ANALYSIS OF ELONGATION OF LASHING STRAPS ON MOVEMENTS OF CARGO SECURED BY A TOP-OVER LASHING AT SLIDING IN LONGITUDINAL DIRECTION

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Summary: Load securing by lashing straps is a common lashing method to secure a cargo by lashing. Lashing straps, usually made from polyester, are elastic lashing. For direct lashing methods some pretension is assumed and cargo movement can elongate lashings up to restraining force or up to lashing capacity of lashing straps. When top-over lashing is usually design, cargo movement is not taken into consideration but in longitudinal direction forwards this traditional approach gives too many lashing straps. Therefore if we take into consideration longitudinal movement of a cargo self-tensioning effect of top-over lashing increases the tension force in lashing during cargo movement. The highest the elongation and the length of lashing straps the highest cargo movements are expected. Based on measurement results of elongation of selected lashing straps expected cargo movements in longitudinal direction forwards can be evaluated.

Key words: elongation, lashing strap, tension force, cargo movements, cargo securing

INTRODUCTION

Lashing straps used in cargo securing in Europe shall meet the requirements of the standard EN 12195-2 (8). The standard EN 12195-1 (7) in sec. 5.4.1 defines that the pretension in lashing equipment during transport shall be from 0,05 LC to 0,5 LC. This tension force is set in lashings as pretension or Standard tension force STF which is marked on lashing straps with ratchet tensioner and presents tested pretension with standard hand force SHF of 50 daN (2), (3), (4).

However, the tension force is changing not only during initial tensioning but also during transport due to relaxation of straps, vehicle movements and cargo movements. Usually the force is decreasing therefore the straps must be retensioned during transport if top-over lashing is used (2), (6). However, cargo sliding and tilting cause elongation of the straps and force increase (1) which is similar as tensioning of straps by hydraulic piston by one pull or by several pulls.

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1. MEASUREMENTS OF RELATIVE ELONGATION OF SELECTED LASHING STRAPS

1.1 Theoretical background

Because lashing straps elongate during tensioning relative elongation of straps shall be calculated as follows (4):

$$\varepsilon = \frac{L_e - L_0}{L_0}, \qquad (1)$$

where L_0 initial length at 0,05 LC,

L_e elongated length at tension force up to LC.

According to the standard EN 12195-2 (8) relative elongation at LC (ε_{LC}) shall be maximum of 7%.

Tension force in relation to relative elongation ε in case of linear trend is as follows (4):

$$F_T = \frac{0{,}95 \cdot LC}{\varepsilon_{LC}} \cdot \varepsilon + 0{,}05 \cdot LC \qquad (2)$$

where F_T tension force,

LC lashing capacity,

ε_{LC} maximum elongation at LC,

ε relative elongation at tension force.

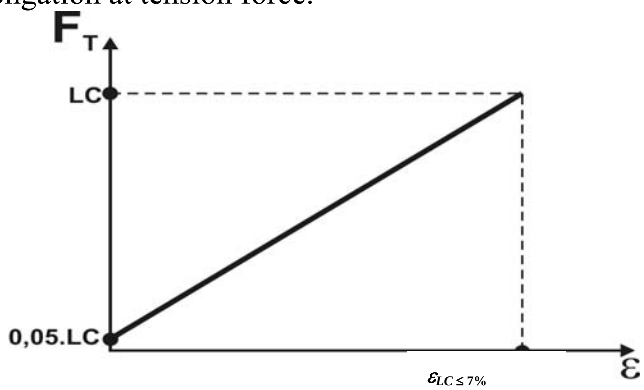


Fig. 1 - Force - elongation diagram – linear trend (4)

Relative elongation at tension force using (2) is as follows:

$$\varepsilon = \frac{(F_T - 0{,}05 \cdot LC)}{0{,}95 \cdot LC} \cdot \varepsilon_{LC} \qquad (3)$$

If the tension force is described as a proportion of the lashing capacity r as follows:

$$F_T = r \cdot LC \qquad (4)$$

then the elongation using equation (3) is:

$$\varepsilon = \frac{(r - 0{,}05)}{0{,}95} \cdot \varepsilon_{LC} \qquad (5)$$

1.2 Test equipment

Testing stand to test lashings is used to perform required tests. Hydraulic piston is used to increase the tension force by one pull from 0,05 LC to 0,5 LC. The force is measured by a load-cell. The movement of piston is measured by digital calliper with the resolution of 0,01 mm. Commonly used polyester lashing straps with the width of 50 mm and LC of 2500 daN are used for tests. The straps meet the requirements of the standard EN 12195-2 (8).

Source: Authors

Fig. 2 - Testing stand to test tension forces in lashing straps

Technical parameters of selected web-lashings are given in table below. Testing length of webbing was around 3,5 meters. Eight web-lashings of four different manufacturers are used in tests. Two samples of each manufacturer are to be tested. Each sample is tested five times.

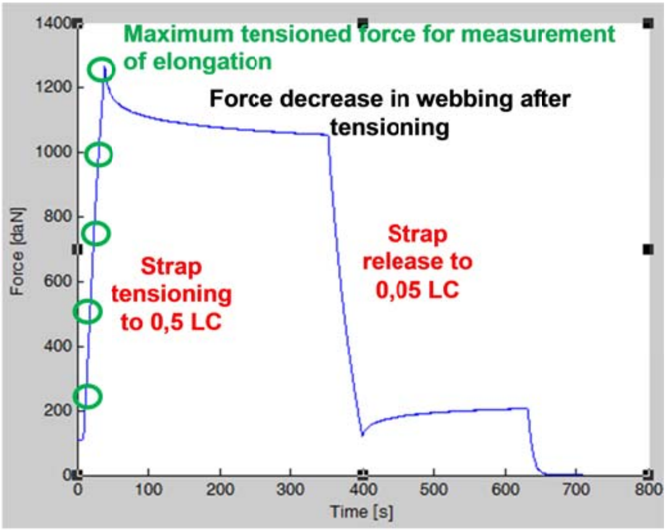
Tab. 1 - Technical parameters of tested polyester lashing straps

Test marking	**Thickness of webbing**	**Length of lashing strap loose end**	**LC – lashing capacity**	**0,05 . LC**	**0,5 LC**	**Marked elongation at LC**	**Webbing colour**
	[mm]	[m]	[daN]	[daN]		[%]	
TL1	2,81	10	2500	125	1250	<7	orange
TL2	2,82	10	2500	125	1250	<7	orange
HL1	2,31	12	2500	125	1250	<7	orange
HL2	2,38	12	2500	125	1250	<7	orange
DL3	2,80	7,5	2500	125	1250	5	orange
DL5	2,75	7,5	2500	125	1250	5	orange
VL1	2,683	7,5	2500	125	1250	5,78	red
VL2	2,63	7,5	2500	125	1250	5,78	red

Source: Authors

1.3 Test method

Test method is performed with hydraulic piston by one pull from 0,05 LC (around 125 daN) to 0,5 LC (around 1250 daN). Then the piston is stopped and the tension force decreases immediately due to the webbing relaxation (see next figure). The relative elongation is evaluated at forces from 0,1 LC to 0,5 LC. Then hydraulics is used again to release the tension force to 0,05 LC. After the hydraulics is stopped the force increased immediately due to the webbing relaxation. Each strap is tested five times.



Source: Authors

Fig. 3 - Force-time diagrams of tensioning test by hydraulic piston by one pull from 0,05 LC to 0,5 LC

1.4 Test results

Results for all test samples are presented for described test method. Elongation is evaluated from initial distance L_0 plus movement of piston is measured by digital calliper with a resolution of 0,01 mm. Estimated elongation ε_{LC} by linear trend varies from 3,758 % for DL lashing straps to 4,343 % for HL lashing straps. For all lashing straps estimated ε_{LC} is 4,095 %.

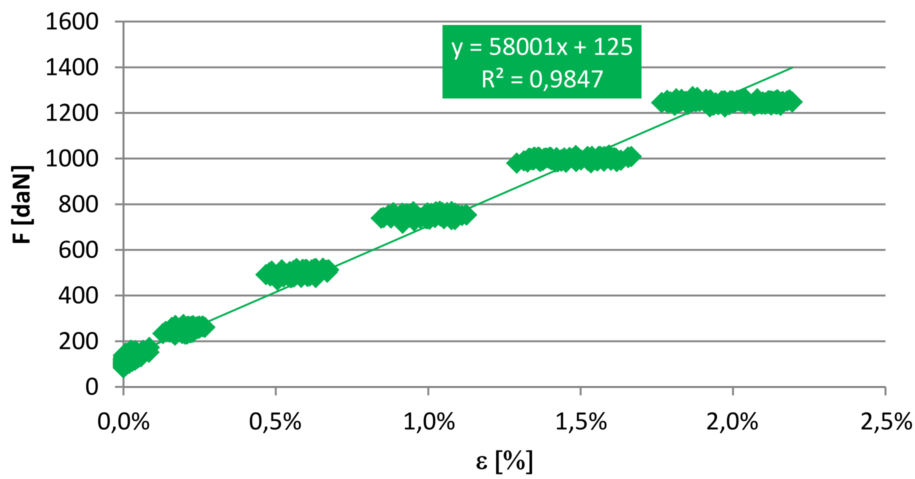


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Fig. 4 - Force-elongation results for all test samples

More detailed results for estimated linear trends for straps samples of different manufacturers are in table below with k coefficient of linear trend, coefficient of determination and calculated ε_{LC}.

Tab. 1 - Force-elongation results for all test samples

Lashing straps	Average measured distance L_0	k	R^2	ε_{LC}
DL	3508,2 mm	63192	0,9933	3,758%
VL	3499,7 mm	58686	0,9936	4,047%
TL	3504,6 mm	56758	0,9821	4,184%
HL	3523,3 mm	54689	0,9946	4,343%
ALL	3508,0 mm	58001	0,9847	4,095%

Source: Authors

The lowest estimated ε_{LC} is for DL lashing straps. The highest estimated ε_{LC} is for HL lashing straps.

Following table specifies multiplication of ε_{LC} using equation (3) for different tension forces F_T for tested lashing straps.

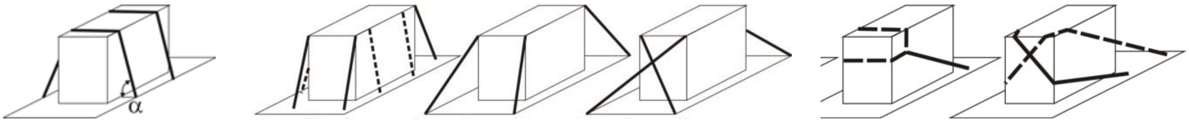
Tab. 2 – Elongation at different tension forces according equation (3) for tested lashing straps

			DL STRAPS	VL STRAPS	TL STRAPS	HL STRAPS	ALL STRAPS
F_T	ε	F_T [daN]	$\varepsilon_{LC} = 3{,}758\ \%$	$\varepsilon_{LC} = 4{,}047\ \%$	$\varepsilon_{LC} = 4{,}184\ \%$	$\varepsilon_{LC} = 4{,}343\ \%$	$\varepsilon_{LC} = 4{,}095\ \%$
0,05 LC	0	125	0	0	0	0	0
0,1 LC	$\frac{5}{95}\cdot\varepsilon_{LC}$	250	0,198%	0,213%	0,220%	0,229%	0,216%
0,2 LC	$\frac{15}{95}\cdot\varepsilon_{LC}$	500	0,593%	0,639%	0,661%	0,686%	0,647%
0,3 LC	$\frac{25}{95}\cdot\varepsilon_{LC}$	750	0,989%	1,065%	1,101%	1,143%	1,078%
0,4 LC	$\frac{35}{95}\cdot\varepsilon_{LC}$	1000	1,385%	1,491%	1,542%	1,600%	1,509%
0,5 LC	$\frac{45}{95}\cdot\varepsilon_{LC}$	1250	1,780%	1,917%	1,982%	2,057%	1,940%
0,6 LC	$\frac{55}{95}\cdot\varepsilon_{LC}$	1500	2,176%	2,343%	2,423%	2,514%	2,371%
0,7 LC	$\frac{65}{95}\cdot\varepsilon_{LC}$	1750	2,572%	2,769%	2,863%	2,971%	2,802%
0,8 LC	$\frac{75}{95}\cdot\varepsilon_{LC}$	2000	2,967%	3,195%	3,303%	3,428%	3,233%
0,9 LC	$\frac{85}{95}\cdot\varepsilon_{LC}$	2250	3,363%	3,621%	3,744%	3,886%	3,664%
LC	ε_{LC}	2500	3,758%	4,047%	4,184%	4,343%	4,095%

Source: Authors

2. INFLUENCE OF ELONGATION OF LASHING STRAPS ON MOVEMENT OF A CARGO SECURED BY A TOP-OVER LASHING DURING SLIDING IN LONGIDUTINAL DIRECTION

There are two basic methods to secure a cargo by lashing. The first one is frictional lashing (top-over) based on increased friction force from tensioned lashings. The other one is direct lashing based on direct restraining force of lashing equipment. For top-over lashings cargo movements are not taken into consideration when cargo securing is designed. Direct lashings are based on some pretension during cargo securing and the restraint force, up to lashing capacity, is created during cargo movement.



Source: Authors

Fig. 5 – Selected lashing methods

Securing of heavy cargo by top-over lashing in longitudinal direction, especially forwards, is not recommended due to the highest occurred accelerations in road transport. However, it is possible to take into consideration self-tightening feature of top-over lashing to increase the pretension of the cargo. The friction between the load and the lashing causes self-tightening of the lashings during cargo movement forwards or rearwards. The aim is to study how the distance of cargo movement changes with different pretension of lashings to define safety distance between cargo units to not damage each other when the vehicle is braking.

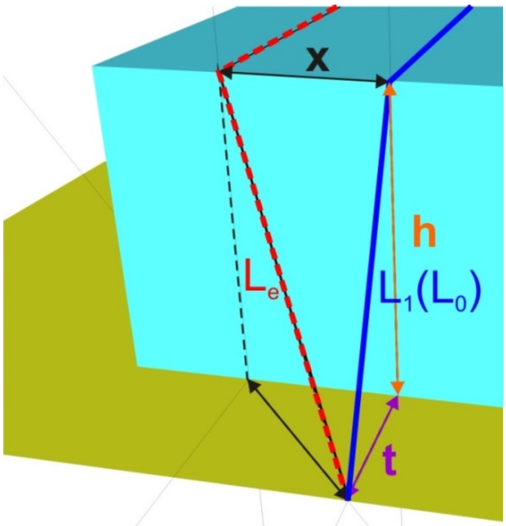


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Fig. 6 – Self-tensioning effect of top-over lashing (blue) with longitudinal movement of cargo (red position after movement)

Because the pretension in lashing before cargo movement shall be from 0,1 LC to 0,5 LC, initial pretension, cargo height and distance from lashing points influences the distance of cargo movement up to LC (distance X in figure above). The highest the initial pretension the smallest the cargo movement x which can be calculated as follows:

$$X = \sqrt{L_e^2 - h^2 - t^2} \quad [\text{mm}] \tag{6}$$

where

Le elongated length after cargo movement to specified tension force,

h cargo height,

t cargo distance from lashing points.

$$L_1(L_0) = \sqrt{h^2 + t^2} \quad [\text{mm}] \tag{7}$$

where

L_0 initial length at 0,05 LC if used as initial pretension,

L_1 elongated length at initial pretension,

so

Initial length at 0,05 LC is calculated from length L_1 using (1) as follows:

$$L_0 = \frac{L_1}{\varepsilon_1 + 1} \quad [\text{mm}] \tag{8}$$

Elongated length L_e at specified tension force using (1) is as follows:

$$L_e = L_0 \cdot (\varepsilon_e + 1) = L_1 . \frac{(\varepsilon_e + 1)}{(\varepsilon_1 + 1)} [\text{mm}] \tag{9}$$

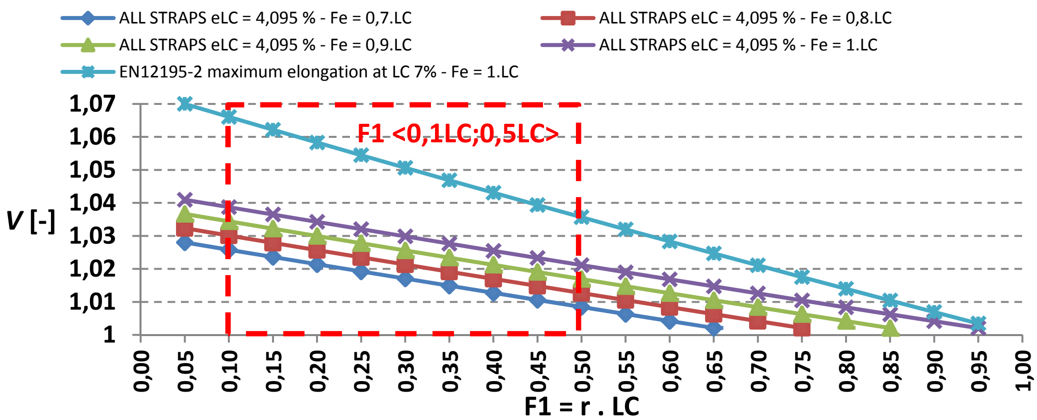
Then elongated length after cargo movement with different initial pretension and different final tension force after cargo movement using (3) is:

$$L_e = L_1 . \frac{\left(\frac{F_e - 0{,}05LC}{0{,}95LC} \cdot \varepsilon_{LC} + 1\right)}{\left(\frac{F_1 - 0{,}05LC}{0{,}95LC} \cdot \varepsilon_{LC} + 1\right)} = L_1 . \frac{(F_e - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}{(F_1 - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC} \quad [\text{mm}] \tag{10}$$

$$\text{or} \quad L_e = L_1 . \frac{(r_e - 0{,}05) \cdot \varepsilon_{LC} + 0{,}95}{(r_1 - 0{,}05) \cdot \varepsilon_{LC} + 0{,}95} [\text{mm}] \tag{11}$$

We can use following substitution for coefficient V as a ratio of L_e to L_1:

$$V = \frac{(F_e - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}{(F_1 - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC} \; [-] \quad \text{or} \quad v = \frac{(r_e - 0{,}05) \cdot \varepsilon_{LC} + 0{,}95}{(r_1 - 0{,}05) \cdot \varepsilon_{LC} + 0{,}95} \tag{12}$$



Source: Authors

Fig. 6 – Coefficient V as a ratio of L_e to L_1

When initial pretension is 0,1 LC/0,5 LC and F_e = LC then V coefficient for all tested straps is 1,0387/1,0211. Figure above also shows a boundary with maximum elongation at LC of 7% specified by the standard EN 12195-2 (8). For this curve for 0,1 LC/0,5 LC maximum V is 1,066/1,0357.

The distance of cargo movement X using (6) and (7) is:

$$X = \sqrt{\left[L_1 . \frac{(F_e - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}{(F_1 - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}\right]^2 - h^2 - t^2} = L_1 . \sqrt{\left[\frac{(F_e - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}{(F_1 - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}\right]^2 - 1} \text{ [mm]} \quad (13)$$

We can use following substitution as f coefficient as a ratio of X to L_1:

$$f = \sqrt{\left[\frac{(F_e - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}{(F_1 - 0{,}05LC) \cdot \varepsilon_{LC} + 0{,}95LC}\right]^2 - 1} \text{ or } f = \sqrt{\left[\frac{(r_e - 0{,}05) \cdot \varepsilon_{LC} + 0{,}95}{(r_1 - 0{,}05) \cdot \varepsilon_{LC} + 0{,}95}\right]^2 - 1} \quad (14)$$

so the cargo movement X is as follows:

$$X = L_1 . f \quad (15)$$

Following picture shows the f coefficient of cargo movement for various initial pretensions F_1 of tested lashing straps up to $F_e = LC$.

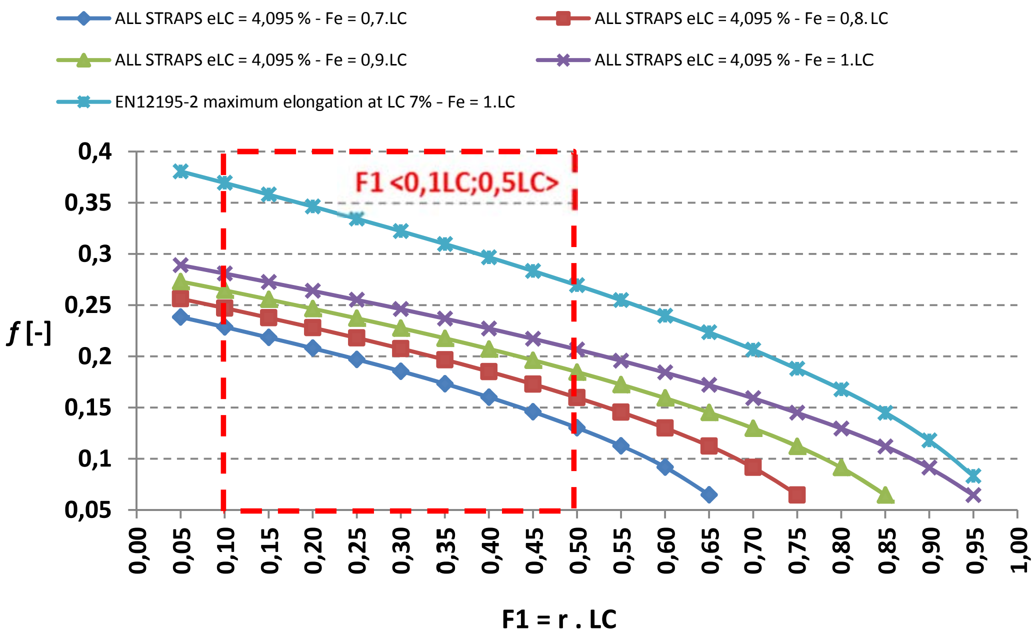


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Fig. 7 – f coefficient as a percentage of L_1 to represent a cargo movement X

The coefficient f which represents a percentage of initially pretensioned length L_1 represents a cargo movement X. When initial pretension is 0,1/0,5 LC and F_e = LC the movement presents 28,09/20,67 % of L_1 for test results of all straps. The boundary with maximum elongation at LC of 7% specified by the standard EN 12195-2 (8). For this curve for 0,1LC/0,5 LC and F_e = LC coefficient V is 36,95% / 26,94% of L_I.

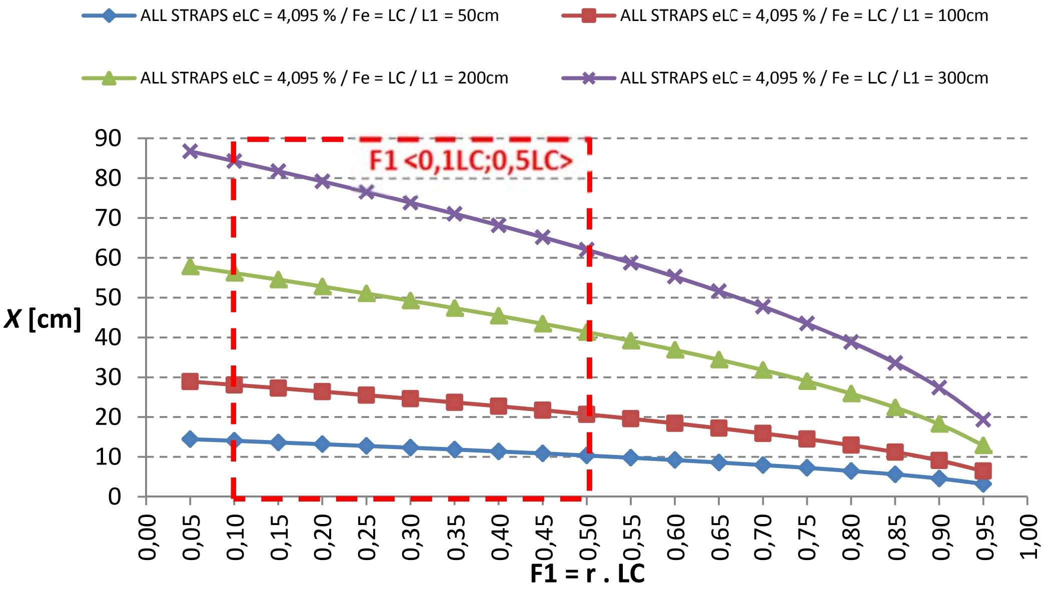

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Fig. 8 – Cargo movement X at different F_I and F_e = LC for L_I 50 cm, 100 cm, 200 cm and 300 cm

Previous figure specifies cargo movement for selected length L_I and different pretensions. For L_I =100 cm expected cargo movement for pretension from 0,1 LC to 0,5 LC is from 21 to 28 cm for e_{LC} af all tested straps. However, if L_I = 300 cm than expected movement for specified pretensions is from 62 to 85 cm.

CONCLUSIONS

Elongation of lashings straps influence length of lashing straps and tension force increase in lashing straps. The highest the initial pretension the smallest cargo movements are expected. If the length of lashing straps is long than large cargo movements can be expected. Paper takes into consideration only the geometry of movement of solid cargoes. The influence of strap-cargo friction is not taken into consideration but large cargo movements can influence sliding of strap instead of tensioning or sharp edges can cut strap which must be prevented. Self-tensioning effect of top-over lashing works better with high strap-cargo friction e.g. when anti-slip mats are between cargo and straps but this is contradicting other theory of the transmission of the force over the corners at top-over lashing (more details in (9)).

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