DEKRA Niederlassung Bielefeld

Fachbereich: Fahrzeugtechnik / Verkehrsunfallanalyse
Ladungssicherung

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DEKRA

Comparison of calculation methods using practical tests of friction-locking, mechanical interlocking and combined measures used to secure cargo

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1 Introduction

Introduction

Within the scope of a diploma thesis coached by DEKRA Automobil GmbH, location Bielefeld, driving tests were conducted to analyse calculated numbers of tie-down lashings.

The numbers of lashings were calculated according the formulas for tie-down lashing in DIN EN 12195-1:2004, VDI 2700 Part 2:2011 (green print), DIN EN 12195-1:2011 und VDI 2700 Part 2: 2002.

Herewith the friction coefficient varied as a parameter for the formulas used.

This value was determined for all formulas used on the basis of self conducted tests in line with the standards and guidelines.

2 Determination of friction coefficient

Determination of the friction coefficient – tensile test

The determination of the friction coefficient was conducted on a loading platform of a truck with 7.5 tons payload.

This vehicle is normally used for automotive industry part-load traffic.

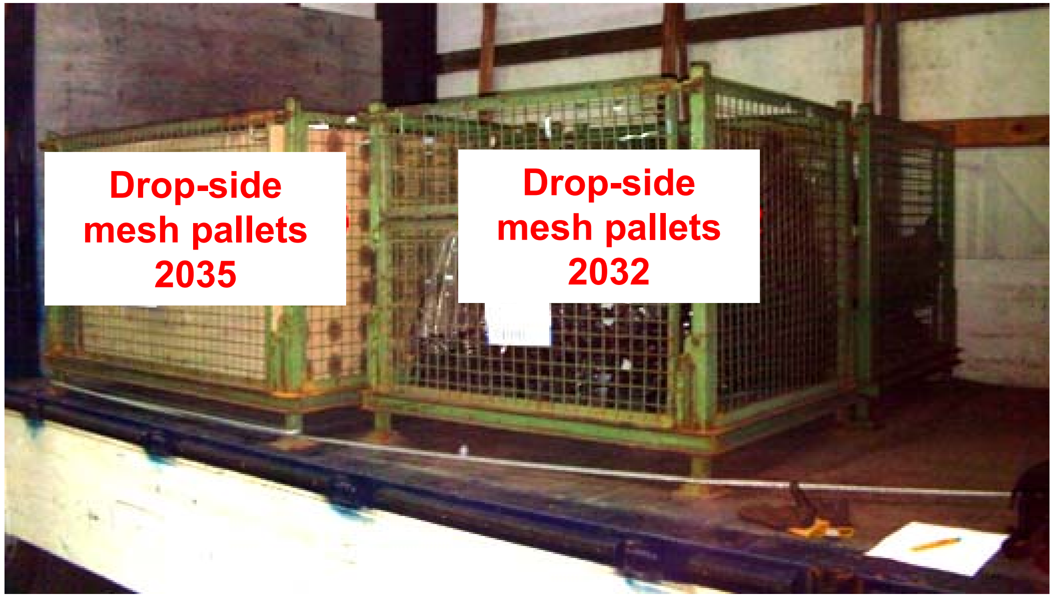
The loading platform was dry, swept, free of oil or other greased stuff and with unexceptional abrasion.

The tensile test runs in line with VDI 2700 Part 14.

Material coupling: drop-side mesh pallet (steel base T 5 9012) against film-faced plywood with individual steel bases partially standing on the steel frame of the loading platform as well.

Determination of the friction coefficient – tensile test

Experimental set-up: Alignment of the drop-side mesh pallets



drop-side mesh pallets 2032

m_1 = 300.24 kg + 290.592 kg

m_1 = 590.832 kg

drop-side mesh pallets 2035

m_2 = 2 · 1.005 kg = 2.010 kg

Mass of the entire test load to be pulled

$m_1 + m_2$ = 2,600.832 kg

Determination of the friction coefficient – tensile test

The raw data determined were transferred into an excel sheet designed for the test and then evaluated.

For the evaluation of the single test hubs the first tensile-force peak (corresponding to the static friction coefficient) remained unconsidered.

The dynamic friction coefficient directly determined firsthand was μ = 0.39 and was calculated by using the formula:

$\mu = F_Z / F_G$ (F_Z = tension force F_G = weight force)

For the calculations conducted afterwards this value has to be converted and replaced according to VDI 2700 Part 14 und DIN EN 12195-1 (2011) Annex B.

Determination of the friction coefficient – tensile test

In all further calculations regarding the number of lashings the following friction coefficients have to be used:

Standard respectively Guideline	VDI 2700 Part 2:2002	DIN EN 12195-1 :2004 VDI 2700 Part 2:2011 (green print)	DIN EN 12195-1:2011
Friction coefficient µ	0.37	0.37	0.40

Difference: 0.40 – 0.37 = 0.03 respectively 7,5 %

According to VDI 2700, Part14 : Factor 0.95 respectively 5% reduction

According to EN 12195-1, Annex B: 2.5 % reduction

3 Calculation of the number of lashings

Calculation of the number of lashings

Using the now known friction coefficient for the material coupling given the required number of lashings for the standards and guidelines mentioned can be calculated.

The calculation goes separate for the drop-side mesh pallets 2035 as well as for the drop-side mesh pallets 2032 because they have different masses and do not form a common unit.

With the vertical angle of 87.4° the sine value used in the calculations is near 1.0 and therefore it can be neglected.

Calculation of the number of lashings

Calculation according to VDI 2700 Part 2:2002

drop-side mesh pallets 2035:

$n = m \cdot g \cdot (c_x - \mu) / 2 \cdot ST_F \cdot \mu$

$n = 2{,}010\ kg \cdot 9.81\ m/s^2 \cdot (0.8 - 0.37) / 2 \cdot 5{,}000\ N \cdot 0.37$

$n = 2.29$

n = 3 lashings (rounded up)

n = 2 according to DEKRA Bielefeld practical approach (rounded figure)

Calculation of the number of lashings

Calculation according to VDI 2700 Part 2:2002

drop-side mesh pallets 2032:

$n = m \cdot g \cdot (c_x – \mu) / 2 \cdot ST_F \cdot \mu$

$n = 590.832 \text{ kg} \cdot 9.81 \text{ m/s}^2 \cdot (0.8 – 0.37) / 2 \cdot 5{,}000 \text{ N} \cdot 0.37$

n = 0.67

n = 1 lashing (rounded up)

n = 1 according to DEKRA-Bielefeld practical approach

(> 0,5 rounded up as well)

Calculation of the number of lashings

Overall result according to VDI 2700 Part 2:2002

According VDI 2700 Part 2:2002 for a securing of the entire cargo against sliding in total 3 + 1 = **4 lashings** are necessary, 3 lashings over the drop-side mesh pallets 2035 und 1 lashing over the drop-side mesh pallet 2032.

Based on 15 years of experience of the DEKRA-Bielefeld cargo-securing team 2 + 1 = **3 lashings** meet the real-life requirements.

Calculation of the number of lashings

Calculation according to DIN EN 12195-1:2004

and VDI 2700 Part 2:2011 (green print)

drop-side mesh pallets 2035:

$n = m \cdot g \cdot (c_x – \mu) / 1{,}5 \cdot ST_F \cdot \mu$

$n = 2{,}010\ kg \cdot 9.81\ m/s^2 \cdot (0.8 – 0.37) / 1.5 \cdot 5{,}000\ N \cdot 0.37$

$n = 3.06$

n = 4 lashings (rounded up)

Calculation of the number of lashings

Calculation according to DIN EN 12195-1:2004

and VDI 2700 Part 2: 2011 (green print)

drop-side mesh pallets 2032:

$n = m \cdot g \cdot (c_x - \mu) / 1.5 \cdot ST_F \cdot \mu$

$n = 590.832 \text{ kg} \cdot 9.81 \text{ m/s}^2 \cdot (0.8 - 0.37) / 1.5 \cdot 5{,}000 \text{ N} \cdot 0.37$

$n = 0.90$

n = 1 lashing (rounded up)

Calculation of the number of lashings

Overall result according to DIN EN 12195-1:2004

and VDI 2700 Part 2:2011 (green print)

According to DIN EN 12195-1 (2004) and VDI 2700 Part 2:2011 (green print) for a securing of the entire cargo against sliding in total 4 + 1 = **5 lashings** are necessary, 4 lashings over drop-side mesh pallets 2035 und 1 lashing over drop-side mesh pallets 2032.

Compared to VDI 2700 Part 2: 2002 1 lashing more is necessary.

For a semitrailer with 27 tons payload, (mass approx 10 times as high as the test cargo) 10 additional lashings would be necessary!

Compared to the DEKRA-Bielefeld practical approach there were **20 !** additional lashings.

Calculation of the number of lashings

Calculation according to DIN EN 12195-1:2011

drop-side mesh pallets 2035:

$n = [m \cdot g \cdot (c_x - \mu) / 2 \cdot ST_F \cdot \mu] \cdot 1.25$

$n = [2{,}010\ kg \cdot 9.81\ m/s^2 \cdot (0.8 - 0.4) / 2 \cdot 5{,}000\ N \cdot 0.4] \cdot 1.25$

$n = 2.46$

n = 3 lashings (rounded up)

Calculation of the number of lashings

Calculation according to DIN EN 12195-1:2011

drop-side mesh pallets 2032:

$n = [m \cdot g \cdot (c_x – \mu) / 2 \cdot ST_F \cdot \mu] \cdot 1.25$

$n = [590.832\ kg \cdot 9.81\ m/s^2 \cdot (0.8 – 0{,}4) / 2 \cdot 5{,}000\ N \cdot 0.4] \cdot 1.25$

$n = 0.72$

n = 1 lashings (rounded up)

Calculation of the number of lashings

Overall result according to DIN EN 12195-1:2011

According to DIN EN 12195-1:2011 for a securing of the entire cargo against friction in total 3 + 1 = 4 lashings are necessary, 3 lashings over drop-side mesh pallets 2035 und 1 lashing over drop-side mesh pallets 2032.

This is equivalent to the number of lashings calculated before in accordance with VDI 2700 Part 2:2002.

Calculation of the number of lashings

Comparison of the results

Corresponding to the calculations before the numbers of lashings displayed in the table would be necessary to secure the entire test cargo against sliding:

Number of lashings	VDI 2700 Part 2:2002	DIN EN 12195-1:2004 VDI 2700 Part 2:2011 (g. p.)	DIN EN 12195-1:2011
drop-side mesh pallets 2035	3	4	3
drop-side mesh pallets 2032	1	1	1
total	4	5	4

Corresponding to the real-live approach of DEKRA Bielefeld: 3 lashings

4 Driving tests

Driving tests

To determine how many lashings effectively are necessary to secure the cargo against sliding, braking tests in accordance with DIN EN 12642 Annex B were conducted.

When running this tests the drop-side mesh pallets were secured using in total 3, 4 and 5 lashings. Per webbing assembly only 1 tension element (ratchet) was used.

Setup driving tests

Driving tests

Test 1 – Check-up using 3 lashings (2 + 1) only

In test 1 the cargo was secured using 3 top-over lashings only.

Because it was previously not known whether the cargo would slide, a loose spring lashing was applied.

The first braking runs at approx. 0.5 g deceleration.

The cargo remained in his initial position.

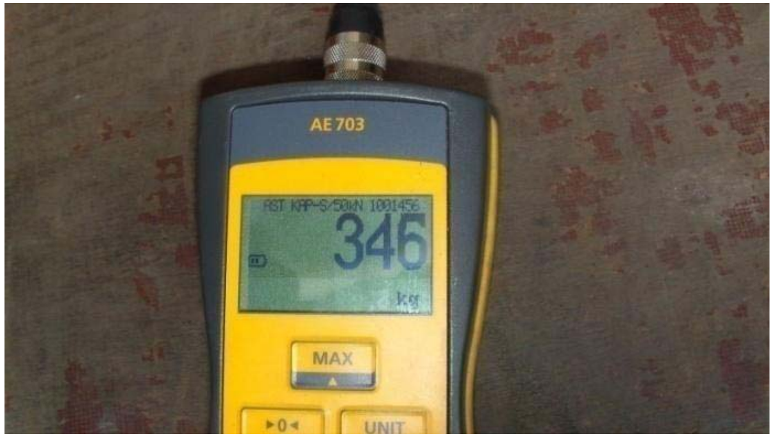
The second braking runs at 0.9 g deceleration with 125 ms impact time.

The cargo slides on the loading platform with small extend and the previously applied loose spring lashing **did not get in action**.

Driving tests

Test 1 – Check-up using 3 lashings (2 + 1) only

Tension force adjusted prior to the test on ratchet side (480 daN)



Tension force reacting at the side without ratchet prior to the test (346 daN)

Measured tension forces correspond to a k-Factor of 1.72

Remark: Friction in accordance with the k-Factor at the top edges of the mesh pallets may result in further securing forces which are not taken into account when using conventional calculations.

Driving tests

Test 1 – Check-up using 3 lashings (2 + 1) only

Position of the mesh pallet prior to the test

(please consider the mixed friction coupling)

Position of the mesh pallet after the test showing sliding with small extend

Driving tests

Results test 1

Test 1 indicated that 3 top-over lashings are just sufficient to secure the cargo against sliding at a deceleration of **0.9 g**.

Sliding of the cargo with small extent was fully stopped again by top-over lashing only.

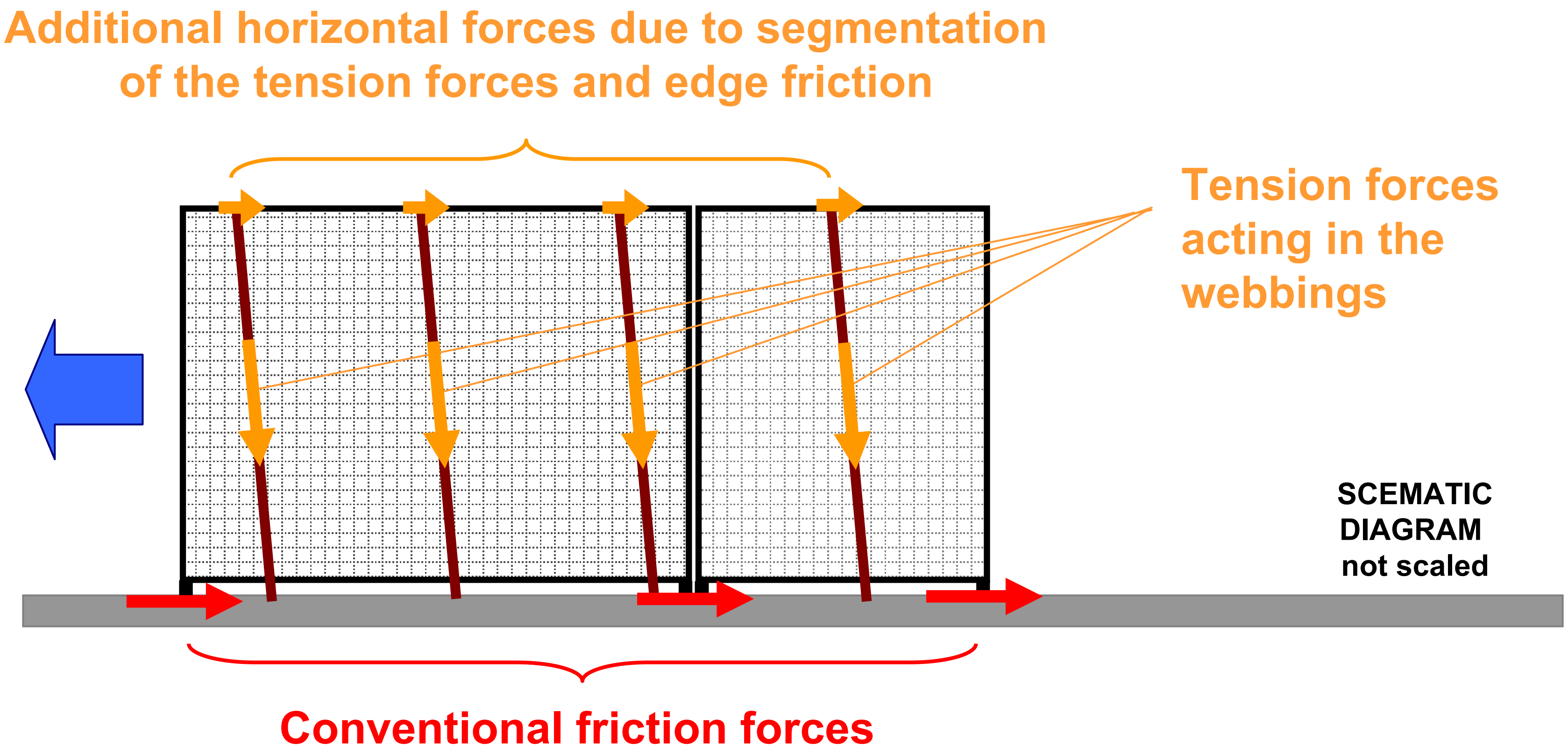
The spring lashing did not get in action.

During sliding the dynamic friction factor, which is lower compared to the static friction factor, appears.

Consequential: During sliding additional securing forces were generated which then prohibited a further sliding of the cargo.

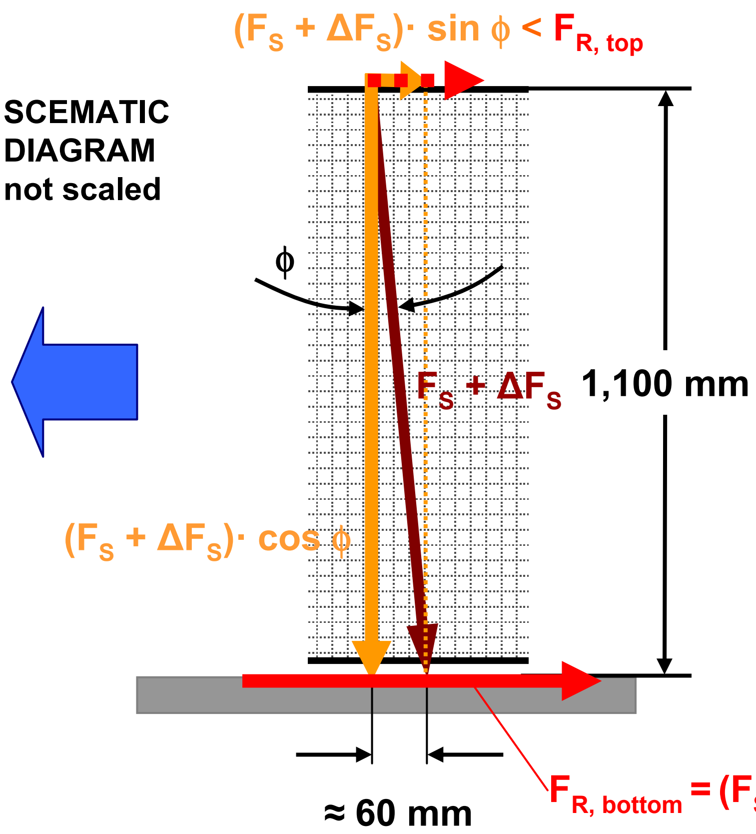
Driving tests

Additional securing forces acting under the assumption of friction at the top edges of the cargo when small cargo shifts occur



Driving tests

Additional securing forces acting under the assumption of friction at the top edges of the cargo when small cargo shifts occur



Calculation example in dependence on test 1

Length of the elongated webbing:

$l + \Delta l = \sqrt{60^2 + 1{,}100^2}$ mm = 1,101.6 mm

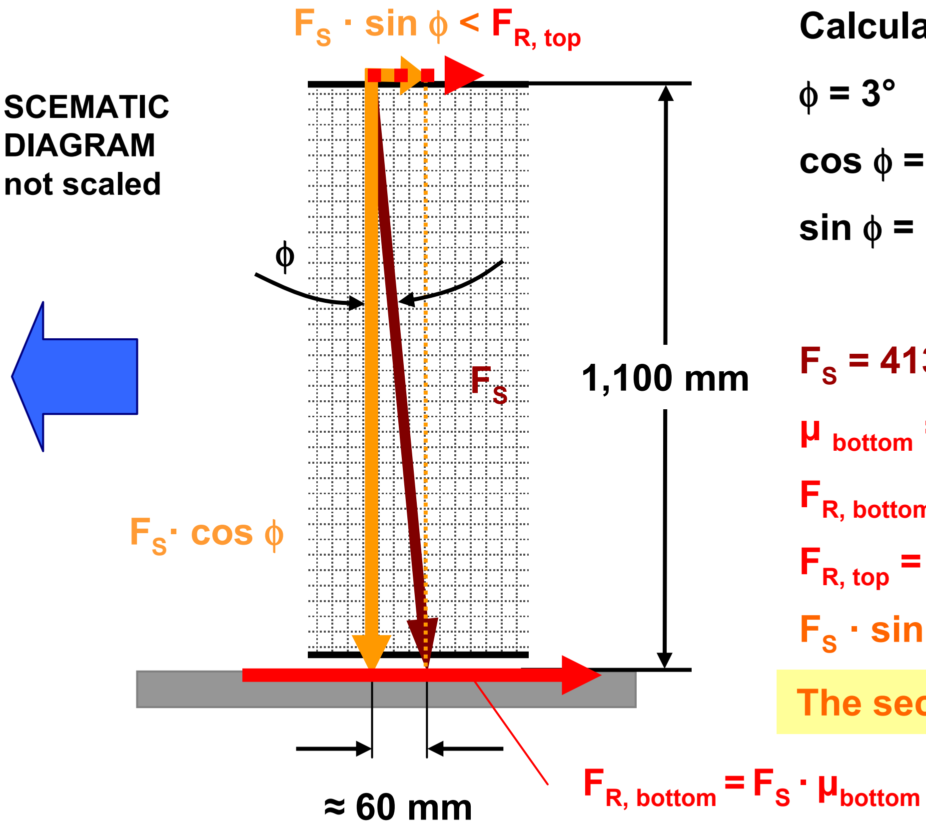
Δl = 1.6 mm (0.15%)

The additional elongation Δl of the webbing is negligible small.

Hence, the additional tension force ΔF_S in the webbing is negligible small as well.

Driving tests

Additional securing forces acting under the assumption of friction at the top edges of the cargo when small cargo shifts occur



Calculation example in dependence on test 1

$\phi = 3°$

$\cos\phi = 0.9986 \approx 1.00$

$\sin\phi = 0.0523 \approx 0.05$

F_S = 413 daN = (480 + 346) daN / 2

$\mu_{bottom} = 0.4$ $\mu_{top} = 0.2$

$F_{R,\ bottom}$ = 413 daN · 0.4 = 165.2 daN

$F_{R,\ top}$ = 413 daN · 0.2 = 82.6 daN

$F_S \cdot \sin\phi$ = 413 daN · 0.05 = 20.7 daN

The securing force increases by approx. 8%

Driving tests

Test 2 – Check-up using 5 lashings (4 + 1)

In test 2 the cargo was secured against sliding using 5 top-over lashings according to DIN EN 12195-1:2004 and VDI 2700 Part 2:2011 (green print).

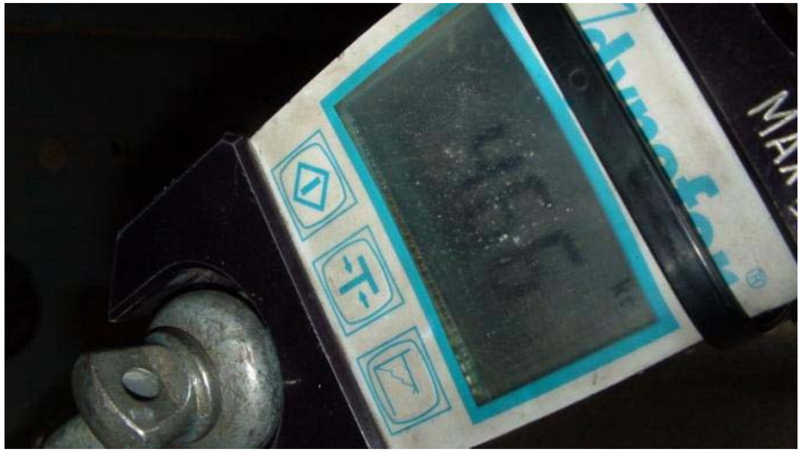
The first braking runs at a deceleration of **0.9 g** with 125 ms impact time.

The cargo remained in its initial position.

Even after a braking at a deceleration curtly by **0.9 g** no sliding of the cargo was detectable.

Driving tests

Test 2 – Check-up using 5 lashings (4 + 1)



Tension force adjusted prior to the test on ratchet side (466 daN)

Tension force reacting at the side without ratchet prior to the test (288 daN)

Measured tension forces correspond to a k-Factor of 1.62

Remark: Friction in accordance with the k-Factor at the top edges of the drop-side mesh pallets may result in further securing forces which are not taken into account when using conventional calculations.

Driving tests

Test 2 – Check-up using 5 lashings (4 + 1)

Position of the mesh pallet prior to the test

Position of the mesh pallet after the test, no shifting detectable

Driving tests

Results test 2

Test 2 indicated that 5 top-over lashings are sufficient to secure the cargo against shifting even at a deceleration of **0.9 g**.

The cargo remained in the initial position, shifting was not detectable.

Driving tests

Test 3 – Check-up using 4 lashings (3 + 1)

In test 3 the cargo was secured against sliding using 4 top-over lashings according to VDI 2700 Part 2:2002 and DIN EN 12195-1:2011.

The braking runs at a deceleration of **0.95 g** with an impact time of 125 ms.

The cargo was sliding with minimal extend.

Regarding the causes of the minimal shifting it firstly should be determined, to what extend the gaps between the cargo and the mesh pallets (movement of the cargo inside the mesh pallets was visible) induced the minimal shifting of the mesh pallets.

Driving tests

Test 3 – Check-up using 4 lashings (3 + 1)

Tension force adjusted prior to the test on ratchet side (479 daN)

Tension force reacting at the side without ratchet prior to the test (285 daN)

Measured tension forces correspond to a k-Factor of 1.60

Remark: Friction in accordance with the k-Factor at the top edges of the drop-side mesh pallets may result in further securing forces which are not taken into account when using conventional calculations.

Driving tests

Test 3 – Check-up using 4 lashings (3 + 1)

Position of the mesh pallet prior to the test

Position of the mesh pallet after the test, minimal shifting detectable

Driving tests

Results test 3

The cargo was minimal shifted under the influence of a deceleration of **0.95 g** with the spring lashing gets into action.

Obviously the shifting of the cargo was induced by a relative movement of the cargo inside the drop-side mesh pallets with subsequent pulse interchange to the drop-side mesh pallet.

During sliding the dynamic friction factor, which is lower compared to the static friction factor, appears.

The minimal shifting of the cargo was fully stopped again by the top-over lashing only.

Driving tests

Additional findings from test 3 – Preparation of test 4

Inside the mesh pallet the cargo was not stored form locked, hence the cargo pushed the front wall of the mesh pallet at a deceleration of 0.95 g.

As a consequence a pulse was induced into the mesh pallet and shifted it at minimal extent.

To eliminate this influence the cargo was secured inside the mesh pallets using adequate measures of blocking.

This was done using square timber, which was stuck between the cargo and the mesh pallet.

Driving tests

Test 4 – Check-up using 4 lashings (3 + 1)

With the subsequent braking (when square timbers stuck between the cargo and the mesh pallets) a deceleration curtly by **0.9 g** was reached with an impact time of 125 ms.

The mesh pallets were standing stable and no sliding was detectable.

Hence, the minimal sliding detected with the previous test was provoked by a pulse with short impact time resulting from the cargo pushing against the walls of the mesh pallets.

Driving tests

Test 4 – Check-up using 4 lashings (3 + 1)

Square timber between cargo and mesh pallets

Driving tests

Test 4 – Check-up using 4 lashings (3 + 1)

Tension force adjusted prior to the test on ratchet side (485 daN)

Tension force reacting at the side without ratchet prior to the test (344 daN)

Measured tension forces correspond to a k-Factor of 1.71

Remark: Friction in accordance with the k-Factor at the top edges of the drop-side mesh pallets may result in further securing forces which are not taken into account when using conventional calculations.

Driving tests

Test 4 – Check-up using 4 lashings (3 + 1)

Position after test 3 was initial position

No further sliding after the test was detectable

Driving tests

Results of tests 3 and 4

Tests 3 and 4 did indicate that 4 top-over lashings are more than sufficient against sliding.

The cargo remains in its initial position after the cargo was blocked inside the mesh pallets.

Shifting was no longer detectable in spite of a deceleration clearly more than **0.8 g**.

5 Conclusion

Conclusion

It can not be confirmed that the use of the new DIN EN 12195-1:2011 results in a reduction of lashing forces that affects road safety.

The use of the older version DIN EN 12195-1:2004 results in an over-securing of the cargo with 1 lashing, compared to the DEKRA practice approach even with 2 lashings.

The mesh pallets remained in their initial positions (small shifting in test 1) and the steadiness of the cargo was not affected.

This is confirmed by all DEKRA drive tests, that a securing of cargo which is in line with the old guideline VDI 2700 Part 2: 2002 with the simple calculation approach (Factor k = 2.0) does not lead to improper shifting of the cargo under the influence of the stipulated accelerations.

Many thanks for your attention!

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