×B [cm] | Timber dimensions h×b [mm] | Weight [ton] | Wood type | Quality |
|---|---|---|---|---|---|
| 1 | 540×118×107 | 32×100 | 2,7 | Spruce | Sawn |
| 2 | 450×122×109 | 47×150 | 2,5 | Spruce | Sawn |
| 3 | 420×126×108 | 50×175 | 2,2 | Spruce | Sawn |
| 4 | 402×115×108 | 27.5×132 | 2,1 | Spruce | Planed |

| Package no. | Strapping | Beams | Stickers |
|---|---|---|---|
| 1 | 4 pcs, steel | 2 pcs, underneath timber | 2 pcs at 2 levels |
| 2 | 3 pcs, steel | 2 pcs, underneath timber | 2 pcs at 2 levels |
| 3 | 5 pcs, plastic | 2 pcs, on top of timber | 2 pcs at 4 levels |
| 4 | 3 pcs, plastic | 3 pcs, on top of timber | 3 pcs at 4 levels |



*Definitions of different components of whole packages of timber:*

1. *Sticker in whole package*
2. *Beam under whole package*
3. *Strapping of the whole package*
4. *Wrapper of the whole package*
5. *Edge protection*
6. *Timber protection*

### 6.3.1 Results

**Package number 1**

| **Force, F** [ton] | **Force, F** [kN] | **Racking force, RF** [ton] | **Distance** (to reference point at top of package) [mm] | **Deformation** (at the top of the front side) [mm] | **Lift** (at the bottom of the back side) [mm] |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 145 | 0 | 0 |
| 0.35 | 3.4 | 0.33 | 130 | 15 | - |
| 0.69 | 6.8 | 0.65 | 115 | 30 | - |
| 0.88 | 8.6 | 0.83 | 100 | 45 | - |
| 1.19 | 11.7 | 1.12 | 90 | 55 | - |
| 1.60 | 15.7 | 1.51 | 70 | 75 | - |
| 1.88 | 18.4 | 1.77 | 55 | 90 | - |
| 2.30 | 22.6 | 2.17 | 35 | 110 | 10 |
| 0 | 0.0 | 0 | 80 | 65 | 0 |

The racking force, RF has been calculated with the following formula:

$$RF = F \cdot cos\,\beta$$

*Package 1 at maximum pulling force*

*Package 1 after test.*

## Package number 2

| Force, F [ton] | Force, F [kN] | Racking force, RF [ton] | Distance (to reference point at top of package) [mm] | Deformation (at the top of the front side) [mm] | Lift (at the bottom of the back side) [mm] |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 160 | 0 | 0 |
| 0.50 | 4.9 | 0.47 | 140 | 20 | - |
| 0.82 | 8.0 | 0.77 | 120 | 40 | - |
| 1.12 | 11.0 | 1.05 | 100 | 60 | - |
| 1.38 | 13.5 | 1.30 | 80 | 80 | - |
| 1.58 | 15.5 | 1.49 | 60 | 100 | - |
| 1.73 | 17.0 | 1.63 | 50 | 110 | 14 |
| 0 | 0 | 0 | 100 | 60 | 0 |

*Package 2 during tests*

## Package number 3

| Force, F [ton] | Force, F [kN] | Racking force, RF [ton] | Distance (to reference point at top of package) [mm] | Deformation (at the top of the front side) [mm] | Lift (at the bottom of the back side) [mm] |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 170 | 0 | 0 |
| 0.40 | 3.9 | 0.38 | 150 | 20 | - |
| 0.70 | 6.9 | 0.66 | 130 | 40 | - |
| 0.95 | 9.3 | 0.89 | 110 | 60 | - |
| 1.11 | 10.9 | 1.04 | 90 | 80 | - |
| 1.30 | 12.8 | 1.22 | 70 | 100 | - |
| 1.50 | 14.7 | 1.41 | 50 | 120 | - |
| 1.80 | 17.7 | 1.70 | 30 | 140 | 40 |
| 0 | 0 | 0 | 70 | 100 | 25 |

*Package 3 at maximum pulling force*

*Package 3 after test.*

**Package number 4**

| Force, F [ton] | [kN] | Racking force, RF [ton] | Distance (to reference point at top of package) [mm] | Deformation (at the top of the front side) [mm] | Lift (at the bottom of the back side) [mm] |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 135 | 0 | 0 |
| 0.30 | 2.9 | 0.28 | 100 | 35 | - |
| 0.40 | 3.9 | 0.38 | 80 | 55 | - |
| 0.55 | 5.4 | 0.52 | 60 | 75 | - |
| 0.70 | 6.9 | 0.66 | 40 | 95 | - |
| 0.77 | 7.6 | 0.73 | 20 | 115 | 15 |
| 0 | 0 | 0 | 25 | 110 | 15 |

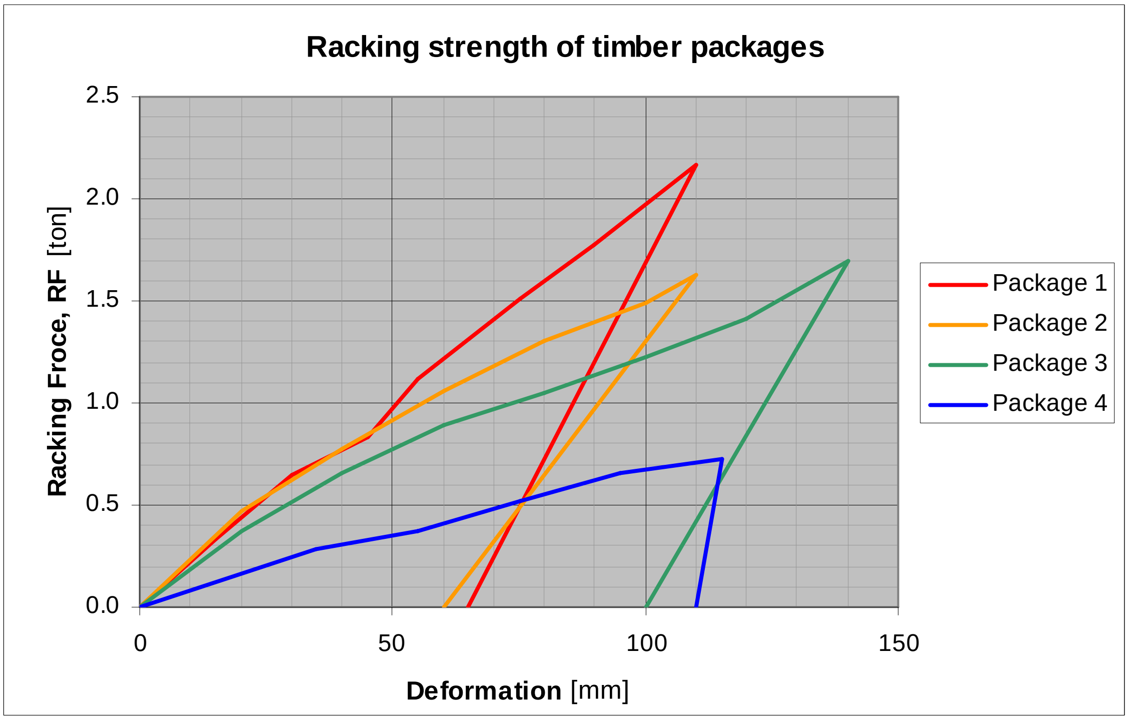
*Package 4 at maximum pulling force*

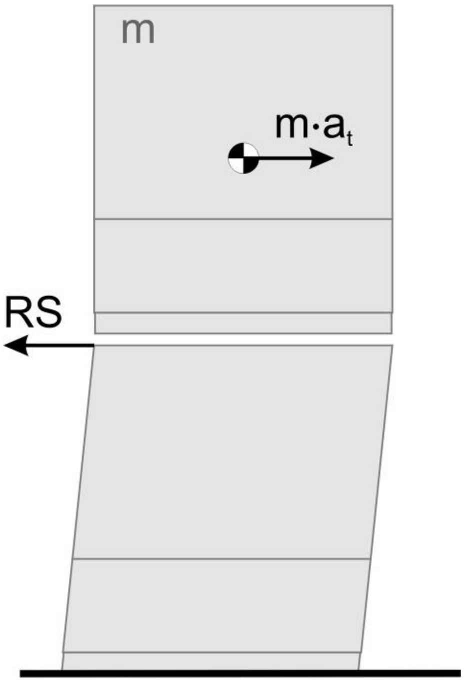
*Package 4 after test.*

When the chains were released, there was no residual elasticity in the binding straps for this package and neither the deformation nor the lift at the bottom of the backside was reduced compared to the values obtained at maximum pulling force.

## All packages

In the diagram below, the deformations of the packages at the top side are plotted as a function of the racking force parallel to the top side of the packages.





The racking strengths, taken as the racking force at 100 mm deformation of the package at the top side, are presented for the four packages in the table below.

| Package no. | Racking Strength [ton] |
|---|---|
| 1 | 1.97 |
| 2 | 1.49 |
| 3 | 1.22 |
| 4 | 0.68 |

The racking strength of timber packages determines their capacity of carrying other packages on top of them without collapsing. The racking strength, *RS*, must be equal to or greater than the mass force, $m \cdot a_t$, that the top packages are exerted to:

$$RS \geq m \cdot a_t$$

# 7 Tests with round wood

The following tests were performed to investigate the properties and behaviour of round wood:

- Friction tests with logs on different surfaces
- Tests of collapsing angle for logs stowed athwart ship
- Test of required support force from uprights for longitudinally stowed logs

## 7.1 Friction tests

For the purpose of establishing friction coefficients for logs stowed on different surfaces, some 40 pieces of logs were placed transversely on the container flat with fixed gables approximately 10 cm from the angle bar. As described in chapter 4, the flat was then inclined until the timber started to slide and the inclination angle was measured.

Some of the logs were stowed directly on the plywood flooring, some were stowed on painted steel sheets and the rest on top of the others, so that three different material contacts were obtained:

- Log – plywood
- Log – painted steel
- Log – log

*Stowage of logs on container flat.*

*Start of inclination test.*

The tests were performed on February 7th and the temperature was around +3 °C. Prior to the test both the logs and the container flat had been covered by snow, which had however started to melt so that the contact surface was more wet than snowy or icy.

### 7.1.1 Results

The container was inclined until the logs started to slide and the inclination angle was then measured. The logs stowed on the metal sheets slid first, while those stowed on top of the others slid last.

| Material combination | Condition | Inclination angle | Static coefficient of friction |
|---|---|---|---|
| Log – Painted steel sheet | Wet | 21° | 0.38 |
| Log - Plywood | Wet | 32° | 0.62 |
| Log - Log | Wet | 38° | 0.78 |

The static friction coefficients have been calculated in accordance with the method described in chapter 4.

*The logs on steel sheets slid at 21°.*

*The logs on plywood slid at 32°.*

*The logs in the top layer slid at 38°.*

*The container flat after unloading of test logs.*

## *7.2 Inclination test with transversely stowed logs*

In order to study the behaviour of an unsecured tier of transversely stowed logs, approximately 20 ton of pulp wood was loaded onto the container flat, which was then inclined sideways till movement of the logs occurred.

The logs in the bottom layer were stowed at least 10 cm away from the angle bar. Some of them were stowed on painted steel sheets and some directly on the plywood flooring.

*20' Container flat with fixed gables loaded with approximately 20 ton pulp wood.*

*All logs in the bottom layer were stowed at least 10 cm from the angle bar along one of the sides of the flat*

The test was performed on February 6th. The temperature was around 0 °C. While loading the logs and performing the tests it both rained and snowed. During loading, snow was sprinkled over the logs.

### 7.2.1 Results

The logs started to slide at an angle of 30°. Movement started simultaneously over the whole height of the stack as the friction was overcome at the bottom. The movement started at the side of the flat where steel sheets had been put underneath the logs.

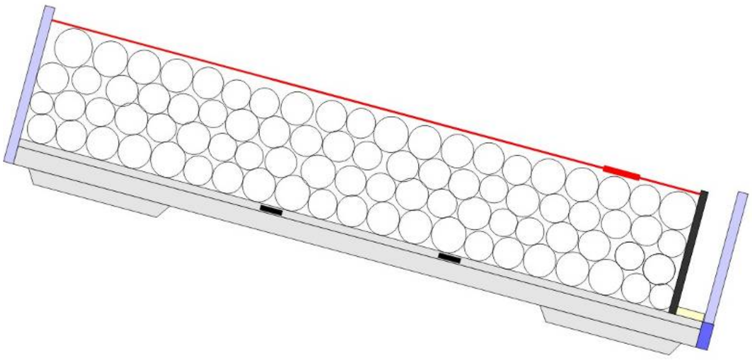
*A container, manoeuvred by a fork lift, was used to prevent the logs from moving too far away from the container flat.*

*The logs started to move against the painted steel sheet at 30°.*

It has been concluded that the movement was initiated by the loss of static friction force between the logs and the steel sheets. The result is consistent with the friction tests described in chapter 7.1. The fact that the stack started to slide at a greater angle than a few loose logs on the steel sheets can be explained by the additional friction forces against the gables acting on the stack.

## 7.3 Tests of required support from uprights

In order to investigate the behaviour of logs stowed longitudinally between uprights onboard vessels, approximately 40 ton pulp wood was loaded on the cassette between two of the fixed uprights and the two loose uprights, which were blocked at the bottom and held in place by chains at the top, as illustrated in the figure below.



*Setup for test of longitudinally stowed logs, supported by uprights.*

The cassette was inclined, with the loose uprights at the lower end, to different angles and the tensions in the two chains were measured with dynamometers.

Prior to loading, the cassette was covered with snow and ice. While loading the logs onto the cassette, snow was sprinkled over the logs in different layers.

The test was performed on February 6th and the temperature was around 0 °C. During the loading of the cargo and the tests it both rained and snowed.

*Cassette prior to loading.*

*Sprinkling of snow between layers during loading.*

*Loose uprights supporting the logs at one end of the flat. The uprights were bottom blocked and supported by chains at the top.*

*Forces in the chains were measured with dynamometers.*

### 7.3.1 Results

| **Inclination angel** [°] | **Tension force** [ton] | | **Distance** [cm] | **Comment** |
|---|---|---|---|---|
| | *Left* | *Right* | *Location A* * | |
| 0 | 0.50 | 0.50 | 25 | Prior to inclination |
| 5 | 0.25 | 0.36 | 24 | The cassette sags so that the lashings become less tightened. |
| 10 | 0.30 | 0.40 | 23.5 | |
| 15 | 0.37 | 0.48 | 23 | |
| 20 | 1.35 | 1.78 | - | The cargo packs itself towards the lower end. The pulling force at the top of the upper uprights increased and they lost the support from the cargo. As a result of this, the upper uprights were deformed. |
| 25 | 1.40 | 1.77 | - | |
| 30 | 1.50 | 1.91 | - | |
| 34 | 2.00 (max) | - | - | Total collapse. |

** Distance A measured between the lower uprights on left side at a height of 1.20 above the platform floor.*

At an inclination angle of 20 degrees, the cargo moved and packed itself against the lower uprights and a sudden increase in tension force in the lashings were noted. The movement of the cargo resulted in the loss of support from the cargo for the upper uprights which, together with the sudden increase in chain tension, resulted in a slight bending of these uprights.

At an inclination angle of 34 degrees the logs again started to move and pack themselves further against the lower uprights. Due to the increase in chain tension the upper uprights gave way and the whole arrangement collapsed.

*5° inclination*

*10° inclination*

*15° inclination*

*20° inclination. The logs have shifted towards the lower end.*

*25° inclination*

*30° inclination*

*Approximately 33° inclination*

*After collapse at 34° inclination*

The following formulas have been used to calculate the values presented in the table below:

$$M_{measured} = F \cdot h$$

$$M_{calculated} = max\left( \frac{1}{80} \cdot m \cdot H,\ \ \frac{1}{6} \cdot m \cdot \left(a_t - \mu_{static} \cdot 0.7 \cdot a_v\right) \cdot H \right)$$

*where:*

$M_{measured}$ = *Bending moment in tonmeters, calculated from measured force in each chain*
$M_{calculated}$ = *Bending moment in tonmeters, calculated by theoretic formulas proposed to be inserted in the new Code of Safe Practice for Ships Carrying Timber Deck Cargoes (For further background on this, see report on research on required upright bending moment resistance performed at Högskolan på Åland. The report will be published on http://www.mariterm.se/timra.html)*
$F$ = *Measured force in each chain in ton*
$h$ = *Height of uprights in meters*
$m$ = *Mass of cargo section in ton*
$H$ = *Height of cargo stow in meters*
$a_t$ = *transverse acceleration in fractions of 1.0 g*
$a_v$ = *vertical acceleration in fractions of 1.0 g*
$\mu_{static}$ = *Coefficient of static friction between the cargo and the platform*

$\mu_{static}$ = *0.3 for unbarked round wood on snowy plywood (estimated)*

| **Inclination angel** | **Accelerations** [g] | | **Measured bending moment in right upright** | **Measured bending moment in left upright** | **Calculated bending moment** | **Calc. bending moment, incl. a safety factor of SF=1.35** |
|---|---|---|---|---|---|---|
| [°] | $a_t$ | $a_v$ | [tonmeter] | [tonmeter] | [tonmeter] | [tonmeter] |
| 0 | 0.00 | 1.00 | 1.3 | 1.3 | 1.3 | 1.8 |
| 5 | 0.09 | 1.00 | 0.6 | 0.9 | 1.3 | 1.8 |
| 10 | 0.17 | 0.98 | 0.8 | 1.0 | 1.3 | 1.8 |
| 15 | 0.26 | 0.97 | 0.9 | 1.2 | 1.3 | 1.8 |
| 20 | 0.34 | 0.94 | 3.4 | 4.5 | 2.6 | 3.5 |
| 25 | 0.42 | 0.91 | 3.5 | 4.4 | 4.2 | 5.6 |
| 30 | 0.50 | 0.87 | 3.8 | 4.8 | 5.7 | 7.7 |
| 34 | 0.56 | 0.83 | 5.0 | 6.3 * | 6.9 | 9.3 |

** This value has been estimated based on reading of maximum force in the left chain after collapse and trend between forces in the two lashings at lower inclination angles.*

In the diagram above, the vertical and transverse accelerations acting on the cargo have been calculated as functions of the inclination angle, α, by using the following formulas:

$$a_t = \sin\alpha$$

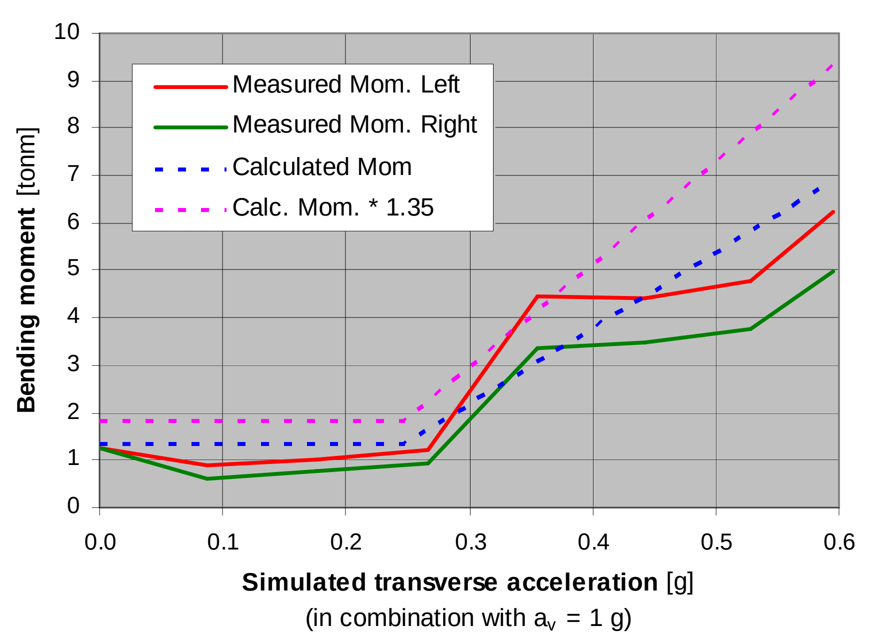
$$a_v = \cos\alpha$$

With the help of the formulas presented in chapter 5, the lashing forces can alternatively be calculated based on a vertical acceleration $a_v = 1\ g$ and a simulated transverse acceleration taken as a function of the lashing angel and the coefficient of friction. In the diagram below, the two different set of accelerations are presented for each inclination angle.

| Inclination angle, α [°] | Real accelerations [g] $a_t$ | $a_v$ | Simulated transverse acceleration * $a_v = 1\ g$ $\mu_{dynamic} = 0.21$ $a_t$ [g] | Calculated bending moment ** [tonmeter] | Calc. bending moment, incl. a safety factor of SF=1.35 ** [tonmeter] |
|---|---|---|---|---|---|
| 0 | 0.00 | 1.00 | 0.00 | 1.3 | 1.8 |
| 5 | 0.09 | 1.00 | 0.09 | 1.3 | 1.8 |
| 10 | 0.17 | 0.98 | 0.18 | 1.3 | 1.8 |
| 15 | 0.26 | 0.97 | 0.27 | 1.3 | 1.8 |
| 20 | 0.34 | 0.94 | 0.35 | 2.6 | 3.5 |
| 25 | 0.42 | 0.91 | 0.44 | 4.2 | 5.6 |
| 30 | 0.50 | 0.87 | 0.53 | 5.7 | 7.7 |
| 34 | 0.56 | 0.83 | 0.60 | 6.9 | 9.3 |

** The simulated transverse acceleration corresponding to each inclination angle in the table above has been determined by the diagram in chapter 5 of this report for a dynamic coefficient of friction* $\mu_{dynamic} = 0.21$ $(\mu_{dynamic} = \mu_{static} \cdot 0.7 = 0.3 \cdot 0.7)$.

*** Regardless of which set of accelerations that is used, the formula above will give exactly the same bending moment.*



*Measured and calculated bending moments as a function of the simulated transverse acceleration.*

# 8 Field trip to vessels carrying timber deck cargoes

In connection with the practical tests, field trips were carried out to two small vessels, out of which one were loading and the other unloading timber deck cargoes in Sundsvall. The stowage patterns and securing arrangements for these deck loads are presented and evaluated below.

## 8.1 Vessel loaded with timber packages

Whole packages with square sawn timber were loaded on February 7th at the Tunadal terminal in Sundsvall onto the deck of the vessel M/V Nordgard for transport in the Baltic and the North Sea.

The packages were loaded in two layers and in 10 rows on deck. The packages were covered with tarpaulins and secured by top over lashings. The lashings were of the type specially developed to suit the requirements of the current Timber Deck code, thus assumingly having a MBL of 13.6 ton and tensioning system generating a pretension of 2.7 ton in the horizontal part and 1.6 ton in the vertical parts. Each stow was secured with at least two lashings.

Assuming that the deck had been well prepared and cleaned prior to loading, the coefficient of friction is taken as $\mu=0.45$ for the contact surface between the cargo and the deck. This is to be considered a very generous figure, given the conditions with snow and rain having falling recently and temperatures being around 0 °C. With less careful preparation of the deck, the coefficient of static friction could be as low as $\mu=0.05$, as was seen in the friction tests with timber packages described in chapter 6.1.

The average weight of the packages can be assumed to be 2.15 ton, based on the average weight of the packages used in the tests with lashing arrangements described in chapter 6.2.

The maximum acceptable transverse acceleration for the vessel during the voyage in order to avoid cargo shifting can be calculated by the following formula:

*Acceptable transverse acceleration with top-over lashing securing arrangement:*

$$a_t = \frac{(m \cdot g_0 + 2 \cdot n \cdot PT_V) \cdot \mu_{static} - PW - PS}{m}$$

*Data for one stow:*

$m$ = *weight of cargo* = *43 tons*
$n$ = *number of lashings* = *2 pcs*
$PT_V$ = *pre-tension in vertical part of lashing* = *16 kN*
$PW$ = *force by wind pressure* = $1\ kN/m^2 \Rightarrow PW \approx 9\ kN$
$PS$ = *force by sea sloshing* = $1\ kN/m^2 \Rightarrow PW \approx 9\ kN$

$a_t = 4.7\ m/s^2$

By performing the same calculations, but assuming snow and icy conditions giving a coefficient of friction as low as $\mu=0.05$, would give a maximum allowable transverse acceleration of $a_t = 0.15\ m/s^2$.

With the vessel particulars given below, the expected transverse acceleration according to Annex 13 on deck low at the most forward stowage position utilised is $a_t = 8.3\ m/s^2$.

*Assumed vessel particulars:*

$L_{PP} = 80\ m$
$V = \text{Service speed} = 18\ \text{knots}$
$B = 12\ m$
$GM \leq 0.90\ m$

With reduction of the accelerations for expected significant wave height, performed by multiplying the Annex 13 accelerations with the factor given by the formula below, the maximum transverse acceleration on deck high can be expected to be $a_t = 7.0\ m/s^2$.

*Reduction factor for limited wave heights:*

$$r = \sqrt[3]{\frac{H_S}{19.6}}$$

$H_S$ = *Significant wave height.*

*For the North Sea* $H_S = 12$ *meters and* $r = 0.85$

The calculations clearly indicate that the securing arrangement can be expected to fail should the vessel encounter unfavourable weather conditions, which is by the way not so unlikely at the North Sea in the winter season.

## 8.2 Vessel loaded with pulp wood

The second vessel visited was unloading pulp wood at the Östrand Terminal in Sundsvall at February 7th. Unfortunately, the test team arrived during the last stages of unloading and only a small part of the deck load remained. The vessel had arrived to Sundsvall from one of the Baltic states.

Four tires of logs had been loaded longitudinally between uprights and the rest of the logs had been stowed transversally in between the longitudinal stows. There were no rails or other bottom blocking devices so the transversely stowed logs had been secured purely by friction.

At the outer ends of the transverse stows, a single longitudinally stowed log had been placed underneath the rest of the logs in order to create an inward slope. Contrary to popular believe, this method does not prevent the transversely stowed logs from shifting, but in effect reduces the friction force between the logs and the vessels deck since the longitudinal log may roll.

*A longitudinally stowed log had been placed at the outer ends of each tire transversely stowed tire in order to create an inward slope. Instead of preventing shifting of these tires, this measure actually reduces the friction force between the logs and the vessels deck.*

Since the logs are only secured by friction, the stows would shift of the side of the vessel at a transverse acceleration of approximately 4 m/s$^2$ if the coefficient of static friction is taken as 0.38 as indicated by the tests described in chapter 7.1.

# Appendix A – Practical tests for determining the efficiency of cargo securing arrangements

The efficiency of a securing arrangement can be tested by a practical inclining test according to the following description.

The cargo (alternatively one section of the cargo) is placed on a lorry platform or similar and secured in the way intended to be tested.

The securing arrangement is tested by gradually increasing the inclination of the platform to an angle, $\alpha$, according to the formulas, table and diagram below. The inclination is a function of the following parameters:

- the horizontal acceleration $a_h$ for the intended direction (forward, sideways or backward) and the vertical acceleration $a_v$
- the coefficient of friction, $\mu$, between the cargo and the platform bed or between cargo units if stapled
- the ratio of breadth $B$, height $H$ and the number of loaded rows $n$, $\frac{B}{n \cdot H}$, at accelerations sideways
- the ratio of length $L$ and height $H$, $\frac{L}{H}$, at accelerations forward or backward

The required inclining angle, $\alpha$, for a known coefficient of friction, $\mu$, is determined by the following equation:

$$m \cdot g \cdot (\sin\alpha - \mu \cdot \cos\alpha) = m \cdot g \cdot (a_h - \mu \cdot a_v)$$

The required inclining angle, $\alpha$, for a known ratio of breadth, height and number of rows, $\frac{B}{n \cdot H}$, is determined by the following equation:

$$m \cdot g \cdot \left( \sin\alpha - \frac{B}{n \cdot H} \cdot \cos\alpha \right) = m \cdot g \cdot \left( a_h - \frac{B}{n \cdot H} \cdot a_v \right)$$

The required inclining angle, $\alpha$, for a known ratio of length and height, $\frac{L}{H}$, is determined by the following equation:

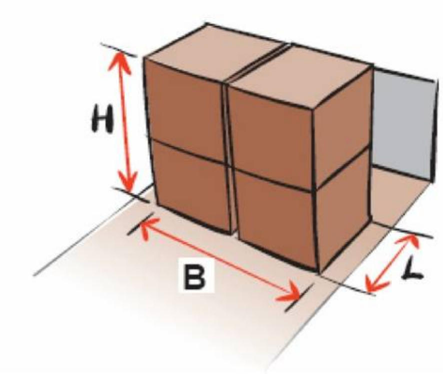
$$m \cdot g \cdot \left( \sin\alpha - \frac{L}{H} \cdot \cos\alpha \right) = m \cdot g \cdot \left( a_h - \frac{L}{H} \cdot a_v \right)$$

In the equations above the left part represents the required securing force in the test condition and the right part the required securing force for the design acceleration.

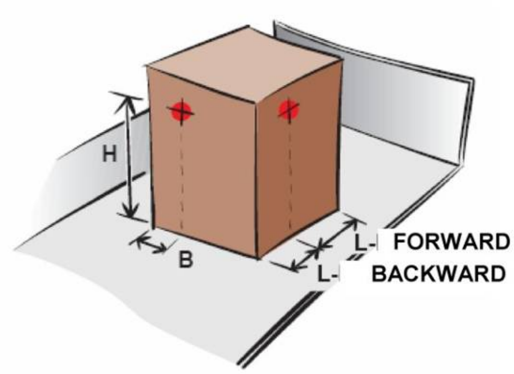
In the equations below a $\gamma$-factor is used. The $\gamma$-factor is the lowest value of the coefficient of friction, $\mu$, and the ratio of breadth, height and number of loaded rows, $\frac{B}{n \cdot H}$, at accelerations sideways. At accelerations forward or backward it is the lowest value of the ratio of length and height, $\frac{L}{H}$, and the coefficient of friction, $\mu$.

For securing arrangements not allowing sliding of the cargo the static coefficient of friction is used else the dynamic friction. If the dynamic friction is unknown it is to be taken as 70% of the static friction.

Definition of $H$, $B$ and $L$ that are to be used when determine the $\gamma$-factor:



*Cargo unit with the centre of gravity close to its geometrical centre (L/2, B/2, H/2). The number of loaded rows in above section is 2.*



*Cargo unit with the centre of gravity away from its geometrical centre.*

The solution to the equations above, with $\mu$ and $\frac{B}{n \cdot H}$ or $\mu$ and $\frac{L}{H}$ expressed as $\gamma$, is:

$$\alpha = 2 \cdot \arctan\left(\frac{-1+\sqrt{1+2\cdot\gamma\cdot a_h - a_h^2}}{2\cdot\gamma - a_h}\right), \qquad \gamma \neq \frac{a_h}{2},$$

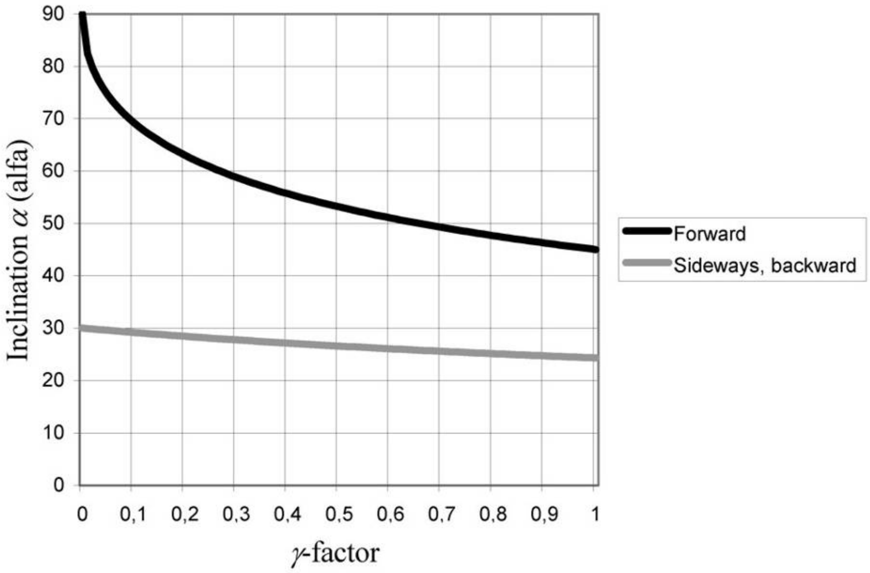
$$\alpha = 2 \cdot \arctan\left(\frac{a_h}{2}\right), \qquad \gamma = \frac{a_h}{2},$$

where

| | |
|---|---|
| $\gamma$ | a factor (the lowest value of $\mu$ and $\frac{B}{n \cdot H}$ or $\frac{L}{H}$) |
| $a_h$ | the design horizontal acceleration in [g] |
| $g$ | gravity acceleration 9.81 m/s$^2$ |

In the table below the inclination $\alpha$ is calculated for different $\gamma$-factors at the acceleration forces 1 $g$ forward and 0.5 $g$ backward and sideways.

| $\gamma$-factor | Required angle | | $\gamma$-factor | Required angle | |
|---|---|---|---|---|---|
| | Forward | Sideways, backward | | Forward | Sideways, backward |
| 0,15 | 65,7° | 28,8° | 0,55 | 52,0° | 26,3° |
| 0,20 | 63,0° | 28,4° | 0,60 | 51,0° | 26,0° |
| 0,25 | 60,7° | 28,1° | 0,65 | 50,1° | 25,8° |
| 0,30 | 58,8° | 27,7° | 0,70 | 49,2° | 25,6° |
| 0,35 | 57,1° | 27,4° | 0,75 | 48,4° | 25,3° |
| 0,40 | 55,7° | 27,1° | 0,80 | 47,6° | 25,1° |
| 0,45 | 54,3° | 26,8° | 0,85 | 46,9° | 24,9° |
| 0,50 | 53,1° | 26,6° | 0,90 | 46,2° | 24,7° |



The securing arrangement is regarded as complying with the requirements if the cargo is kept in position with limited movements when inclined to the prescribed inclination ($\alpha$).

The test method will subject the securing arrangement to stresses and great care should be taken to prevent the cargo from falling off the platform during the test. If large weights are tested the entire platform should be prevented from tipping as well.

*The cargo securing arrangement of a heat exchanger is tested for acceleration forces forward and sideways.*