REPORT

No.: D3.2 – part 1

Tests on the stabilisation of beams

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Task:	3.2
Object:	Stabilisation of beams by torsional restraint

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1 Preliminary remark

Sandwich panels increase the resistance of substructures (beams, purlins) against lateral torsional buckling by restraining the rotations and lateral displacements.
The torsional restraint is governed by the stiffness of the connection of the sandwich panel to the substructure. Recent research carried out at UKA showed that this stiffness significantly depends on the lateral load transferred by the sandwich panel. Formulae for calculating the parameters of this moment-rotation-relation are given for sandwich panels with two different core materials. So far only connections through the lower crimp with two fasteners per element have been investigated. Other types of connections (e.g. connection through upper crimp with calottes) and different core materials are important yet unknown parameters of the moment-rotation-relation.
A design concept for the quantification and calculation of the stabilising effects on beams by sandwich panels was developed within the framework of the EASIE project. The results are presented in deliverable D3.2 – part 1, dealing with the experimental tests. The evaluation of the results can be found in deliverable D3.3 – part 1. Deliverable D3.3 – part 1 is also dealing with the numerical calculations and the derivation of a design concept.

2 Object of testing

2.1 Preliminary remarks

Tab. 1 depicts a compilation of all tests performed. At this, the application, loading and materials are listed.

No.	Application	Loading	Core material	Face material
01	wall	downward	EPS	steel
02	wall		EPS	GFRP
03	wall		PUR	aluminium
04a	roof		PUR	aluminium
04b	roof		PUR	aluminium
05	roof		MW	steel
06	wall		PUR	steel
07	wall	uplift	PUR	steel
08	wall		PUR	steel
09	wall		MW	steel
10	wall		MW	Steel
11	wall		EPS	Steel
12	roof		PUR	steel
13	roof		PUR	steel
14	roof		MW	steel
16	roof	downward	PUR	steel
16k	roof		PUR	steel
17	roof		MW	steel
18k	roof	uplift	PUR	steel
18ok	roof		PUR	steel
19	roof		PUR	steel

Tab. 1: Compilation of performed tests on torsional restraint

2.2 Sandwich panels

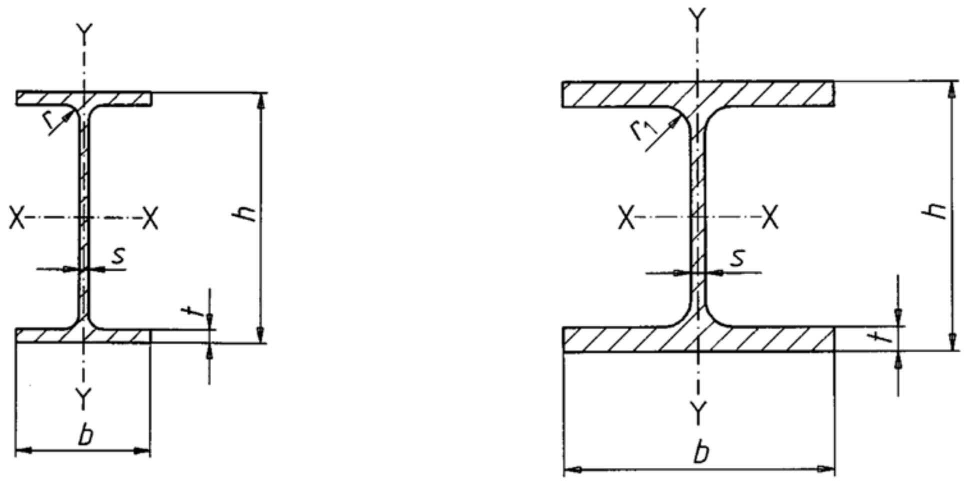
Investigations on roof and wall panels of different producers were performed. In addition to sandwich panels with polyurethane foam core, panels with a core made of mineral wool or EPS were investigated as well. The thicknesses of the core layers varied between 40 mm and 80 mm. The face layers of the panels were made of steel, aluminium or glass-fibre reinforced plastics (GFRP). The thickness varied between 0.40 mm and 0.50 mm for steel faces, and between 0.50 mm and 0.70 mm for the aluminium faces. The thickness of the GFRP-faces was 1,8 mm. Tab. 2 gives a compilation of parameter combinations for the tested sandwich panels.

No.	Core material	Core thickness	Face material	Face thickness
01	EPS	60	steel	0,60 / 0,60
02	EPS	60	GFRP	1,80 / 1,80
03	PUR	60	aluminium	0,65 / 0,65
04a	PUR	58	aluminium	0,70 / 0,50
04b	PUR	58	aluminium	0,70 / 0,50
05	MW	80	steel	0,60 / 0,60
06	PUR	80	steel	0,50 / 0,50
07	PUR	80	steel	0,50 / 0,50
08	PUR	80	steel	0,50 / 0,50
09	MW	80	steel	0,50 / 0,50
10	MW	80	Steel	0,50 / 0,50
11	EPS	60	Steel	0,60 / 0,60
12	PUR	40	steel	0,50 / 0,40
13	PUR	40	steel	0,50 / 0,40
14	MW	80	steel	0,60 / 0,60
16	PUR	40	steel	0,50 / 0,40
16k	PUR	80	steel	0,50 / 0,40
17	MW	40	steel	0,50 / 0,40
18k	PUR	40	steel	0,50 / 0,40
18ok	PUR	40	steel	0,50 / 0,40
19	PUR	40	steel	0,50 / 0,40

Tab. 2: materials and nominal dimensions of the sandwich panels tested

2.3 Beam sections and fasteners

Investigations were performed with hot-rolled medium flange I-beams of type IPE 160 according to DIN 1025-5 and with hot-rolled wide flange I-beams HE 160 B according to DIN 1025-2.



b = 160 mm	h = 160 mm
h = 82 mm	b = 160 mm
s = 5 mm	s = 8 mm
t = 7,4 mm	t = 13 mm
r = 9 mm	r_1 =15 mm

Fig. 1: Beam sections investigated

For fastening the sandwich panels with the beam sections, self-tapping screws made of stainless steel of type Würth FABA Typ BZ 6.3xL were used with seal washers 16 mm. Mutual fastening of the sandwich panels for roof application in the longitudinal joint was done with self-drilling screws of type Würth Zebra Piasta 4,8x22 with undercut and with seal washers 14 mm. The fasteners applied are presented in Fig. 2.

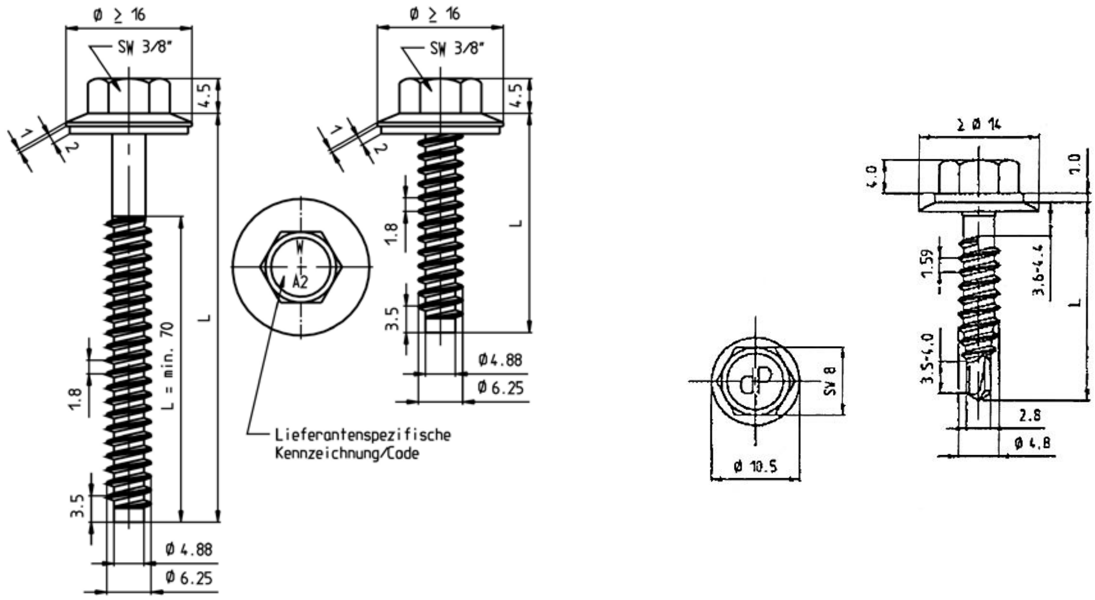


Fig. 2: Fasteners

Several tests were performed with sandwich panels for roof application with fixing in the upper flange by using saddle washers, Fig. 3.

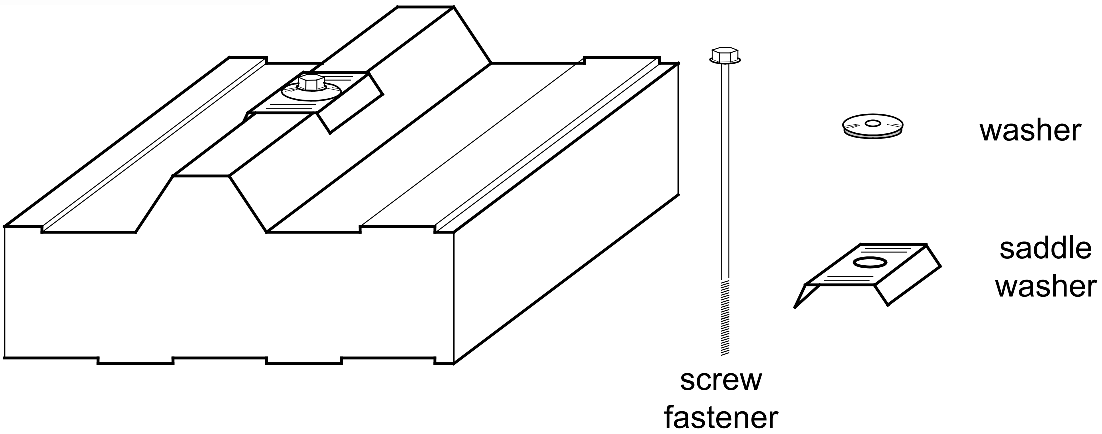


Fig. 3: Saddle washer [4]

The arrangement of the screws was done in combination with double-symmetric I-beams either as alternating fastening or as one-sided fastening. For detailed information about the arrangement of the screws including distances to the edges and between fasteners see chapter 5.

3 Test set-up

The test set-up for performing tests on torsional bedding was designed following [1] and [2]. The set-up is outlined in Fig. 4 and Fig. 5.

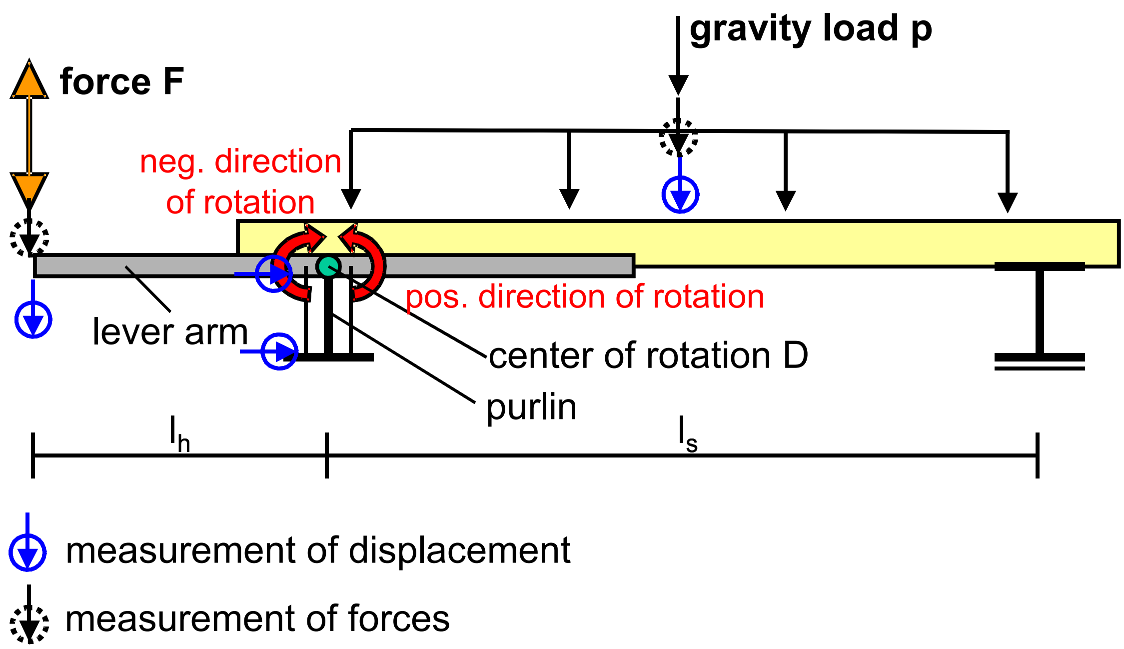


Fig. 4: Test set-up for downward loading

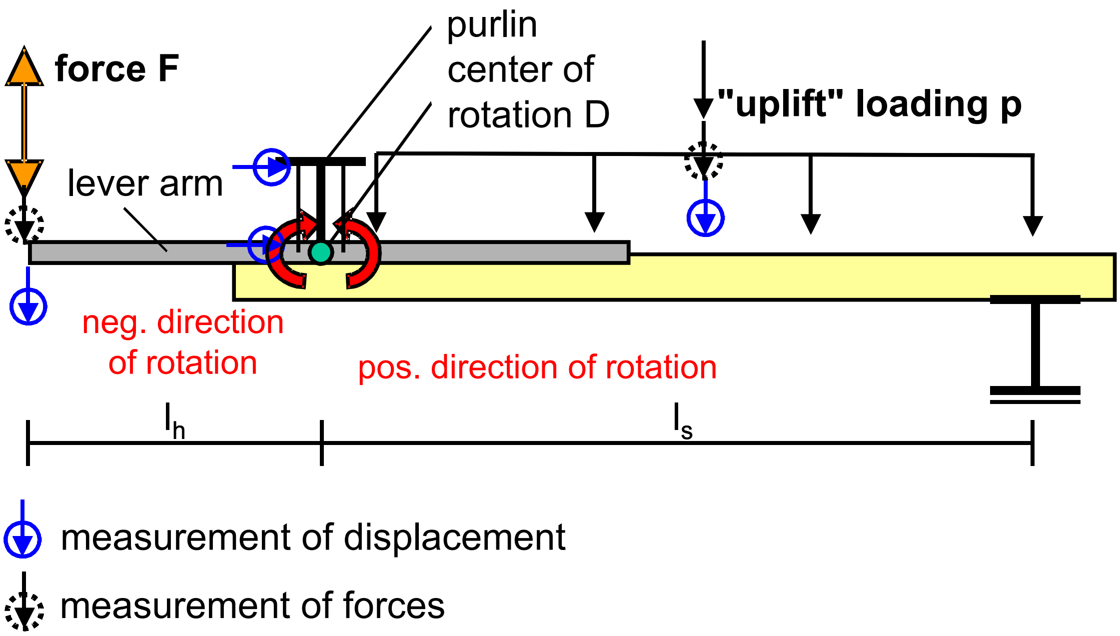


Fig. 5: Test set-up for uplift loading

The test set-up consists of a beam pivoted through a roller bearing, being covered and bolt together as an edge beam of a span with two adjacent sandwich elements, each of width 1 m. The sandwich elements are preloaded through a constant load p_1 during test performance.

At the ends of the beam welded end plates are located, preventing a warping of the beam during test performance. Lever arms are attached rectangular to the longitudinal axis of the beam via these end plates, by means of which the beam can be twisted around the centre of rotation D at simultaneous loading of the sandwich elements according to Fig. 4 and Fig. 5. The lever arms are connected to each other through a transverse truss. The deflection of this system is done through a course controlled hydraulic cylinder loading the transverse truss with the deflection load F. Using roller bearings as well as slide bearings on the second point of support of the sandwich elements it was ensured that neither restraints nor resistances against twisting of the beam occurred from the test set-up.

The displacements v_o and v_u of the upper flange and bottom flange resulting from the rotation of the beam are measured using two cable extension transducers and converted in an appropriate torsion using equation (1).

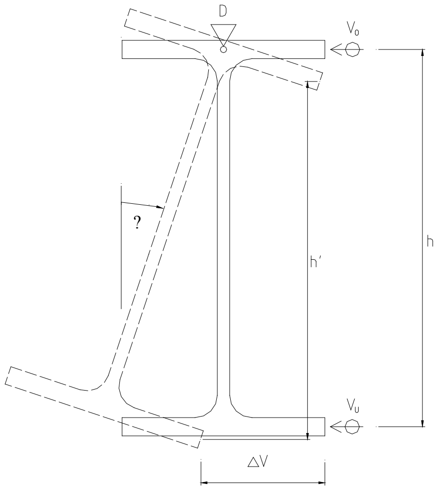


Fig. 6: Centre of rotation D and displacement v_o and v_u

$$\vartheta_M = \arctan\left(\frac{\Delta v_u - \Delta v_o}{h'}\right) = \arcsin\left(\frac{\Delta v_u - \Delta v_o}{h}\right) \quad \textbf{(1)}$$

4 Test performance

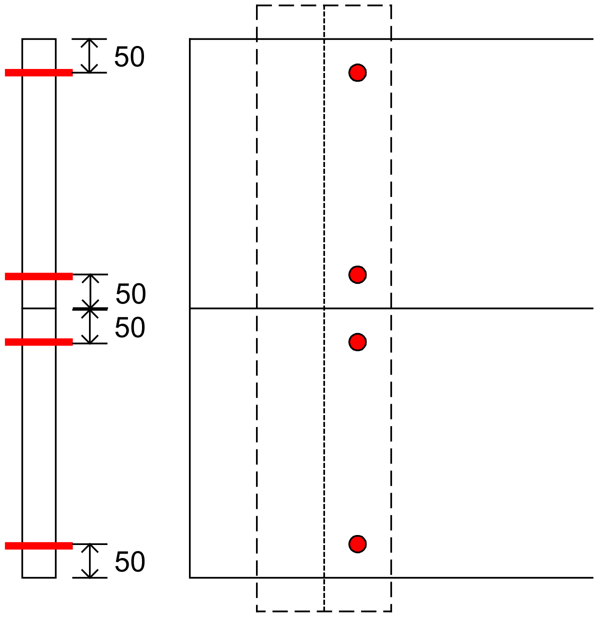
After applying a distributed load p_1 to the sandwich elements, the pivoted beam is deflected by means of lever arms. The deflection is done in several cycles alternating in positive and negative torsion direction, where the amplitude of the deflection increases constantly up to a maximum torsions of ϑ = 0.1rad. After having reached the maximum torsion of ϑ = 0.1rad in positive as well as in negative torsion direction, an increase of the distributed load occurs whereas the beam is in a non-deflected position. After reaching a load p_2, the torsion of the beam is again applied in cyclic loading. Finally, the torsion of the beam is effected under the load p_3. The value of the load p_3 is always in the limit range of the load-bearing capacity of the sandwich panel. Through this method, the influence of an increased load p on the effect of torsional bedding of the sandwich element can be assessed.
The applied torsional moment as well as the resulting torsion of the beam are recorded continuously and presented as moment-torsion-relation using a fully electronic measuring equipment.

5 Results of the tests on torsional restraint

The following pages show the results of the tests on the torsional restraint of beams by sandwich panels. For each test, a table listing all relevant parameters is given, followed by the graphs of the measured relation between the applied rotation and the torsional moment. A separate graph for each load step is given, complemented by a graph combining the results from all load steps. The latter highlights the influence of the value of the distributed load and one may help to compare the graphs. In addition, the load-deflection-curve of the panel is given, enabling the recalculation of the bending stiffness of the panel. The consulted deflection is the deflection at mid-span. If relevant significant pictures are shown for the test.

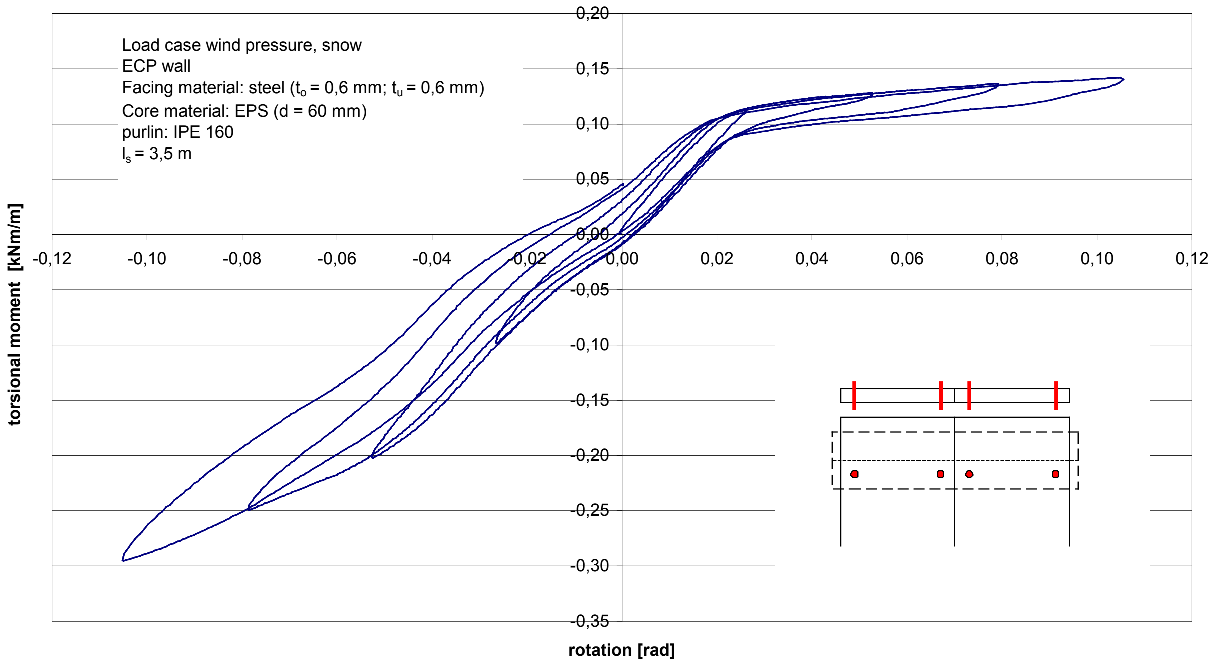
No. 01

Application:	wall
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,60 / 0,60 mm
core material:	EPS
core thickness:	60 mm
beam section:	IPE 160
fasteners:	

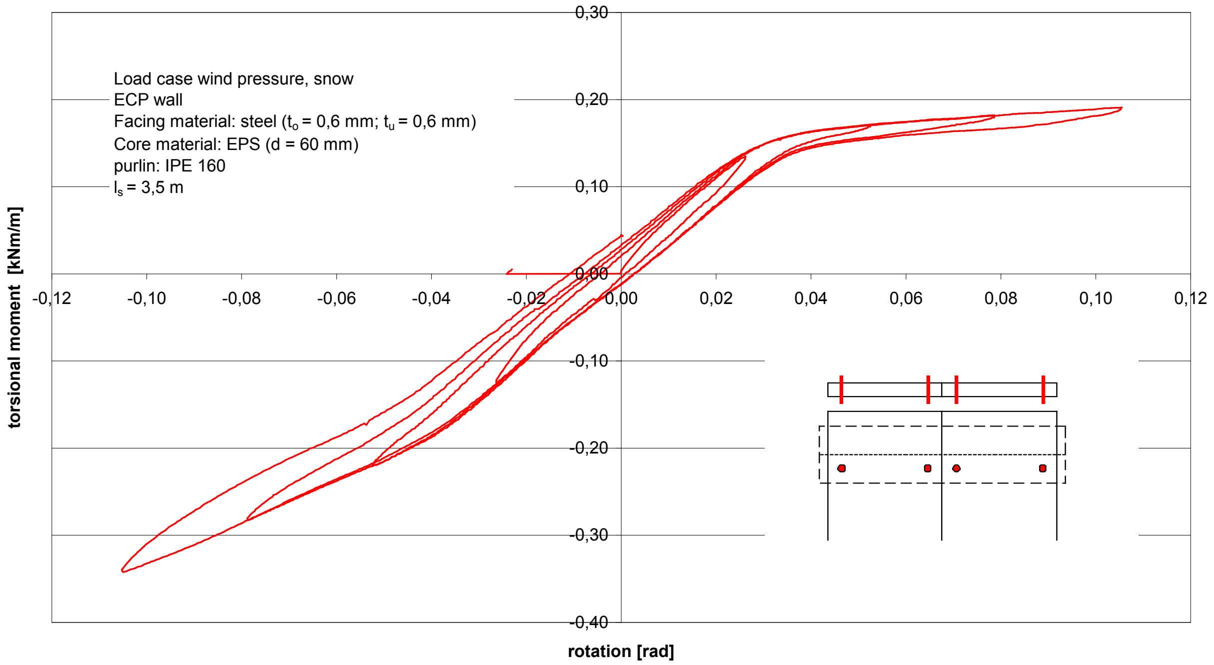


load p_1:	9,1 kN
load p_2:	14,6 kN
load p_3:	20,1 kN
remarks:	wrinkling failure of the panel at load p_3 = 19,70 kN

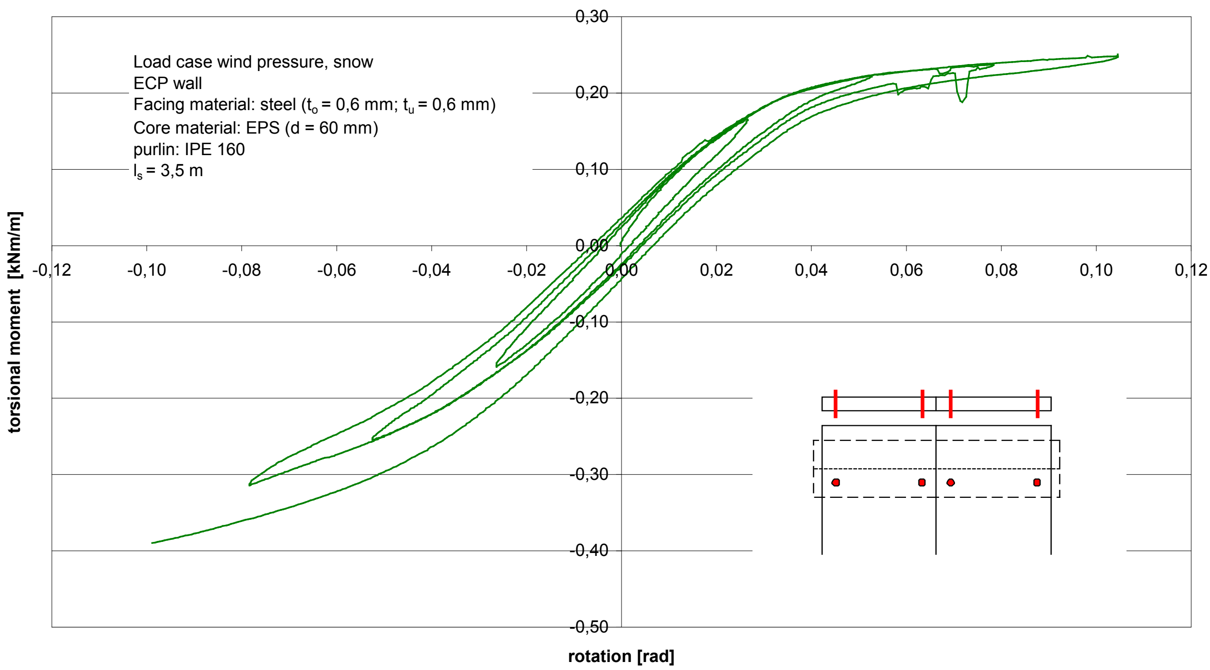
Test 01, q = 1,3 kN/m²



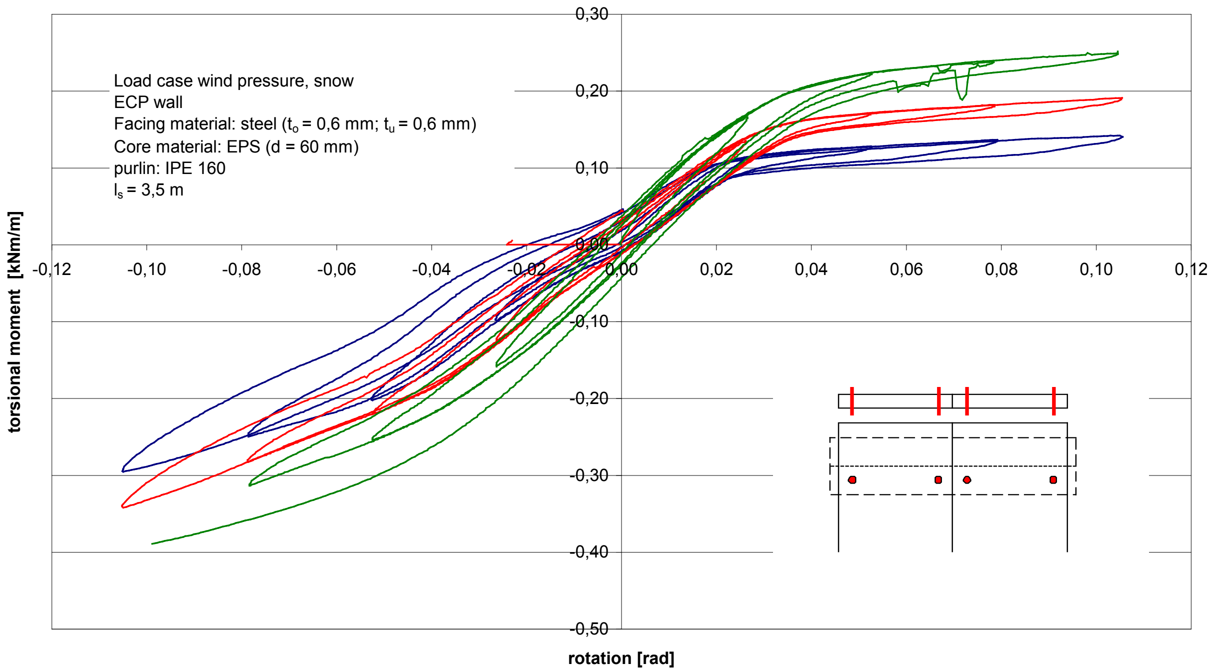
Test 01, q = 2,1 kN/m²



Test 01, q = 2,9 kN/m²



Test 01



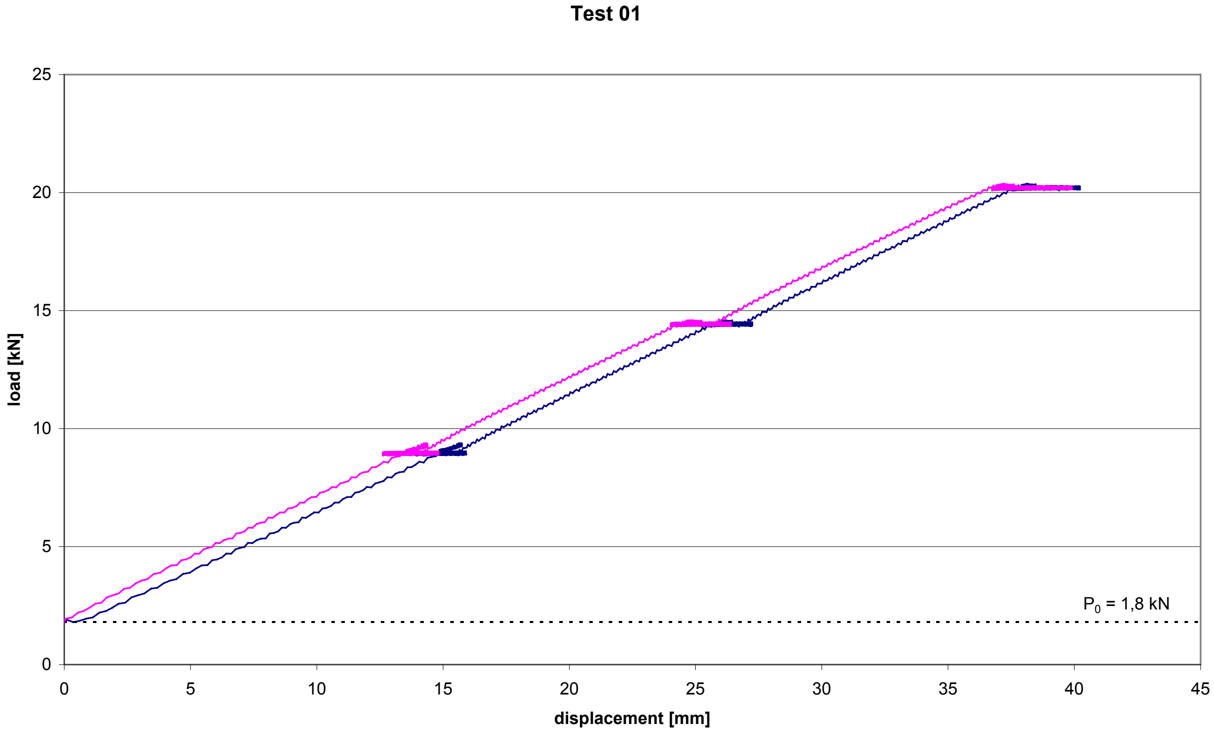
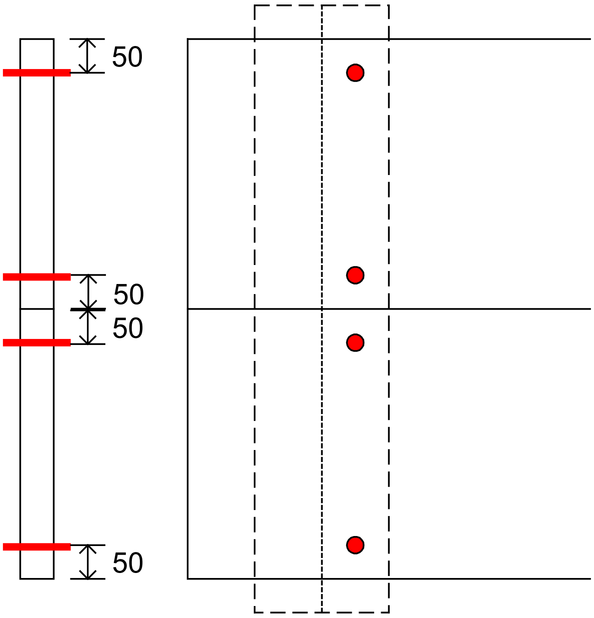


Fig. 7: Wrinkling failure of the panel at load p_3 = 20,1 kN

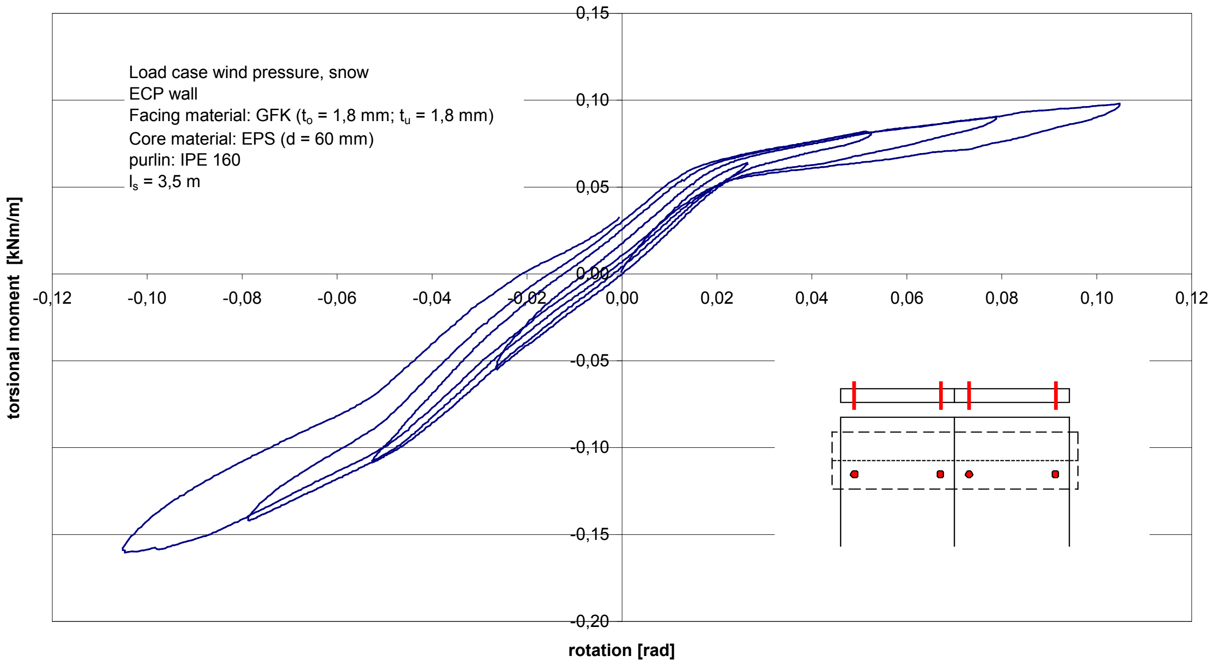
No. 02

Application:	wall
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	GFRP
face thickness:	1,80 / 1,80 mm
core material:	EPS
core thickness:	60 mm
beam section:	IPE 160
fasteners:	

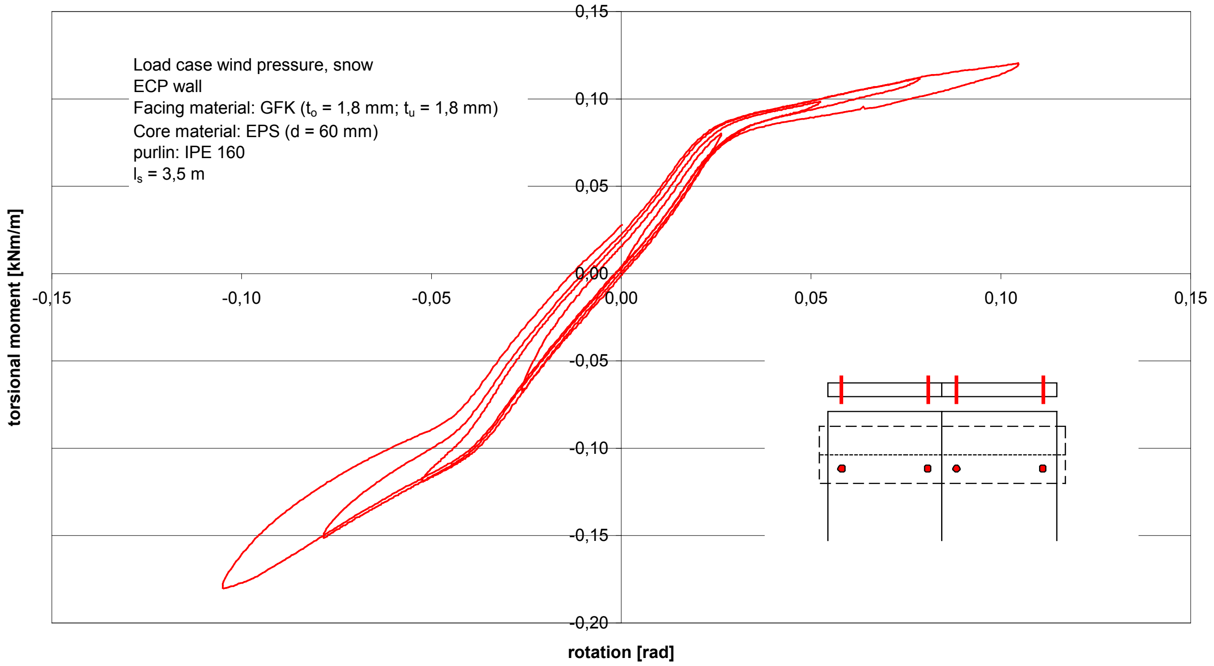


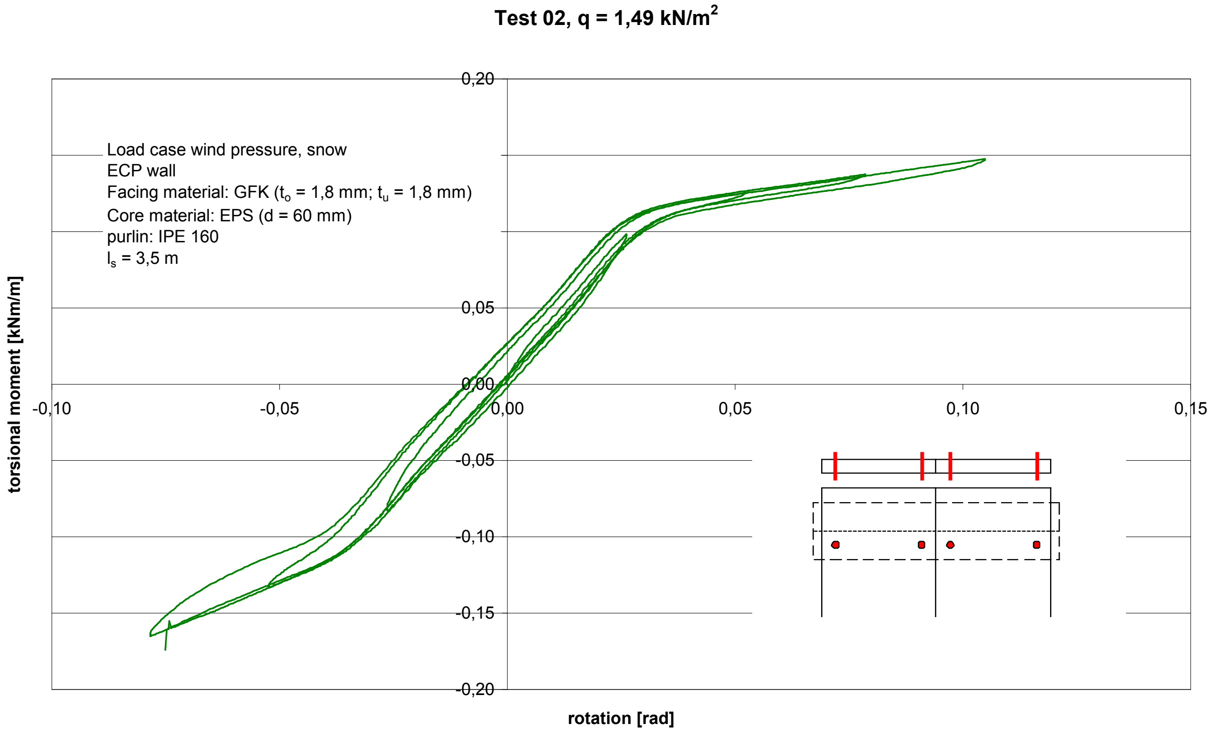
load p_1:	5,2 kN
load p_2:	7,7 kN
load p_3:	10,4 kN
remarks:	Abortion of the test al load p_3 = 10,4 kN during the last cycle due to contact between transverse truss of the lever arms and the load cell.

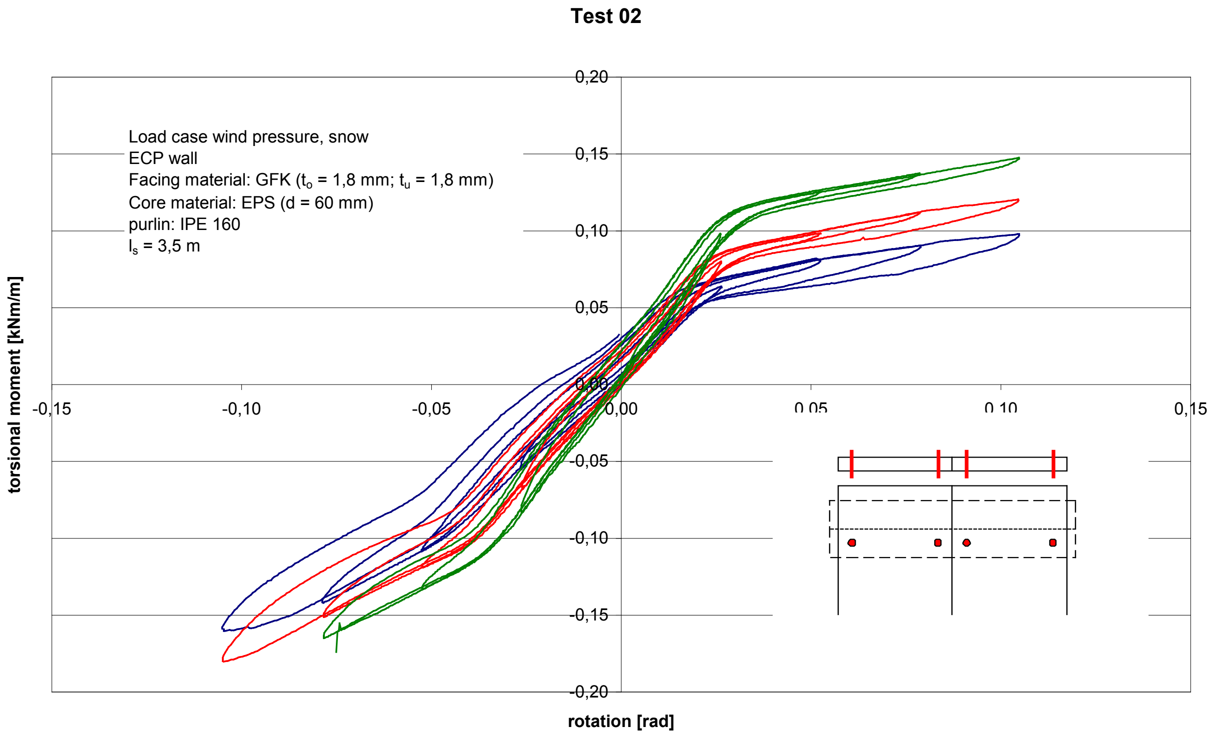
Test 02, q = 0,73 kN/m²



Test 02, q = 1,11 kN/m²




Test 02, q = 1,49 kN/m²
Load case wind pressure, snow
ECP wall
Facing material: GFK (t_o = 1,8 mm; t_u = 1,8 mm)
Core material: EPS (d = 60 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,10
-0,05
0,00
0,05
0,10
0,15


Test 02
Load case wind pressure, snow
ECP wall
Facing material: GFK (t_o = 1,8 mm; t_u = 1,8 mm)
Core material: EPS (d = 60 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,15
-0,10
-0,05
0,00
0,05
0,10
0,15

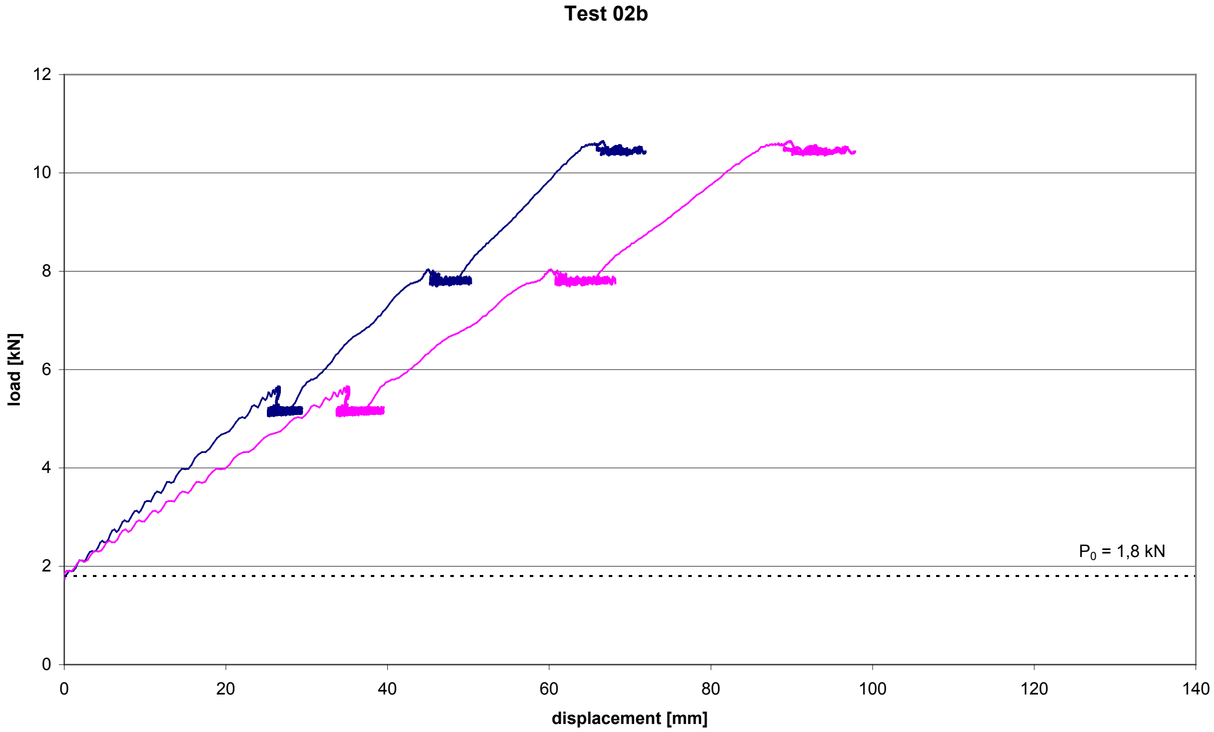
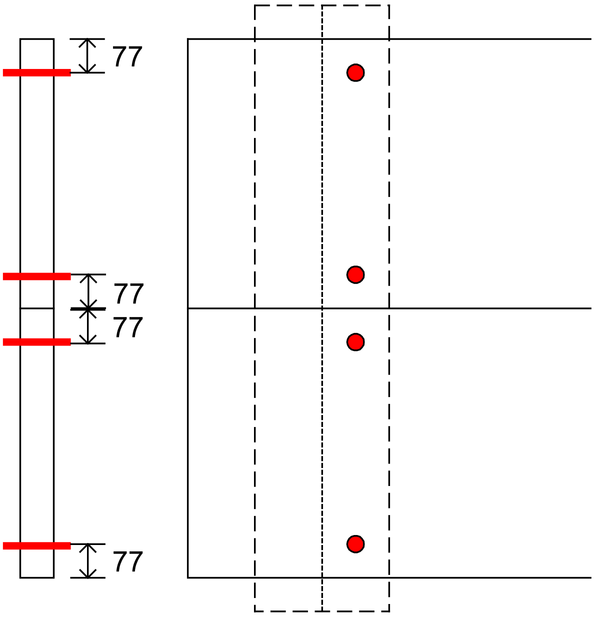


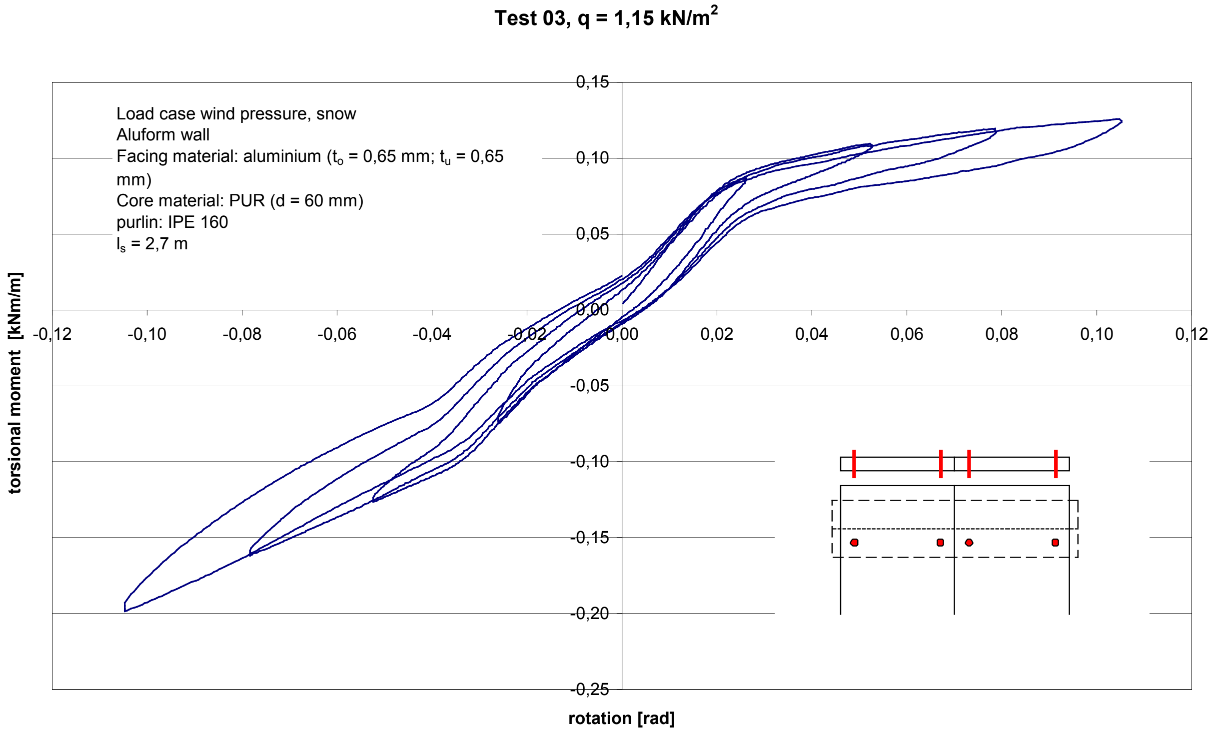
Fig. 8: Indentation of fasteners in the upper face

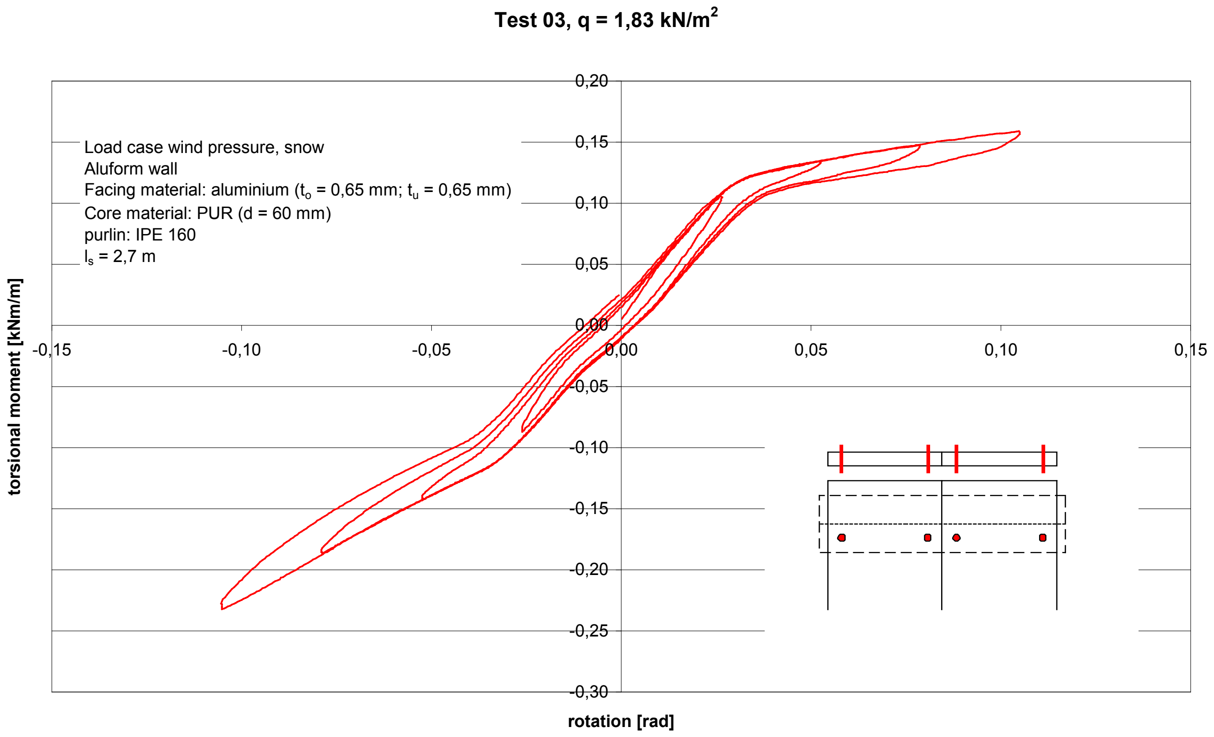
No. 03

Application:	wall
Loading:	downward
length of panel:	3000 mm
Span:	2700 mm
face material:	aluminium
face thickness:	0,65 / 0,65 mm
core material:	PUR
core thickness:	60 mm
beam section:	IPE 160
fasteners:	

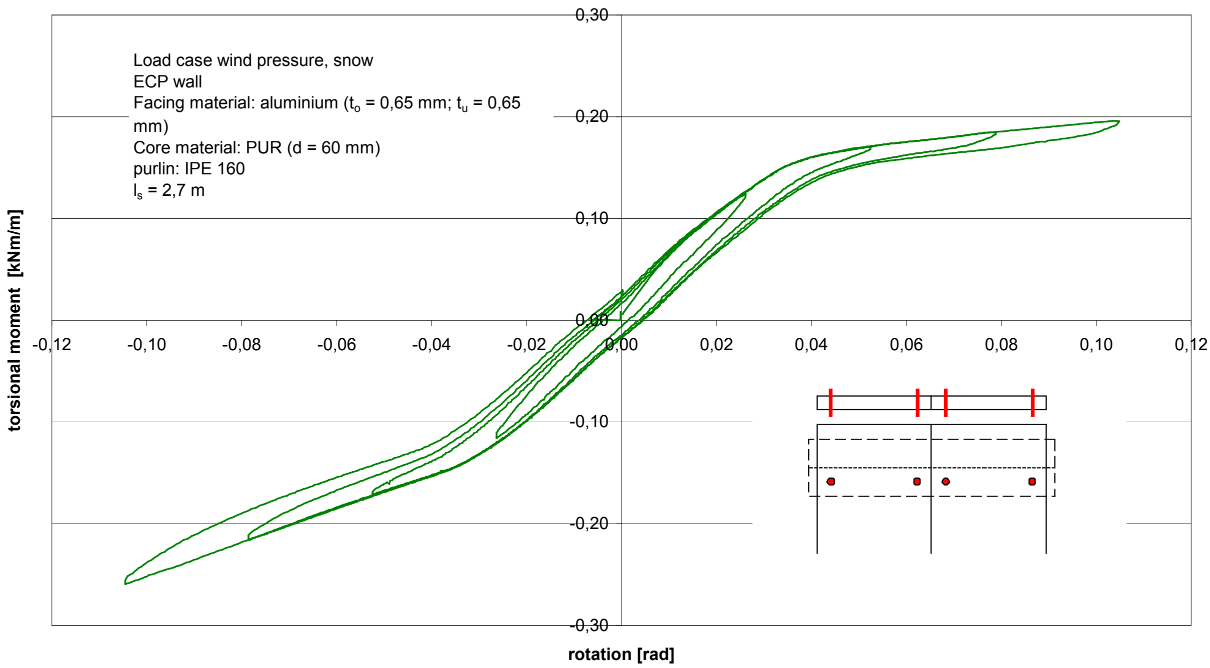


load p_1:	6,2 kN
load p_2:	9,9 kN
load p_3:	13,7 kN
remarks:	

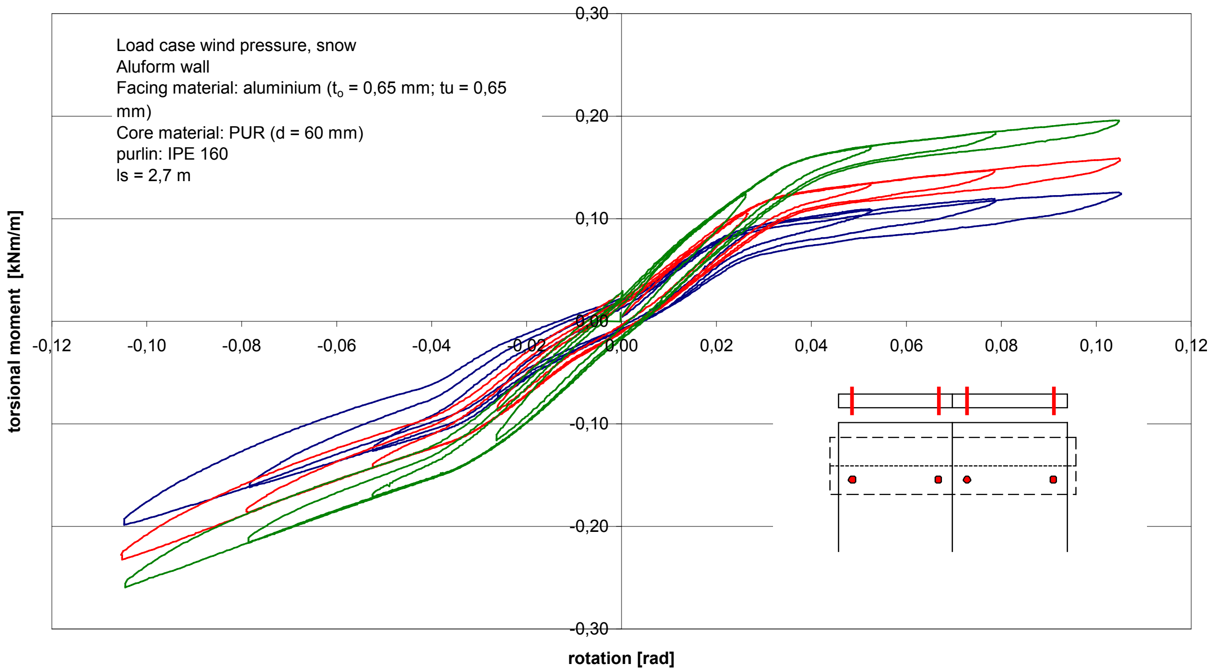

Test 03, q = 1,15 kN/m²
Load case wind pressure, snow
Aluform wall
Facing material: aluminium (to = 0,65 mm; tu = 0,65 mm)
Core material: PUR (d = 60 mm)
purlin: IPE 160
ls = 2,7 m
torsional moment [kNm/m]
rotation [rad]
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

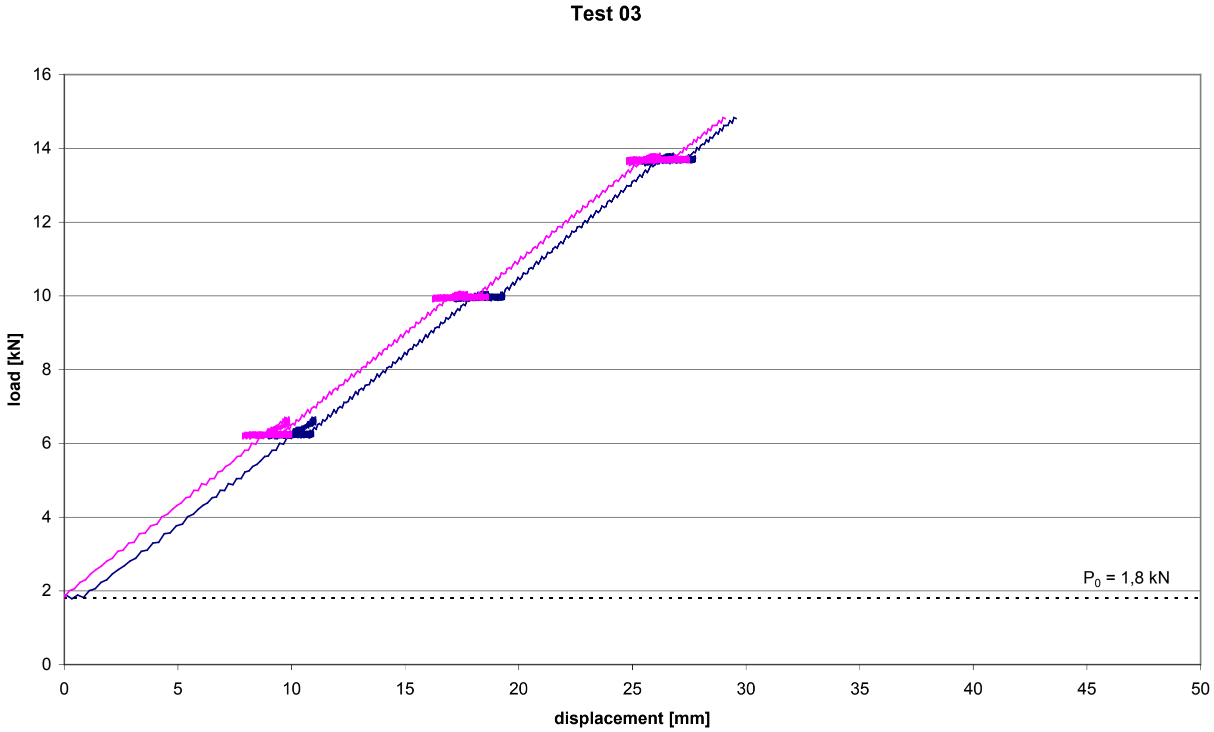

Test 03, q = 1,83 kN/m²
Load case wind pressure, snow
Aluform wall
Facing material: aluminium (to = 0,65 mm; tu = 0,65 mm)
Core material: PUR (d = 60 mm)
purlin: IPE 160
ls = 2,7 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,15
-0,10
-0,05
0,00
0,05
0,10
0,15

Test 03, q = 2,53 kN/m²



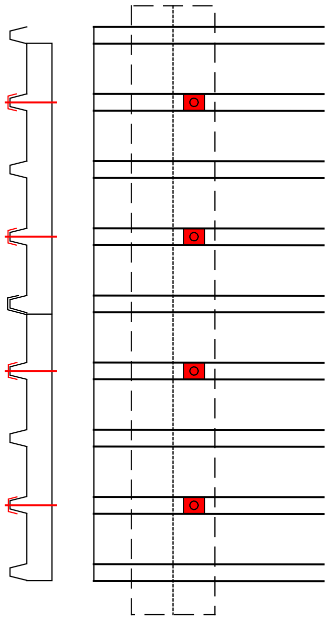
Test 03



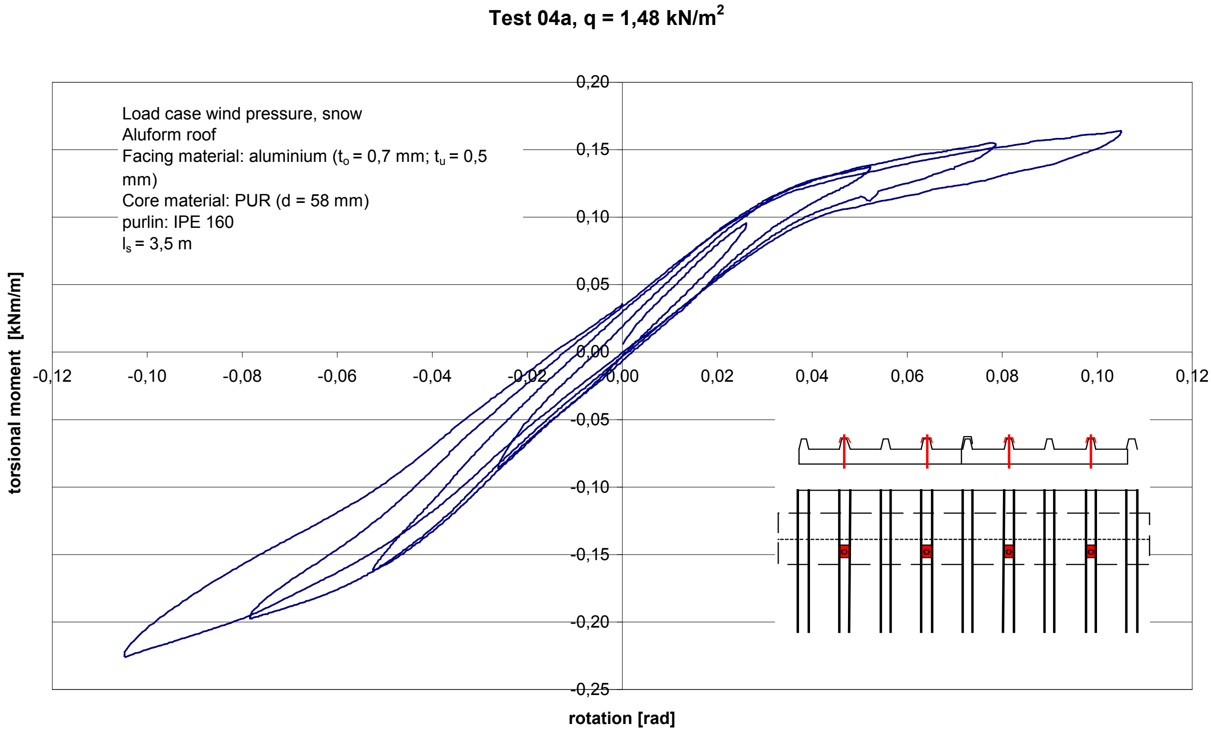

Test 03
load [kN]
displacement [mm]
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
P0 = 1,8 kN

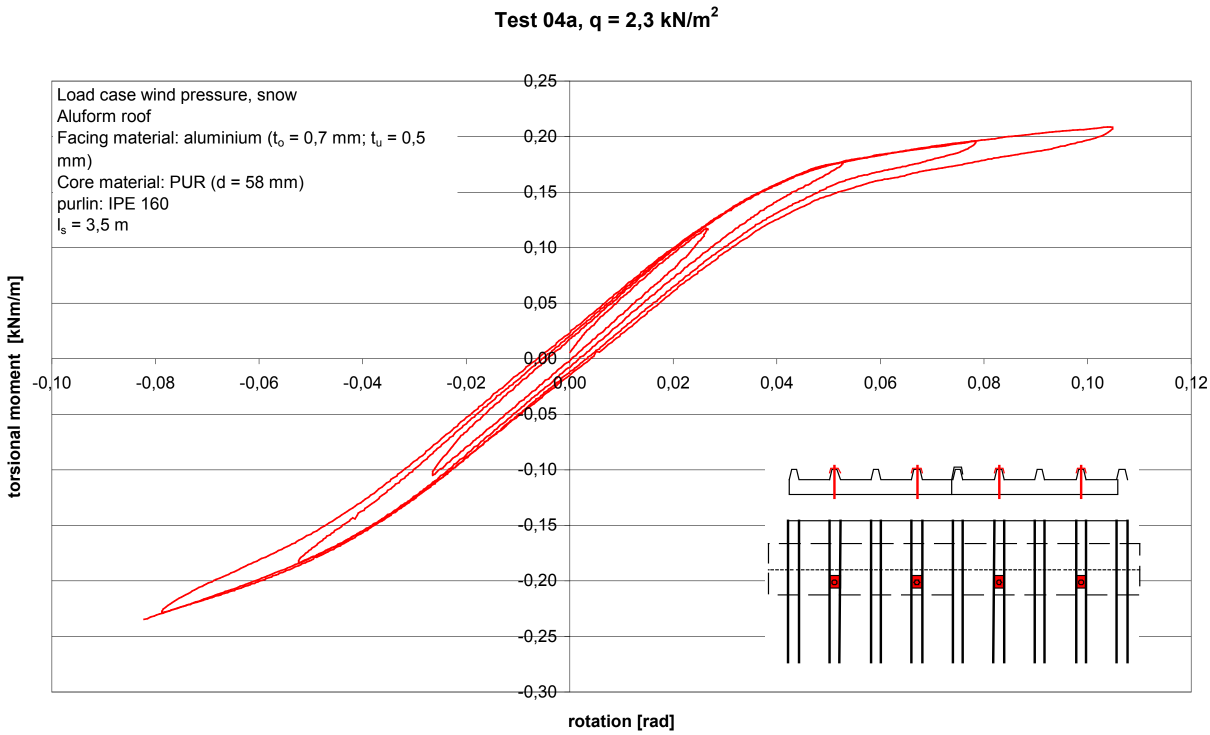
No. 04a

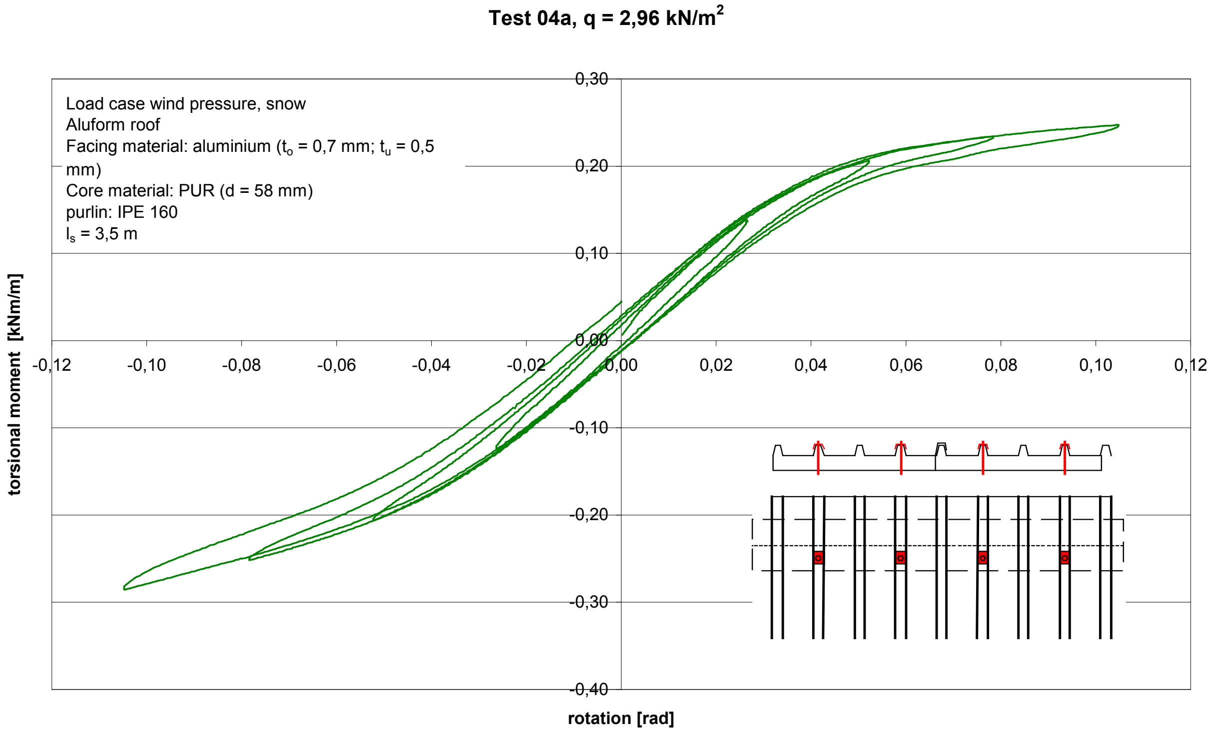
Application:	roof
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	aluminium
face thickness:	0,70 / 0,50 mm
core material:	PUR
core thickness:	58 mm
beam section:	IPE 160
fasteners:	

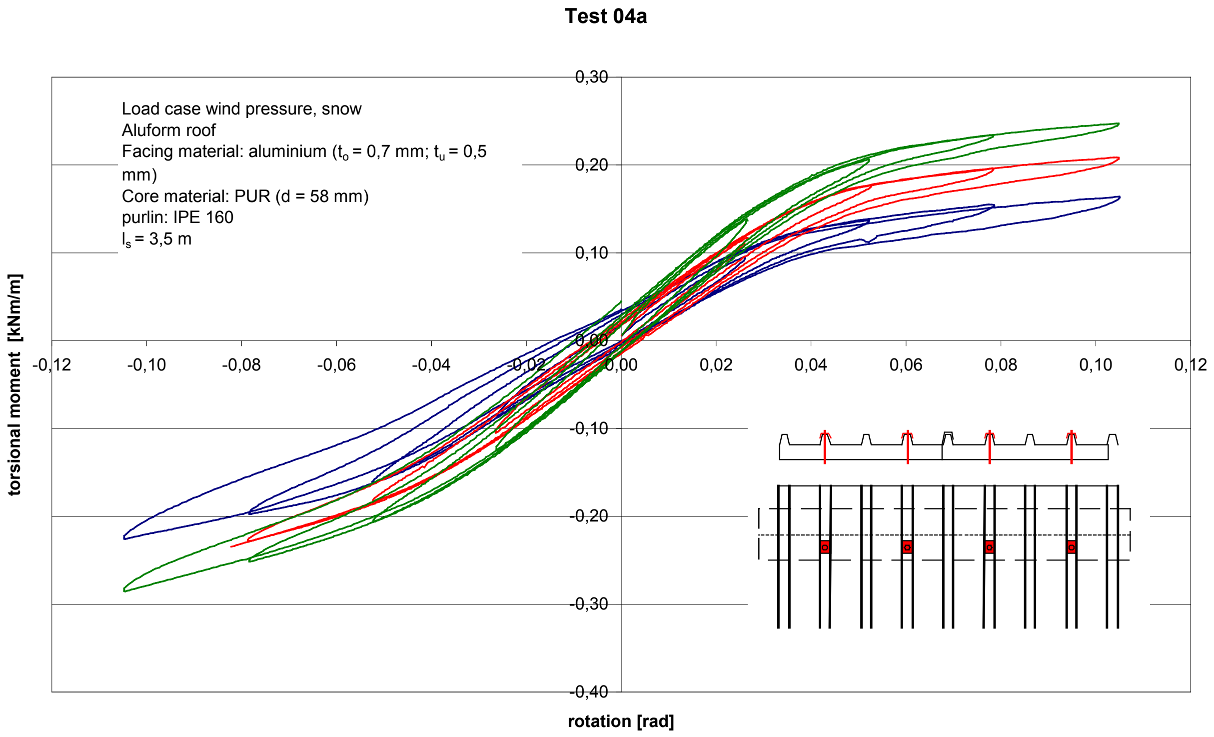


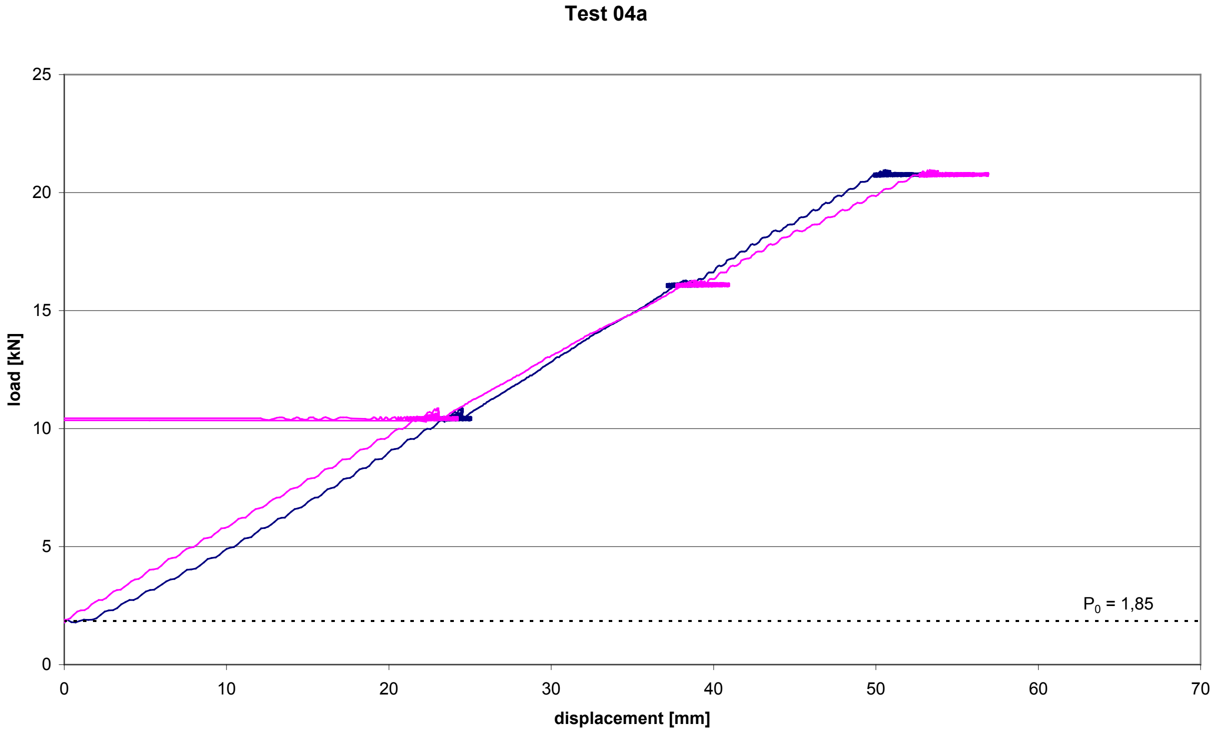
load p_1:	10,5 kN
load p_2:	16,1 kN
load p_3:	20,7 kN
remarks:	


Test 04a, q = 1,48 kN/m2
Load case wind pressure, snow
Aluform roof
Facing material: aluminium (to = 0,7 mm; tu = 0,5 mm)
Core material: PUR (d = 58 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 04a, q = 2,3 kN/m2
Load case wind pressure, snow
Aluform roof
Facing material: aluminium (to = 0,7 mm; tu = 0,5 mm)
Core material: PUR (d = 58 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 04a, q = 2,96 kN/m²
Load case wind pressure, snow
Aluform roof
Facing material: aluminium (t_o = 0,7 mm; t_u = 0,5 mm)
Core material: PUR (d = 58 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,30
0,20
0,10
0,00
-0,10
-0,20
-0,30
-0,40
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 04a
Load case wind pressure, snow
Aluform roof
Facing material: aluminium (t_o = 0,7 mm; t_u = 0,5 mm)
Core material: PUR (d = 58 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,30
0,20
0,10
0,00
-0,10
-0,20
-0,30
-0,40
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12



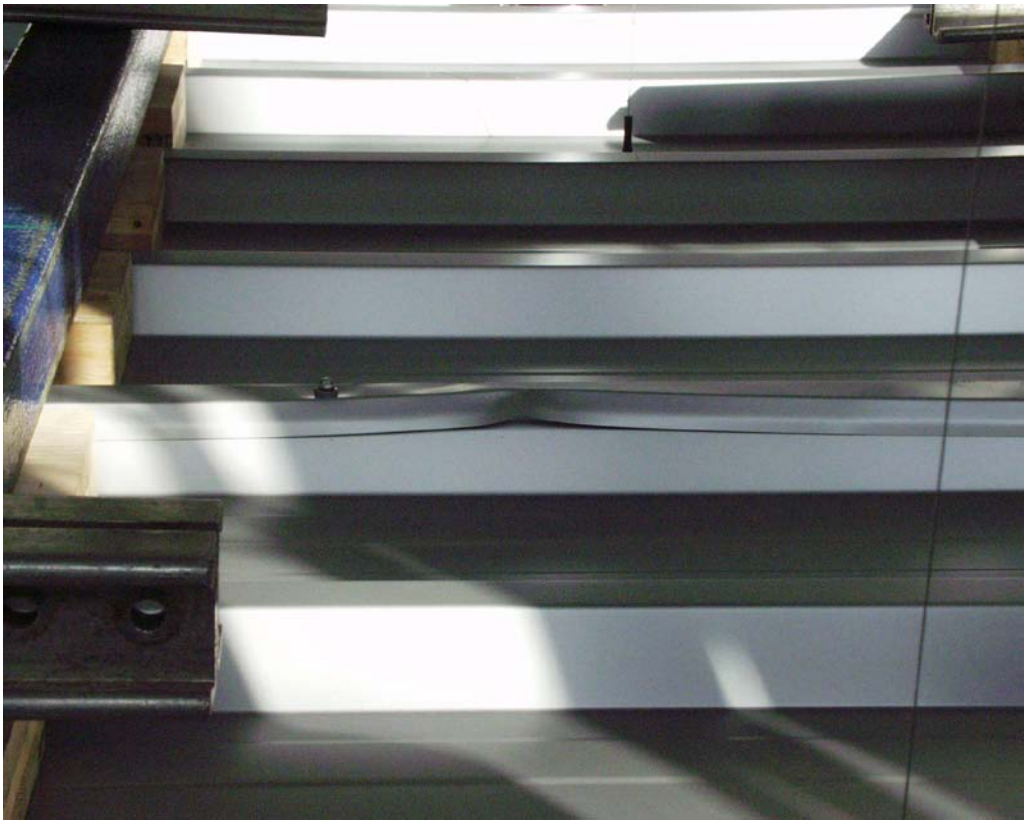
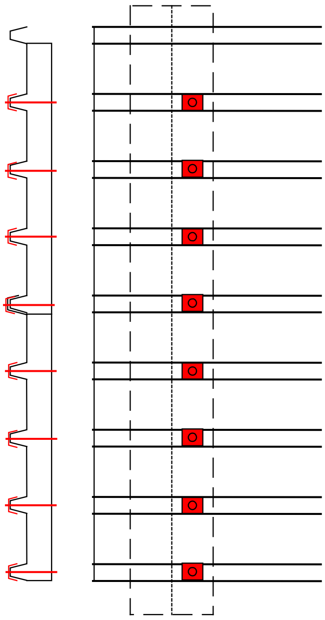


Fig. 9: Buckling of the overlapping unsupported edge

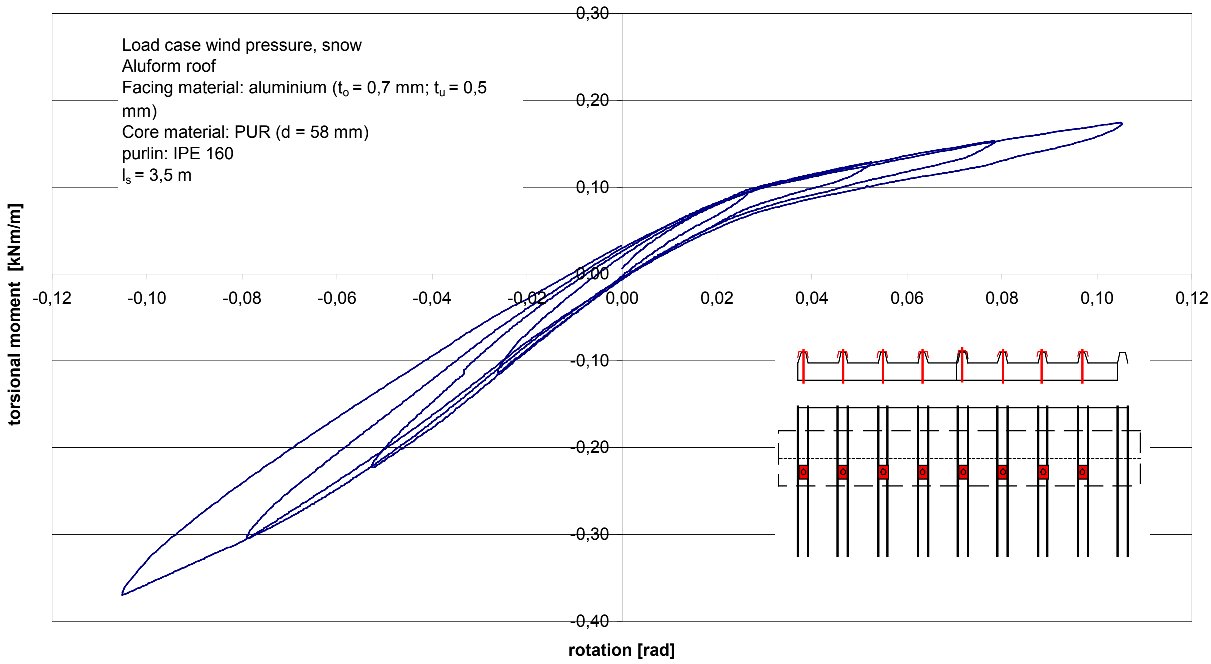
No. 04b

Application:	roof
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	aluminium
face thickness:	0,70 / 0,50 mm
core material:	PUR
core thickness:	58 mm
beam section:	IPE 160
fasteners:	

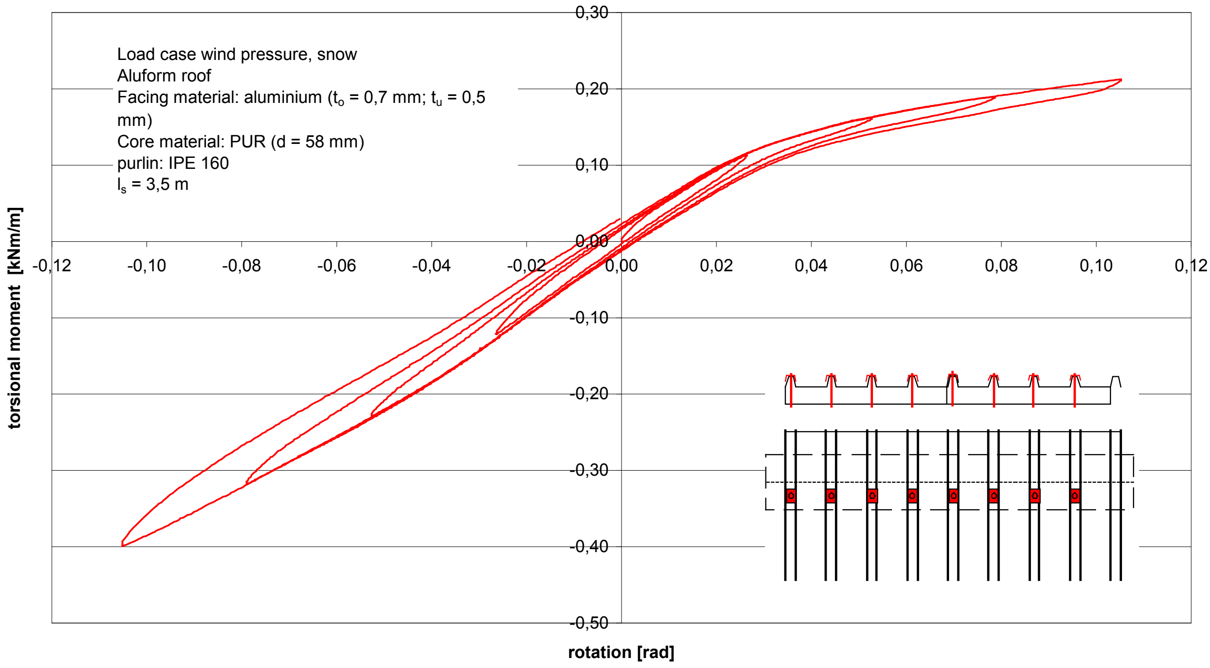


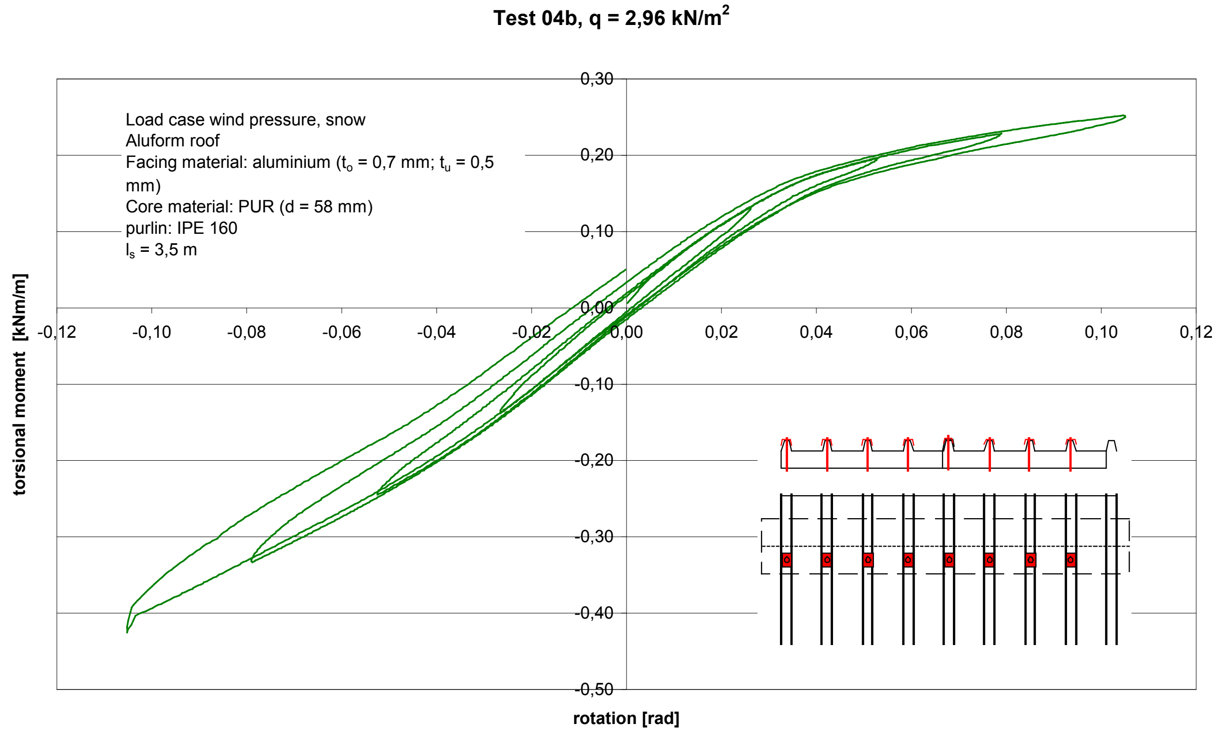
load p_1:	10,5 kN
load p_2:	16,1 kN
load p_3:	20,7 kN
remarks:	panel already tested in test No. 04a, now with additional fasteners

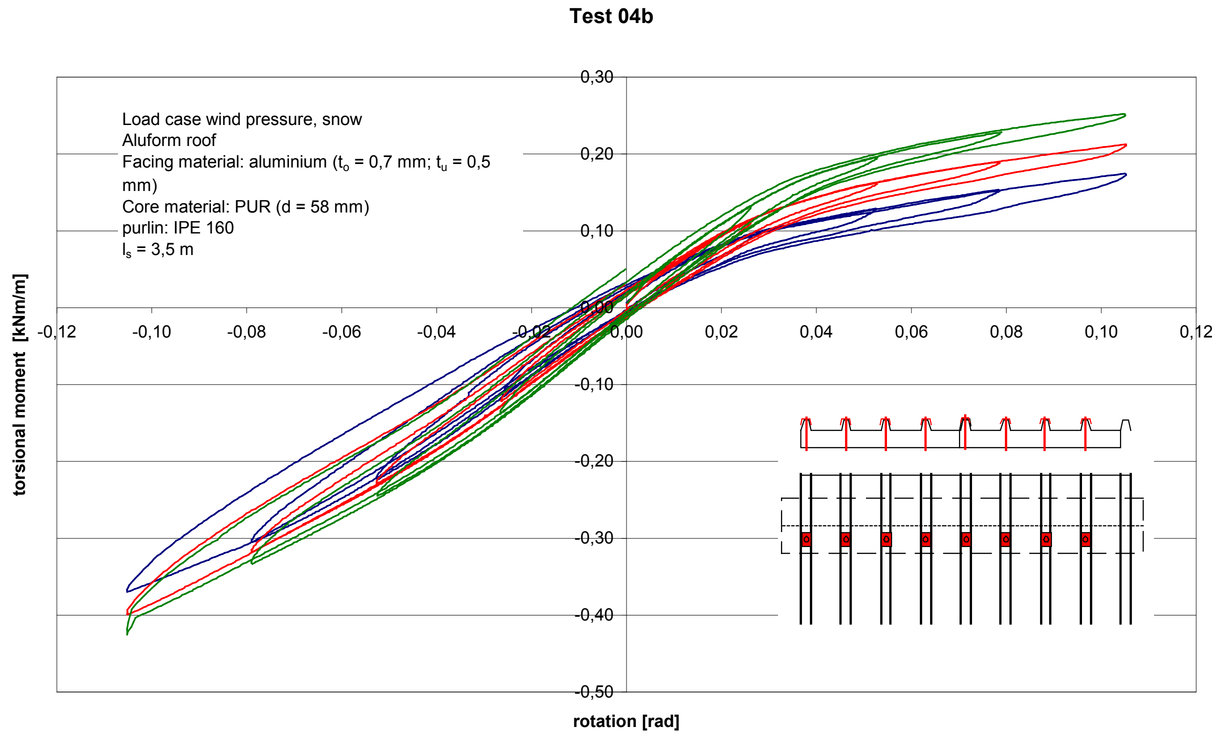
Test 04b, q = 1,48 kN/m²

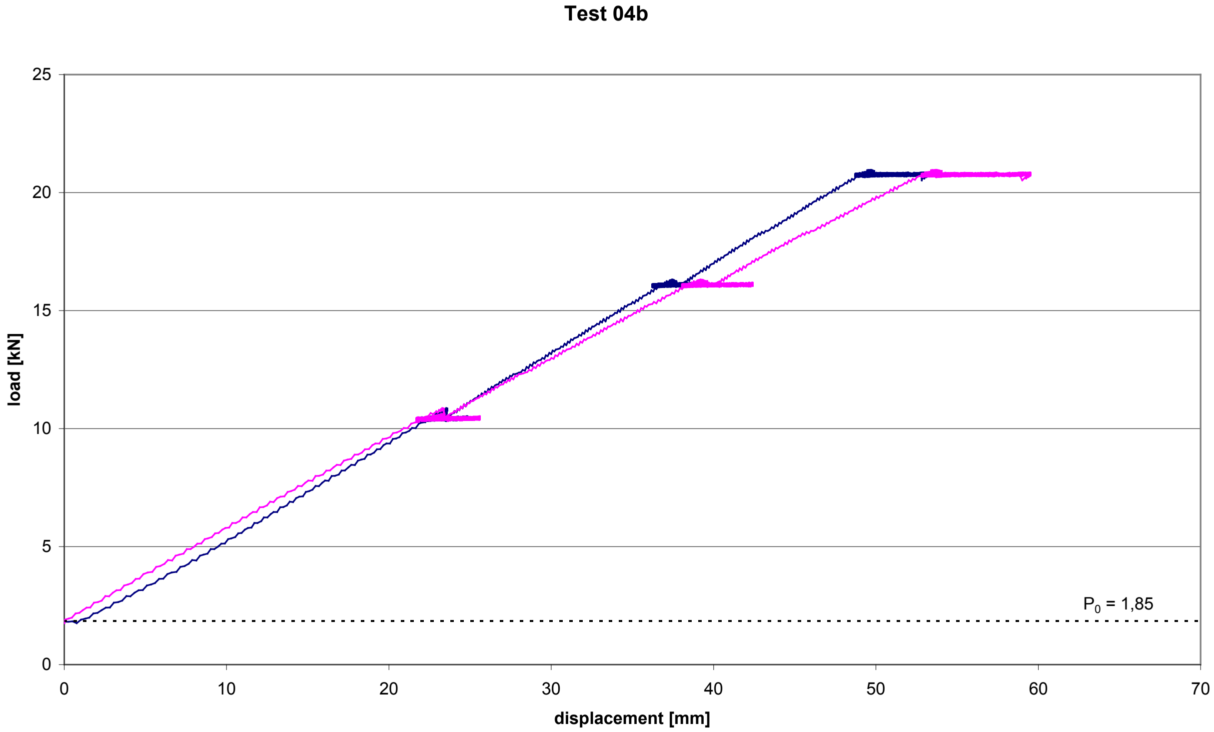


Test 04b, q = 2,3 kN/m²



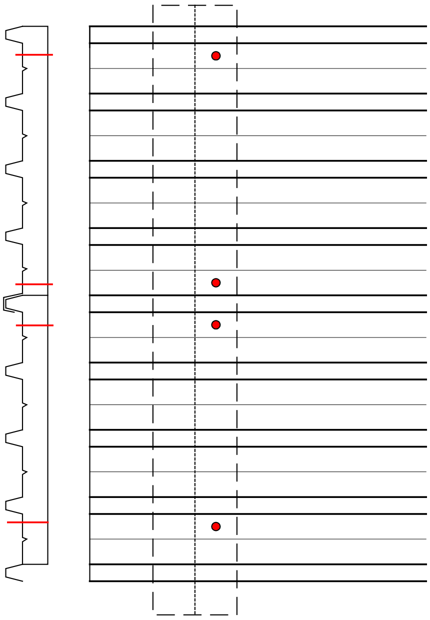

Test 04b, q = 2,96 kN/m²
Load case wind pressure, snow
Aluform roof
Facing material: aluminium (t_o = 0,7 mm; t_u = 0,5 mm)
Core material: PUR (d = 58 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,30
0,20
0,10
0,00
-0,10
-0,20
-0,30
-0,40
-0,50
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 04b
Load case wind pressure, snow
Aluform roof
Facing material: aluminium (t_o = 0,7 mm; t_u = 0,5 mm)
Core material: PUR (d = 58 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,30
0,20
0,10
0,00
-0,10
-0,20
-0,30
-0,40
-0,50
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 04b
load [kN]
displacement [mm]
P_0 = 1,85
0
5
10
15
20
25
0
10
20
30
40
50
60
70

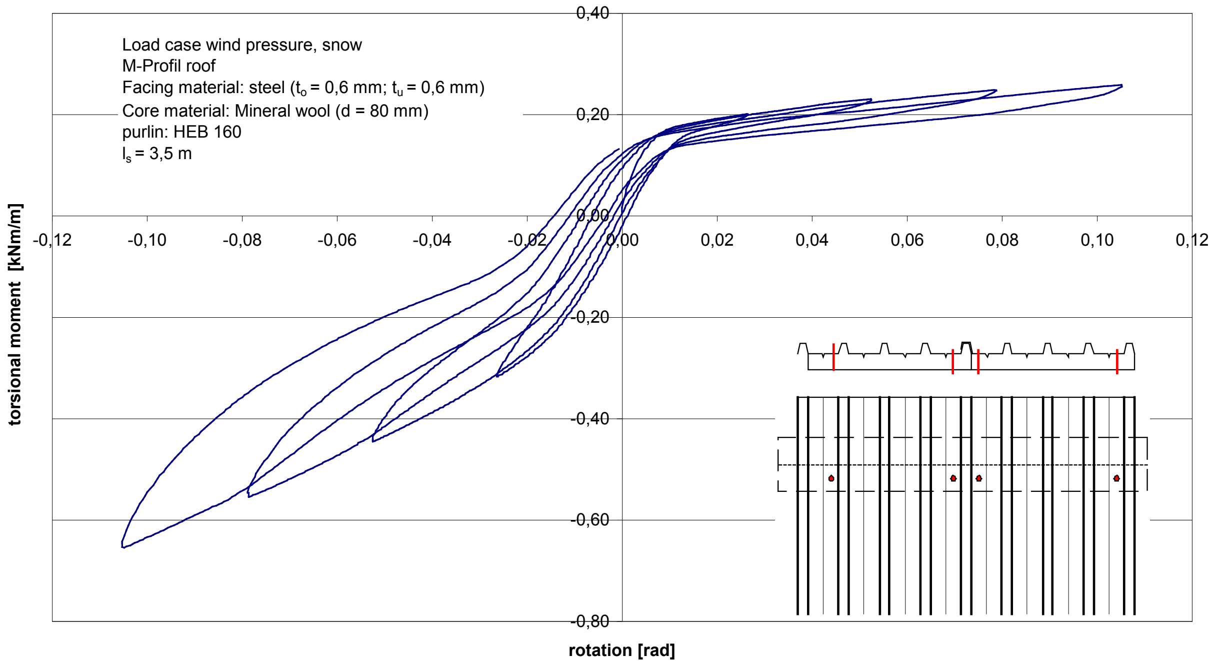
No. 05

Application:	roof
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,60 / 0,60 mm
core material:	MW
core thickness:	80 mm
beam section:	HE 160 B
fasteners:	

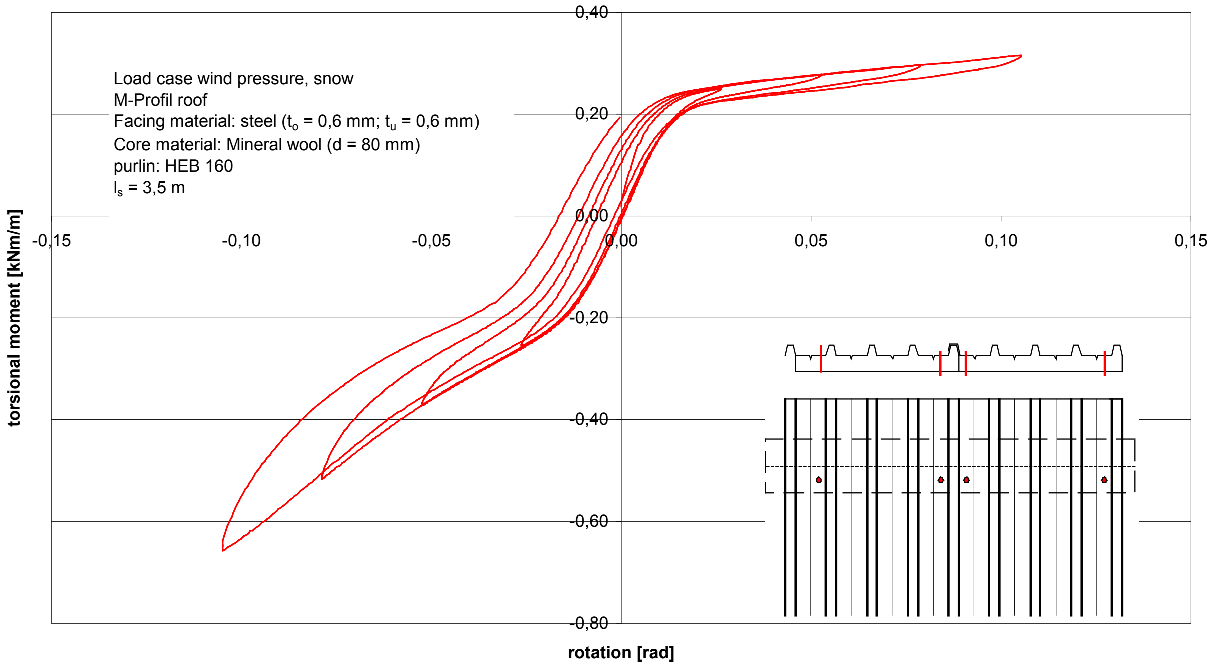


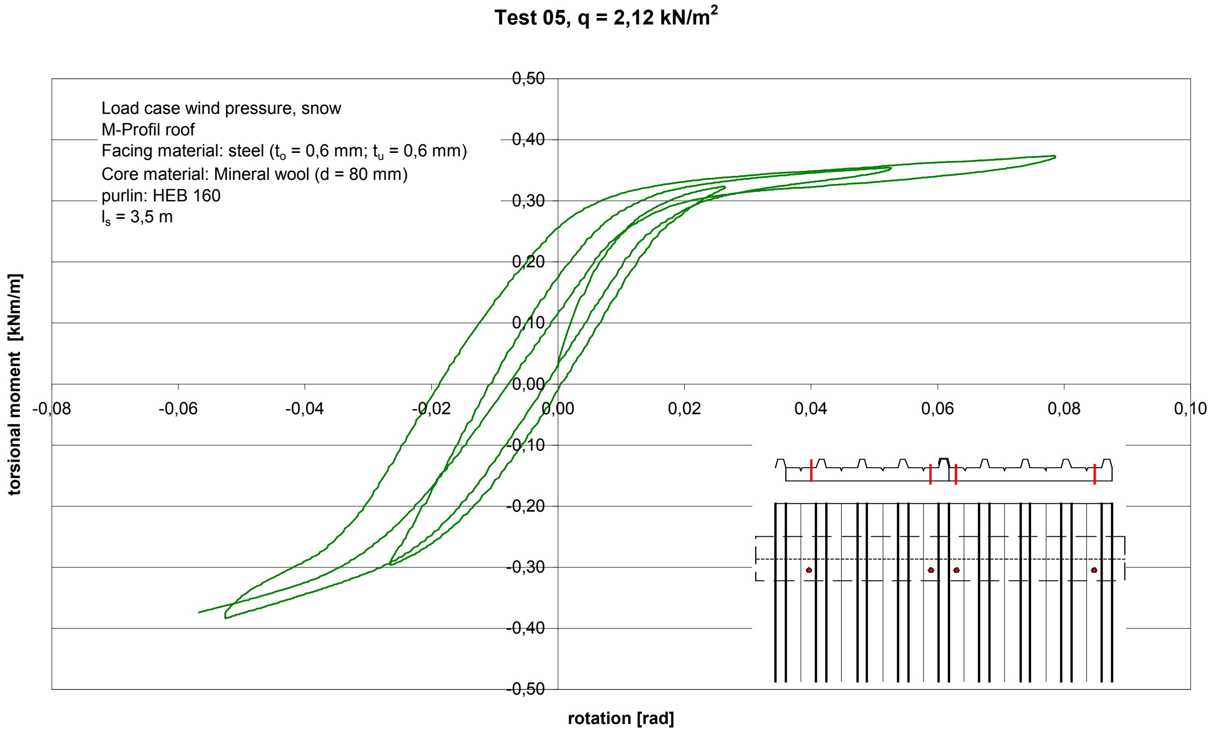
load p_1:	6,6 kN
load p_2:	10,7 kN
load p_3:	14,9 kN
remarks:	shear failure of the panel at load p_3 = 14,9 kN

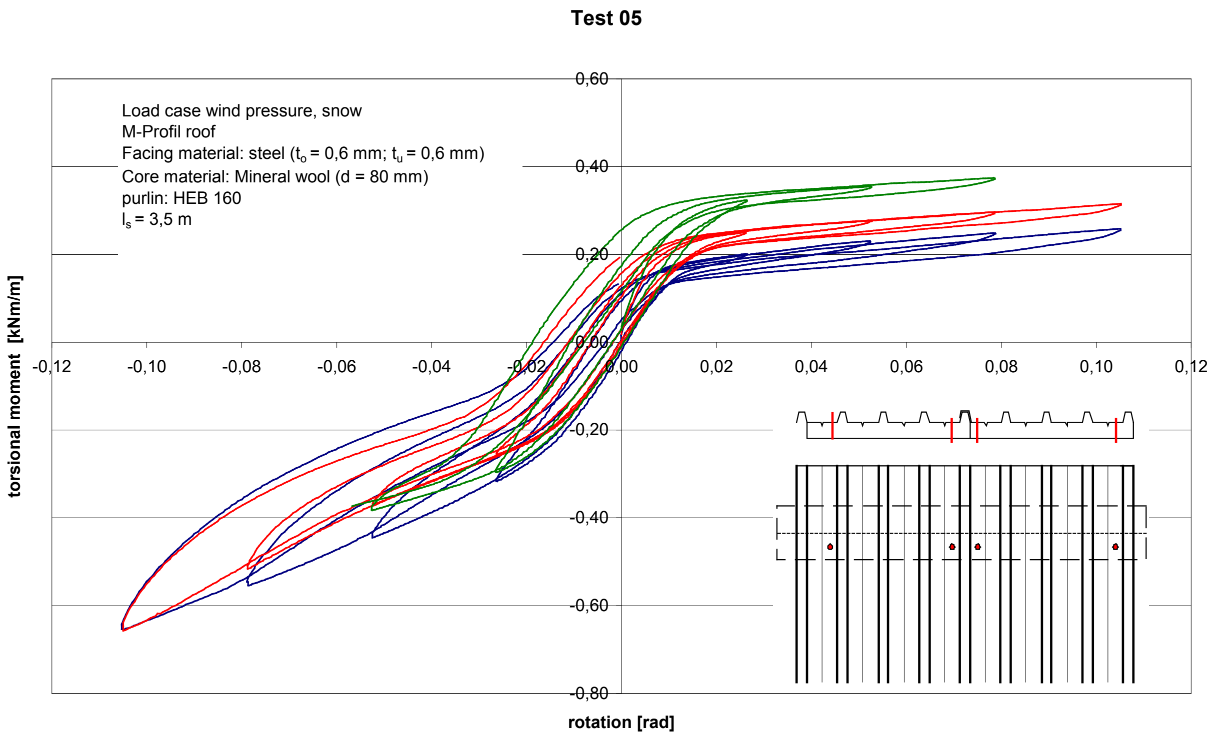
Test 05, q = 0,93 kN/m²

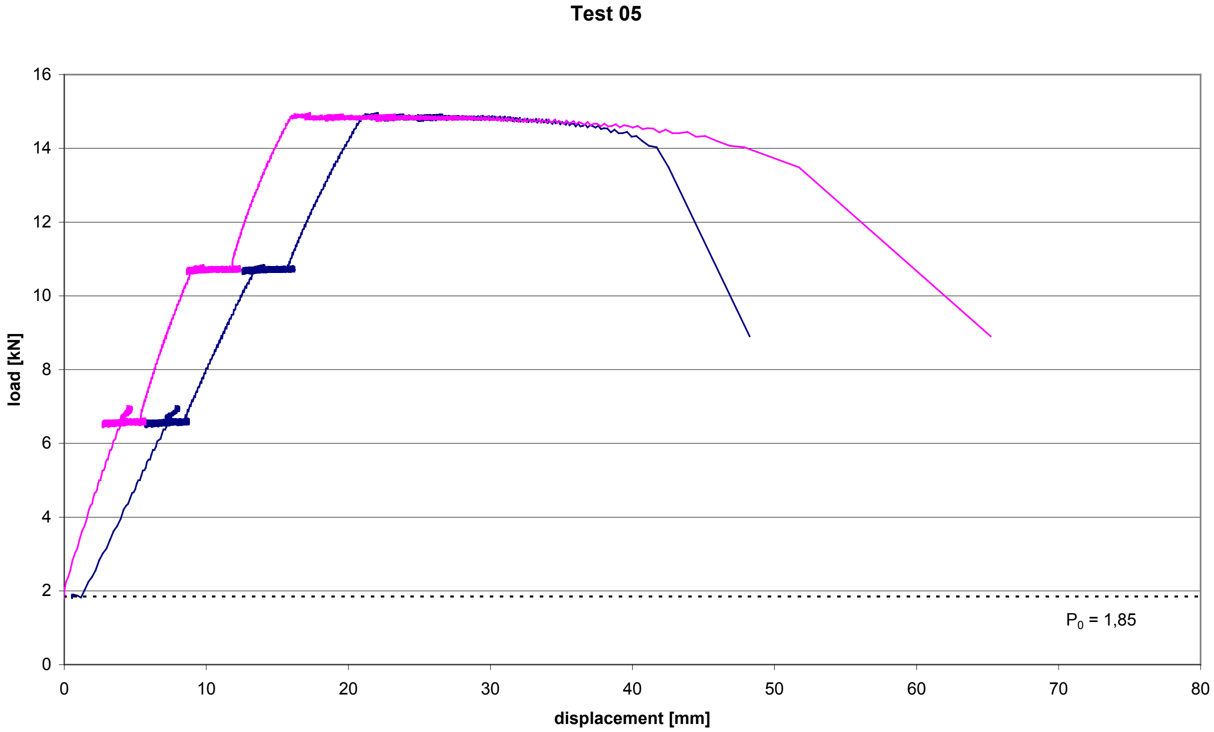


Test 05, q = 1,53 kN/m²




Test 05, q = 2,12 kN/m²
Load case wind pressure, snow
M-Profil roof
Facing material: steel (t_o = 0,6 mm; t_u = 0,6 mm)
Core material: Mineral wool (d = 80 mm)
purlin: HEB 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,50
0,40
0,30
0,20
0,10
0,00
-0,10
-0,20
-0,30
-0,40
-0,50
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10


Test 05
Load case wind pressure, snow
M-Profil roof
Facing material: steel (t_o = 0,6 mm; t_u = 0,6 mm)
Core material: Mineral wool (d = 80 mm)
purlin: HEB 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,60
0,40
0,20
0,00
-0,20
-0,40
-0,60
-0,80
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12



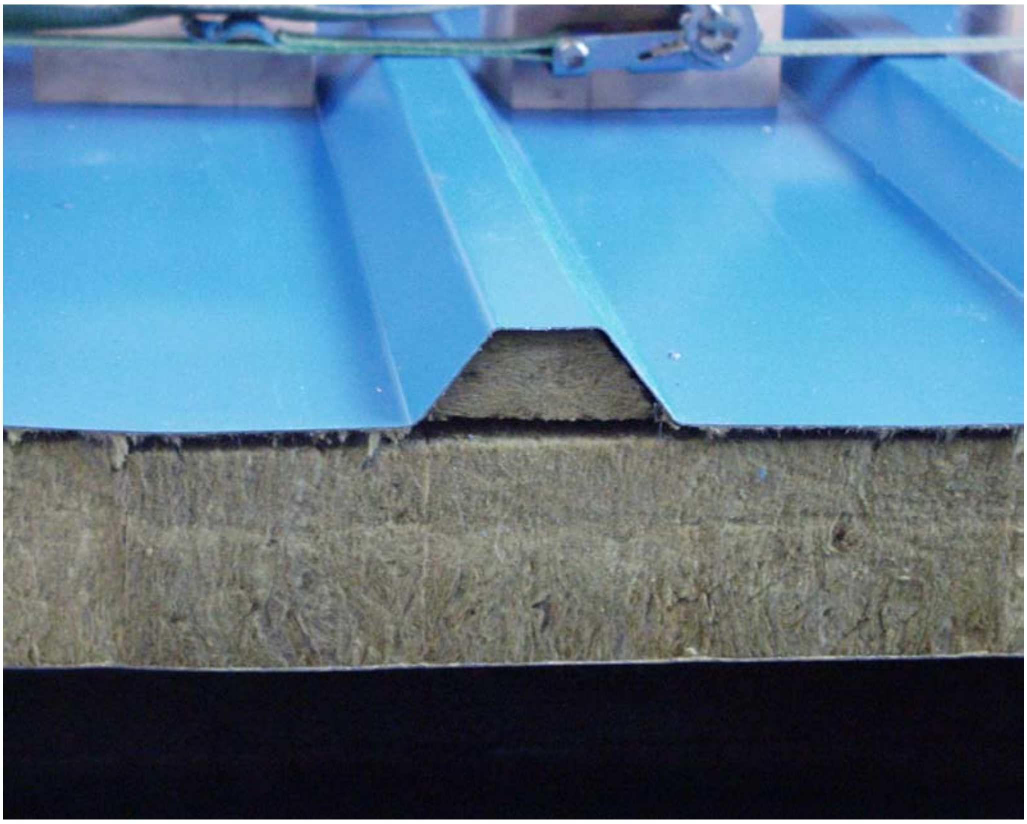
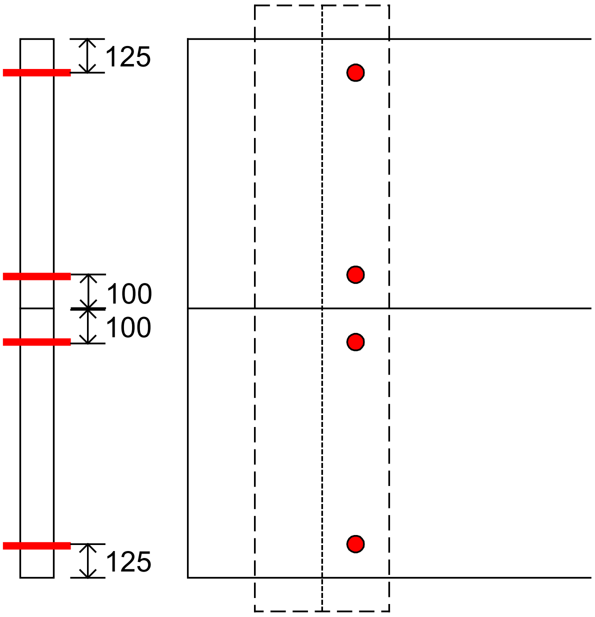


Fig. 10: Shear failure of the panel at load p_3 = 14,9 kN

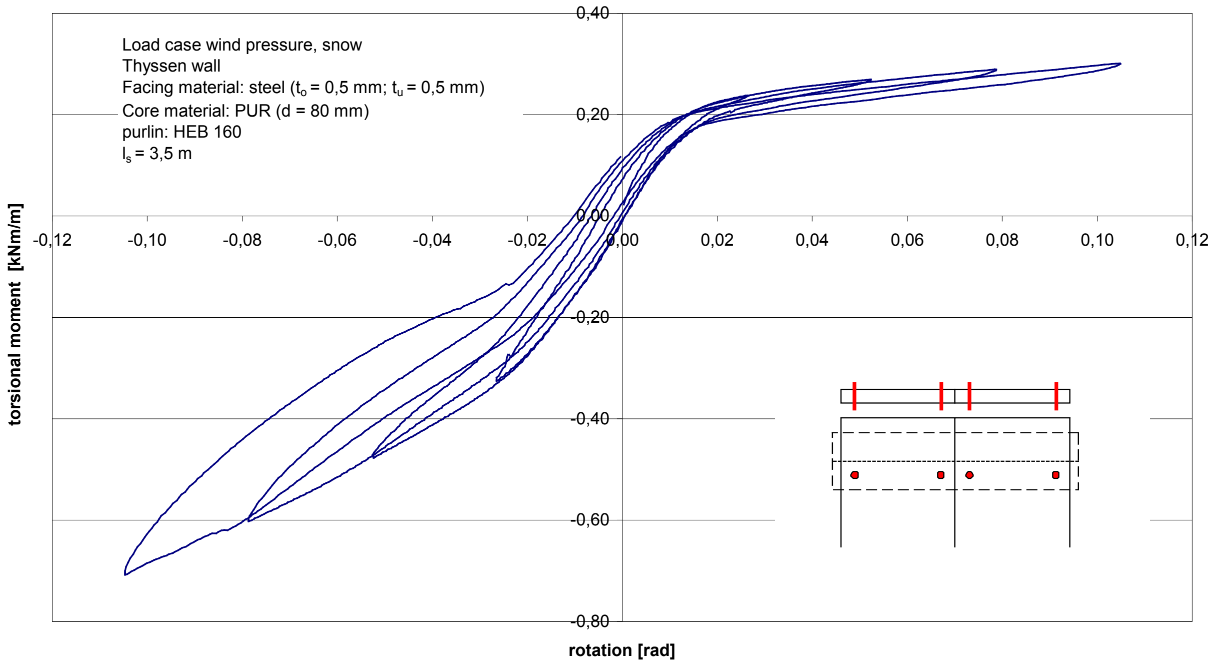
No. 06

Application:	wall
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,50 mm
core material:	PUR
core thickness:	80 mm
beam section:	HE 160 B
fasteners:	

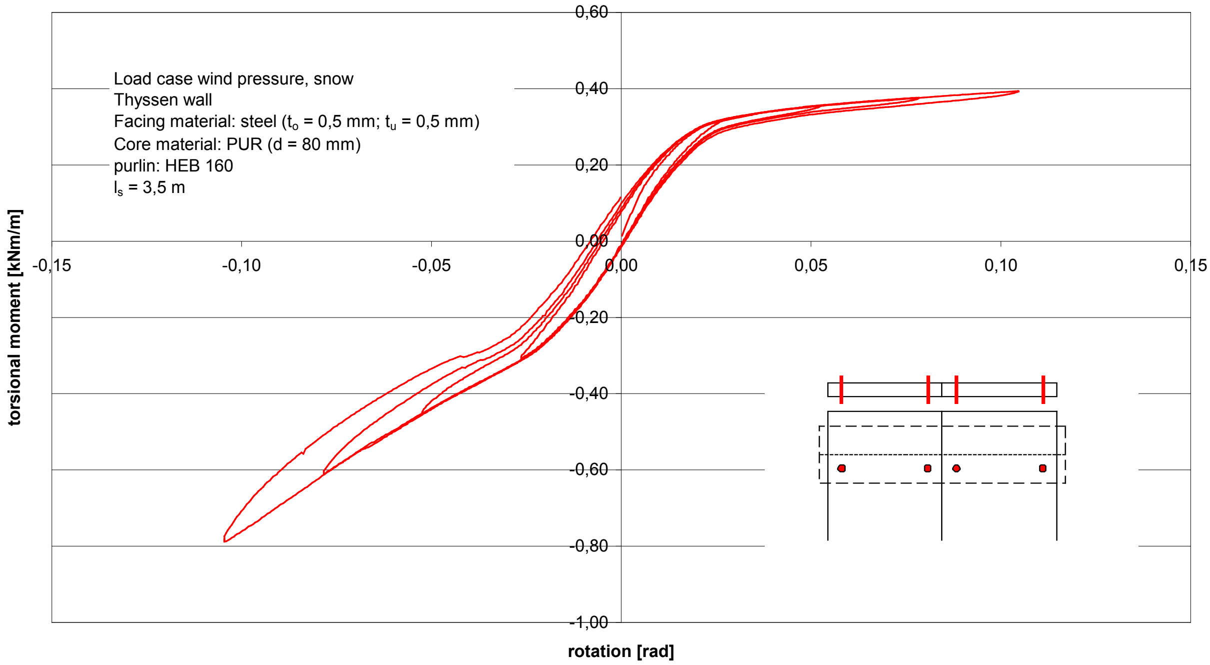


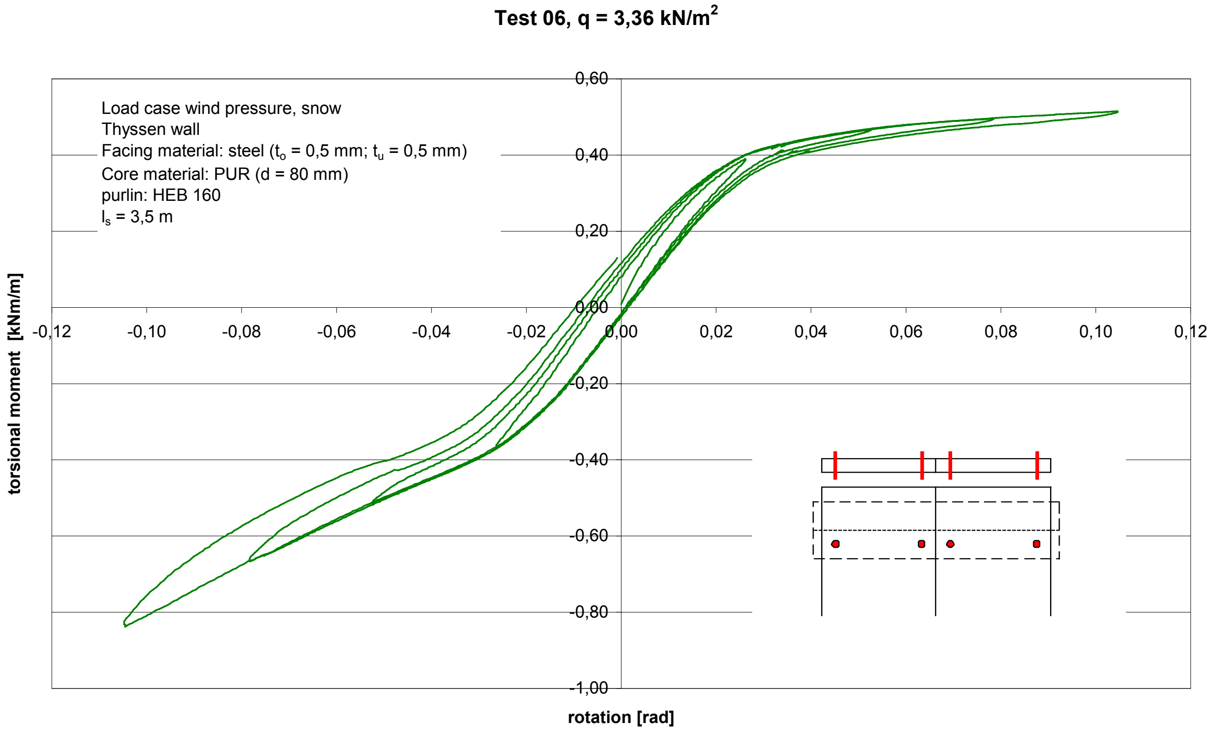
load p_1:	10,5 kN
load p_2:	17,0 kN
load p_3:	23,6 kN
remarks:	

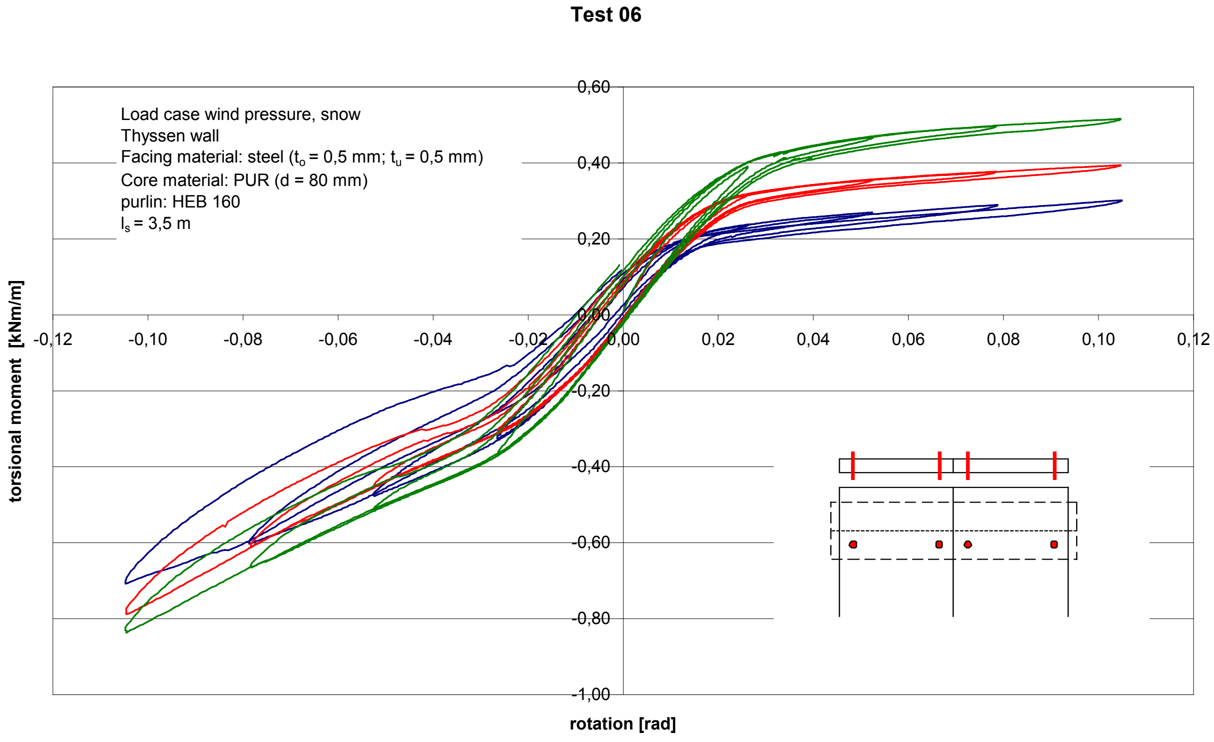
Test 06, q = 1,49 kN/m²

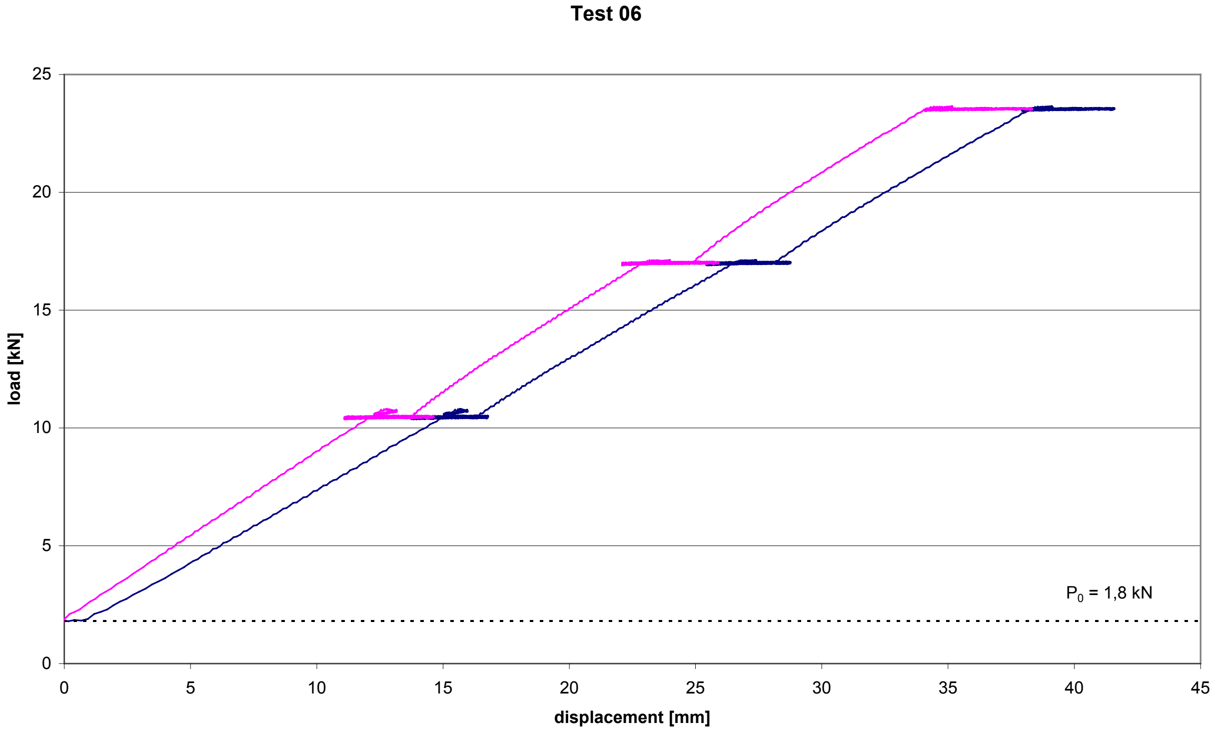


Test 06, q = 2,42 kN/m²



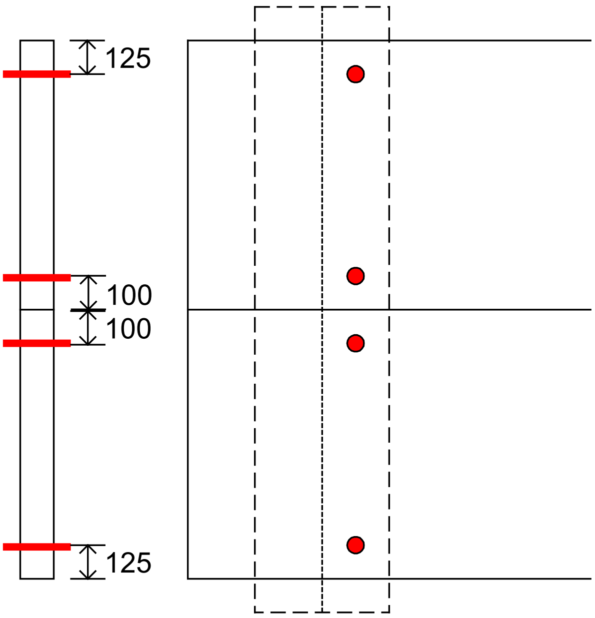

Test 06, q = 3,36 kN/m²
Load case wind pressure, snow
Thyssen wall
Facing material: steel (to = 0,5 mm; tu = 0,5 mm)
Core material: PUR (d = 80 mm)
purlin: HEB 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 06
Load case wind pressure, snow
Thyssen wall
Facing material: steel (to = 0,5 mm; tu = 0,5 mm)
Core material: PUR (d = 80 mm)
purlin: HEB 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 06
load [kN]
displacement [mm]
P0 = 1,8 kN
0
5
10
15
20
25
30
35
40
45

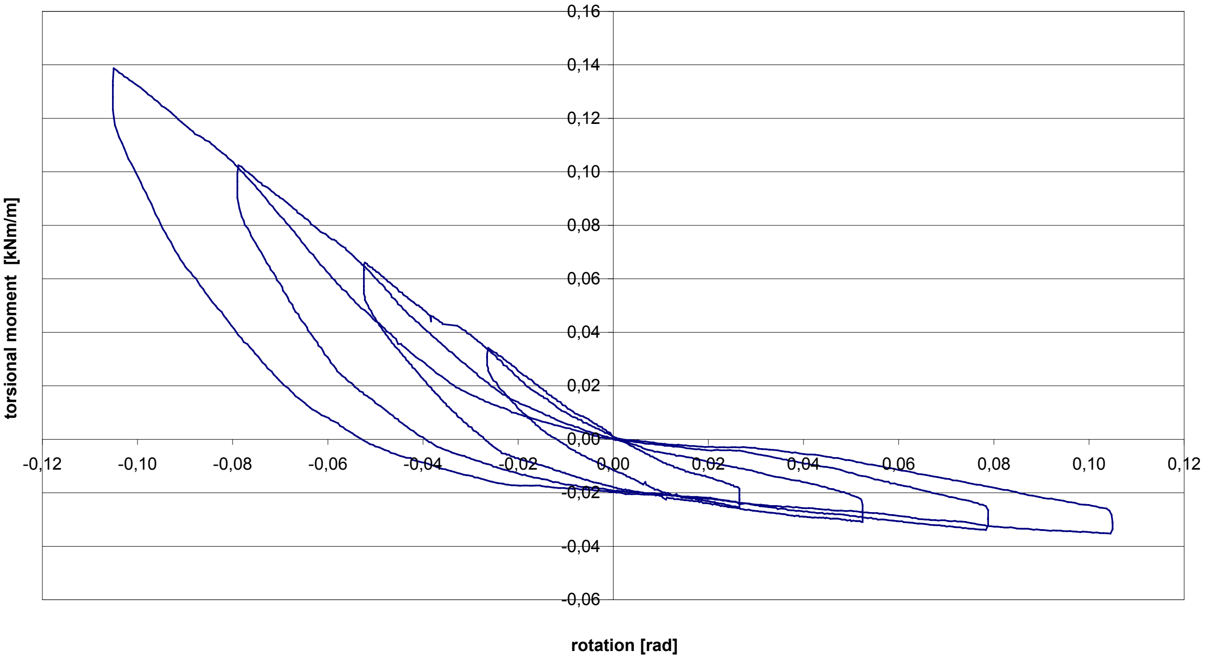
No. 07

Application:	wall
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,50 mm
core material:	PUR
core thickness:	80 mm
beam section:	IPE 160
fasteners:	

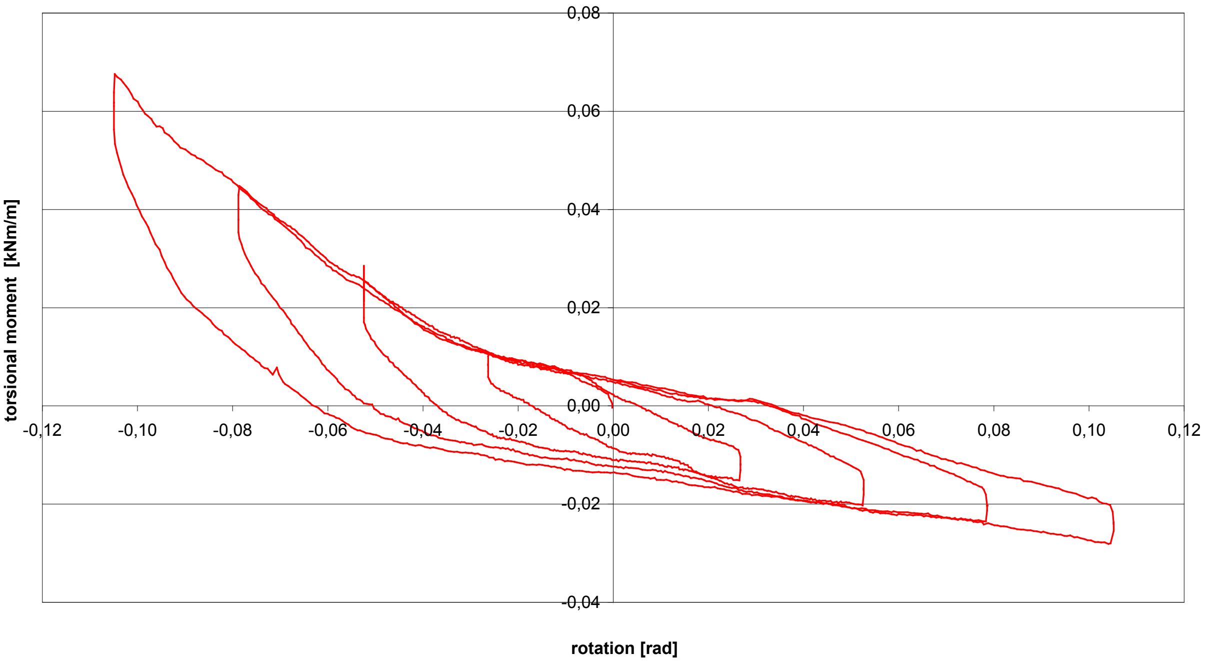


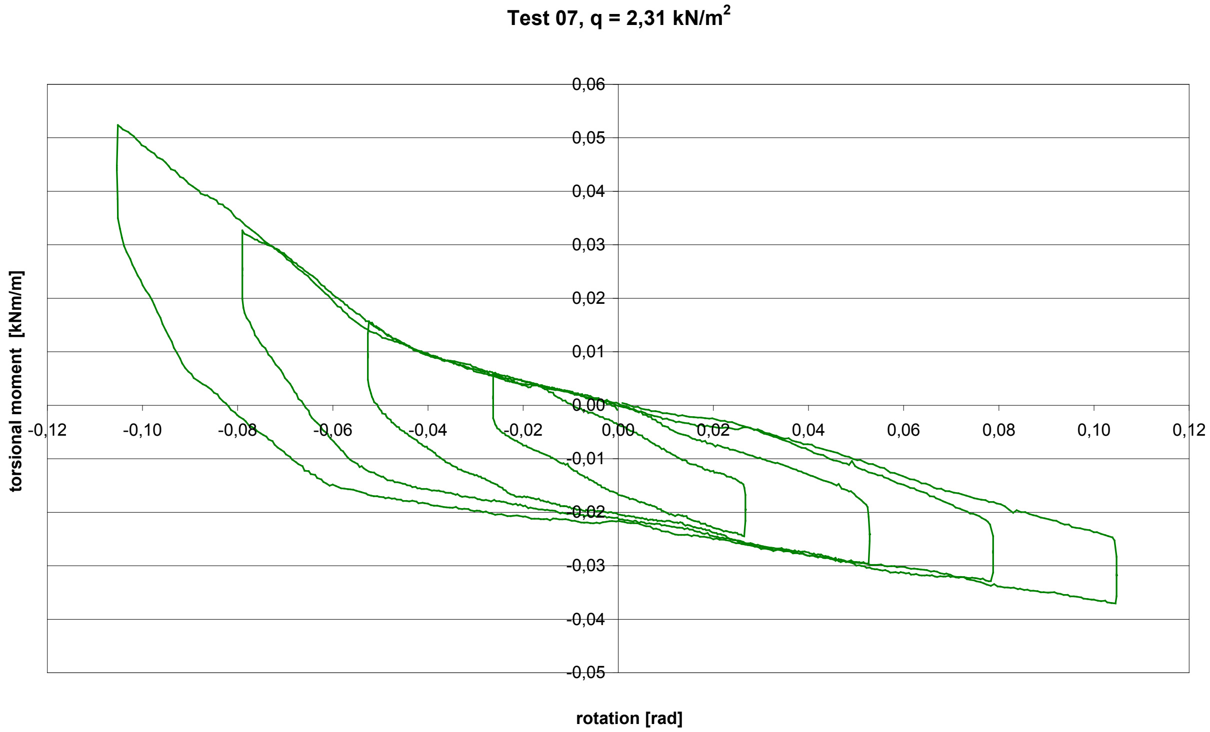
load p_1:	6,5 kN
load p_2:	13,0 kN
load p_3:	16,2 kN
remarks:	

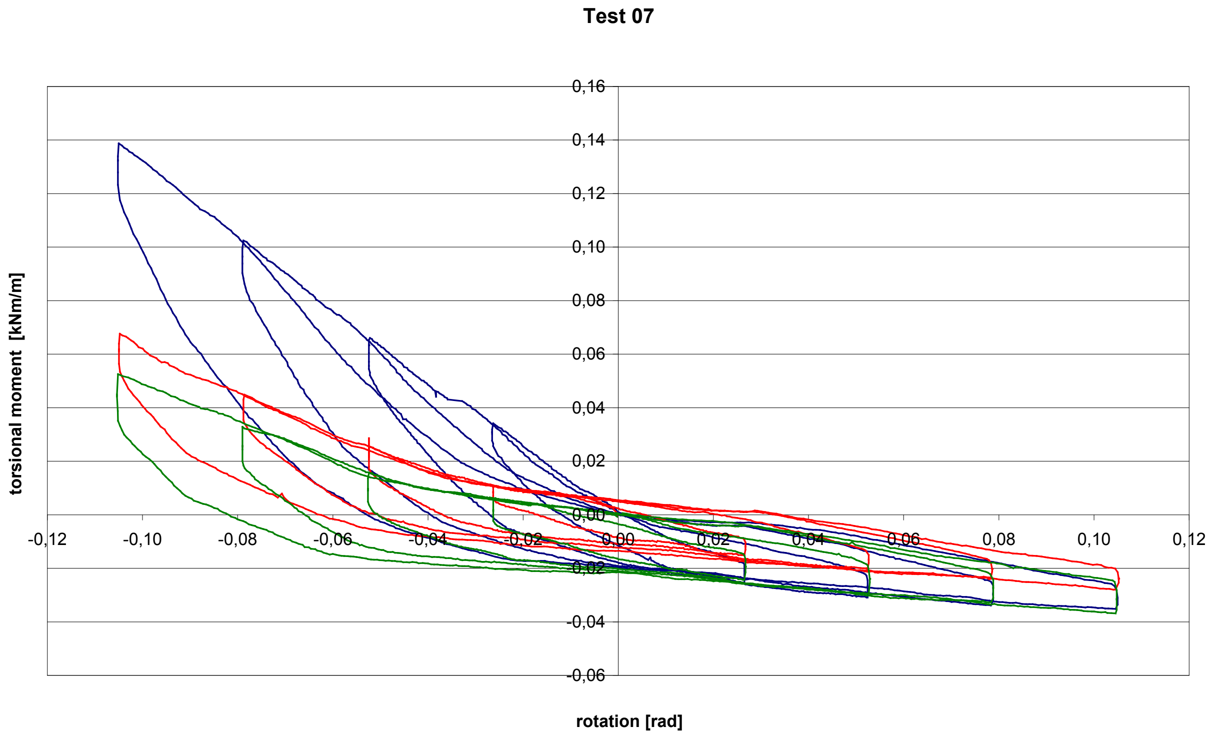
Test 07, q = 0,92 kN/m²



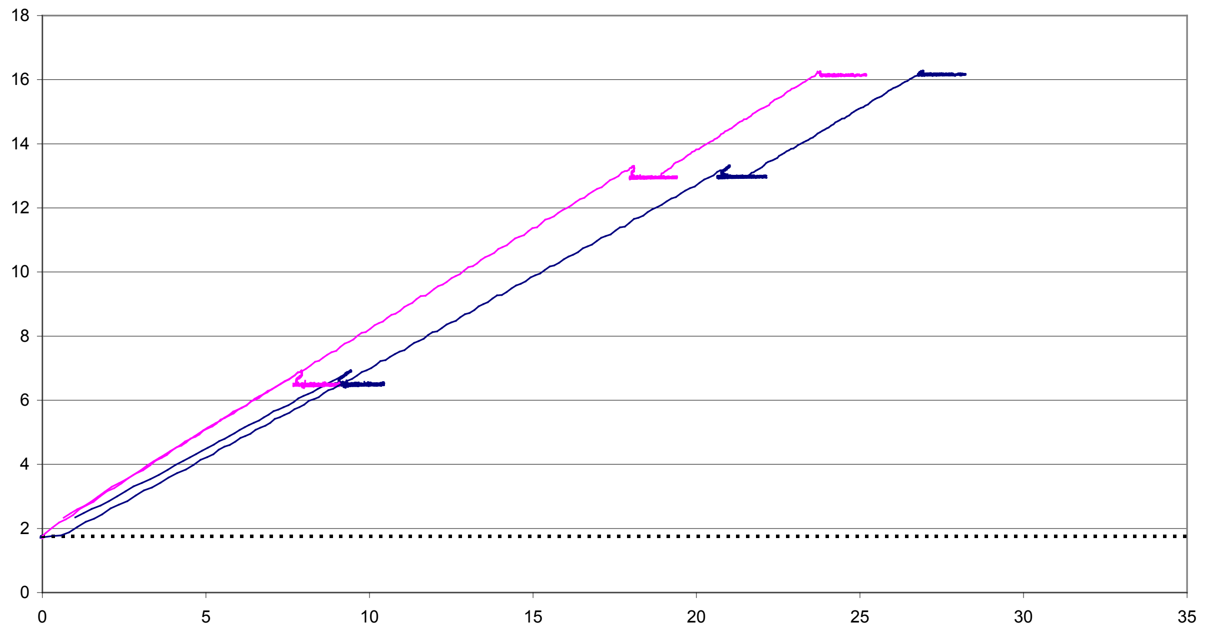
Test 07, q = 1,85 kN/m²




Test 07, q = 2,31 kN/m²
torsional moment [kNm/m]
rotation [rad]
0,06
0,05
0,04
0,03
0,02
0,01
0,00
-0,01
-0,02
-0,03
-0,04
-0,05
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

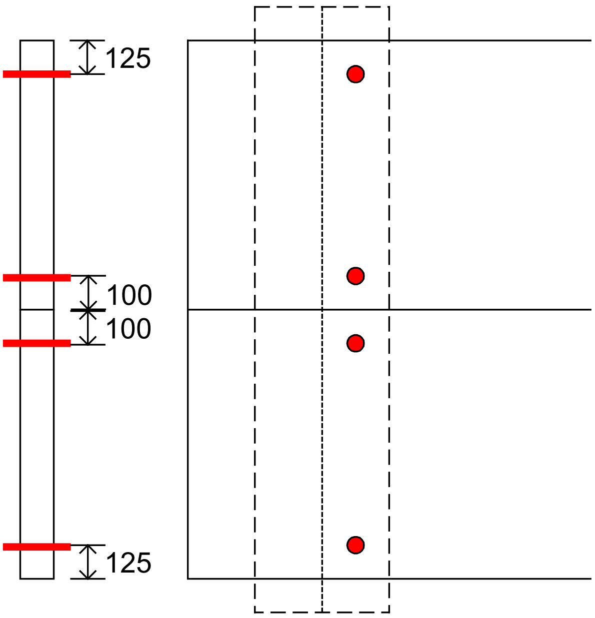

Test 07
torsional moment [kNm/m]
rotation [rad]
0,16
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
-0,02
-0,04
-0,06
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

Test 07

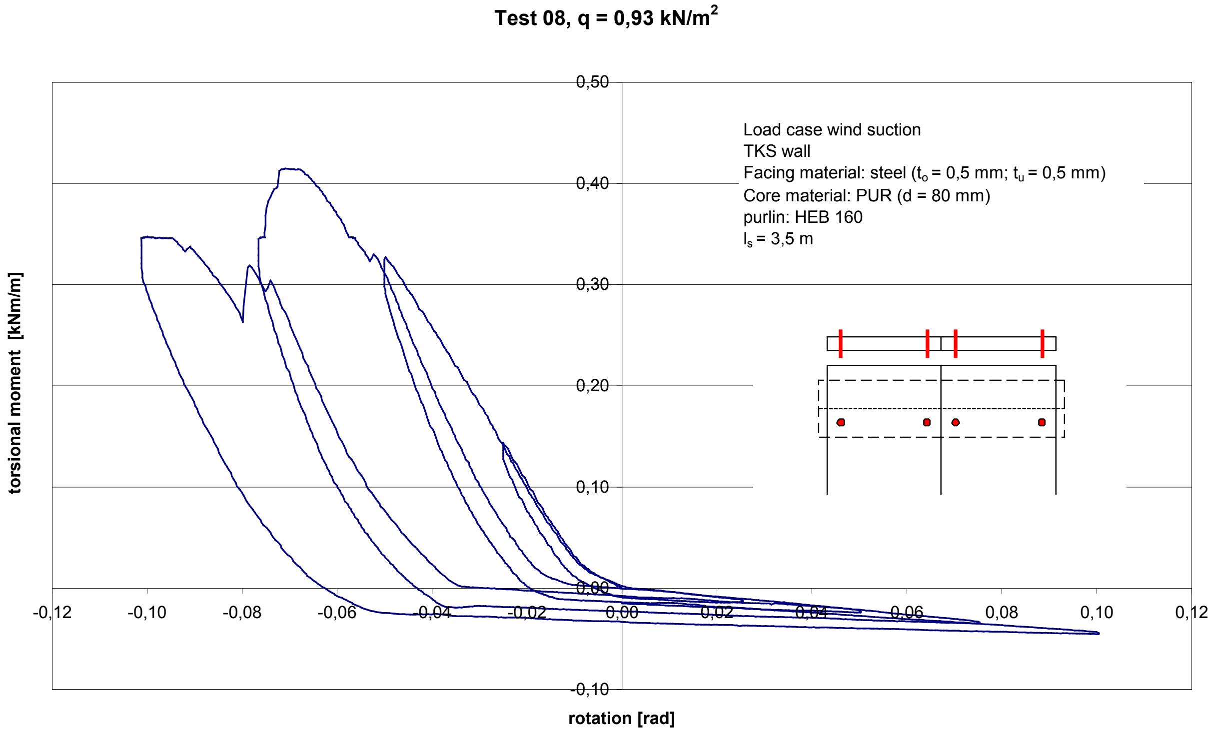


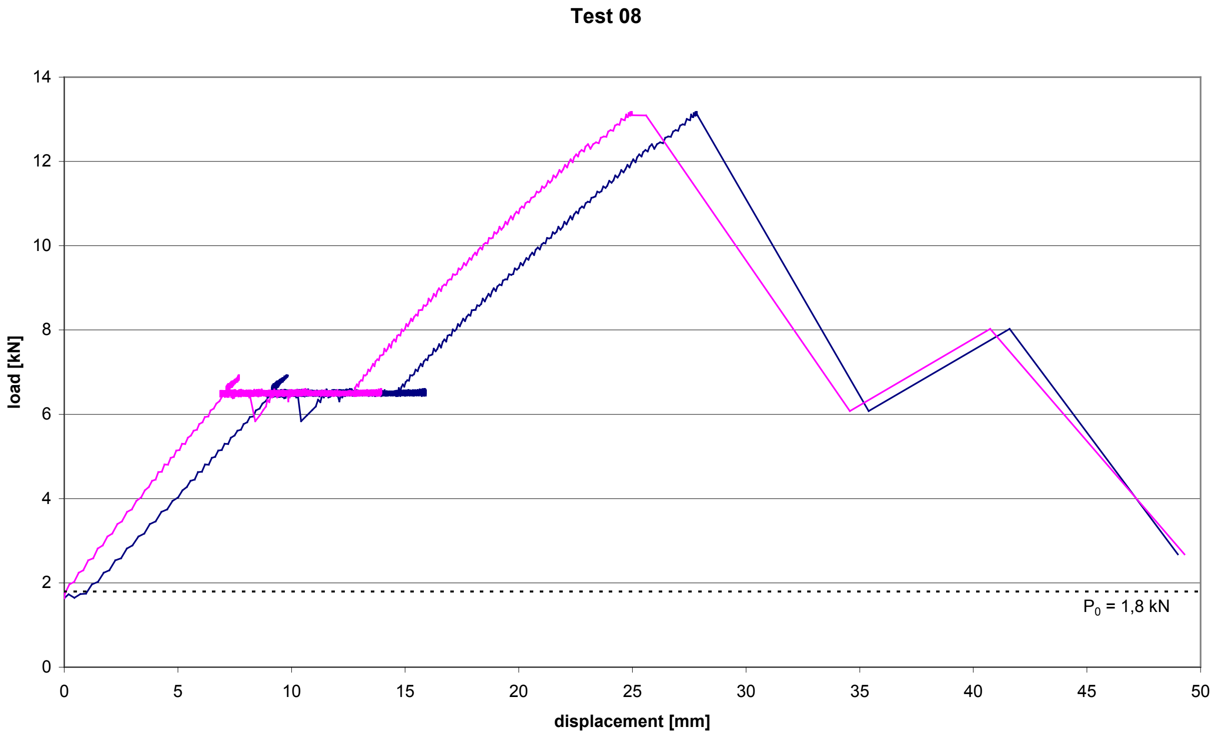
No. 08

Application:	wall
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,50 mm
core material:	PUR
core thickness:	80 mm
beam section:	HE 160 B
fasteners:	



load p_1:	6,5 kN
load p_2:	13,0 kN
load p_3:	16,2 kN
remarks:	Pull-trough failure of the fasteners at load p_2 = 13,0 kN


Test 08, q = 0,93 kN/m²
Load case wind suction
TKS wall
Facing material: steel (t_o = 0,5 mm; t_u = 0,5 mm)
Core material: PUR (d = 80 mm)
purlin: HEB 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,50
0,40
0,30
0,20
0,10
0,00
-0,10
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 08
load [kN]
displacement [mm]
P_0 = 1,8 kN
0
2
4
6
8
10
12
14
0
5
10
15
20
25
30
35
40
45
50

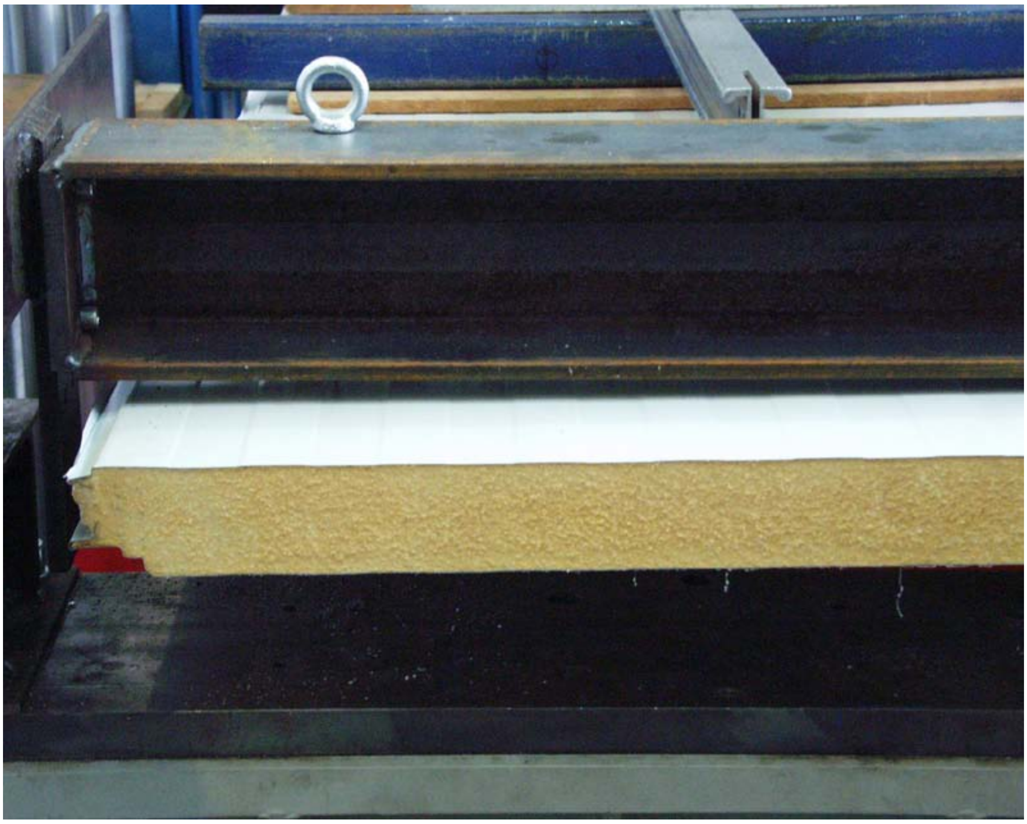
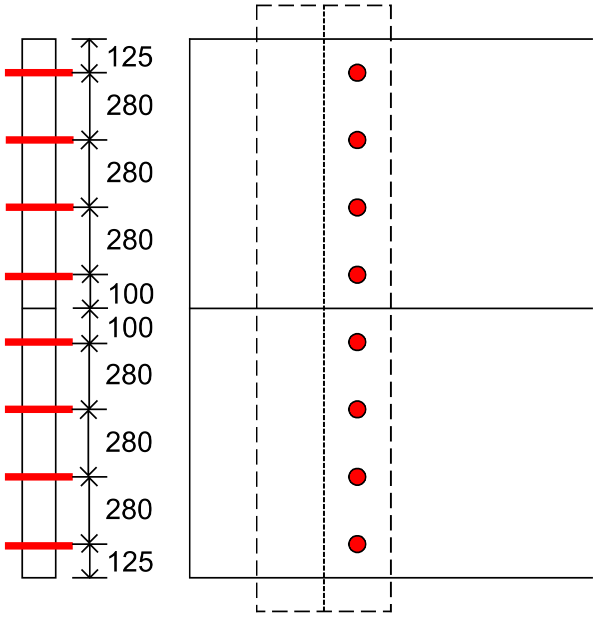


Fig. 11: Gap between face layer and beam

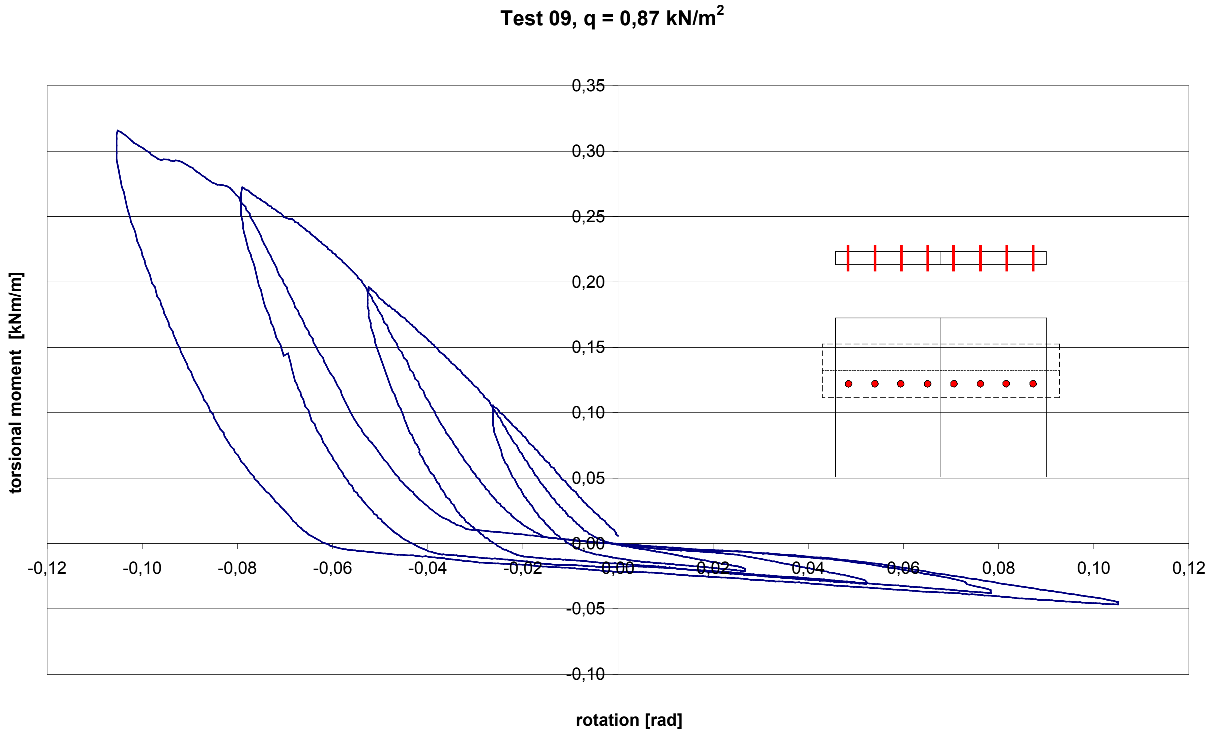
Fig. 12: Pull-trough failure of the fasteners at load p_2 = 13,0 kN

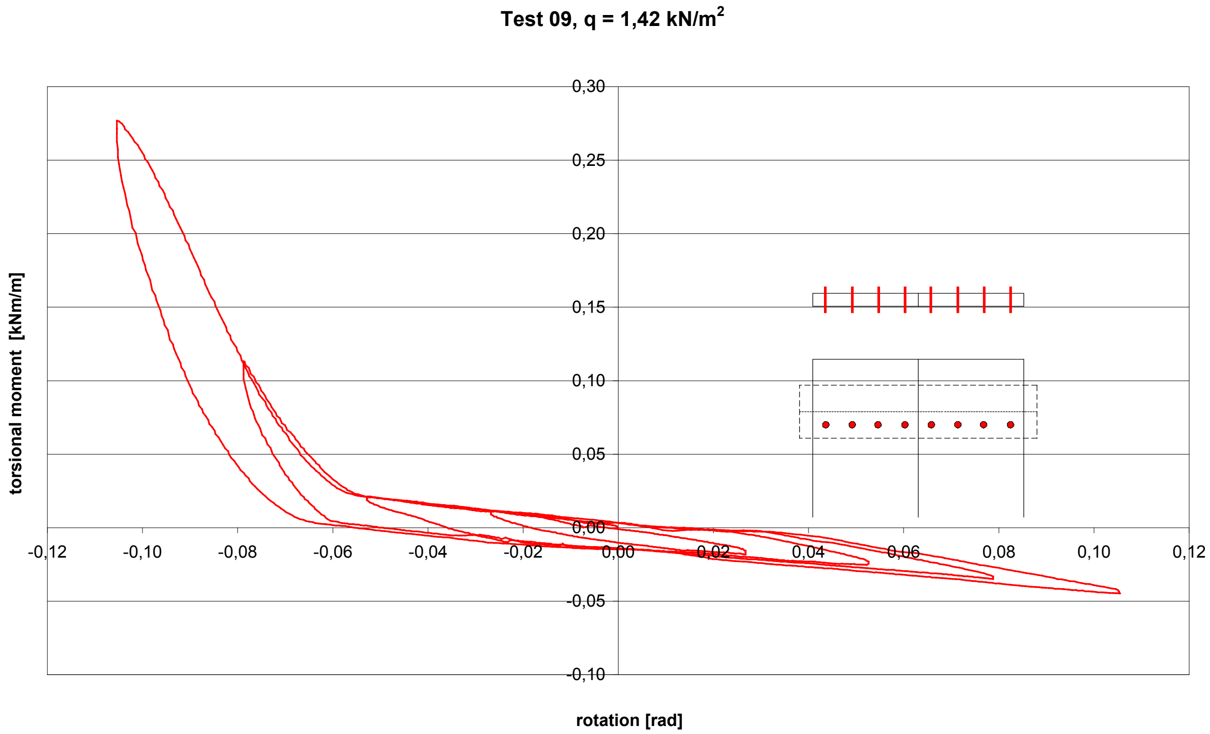
No. 09

Application:	wall
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,50 mm
core material:	PUR
core thickness:	80 mm
beam section:	IPE 160
fasteners:	

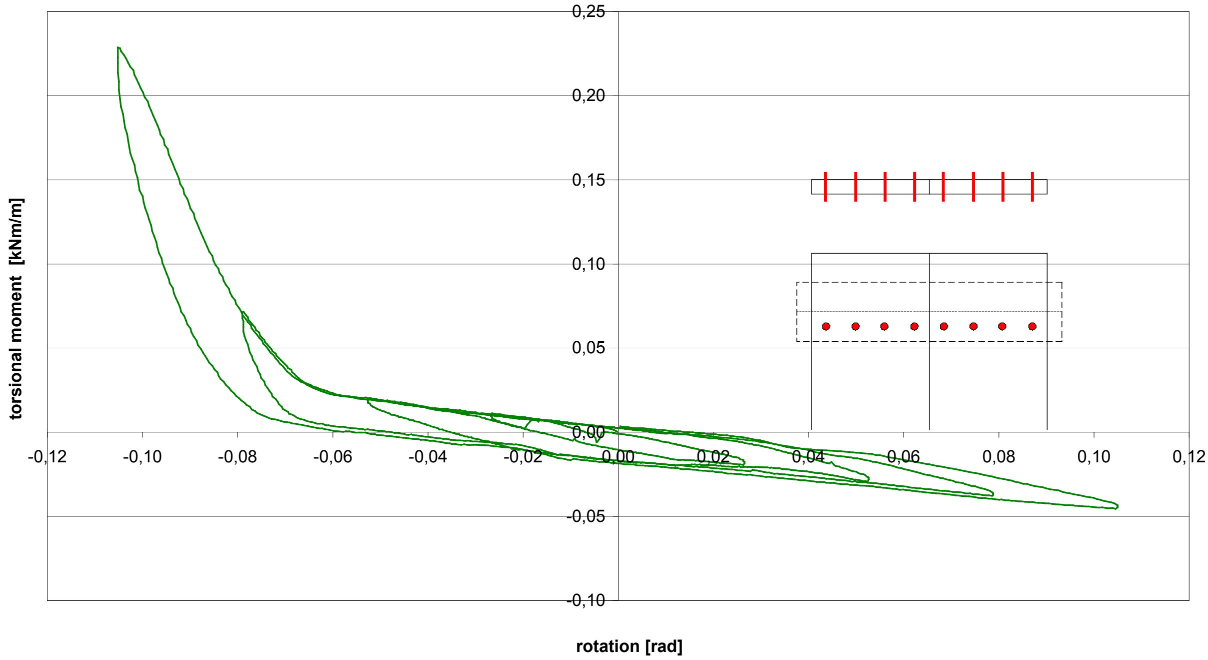


load p_1:	6,2 kN
load p_2:	10,0 kN
load p_3:	13,8 kN
remarks:	

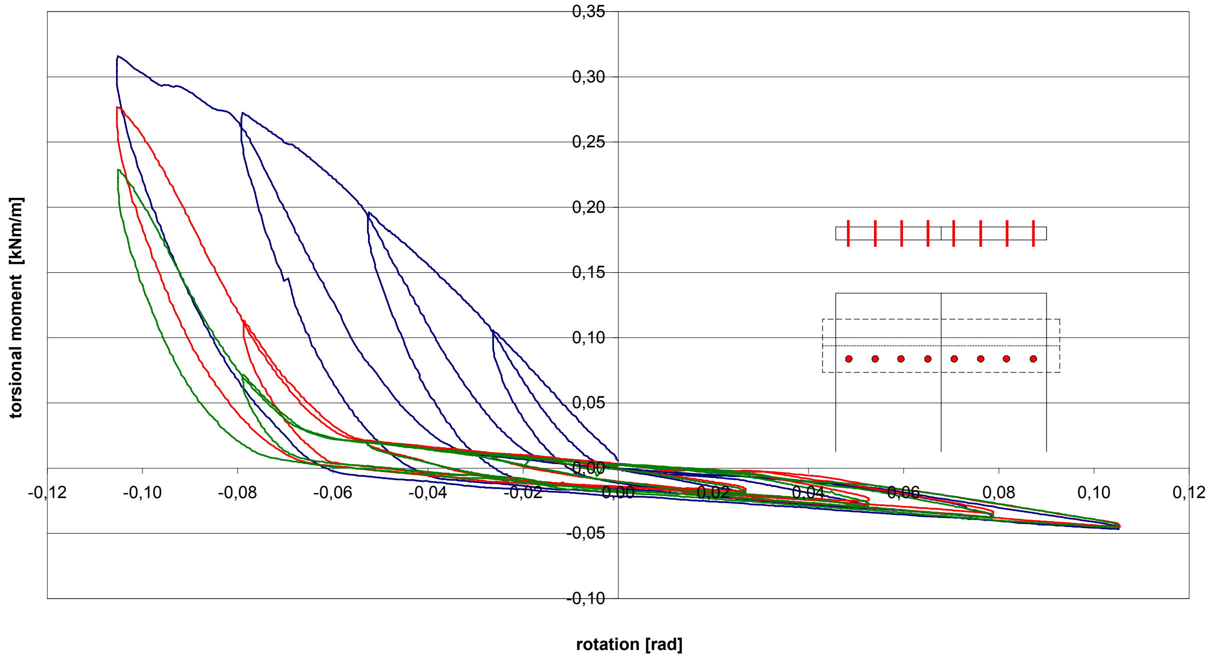

Test 09, q = 0,87 kN/m²
torsional moment [kNm/m]
rotation [rad]
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

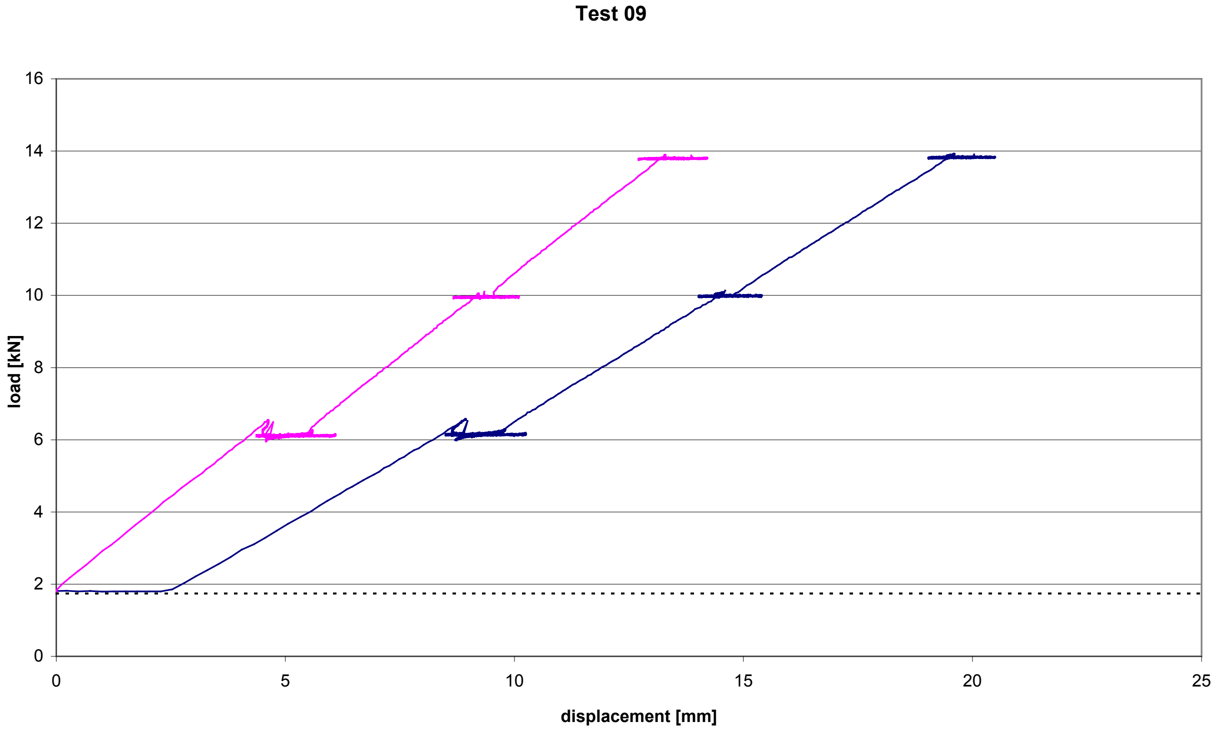

Test 09, q = 1,42 kN/m²
torsional moment [kNm/m]
rotation [rad]
0,30
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

Test 09, q = 1,97 kN/m²



Test 09





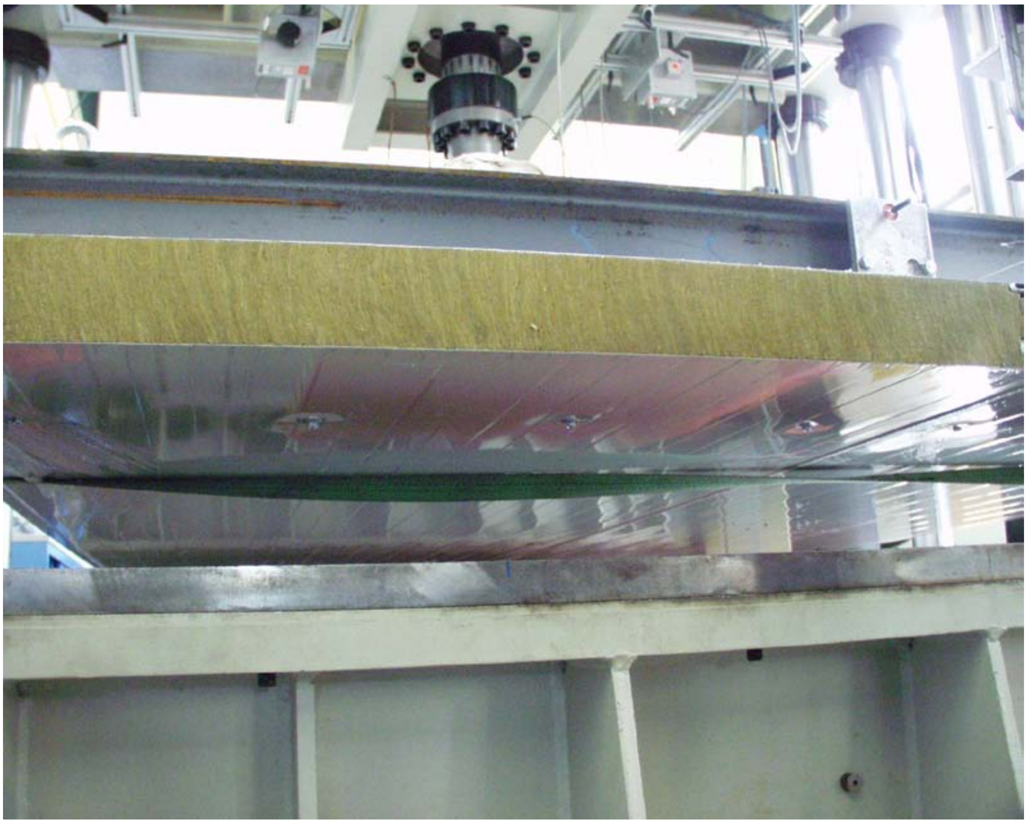
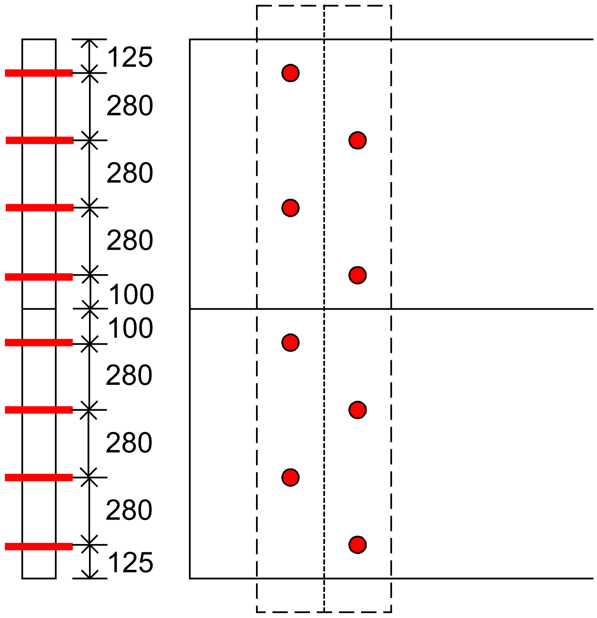


Fig. 13: Indentation of fasteners

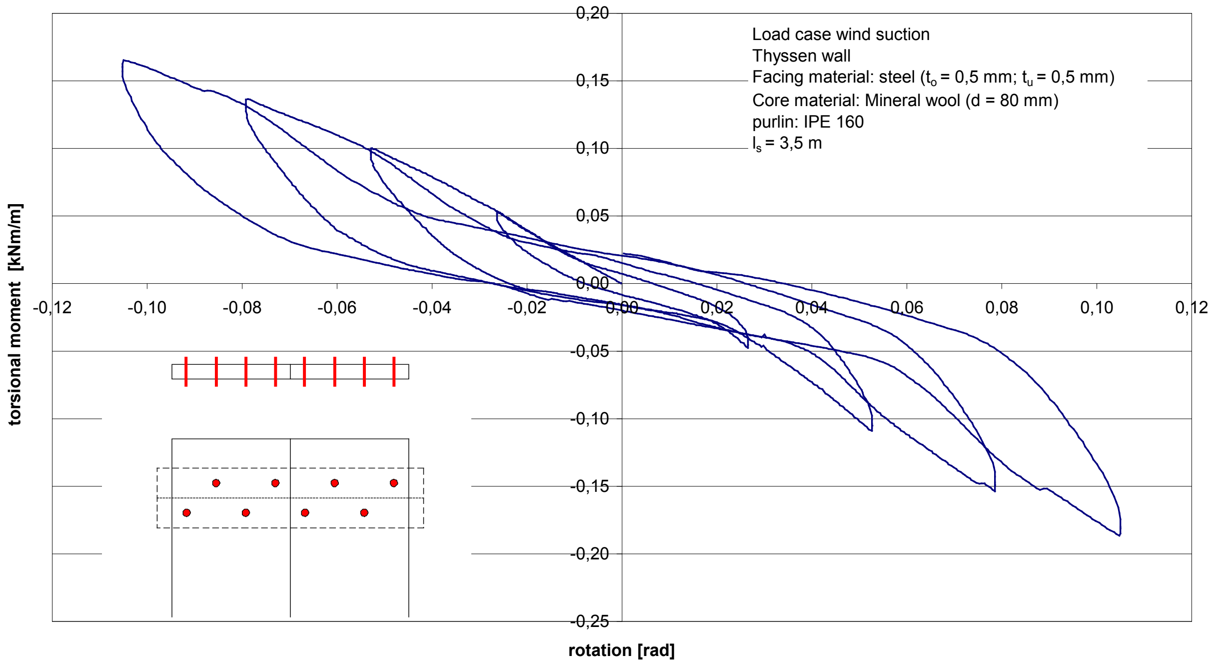
No. 10

Application:	wall
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,50 mm
core material:	MW
core thickness:	80 mm
beam section:	IPE 160
fasteners:	

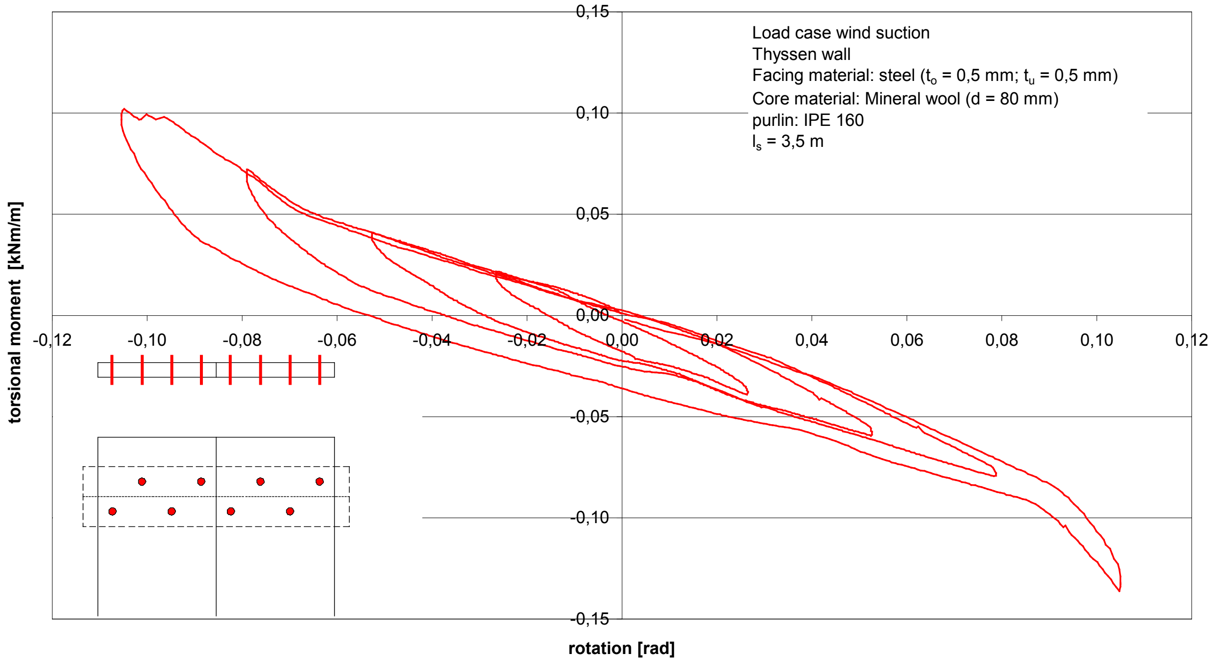


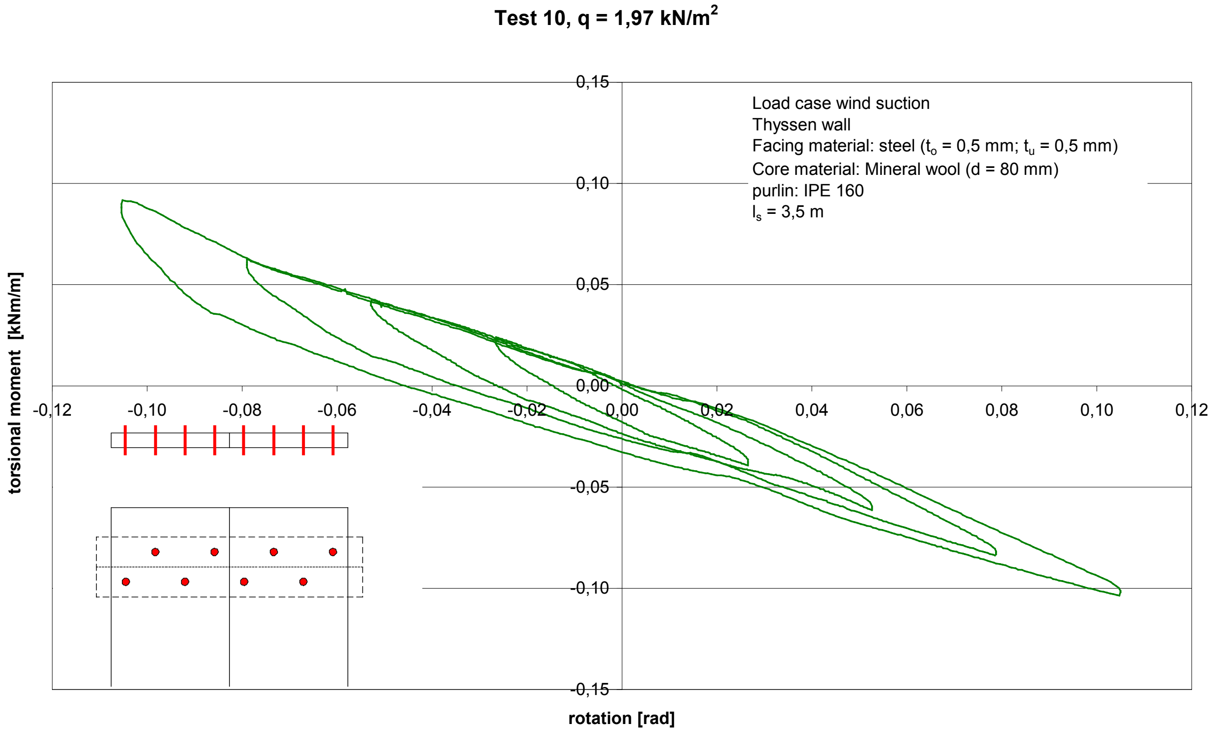
load p_1:	6,2 kN
load p_2:	10,0 kN
load p_3:	13,8 kN
remarks:	

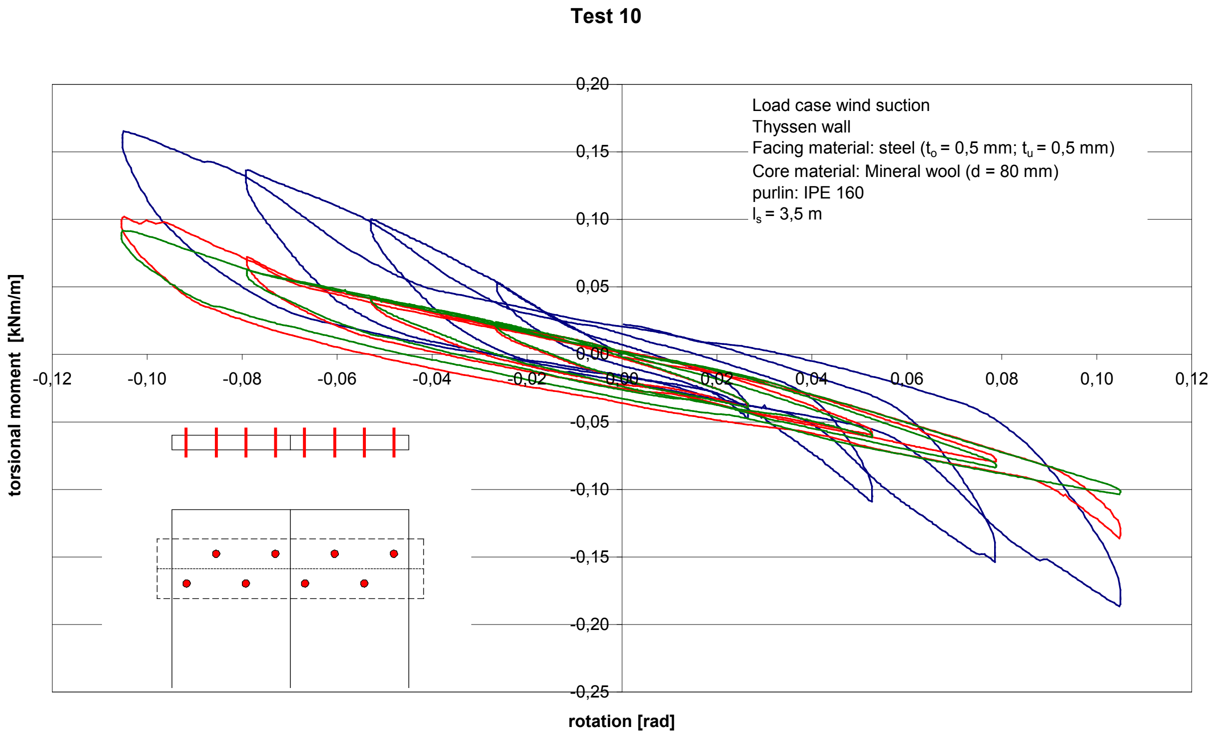
Test 10, q = 0,87 kN/m²



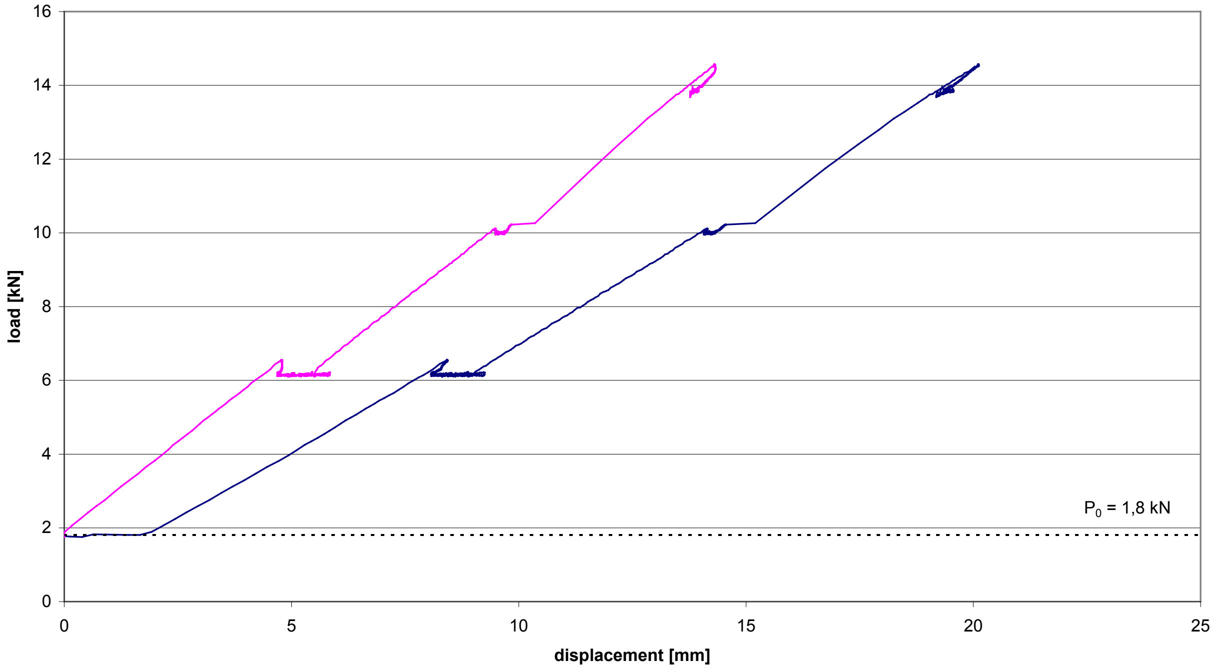
Test 10, q = 1,42 kN/m²




Test 10, q = 1,97 kN/m2
Load case wind suction
Thyssen wall
Facing material: steel (to = 0,5 mm; tu = 0,5 mm)
Core material: Mineral wool (d = 80 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

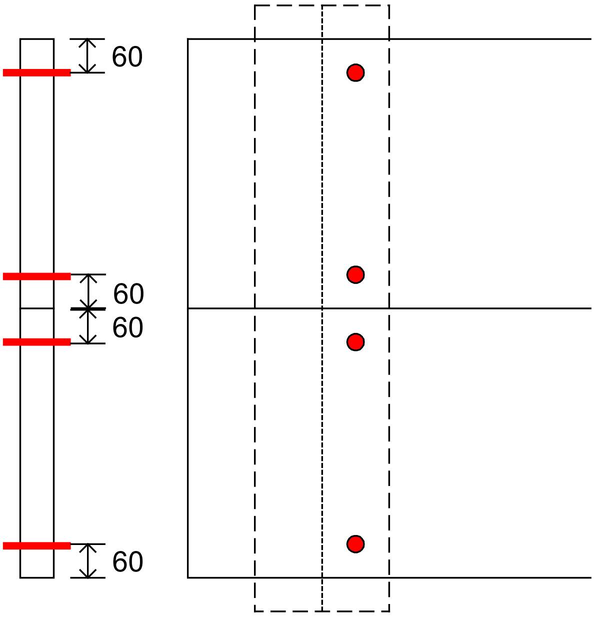

Test 10
Load case wind suction
Thyssen wall
Facing material: steel (to = 0,5 mm; tu = 0,5 mm)
Core material: Mineral wool (d = 80 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

Test 10

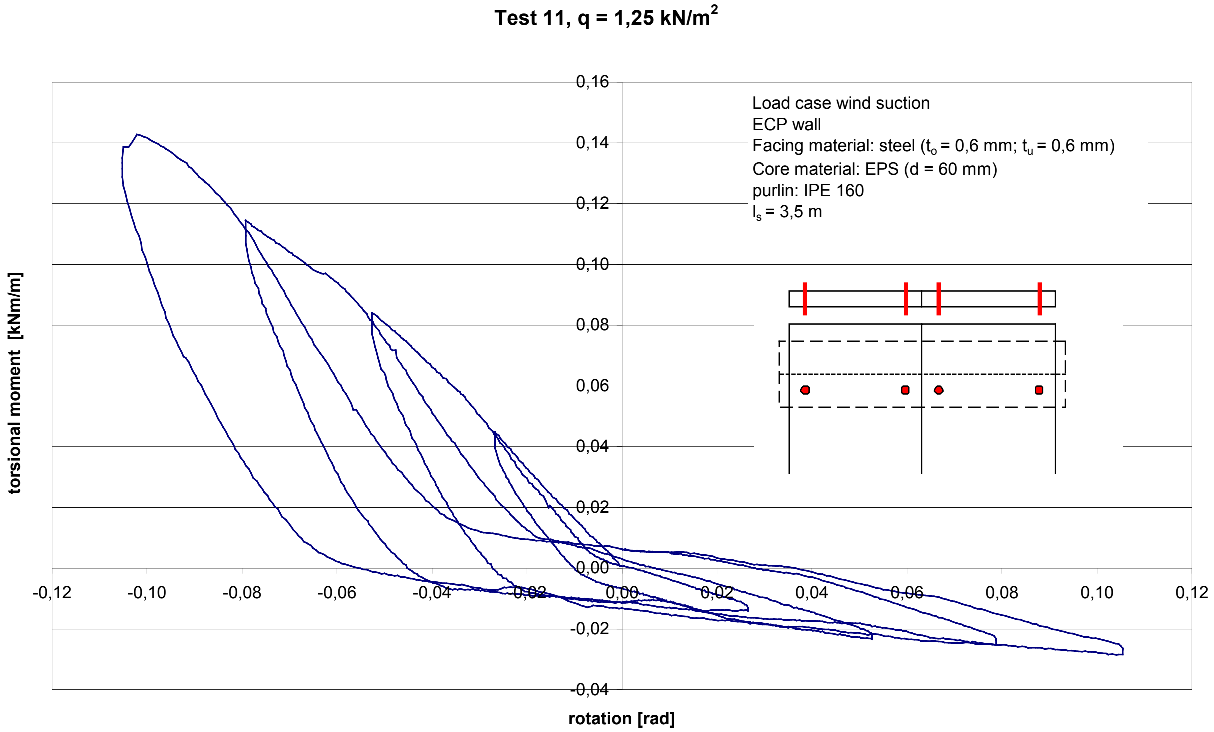


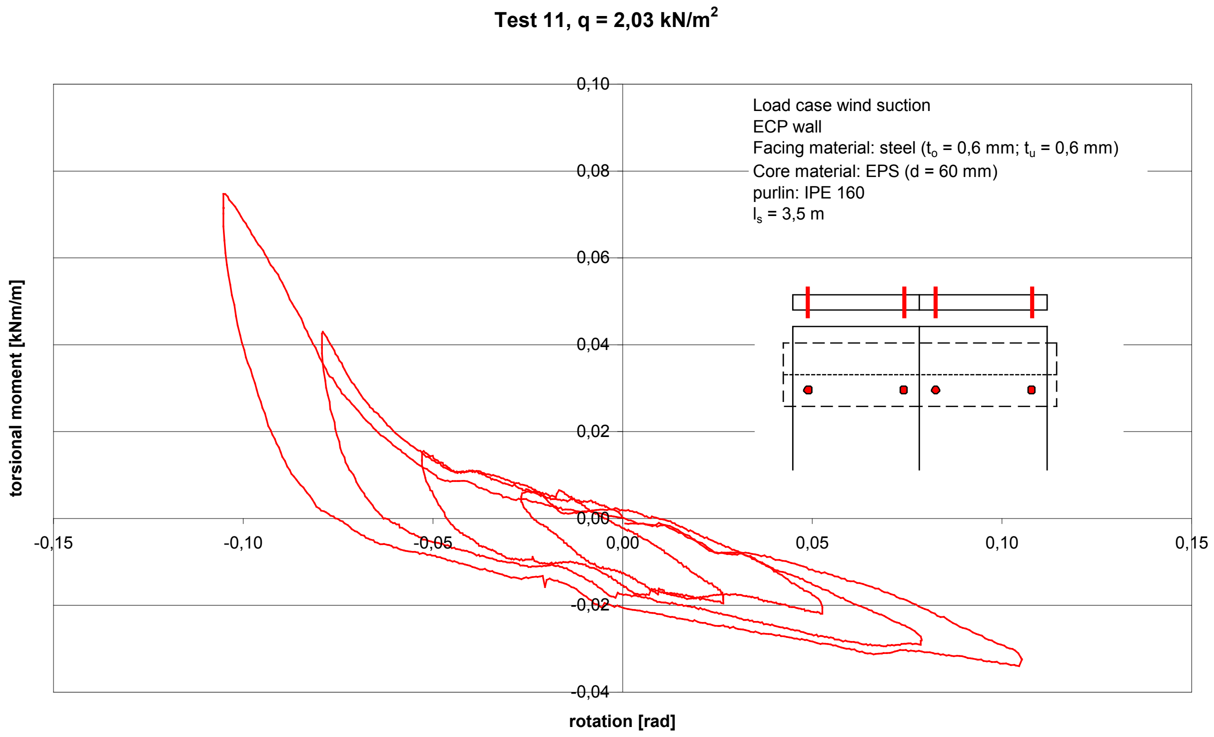
No. 11

Application:	wall
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,60 / 0,60 mm
core material:	EPS
core thickness:	60 mm
beam section:	IPE 160
fasteners:	

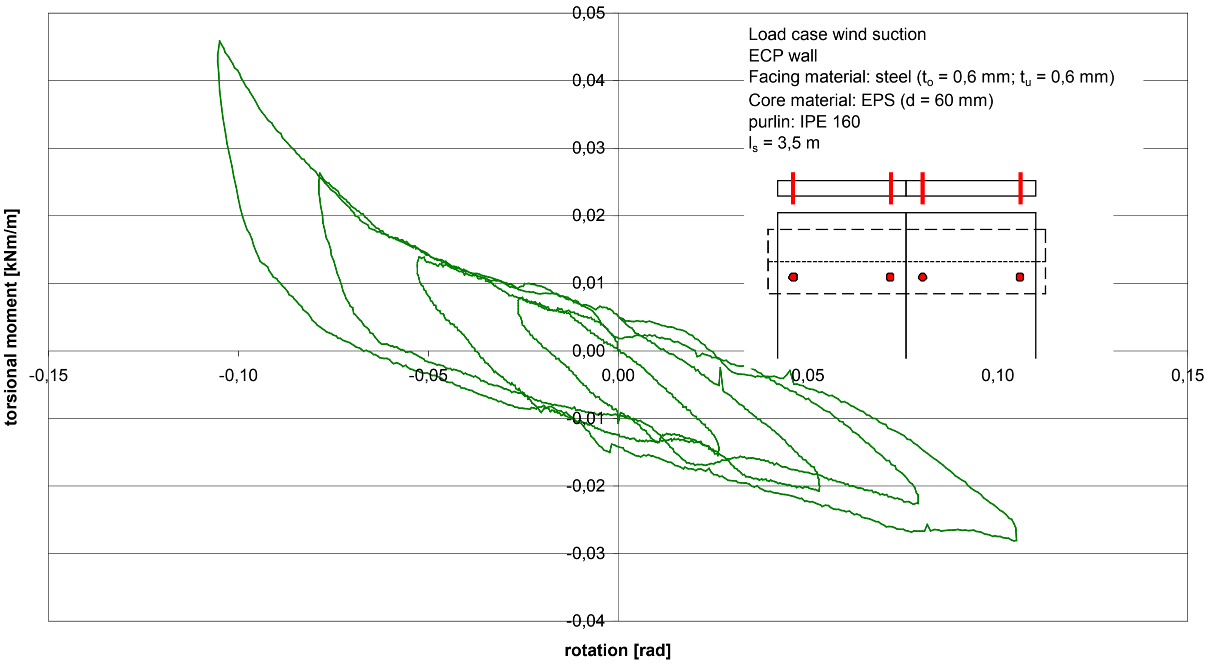


load p_1:	8,8 kN
load p_2:	14,2 kN
load p_3:	19,7 kN
remarks:	

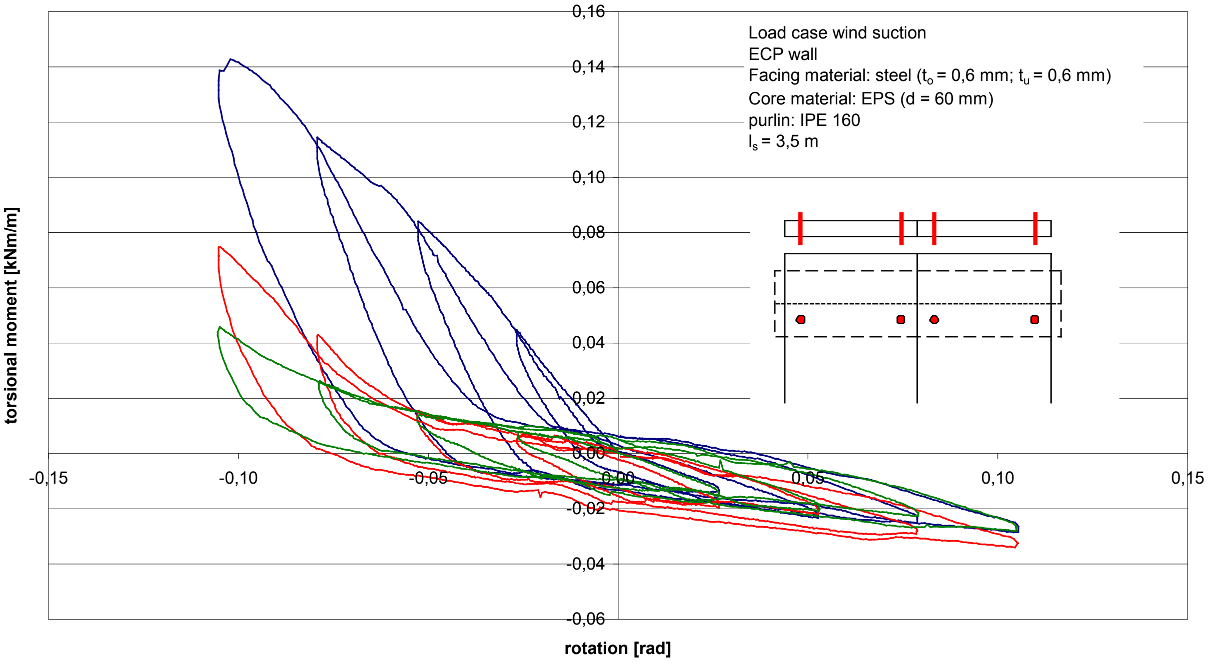

Test 11, q = 1,25 kN/m2
Load case wind suction
ECP wall
Facing material: steel (to = 0,6 mm; tu = 0,6 mm)
Core material: EPS (d = 60 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 11, q = 2,03 kN/m2
Load case wind suction
ECP wall
Facing material: steel (to = 0,6 mm; tu = 0,6 mm)
Core material: EPS (d = 60 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]

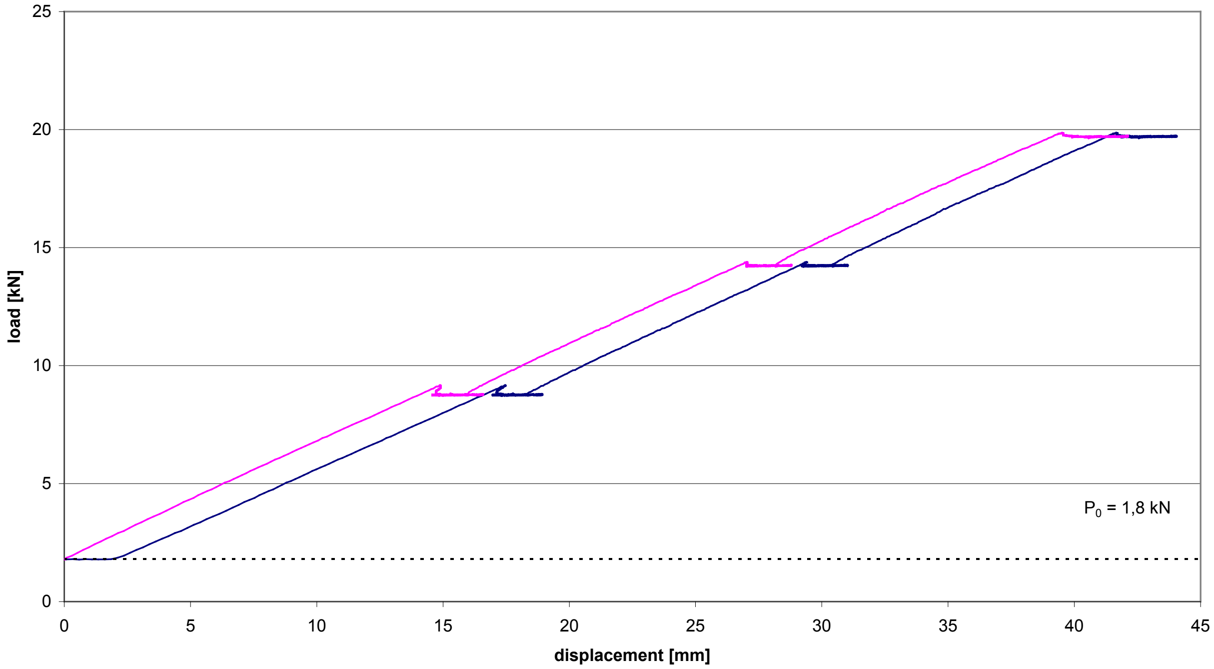
Test 11, q = 2,81 kN/m²



Test 11

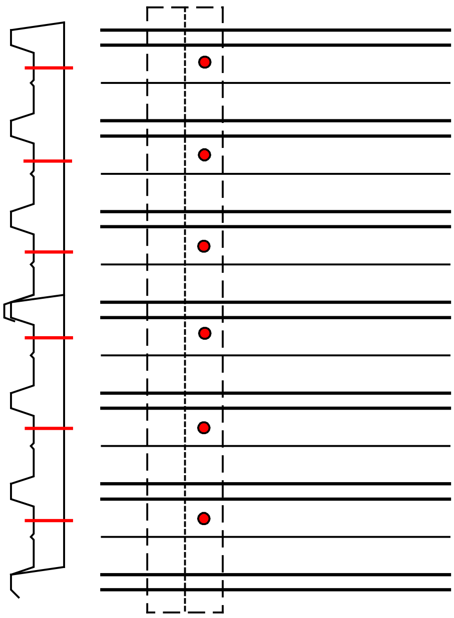


Test 11

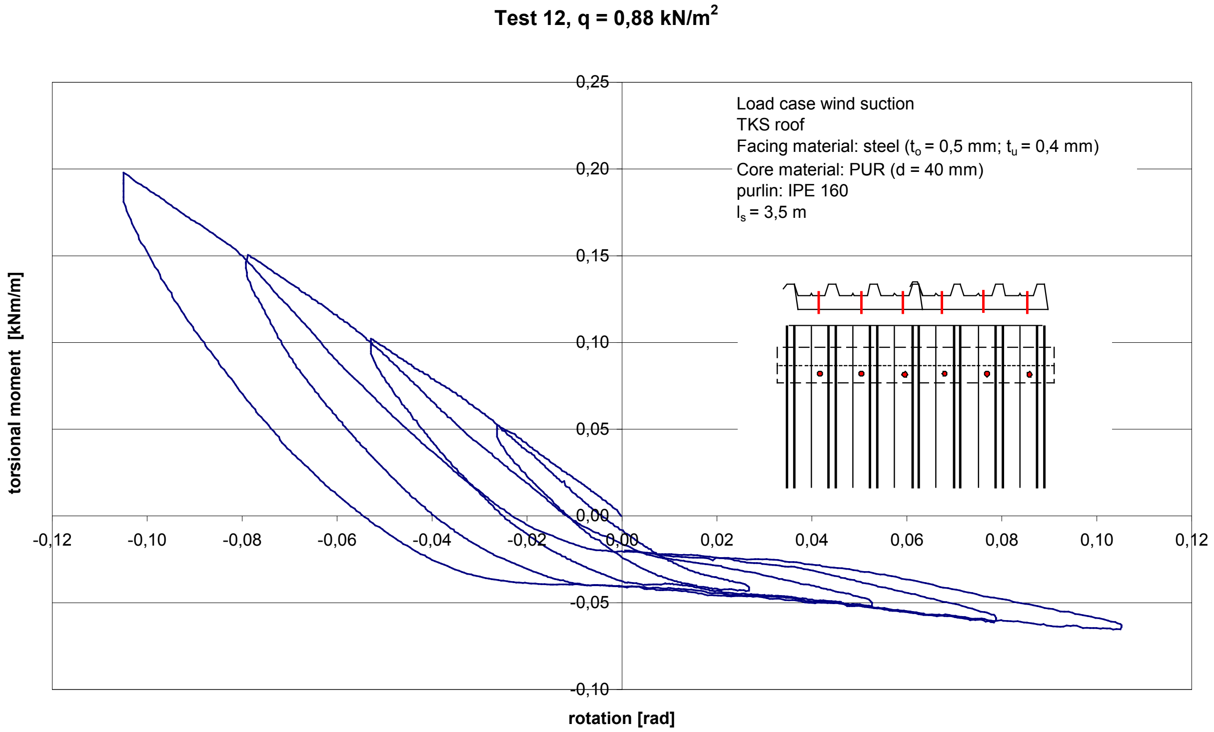

25
20
15
10
5
0
load [kN]
0
5
10
15
20
25
30
35
40
45
displacement [mm]
P0 = 1,8 kN

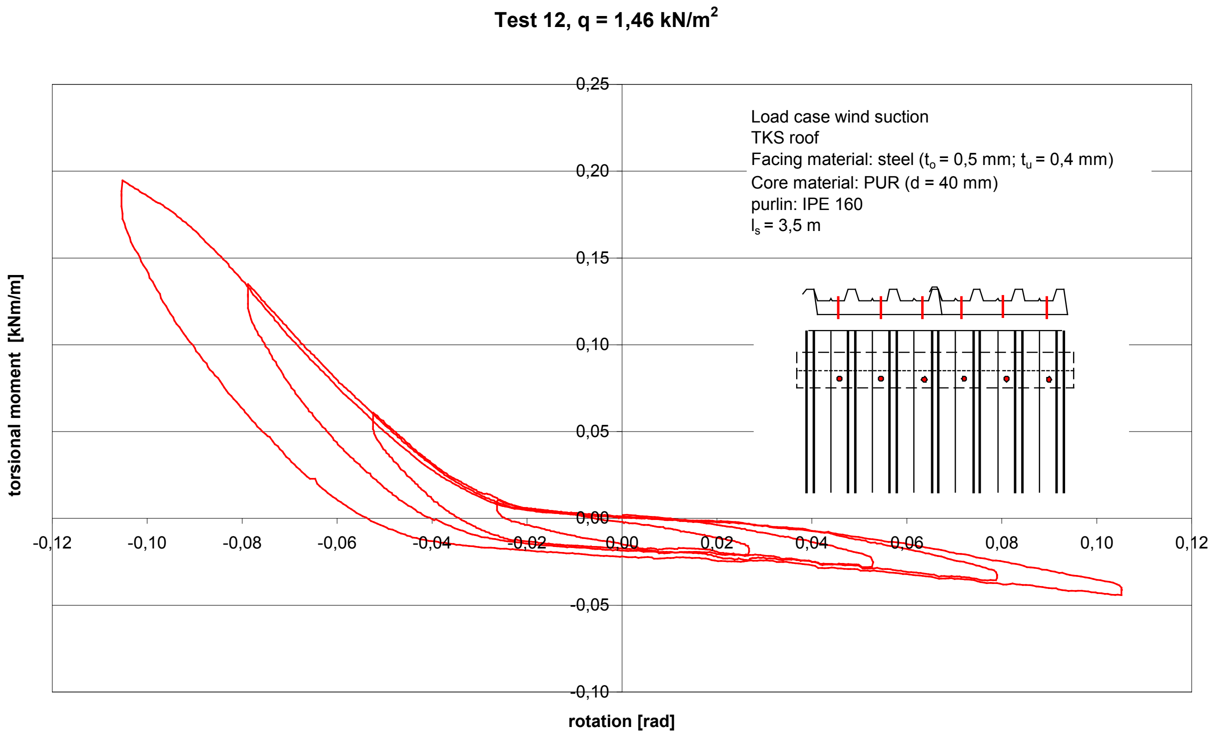
No. 12

Application:	roof
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,40 mm
core material:	PUR
core thickness:	40 mm
beam section:	IPE 160
fasteners:	

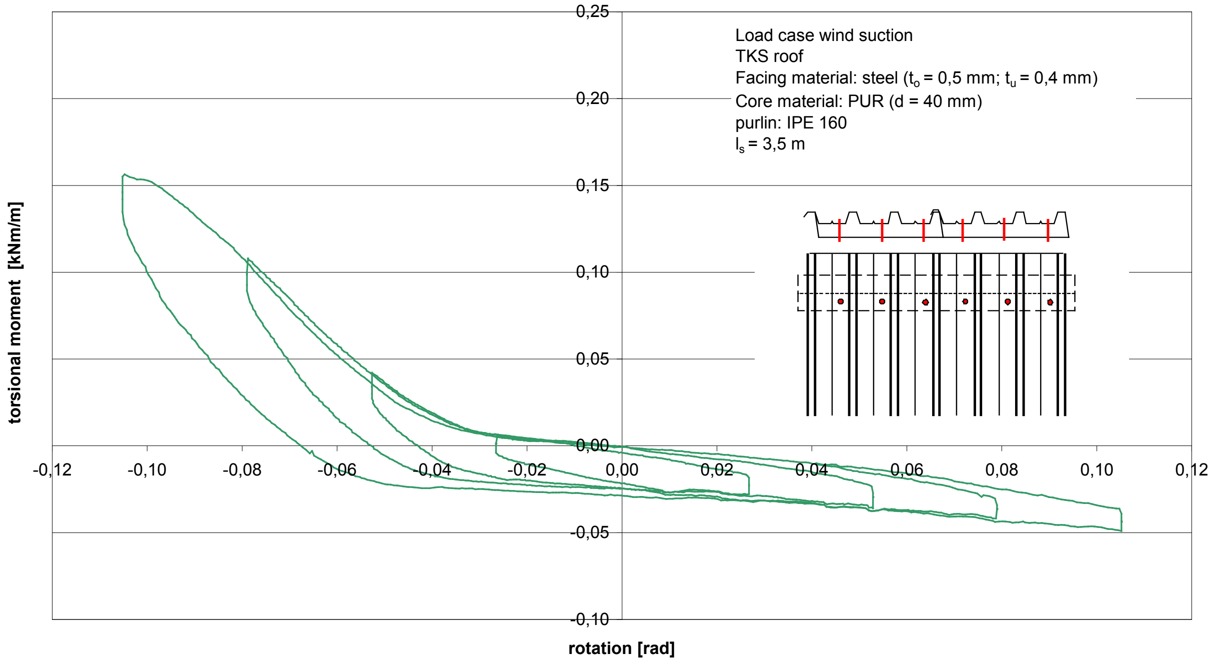


load p_1:	6,3 kN
load p_2:	10,2 kN
load p_3:	14,1 kN
remarks:	

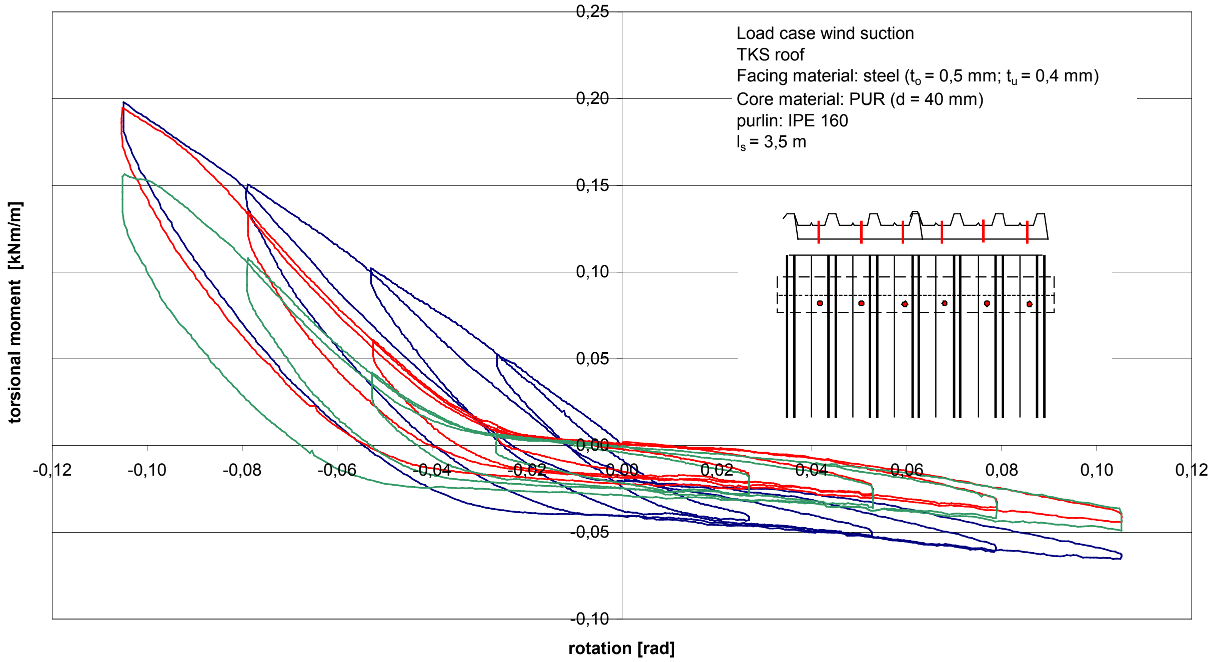

Test 12, q = 0,88 kN/m²
Load case wind suction
TKS roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 12, q = 1,46 kN/m²
Load case wind suction
TKS roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

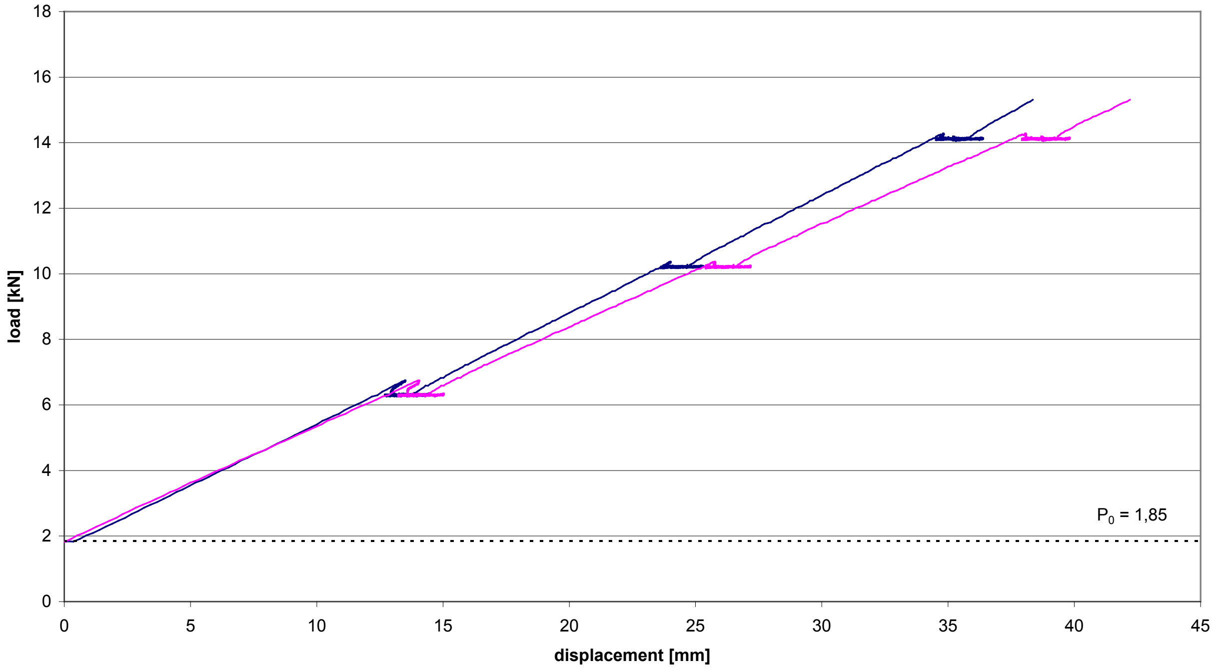
Test 12, q = 2,02 kN/m²



Test 12

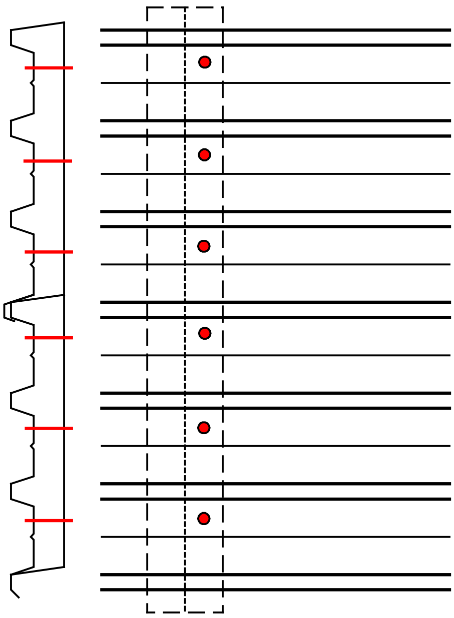


Test 12


18
16
14
12
10
8
6
4
2
0
load [kN]
P_0 = 1,85
0
5
10
15
20
25
30
35
40
45
displacement [mm]

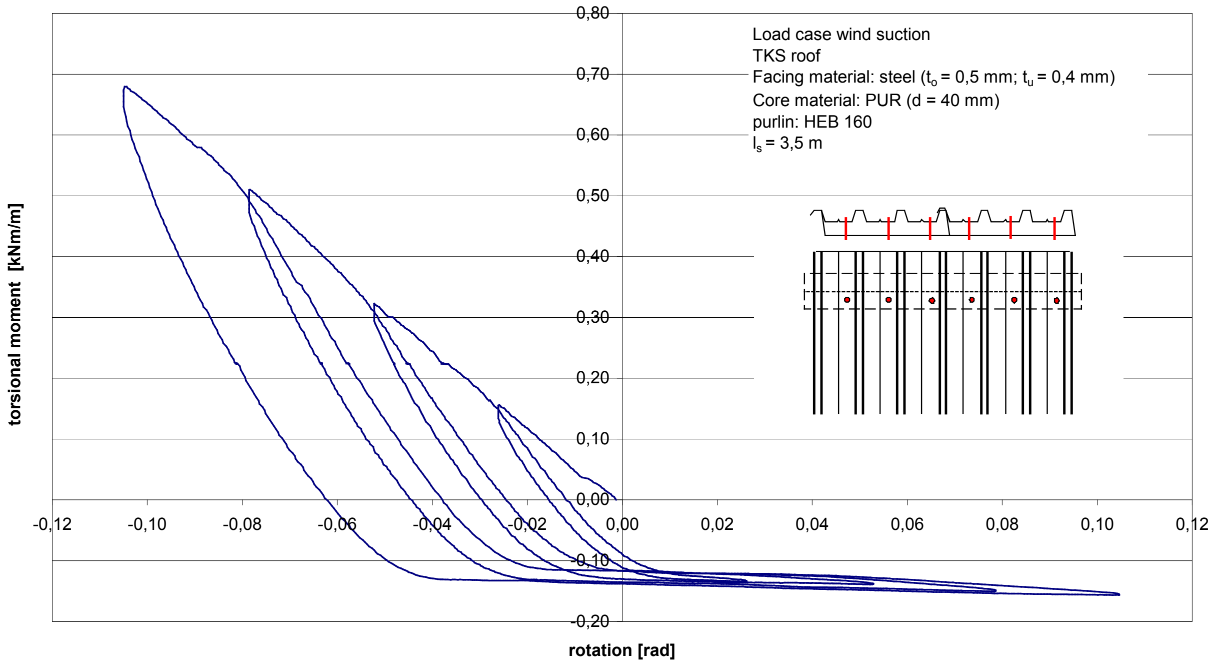
No. 13

Application:	roof
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,40 mm
core material:	PUR
core thickness:	40 mm
beam section:	HE 160 B
fasteners:	

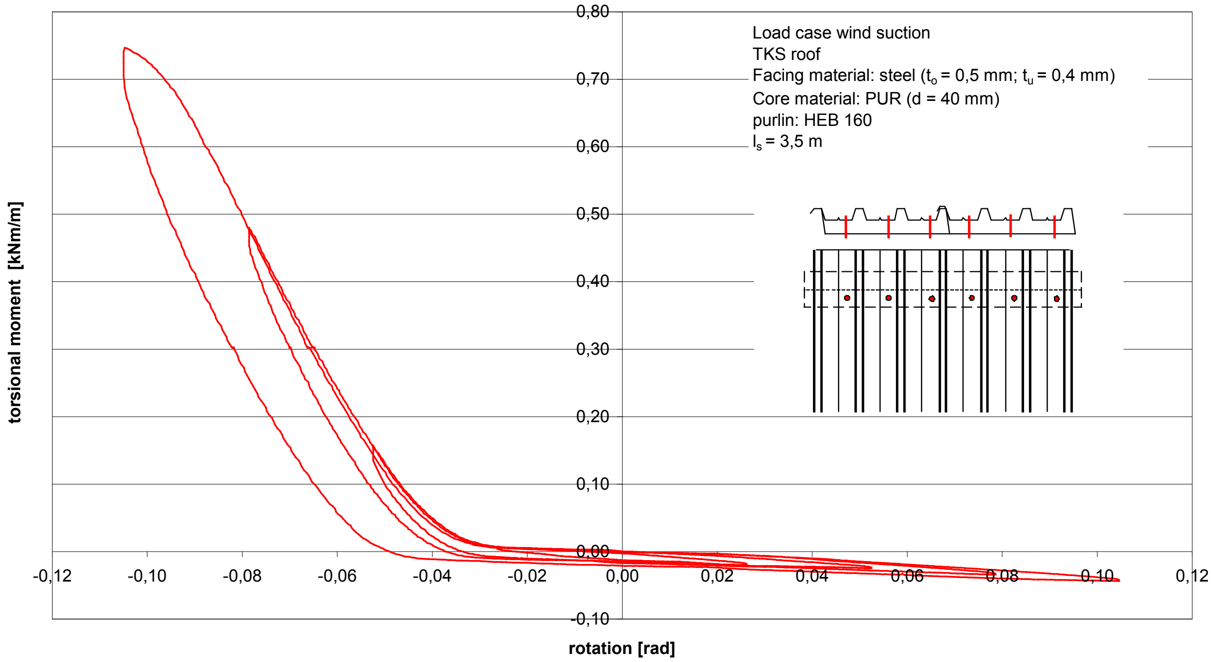


load p_1:	6,3 kN
load p_2:	10,2 kN
load p_3:	14,1 kN
remarks:	Pull-trough failure of the fasteners at load p_3 = 14,1 kN

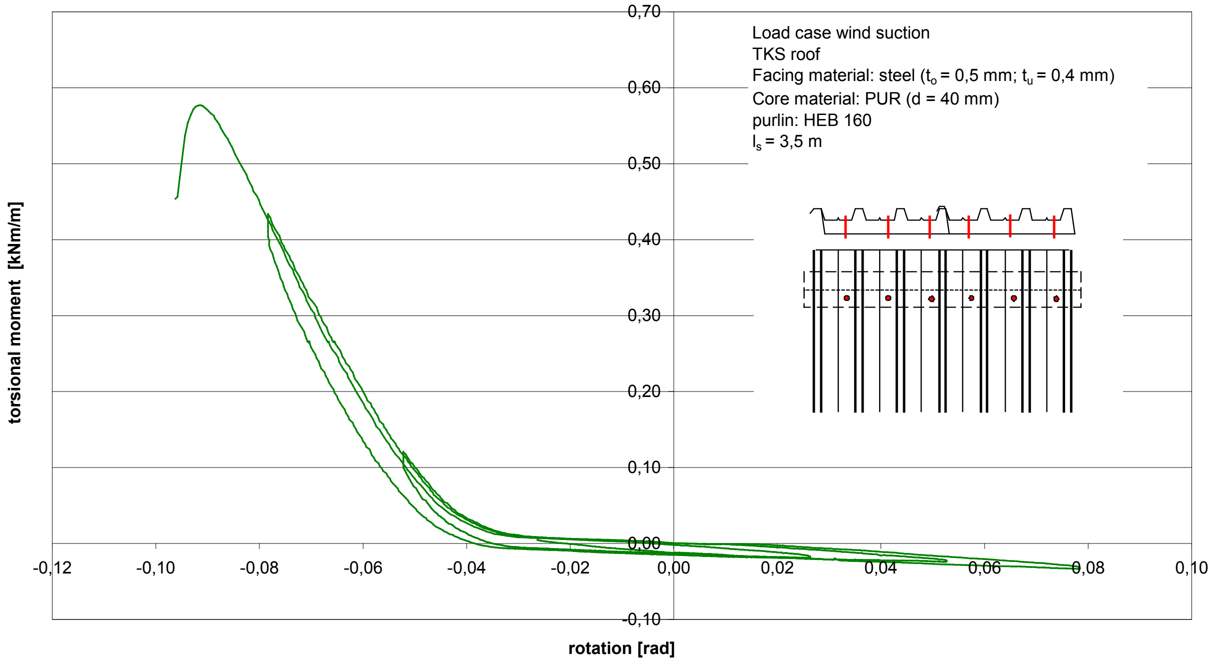
Test 13, q = 0,88 kN/m²



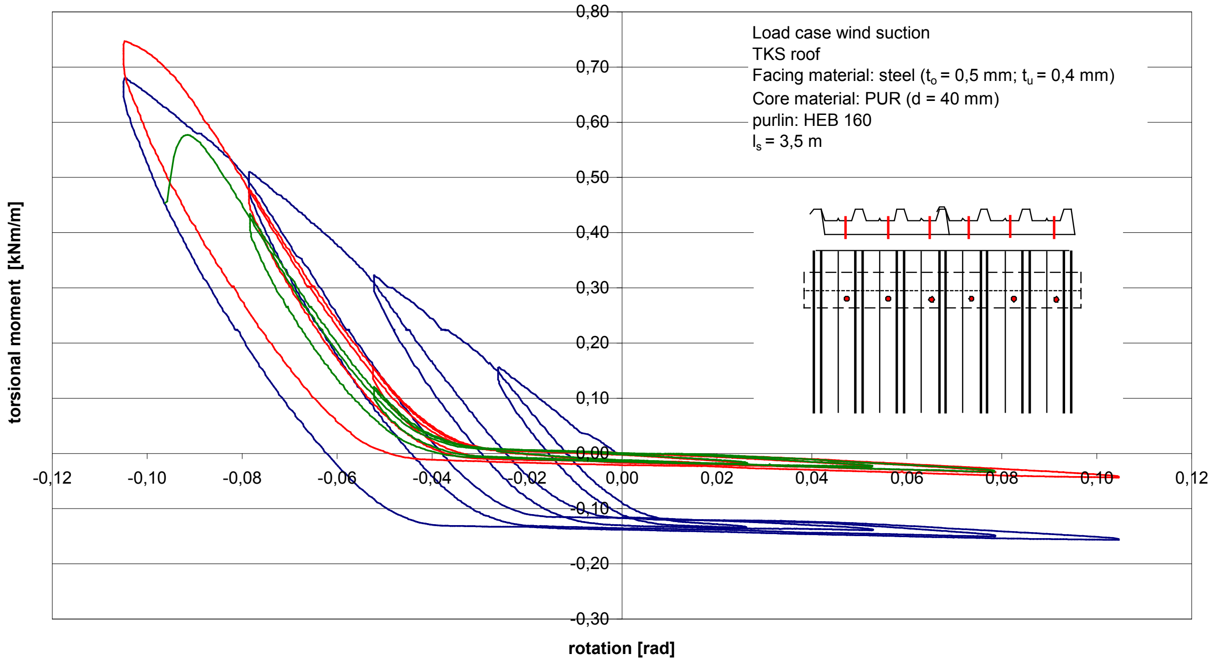
Test 13, q = 1,46 kN/m²

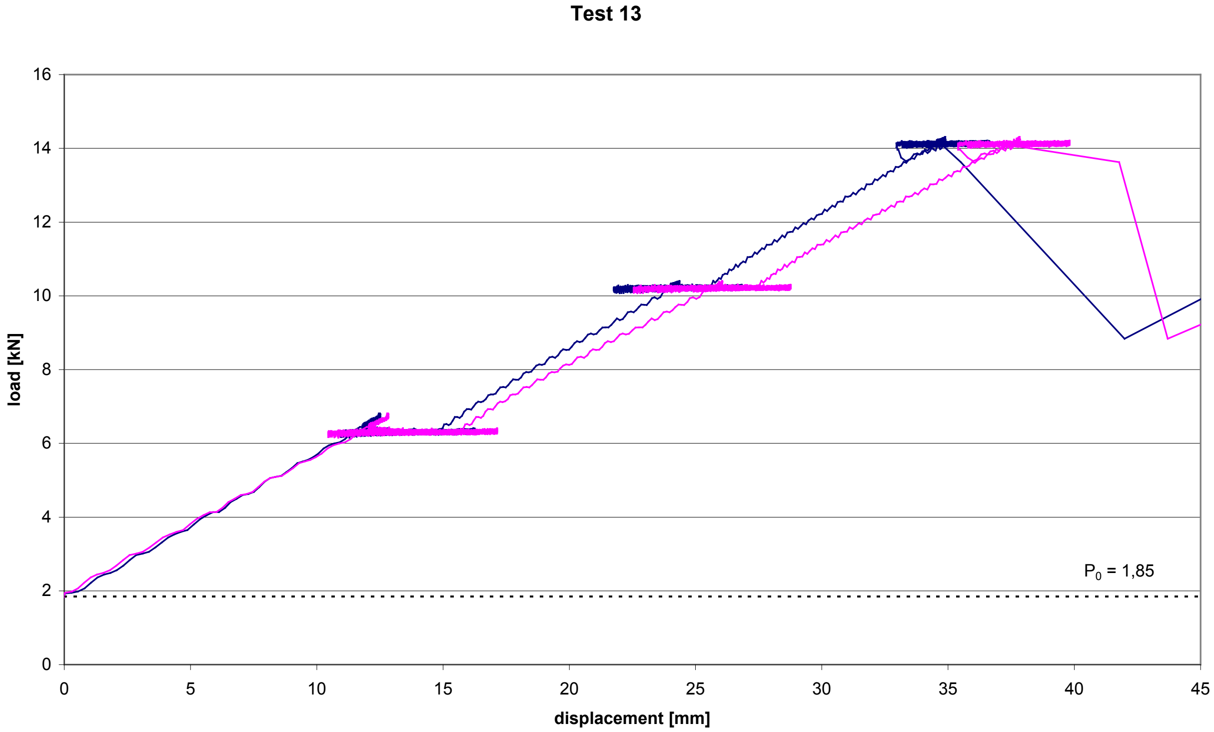


Test 13, q = 2,02 kN/m²



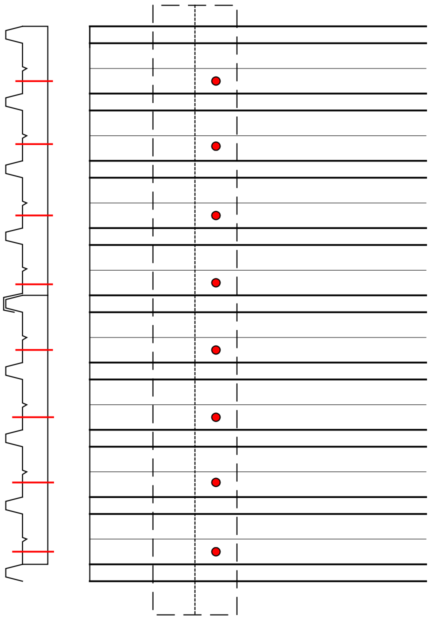
Test 13




Test 13
16
14
12
10
8
6
4
2
0
load [kN]
0
5
10
15
20
25
30
35
40
45
displacement [mm]
P0 = 1,85

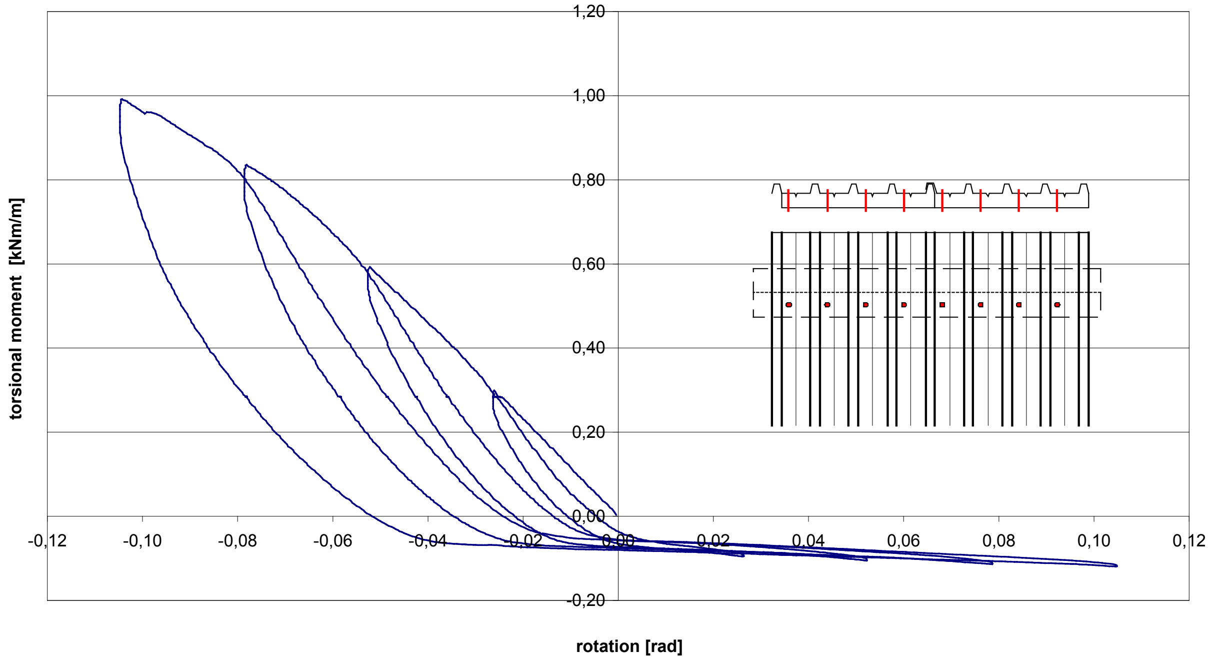
No. 14

Application:	roof
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,60 / 0,60 mm
core material:	MW
core thickness:	80 mm
beam section:	HE 160 B
fasteners:	

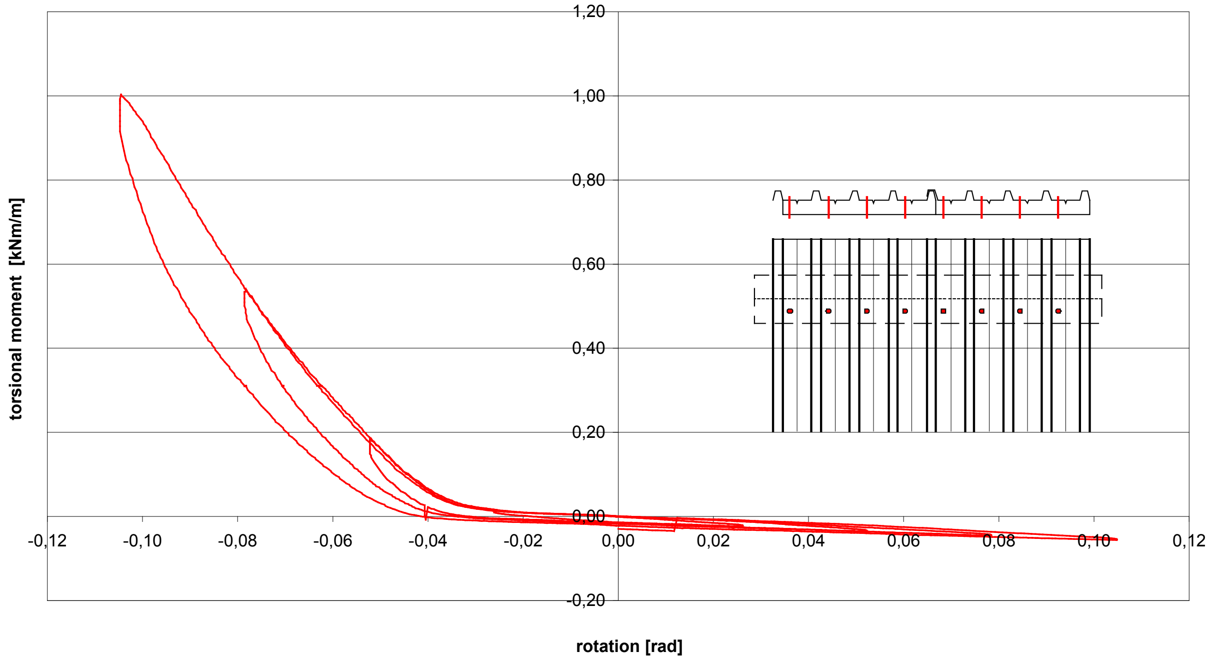


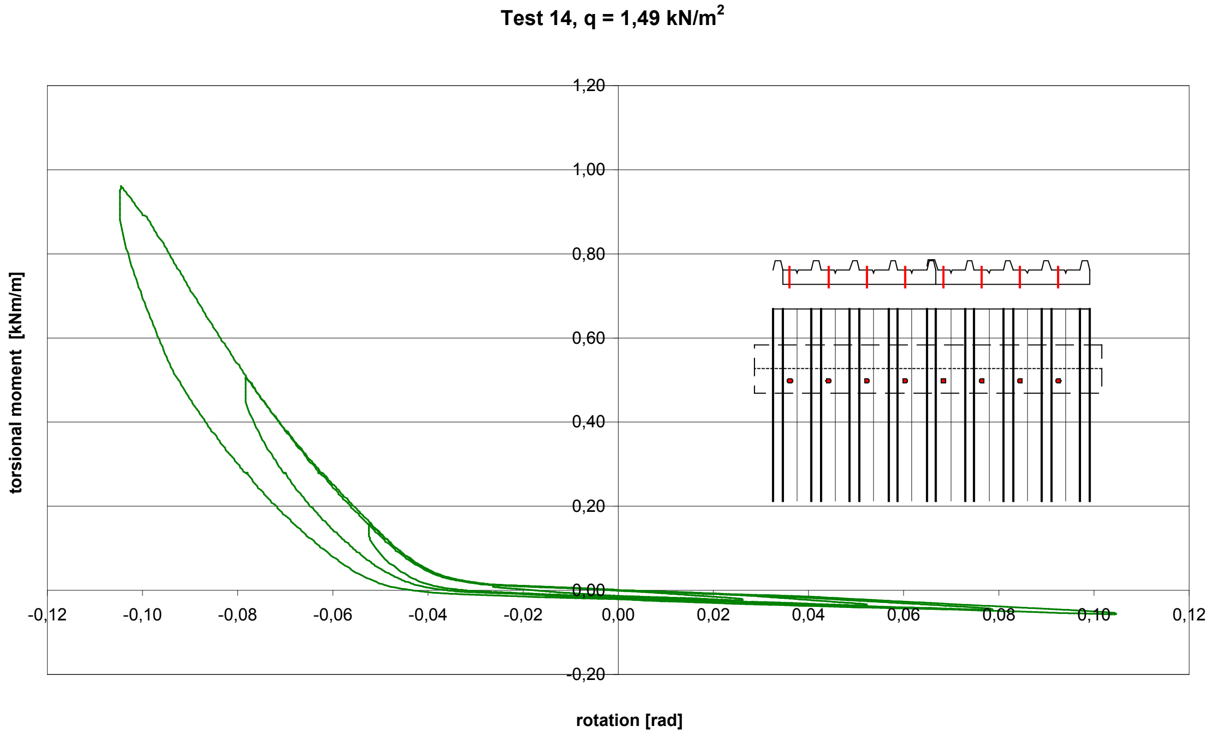
load p_1:	4,7 kN
load p_2:	7,6 kN
load p_3:	10,4 kN
remarks:	

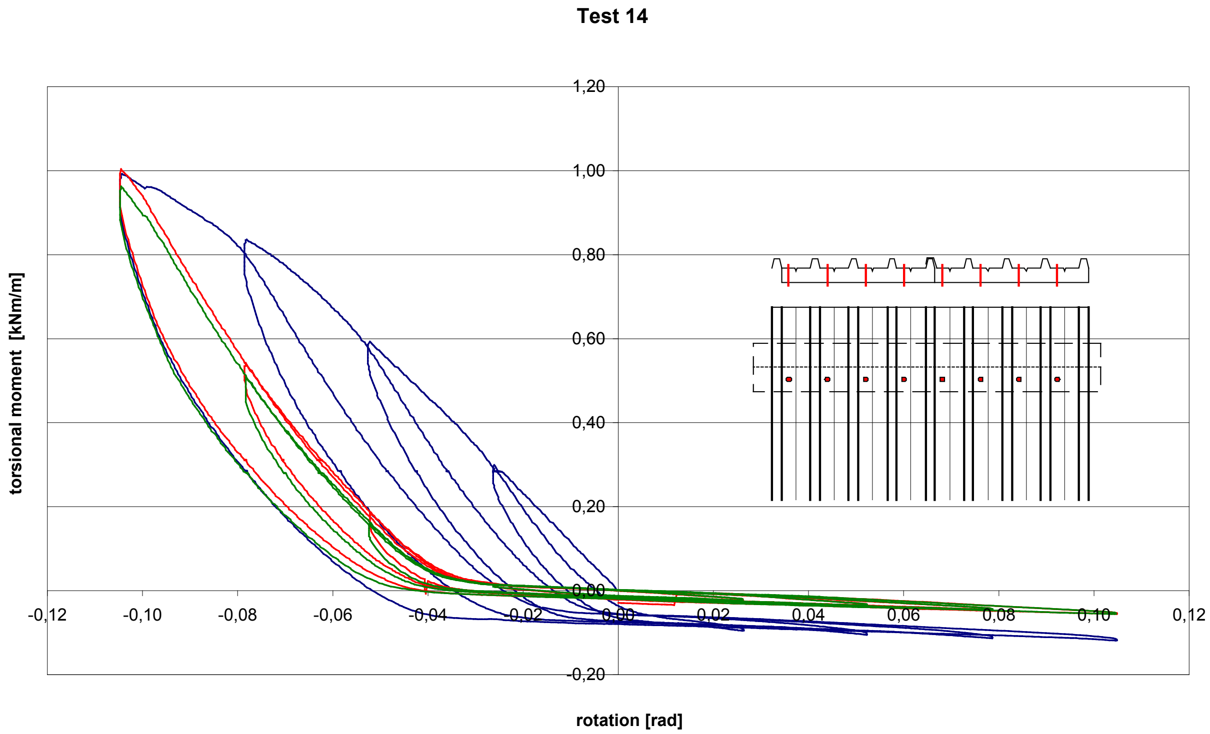
Test 14, q = 0,66 kN/m^2

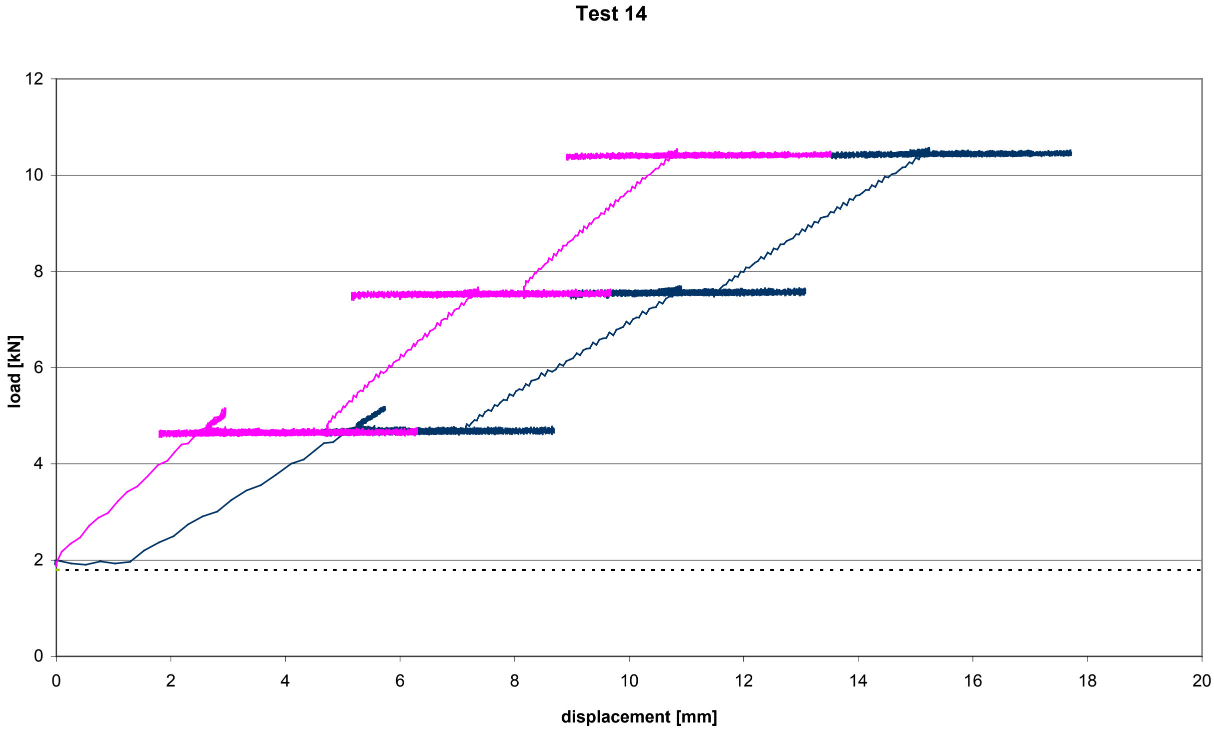


Test 14, q = 1,08 kN/m^2



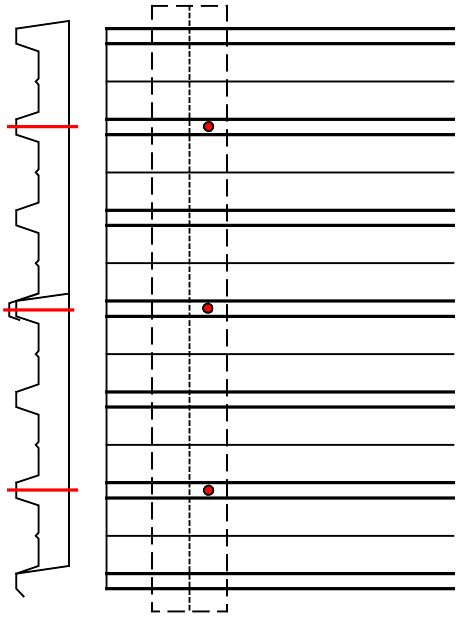

Test 14, q = 1,49 kN/m²
torsional moment [kNm/m]
rotation [rad]
1,20
1,00
0,80
0,60
0,40
0,20
0,00
-0,20
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 14
torsional moment [kNm/m]
rotation [rad]
1,20
1,00
0,80
0,60
0,40
0,20
0,00
-0,20
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 14
12
10
8
6
4
2
0
load [kN]
0
2
4
6
8
10
12
14
16
18
20
displacement [mm]

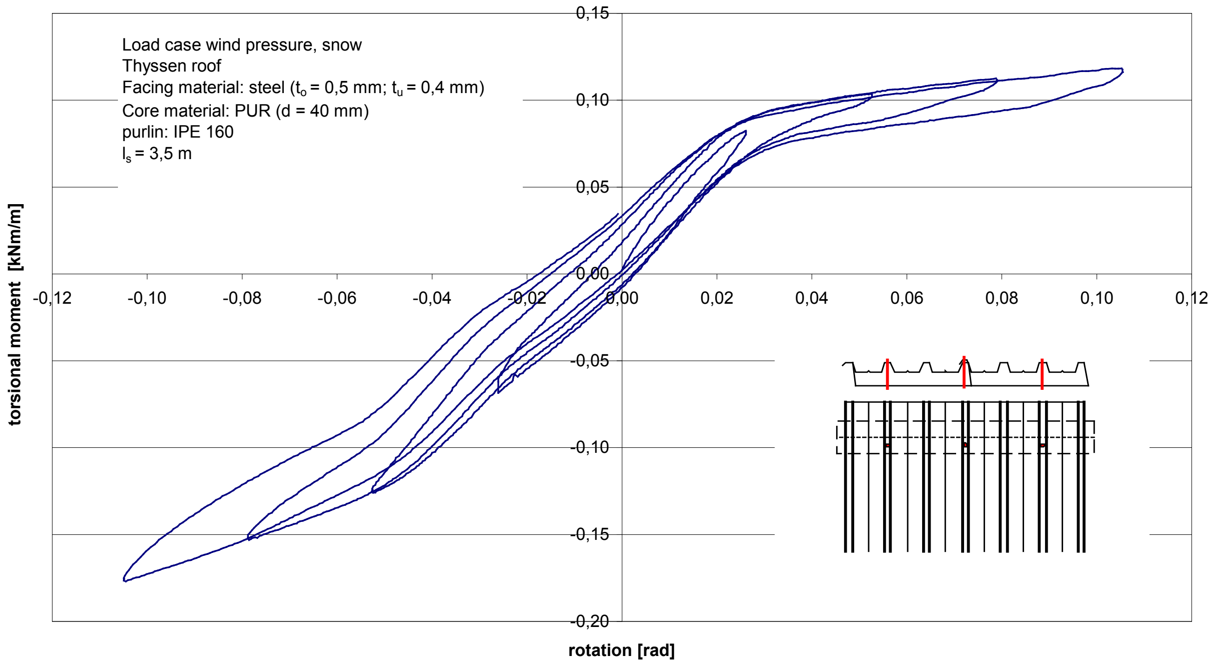
No. 16

Application:	roof
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,40 mm
core material:	PUR
core thickness:	40 mm
beam section:	IPE 160
fasteners:	

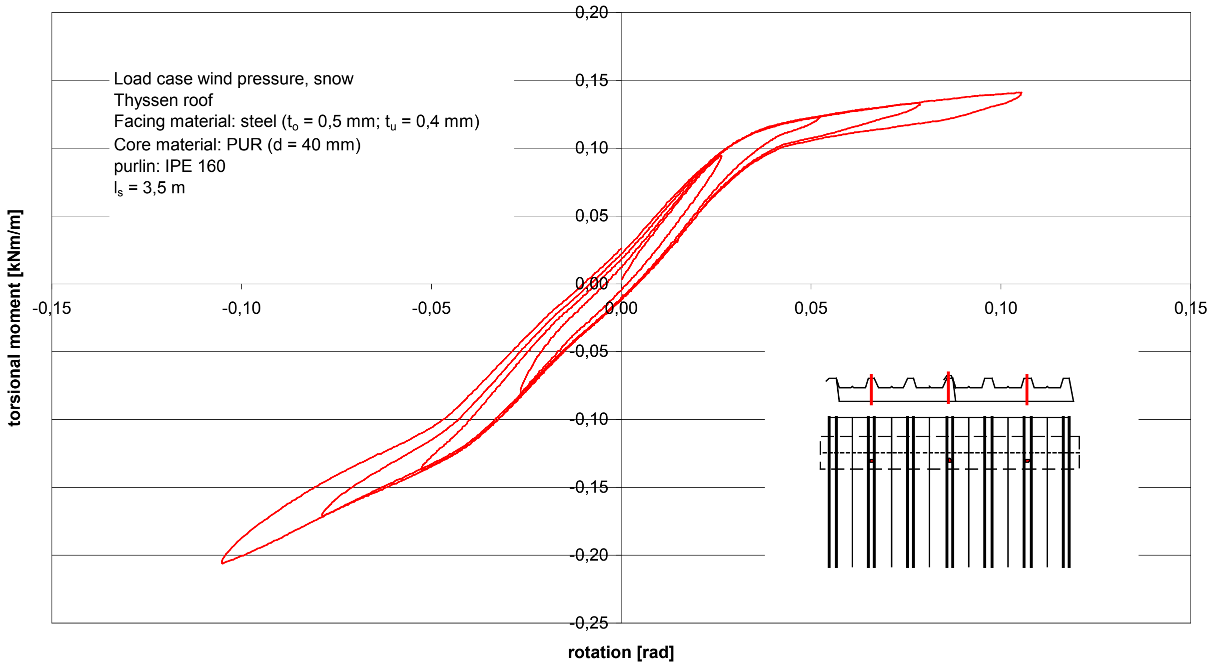


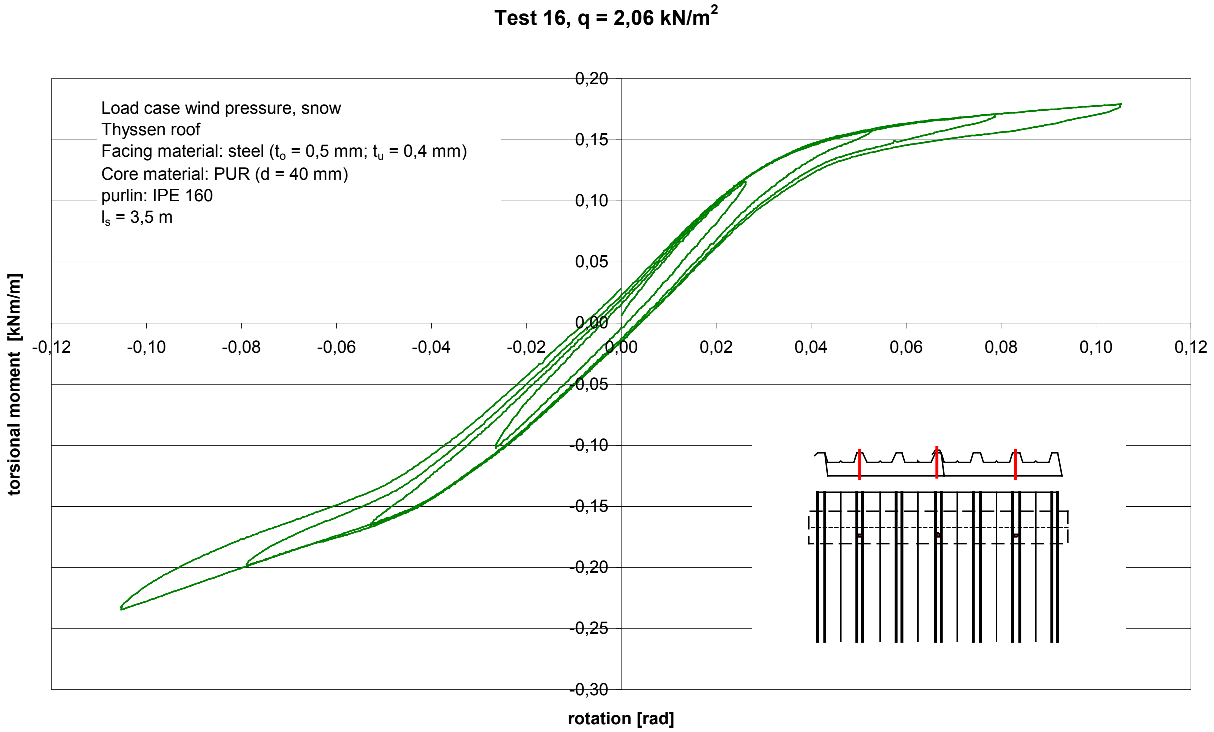
load p_1:	7,5 kN
load p_2:	10,5 kN
load p_3:	14,4 kN
remarks:	

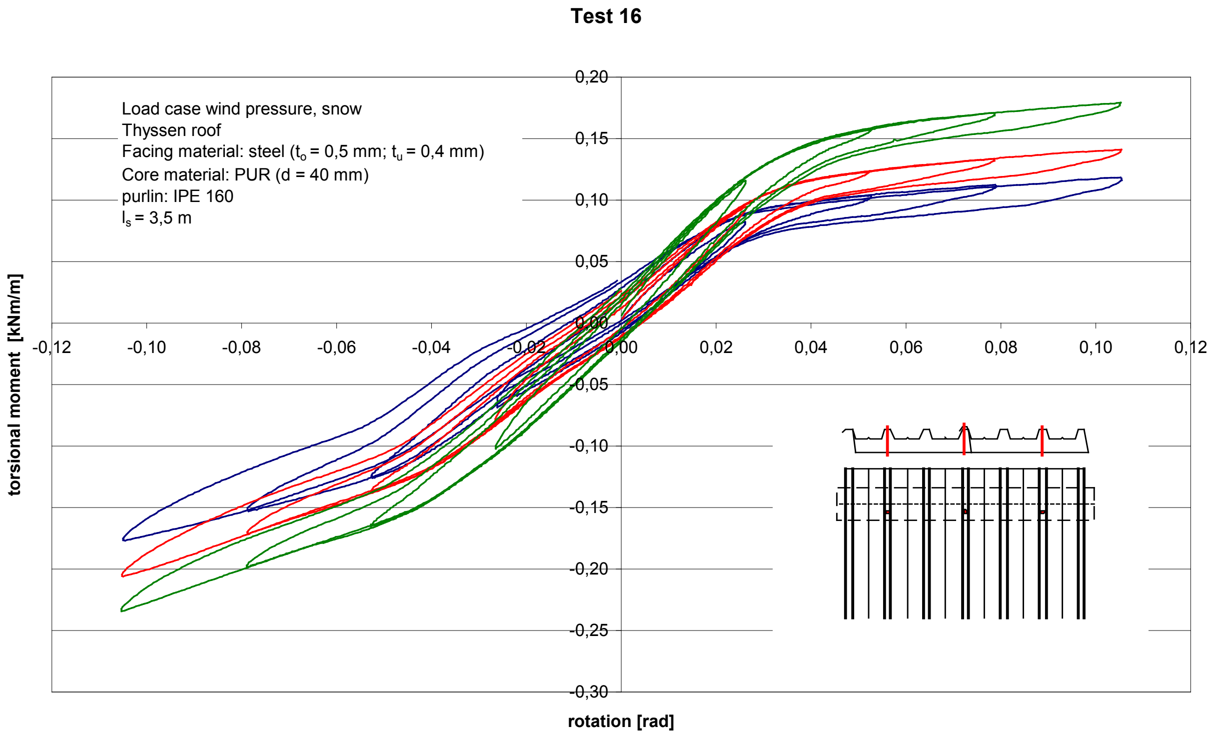
Test 16, q = 1,08 kN/m²



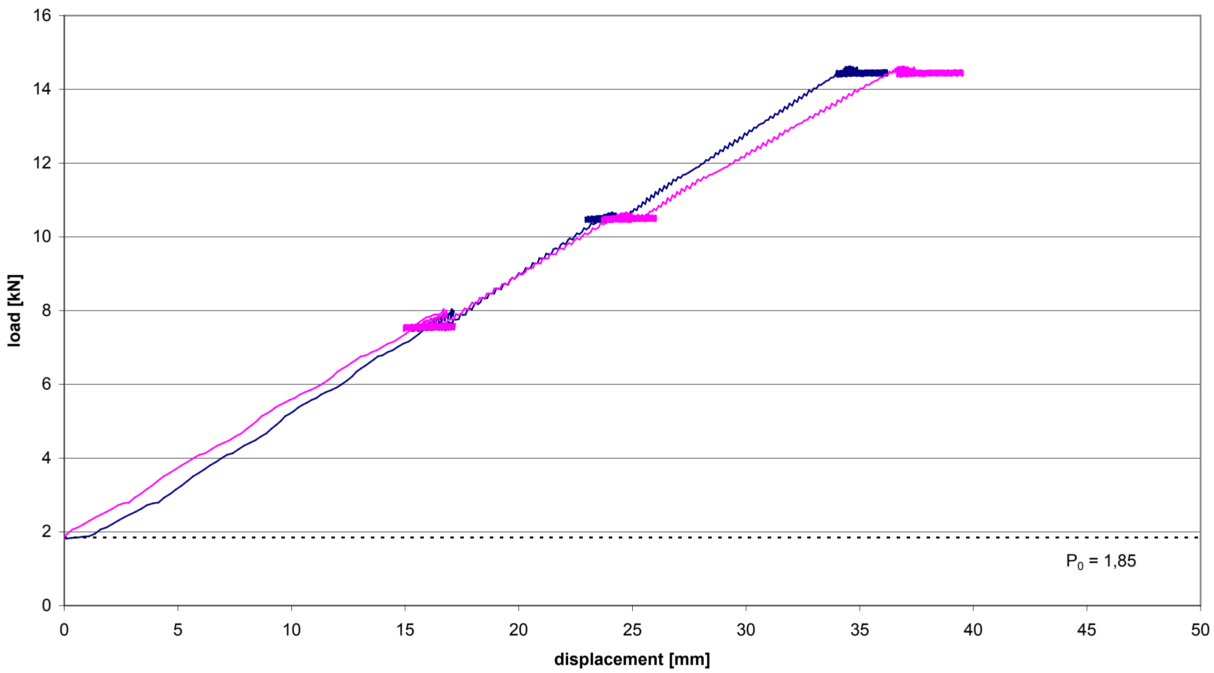
Test 16, q = 1,5 kN/m²




Test 16, q = 2,06 kN/m²
Load case wind pressure, snow
Thyssen roof
Facing material: steel (to = 0,5 mm; tu = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

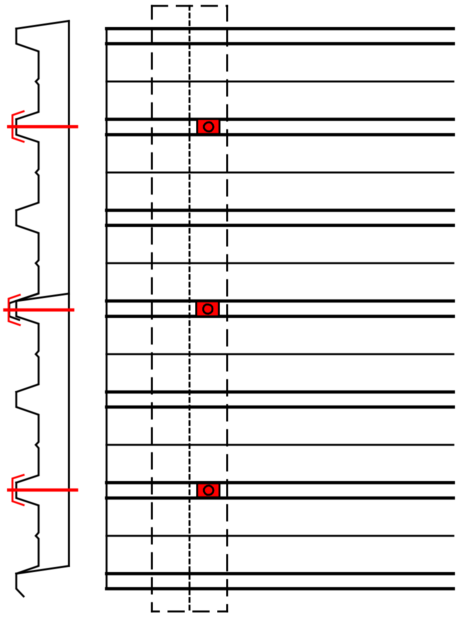

Test 16
Load case wind pressure, snow
Thyssen roof
Facing material: steel (to = 0,5 mm; tu = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

Test 16

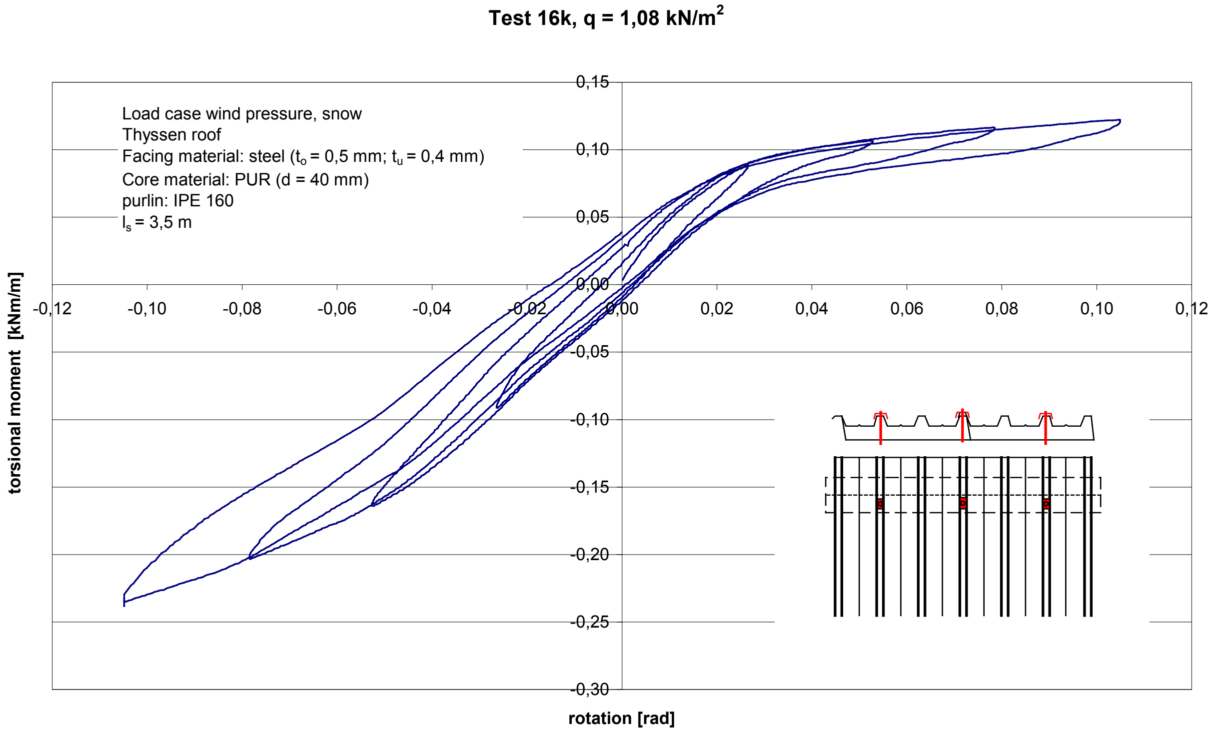

16
14
12
10
8
6
4
2
0
load [kN]
0
5
10
15
20
25
30
35
40
45
50
displacement [mm]
P0 = 1,85

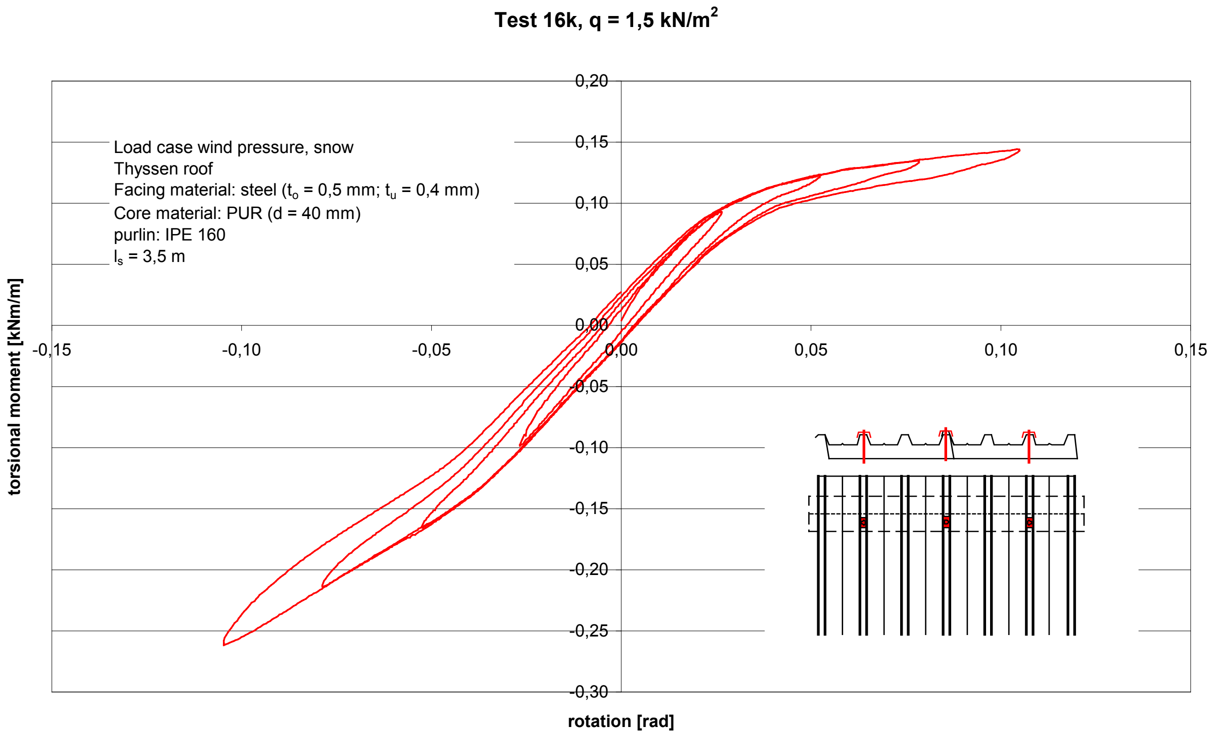
No. 16k

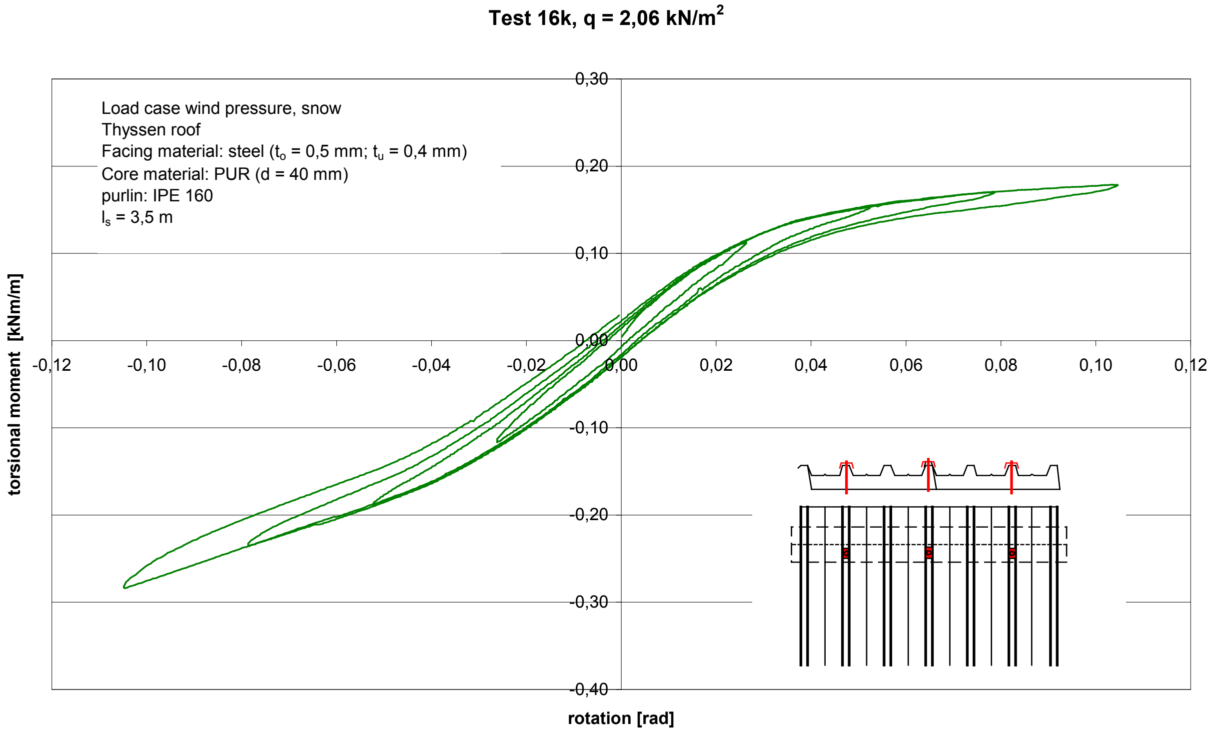
Application:	roof
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,40 mm
core material:	PUR
core thickness:	40 mm
beam section:	IPE 160
fasteners:	

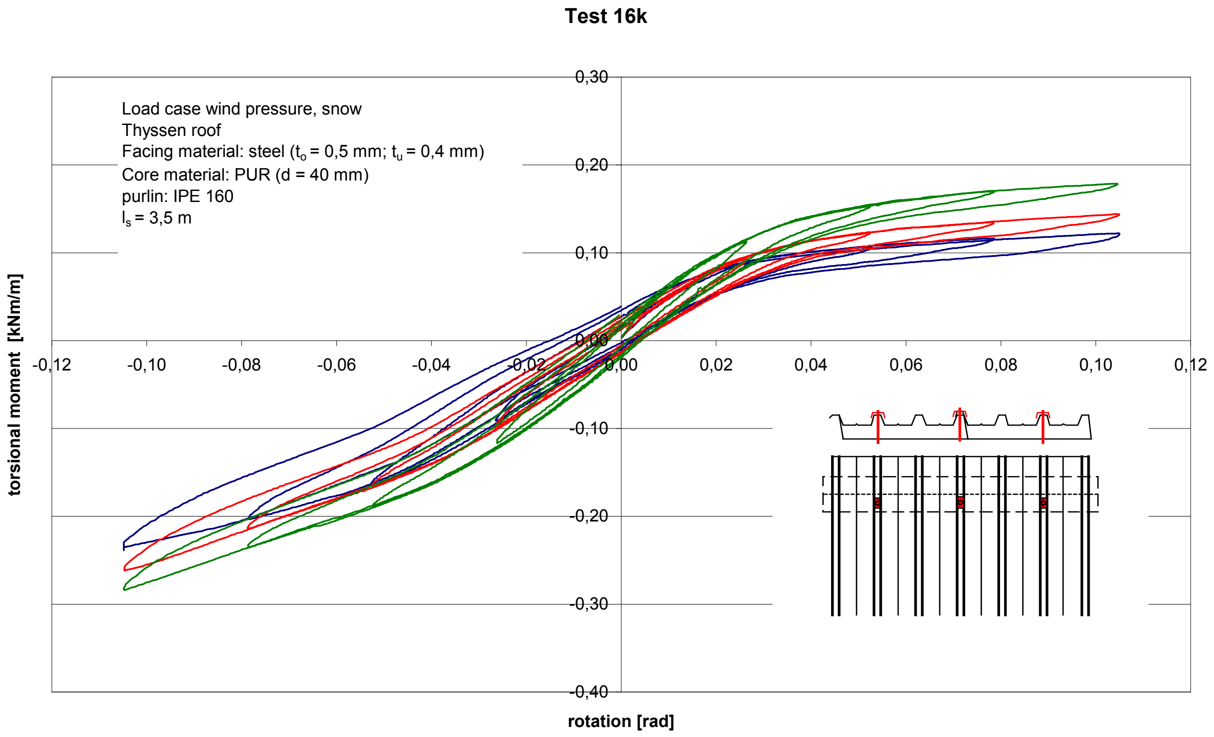


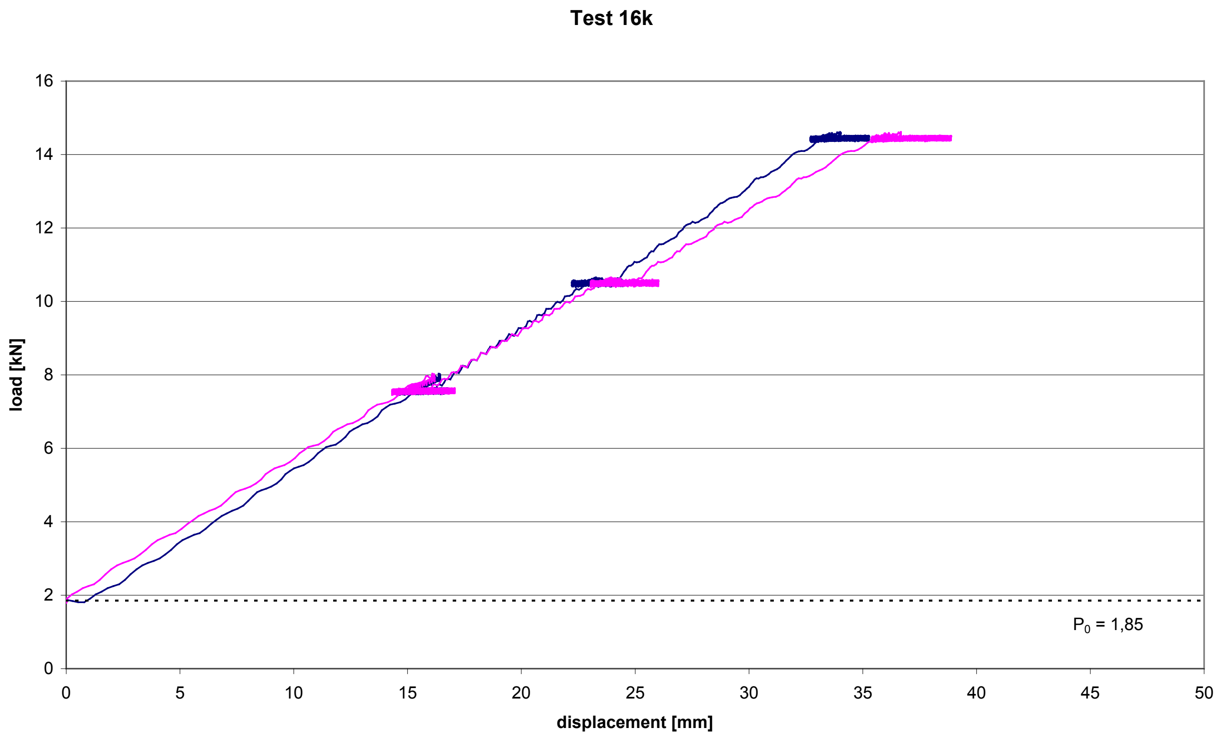
load p_1:	7,5 kN
load p_2:	10,5 kN
load p_3:	14,4 kN
remarks:	


Test 16k, q = 1,08 kN/m²
Load case wind pressure, snow
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 16k, q = 1,5 kN/m²
Load case wind pressure, snow
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,15
-0,10
-0,05
0,00
0,05
0,10
0,15

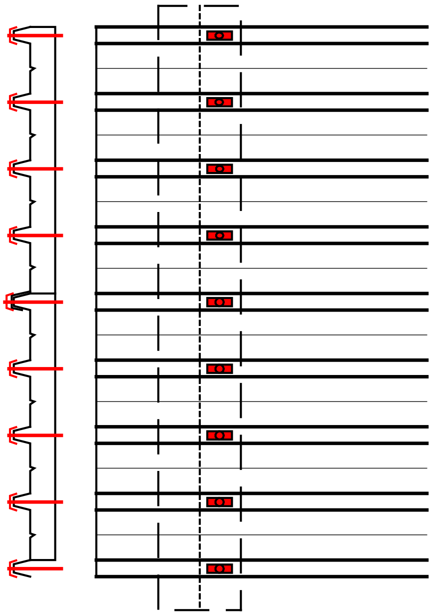

Test 16k, q = 2,06 kN/m²
Load case wind pressure, snow
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 16k
Load case wind pressure, snow
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 16k
16
14
12
10
8
6
4
2
0
load [kN]
0
5
10
15
20
25
30
35
40
45
50
displacement [mm]
P0 = 1,85

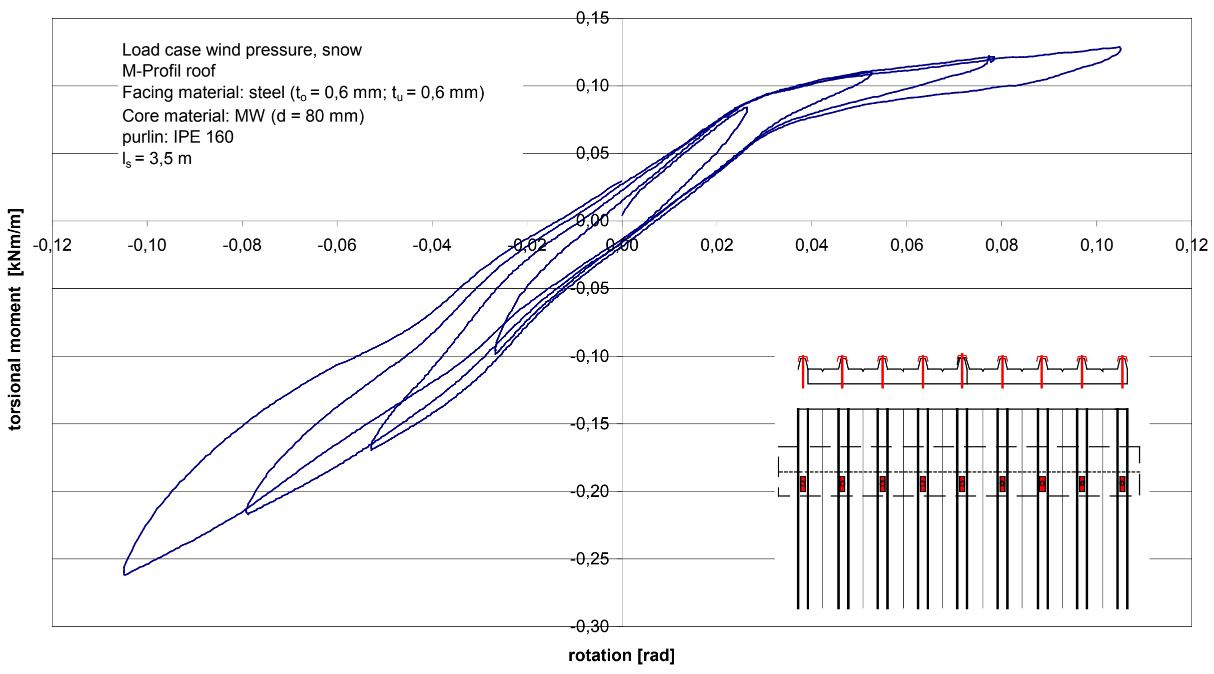
No. 17

Application:	roof
Loading:	downward
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,60 / 0,60 mm
core material:	MW
core thickness:	80 mm
beam section:	IPE 160
fasteners:	

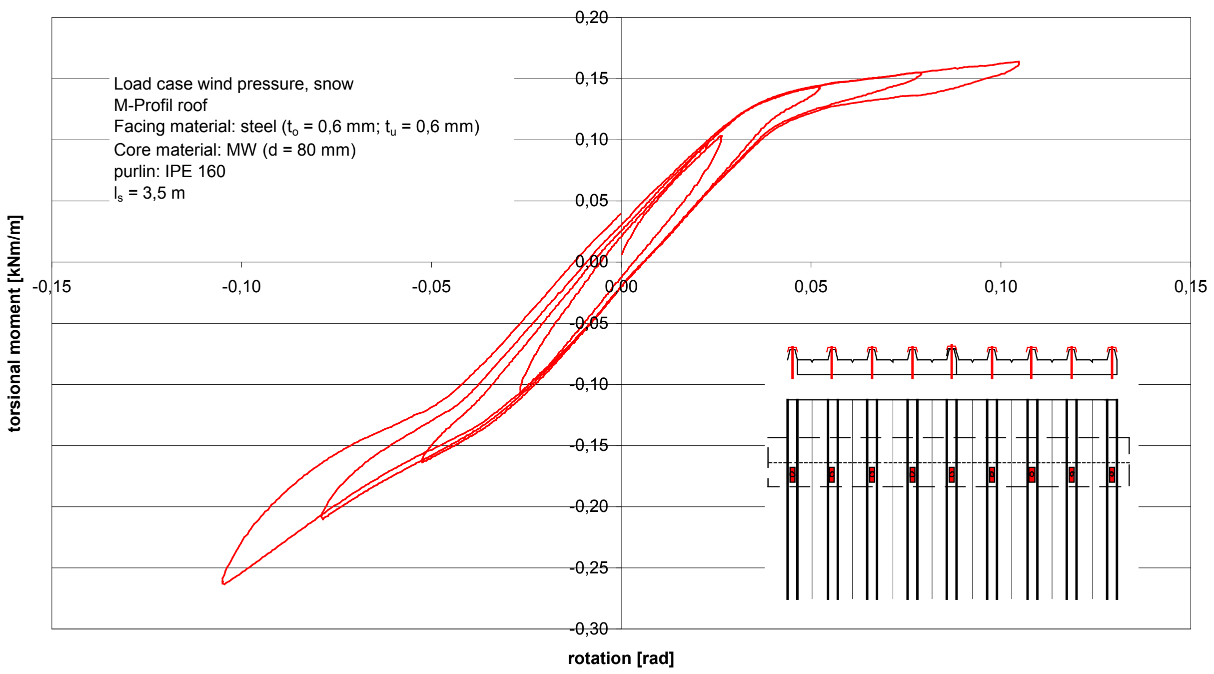


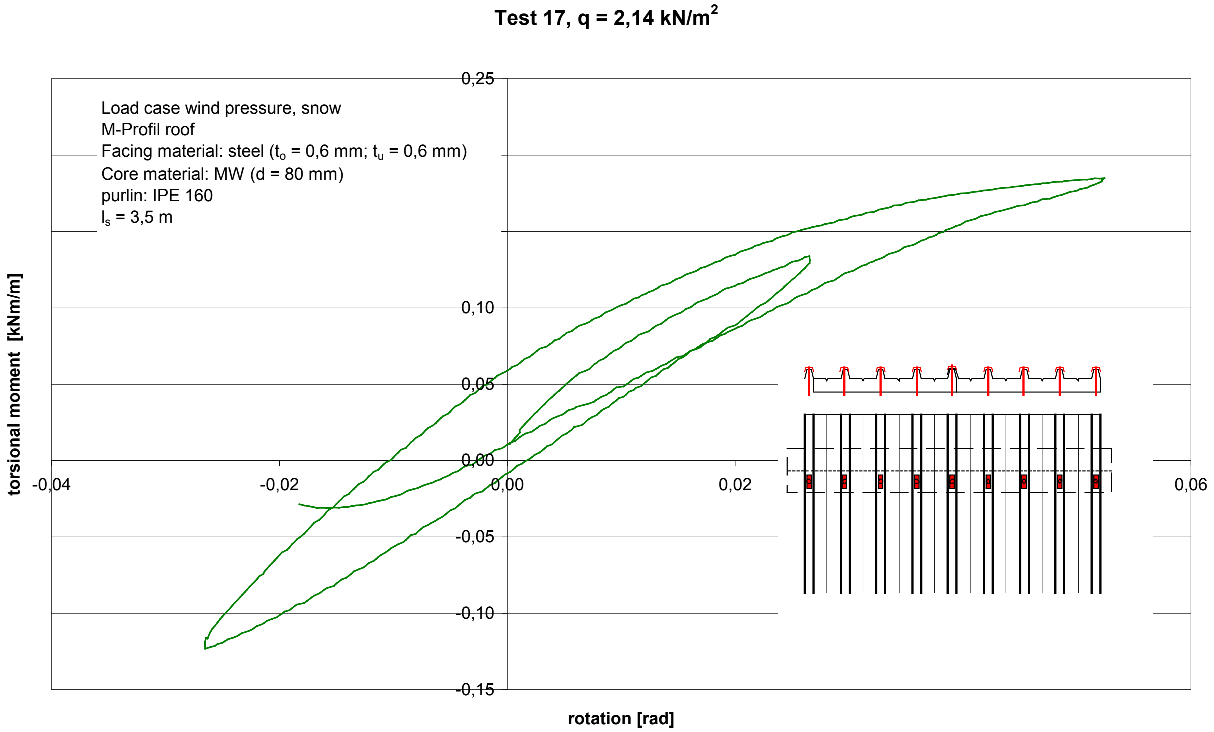
load p_1:	6,1 kN
load p_2:	10,9 kN
load p_3:	15,0 kN
remarks:	shear failure of the panel at load p_3 = 15,0 kN

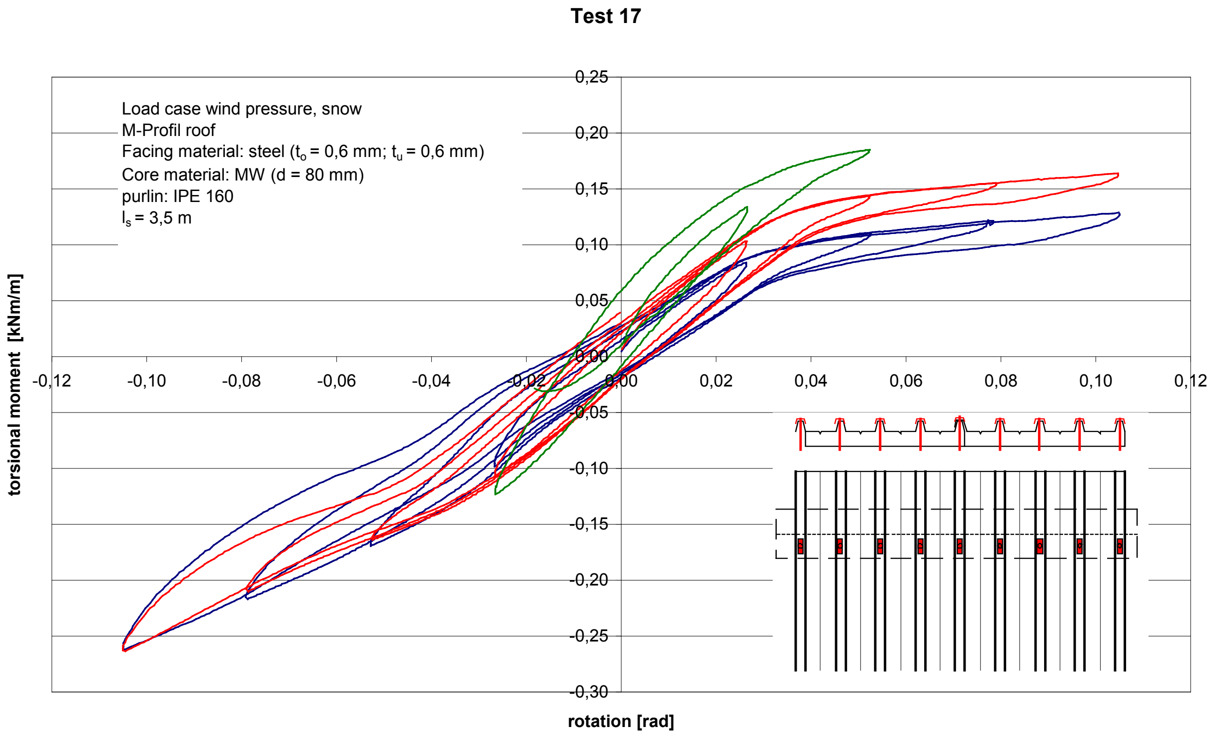
Test 17, q = 0,96 kN/m²



Test 17, q = 1,55 kN/m²




Test 17, q = 2,14 kN/m²
Load case wind pressure, snow
M-Profil roof
Facing material: steel (t_o = 0,6 mm; t_u = 0,6 mm)
Core material: MW (d = 80 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,25
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,04
-0,02
0,00
0,02
0,06


Test 17
Load case wind pressure, snow
M-Profil roof
Facing material: steel (t_o = 0,6 mm; t_u = 0,6 mm)
Core material: MW (d = 80 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,25
0,20
0,15
0,10
0,05
0,00
-0,05
-0,10
-0,15
-0,20
-0,25
-0,30
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

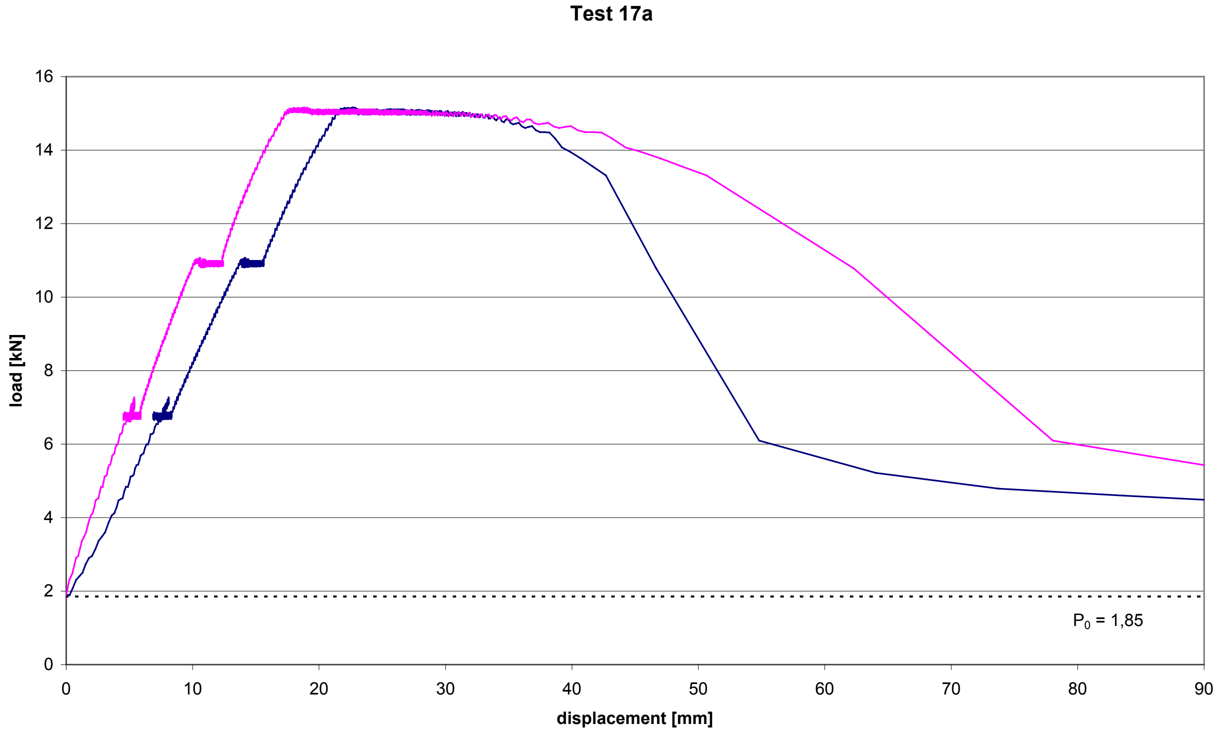
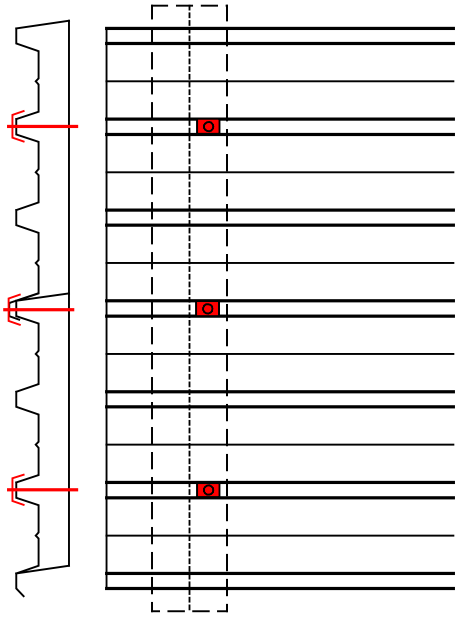


Fig. 14: shear failure of the panel at load p_3 = 15,0 kN

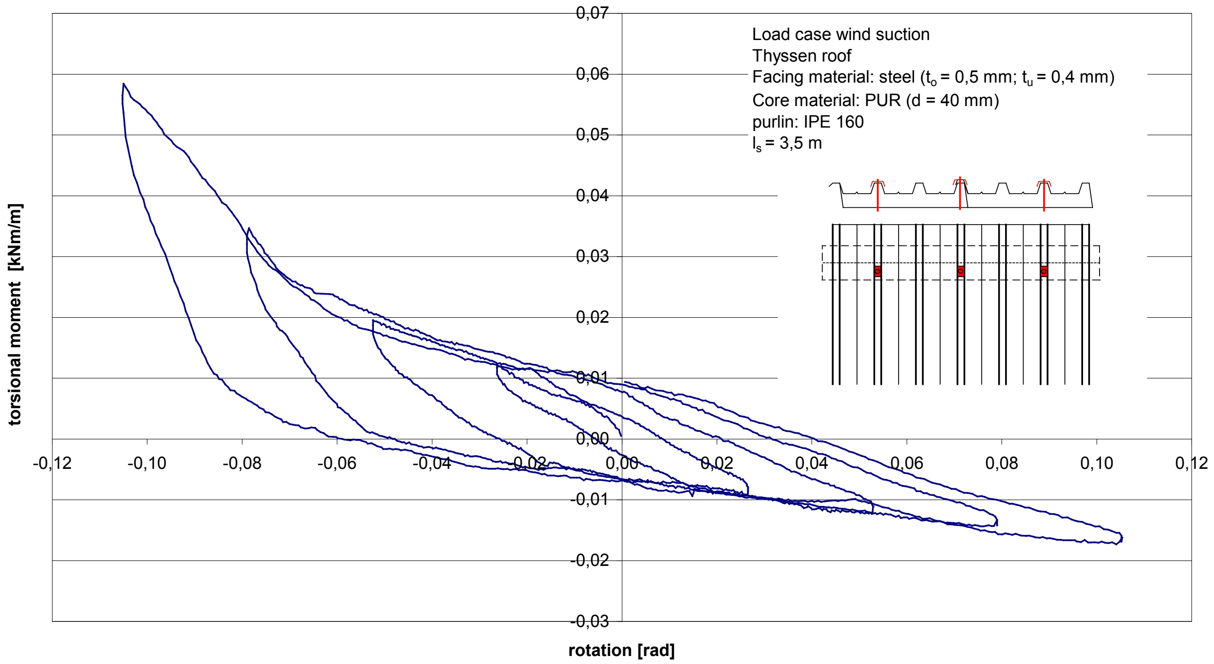
No. 18k

Application:	roof
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,40 mm
core material:	PUR
core thickness:	40 mm
beam section:	IPE 160
fasteners:	

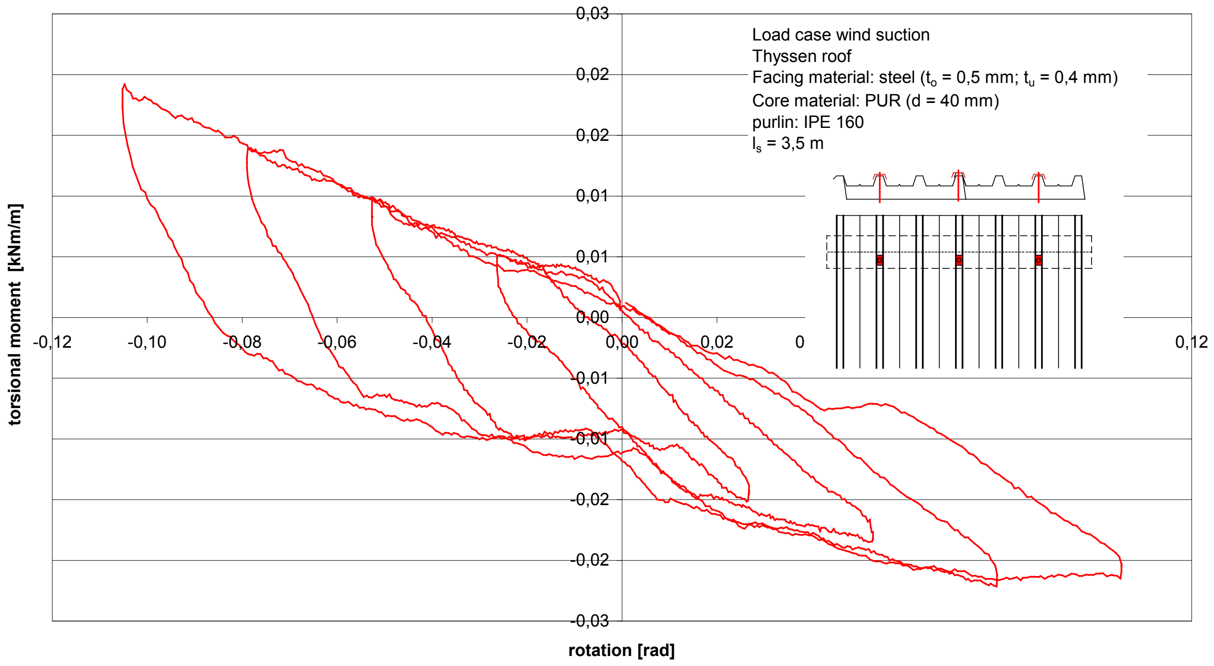


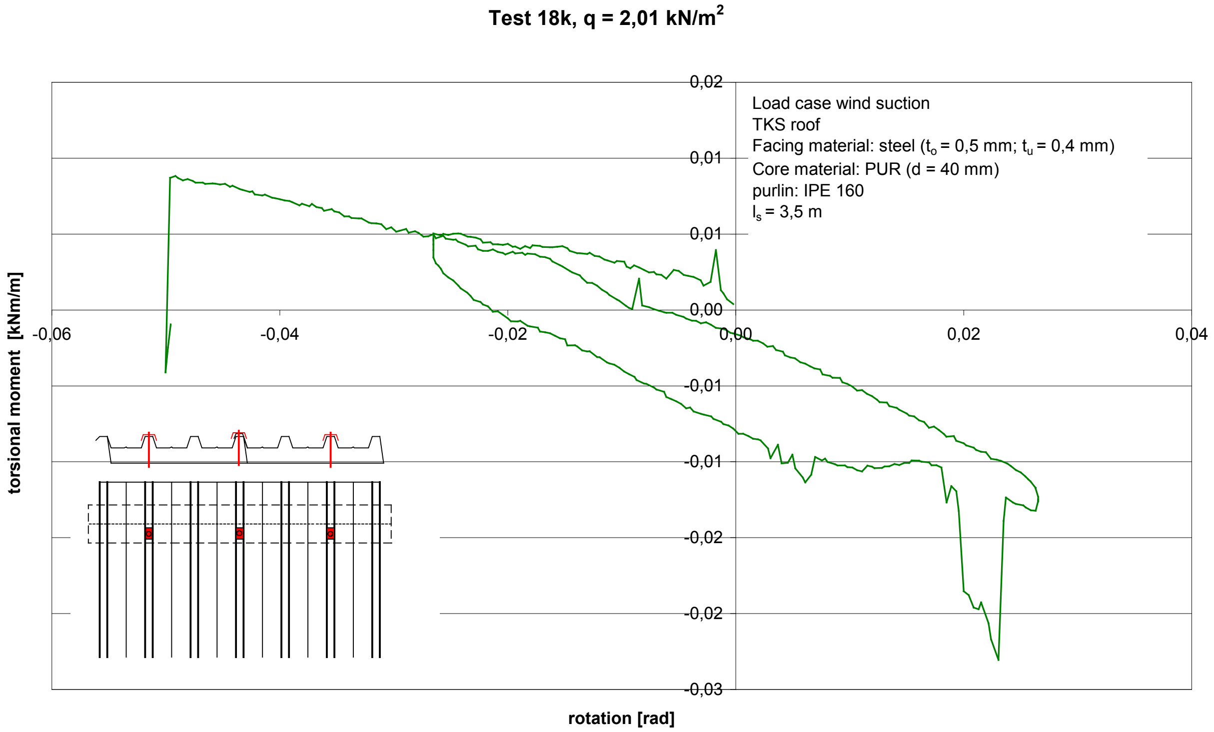
load p_1:	6,3 kN
load p_2:	10,2 kN
load p_3:	14,1 kN
remarks:	wrinkling failure of the panel at load p_3 = 14,1 kN

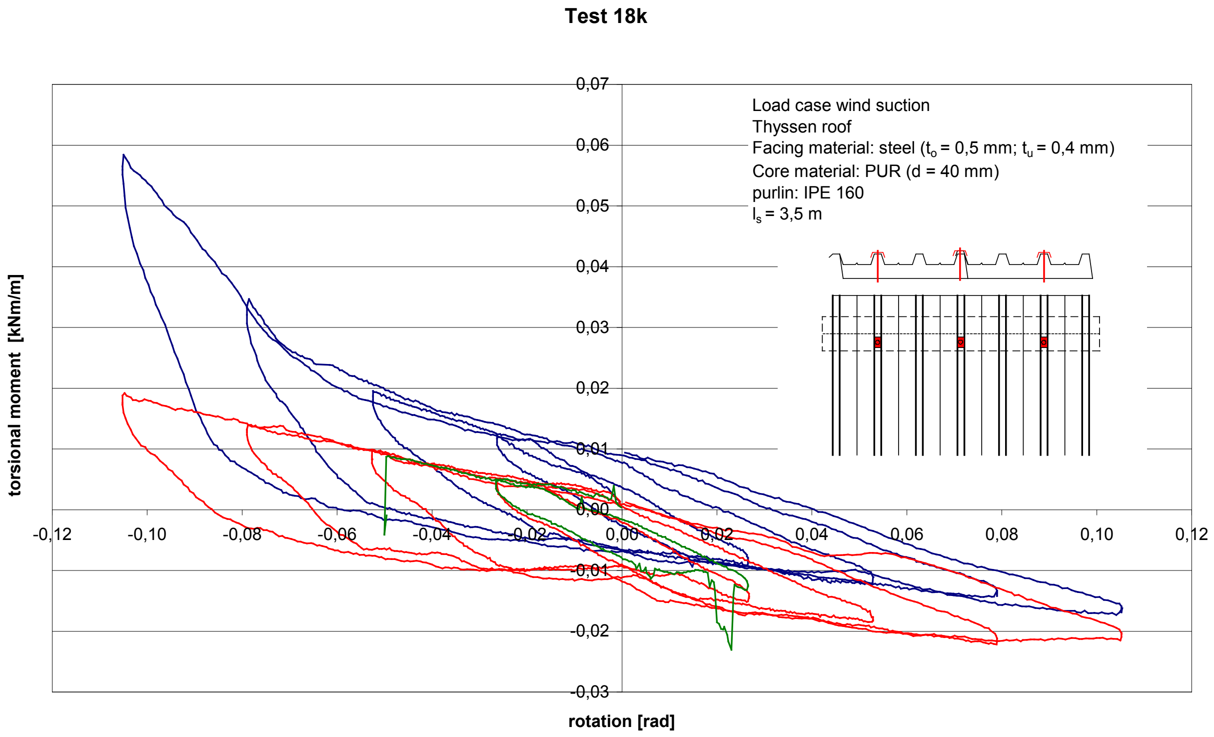
Test 18k, q = 0,9 kN/m^2



Test 18k, q = 1,45 kN/m^2




Test 18k, q = 2,01 kN/m²
Load case wind suction
TKS roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 18k
Load case wind suction
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]

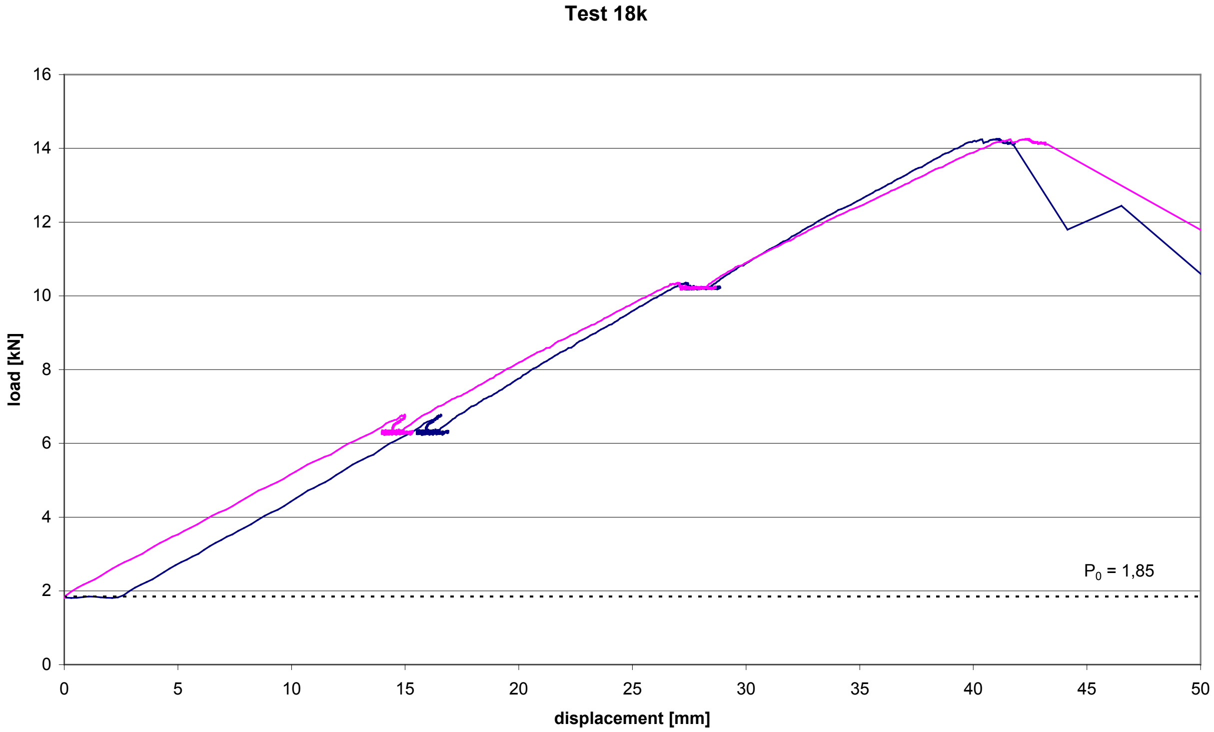


Fig. 15: Gap between face layer and beam

Fig. 16: Indentation of fastener, deformed saddle washer and web crippling

Fig. 17: Wrinkling failure of the panel at load p_3 = 14,1 kN

No. 18ok

Application: roof

Loading: uplift

length of panel: 4000 mm

Span: 3500 mm

face material: steel

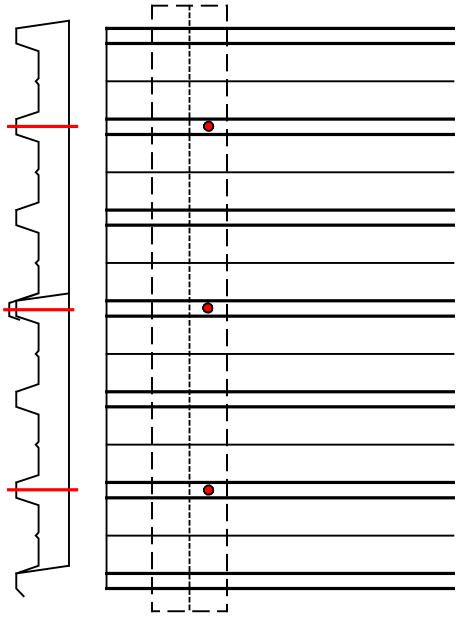
face thickness: 0,50 / 0,40 mm

core material: PUR

core thickness: 40 mm

beam section: IPE 160

fasteners:

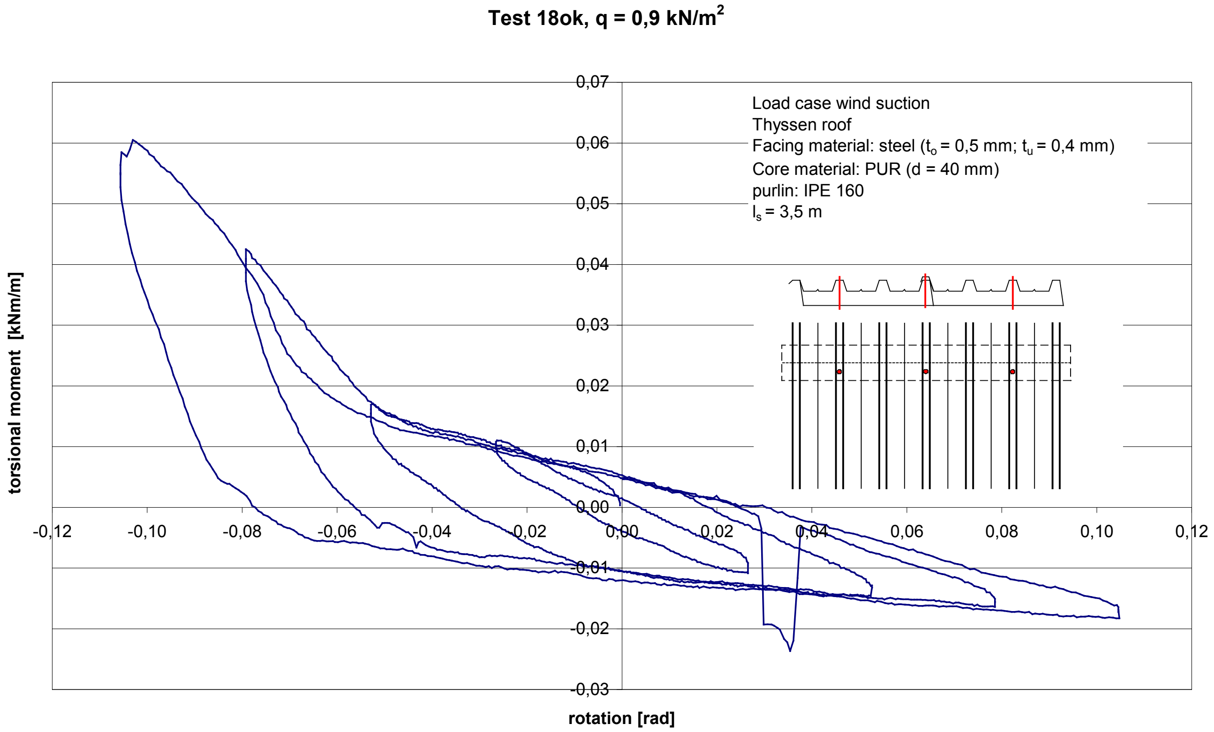


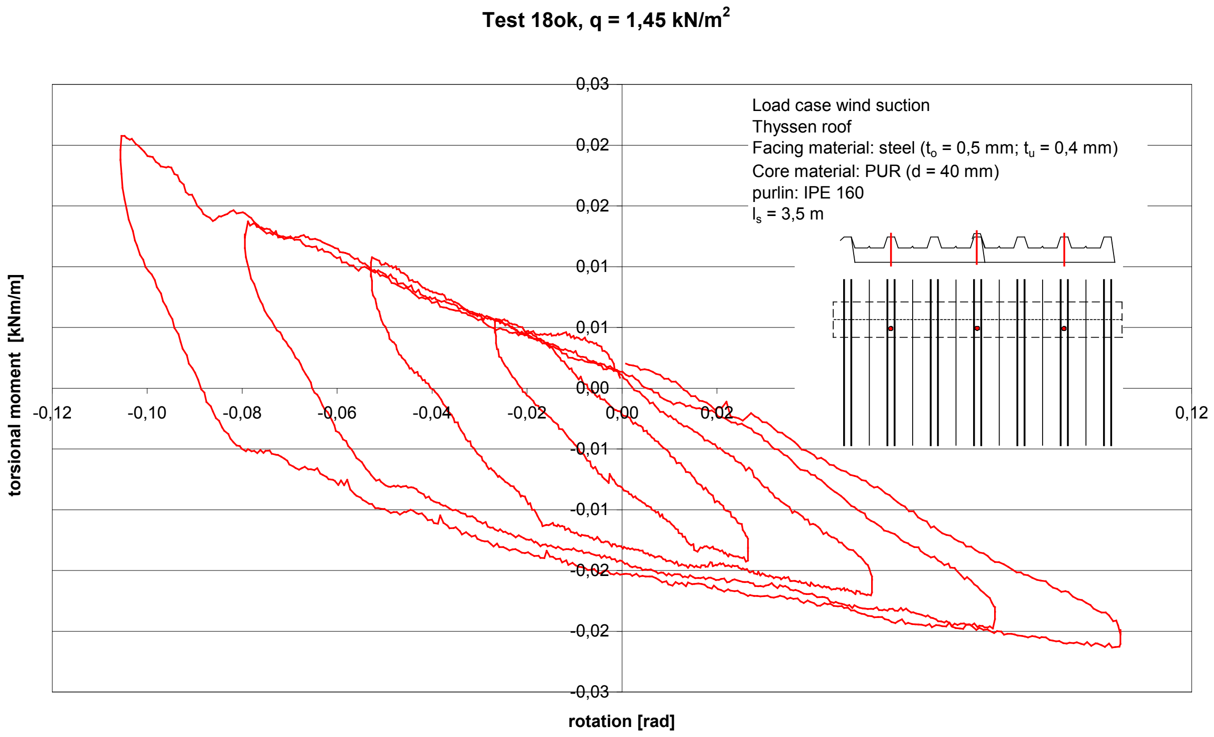
load p_1: 6,3 kN

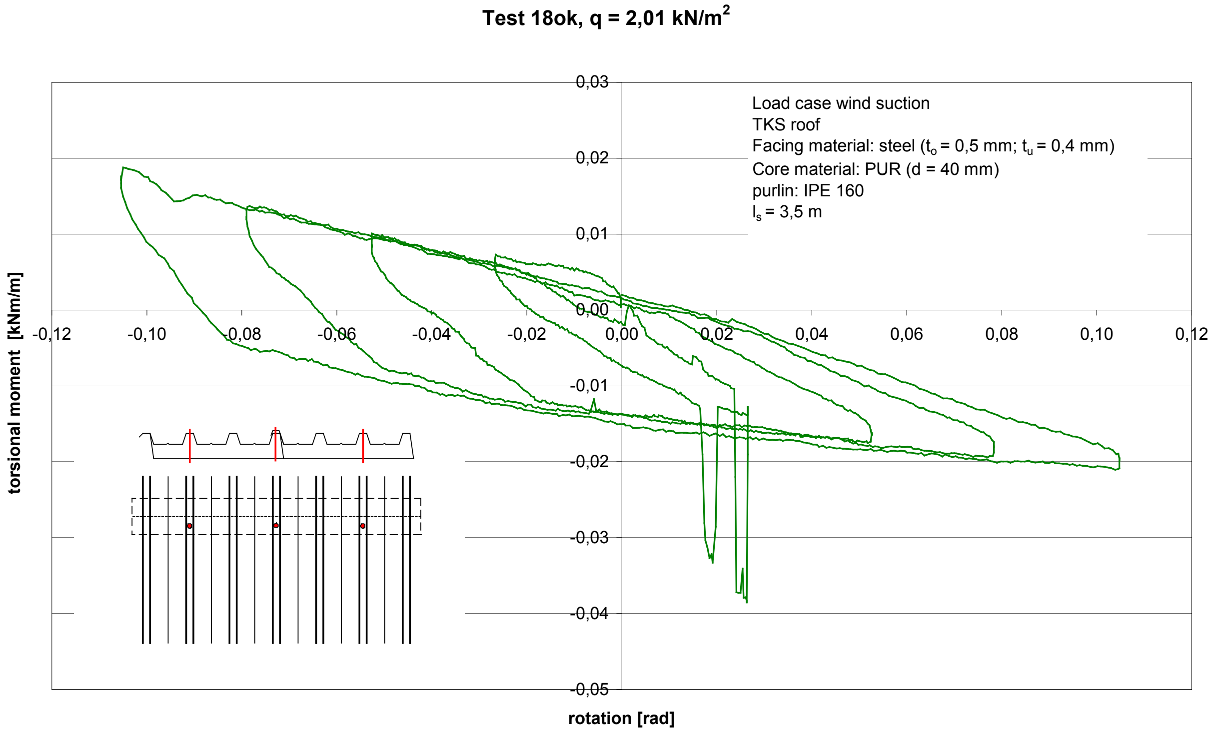
load p_2: 10,2 kN

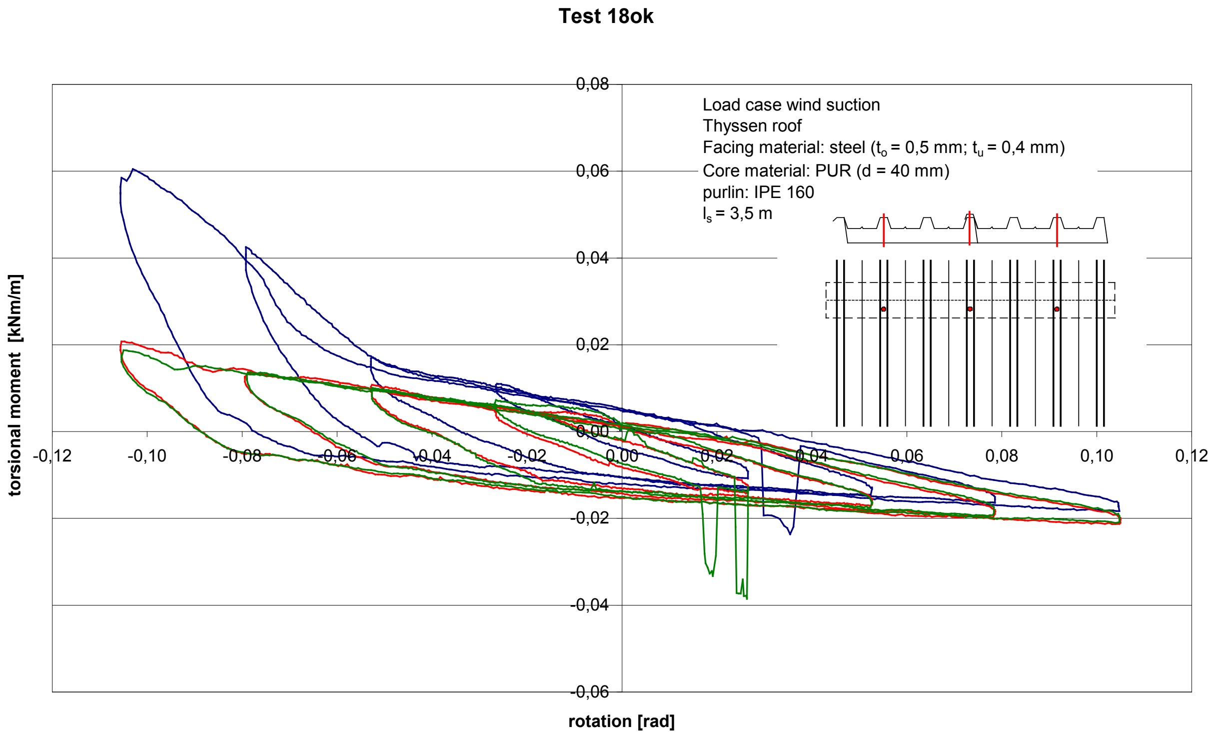
load p_3: 14,1 kN

remarks:


Test 18ok, q = 0,9 kN/m²
Load case wind suction
Thyssen roof
Facing material: steel (to = 0,5 mm; tu = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 18ok, q = 1,45 kN/m²
Load case wind suction
Thyssen roof
Facing material: steel (to = 0,5 mm; tu = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
ls = 3,5 m
torsional moment [kNm/m]
rotation [rad]


Test 18ok, q = 2,01 kN/m²
Load case wind suction
TKS roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,03
0,02
0,01
0,00
-0,01
-0,02
-0,03
-0,04
-0,05
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 18ok
Load case wind suction
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,08
0,06
0,04
0,02
0,00
-0,02
-0,04
-0,06
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

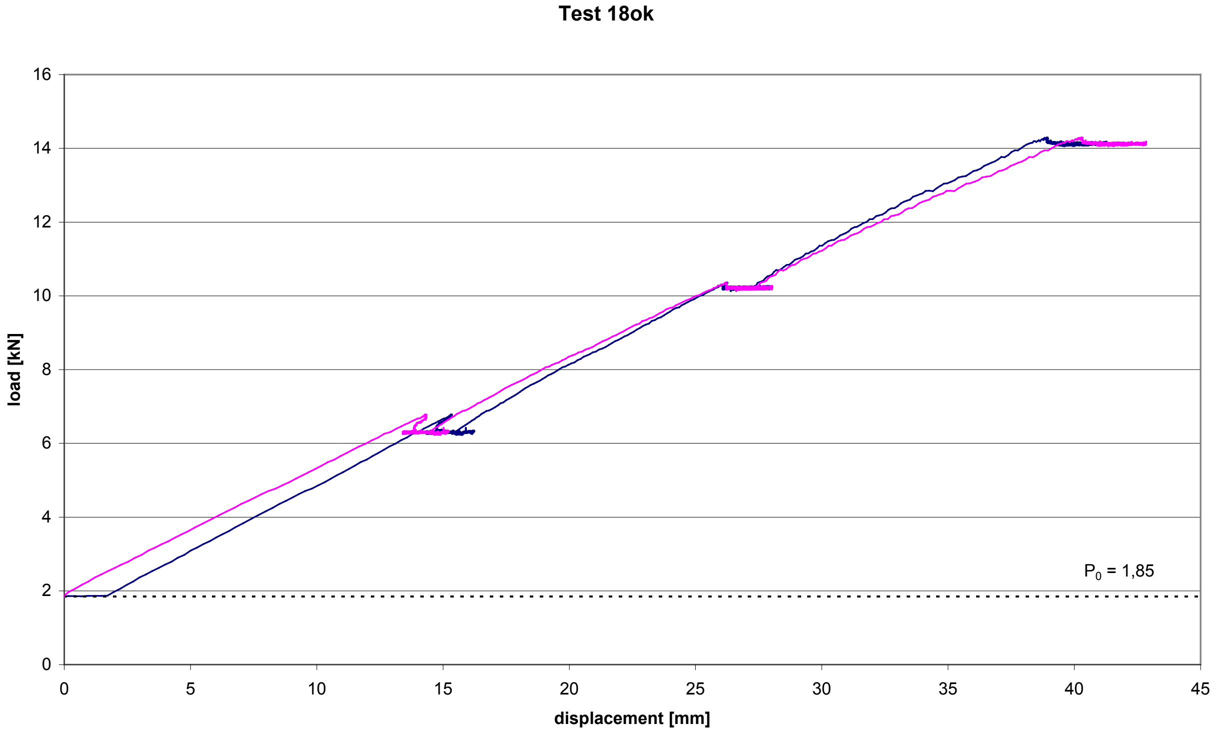
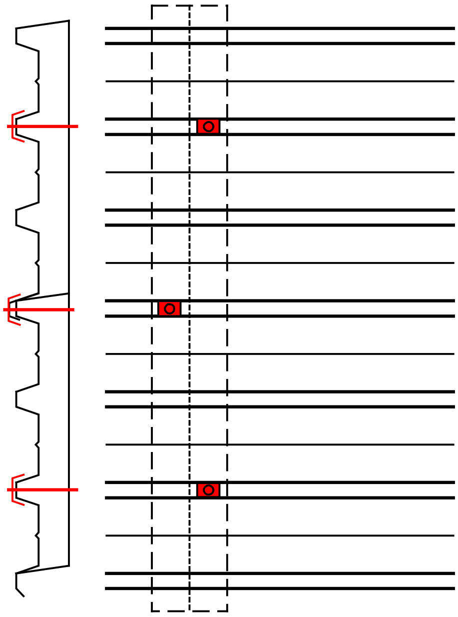


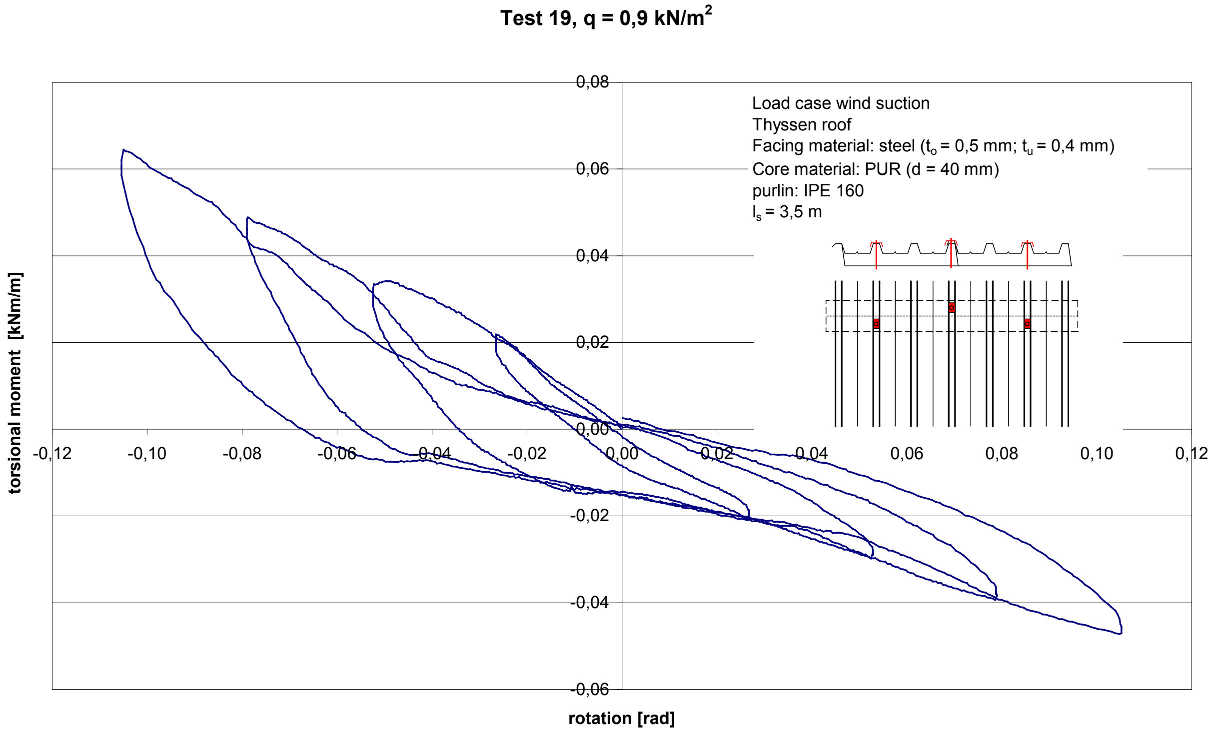
Fig. 18: Indentation of the fastener and web crippling

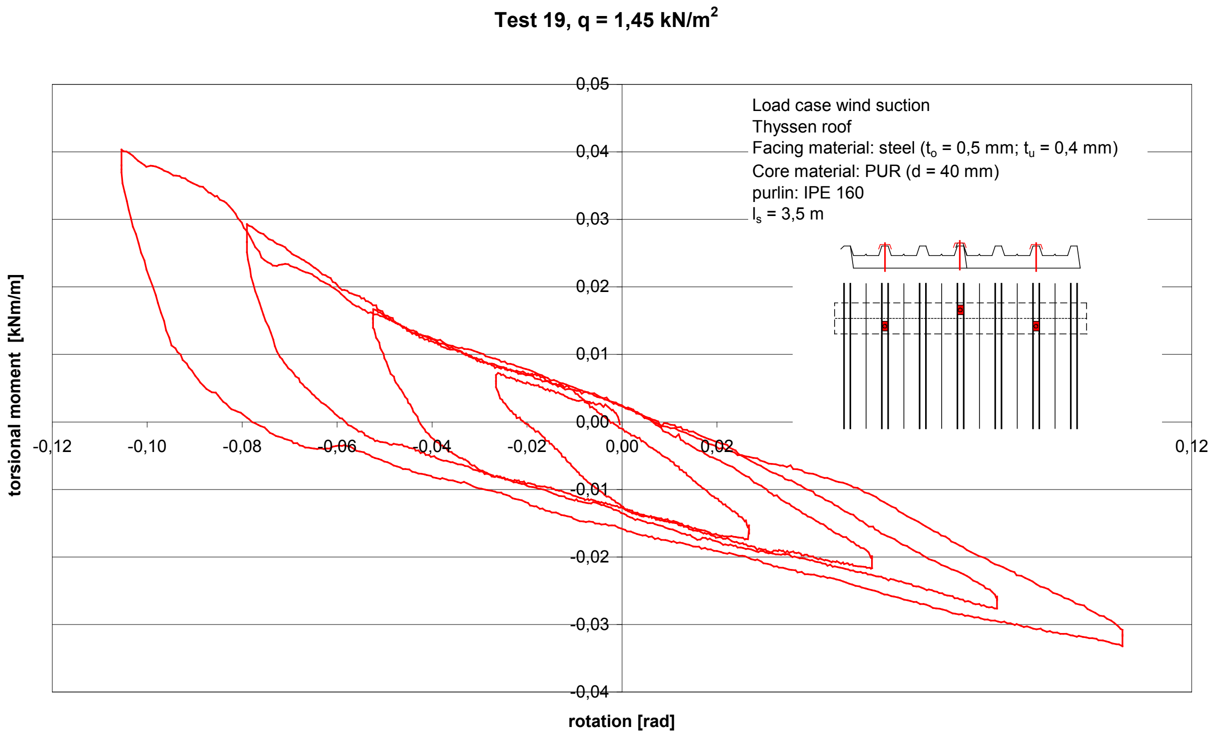
No. 19

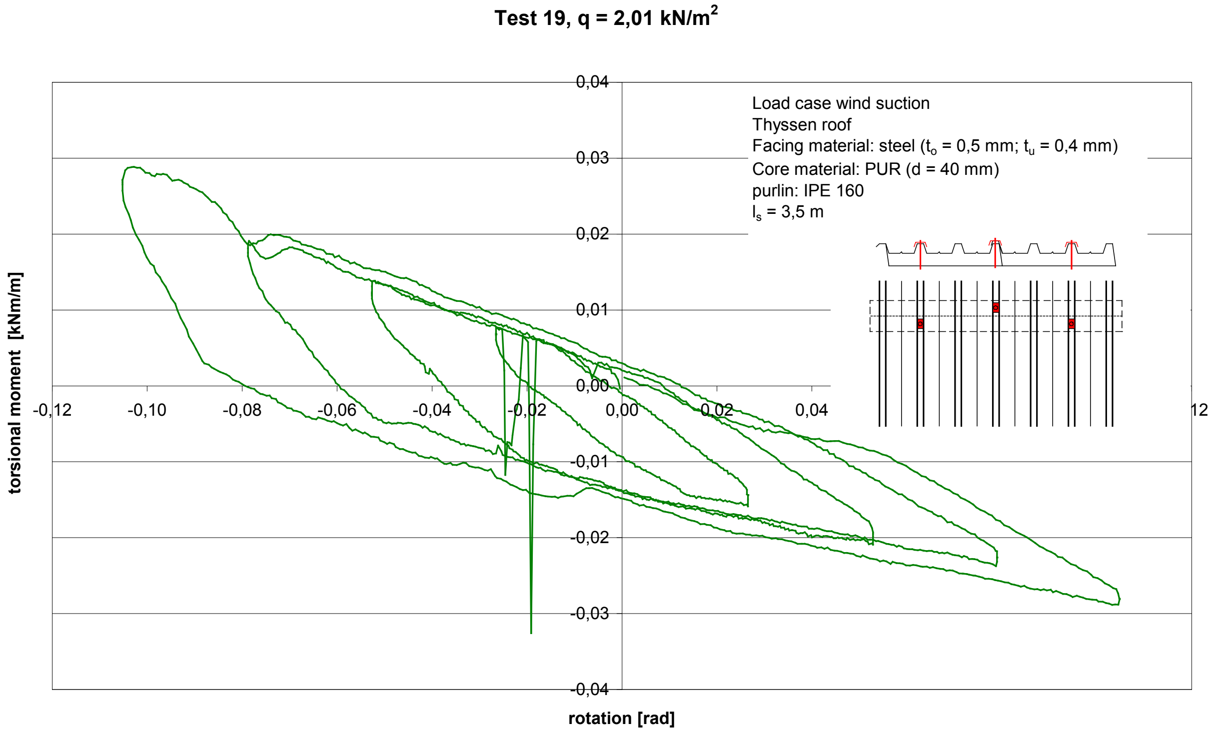
Application:	roof
Loading:	uplift
length of panel:	4000 mm
Span:	3500 mm
face material:	steel
face thickness:	0,50 / 0,40 mm
core material:	PUR
core thickness:	40 mm
beam section:	IPE 160
fasteners:	

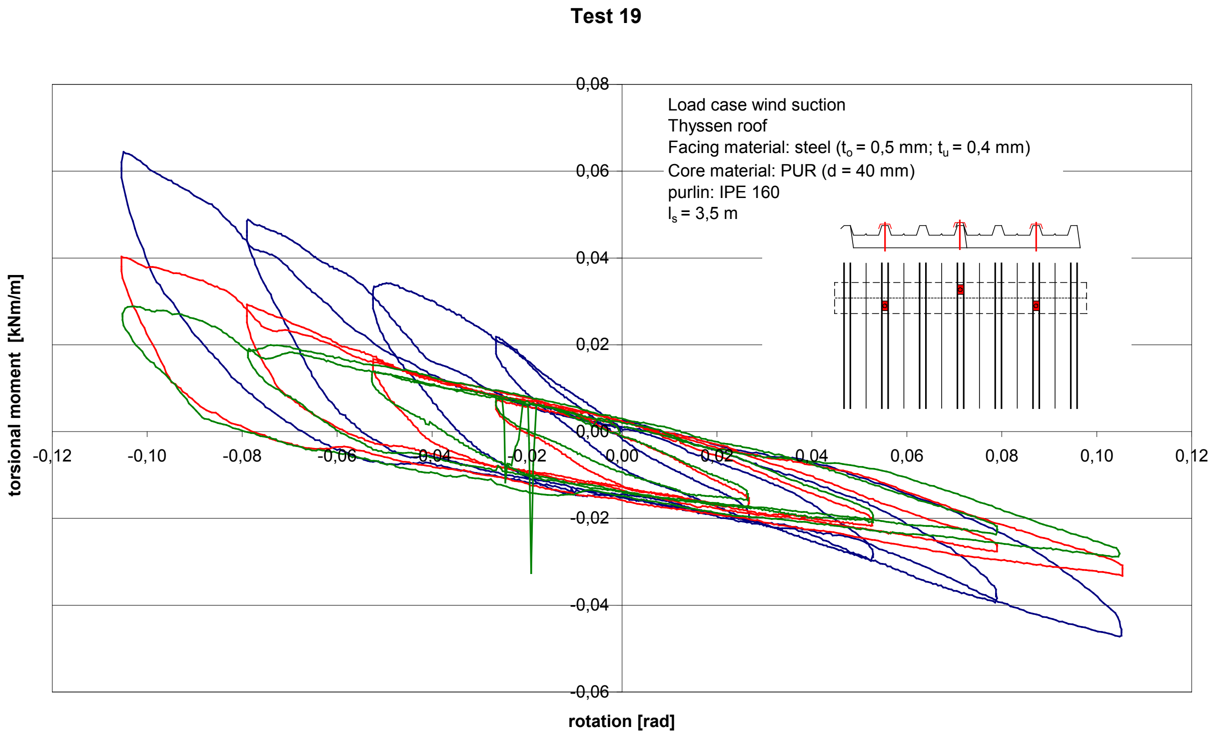


load p_1:	6,3 kN
load p_2:	10,2 kN
load p_3:	14,1 kN
remarks:	

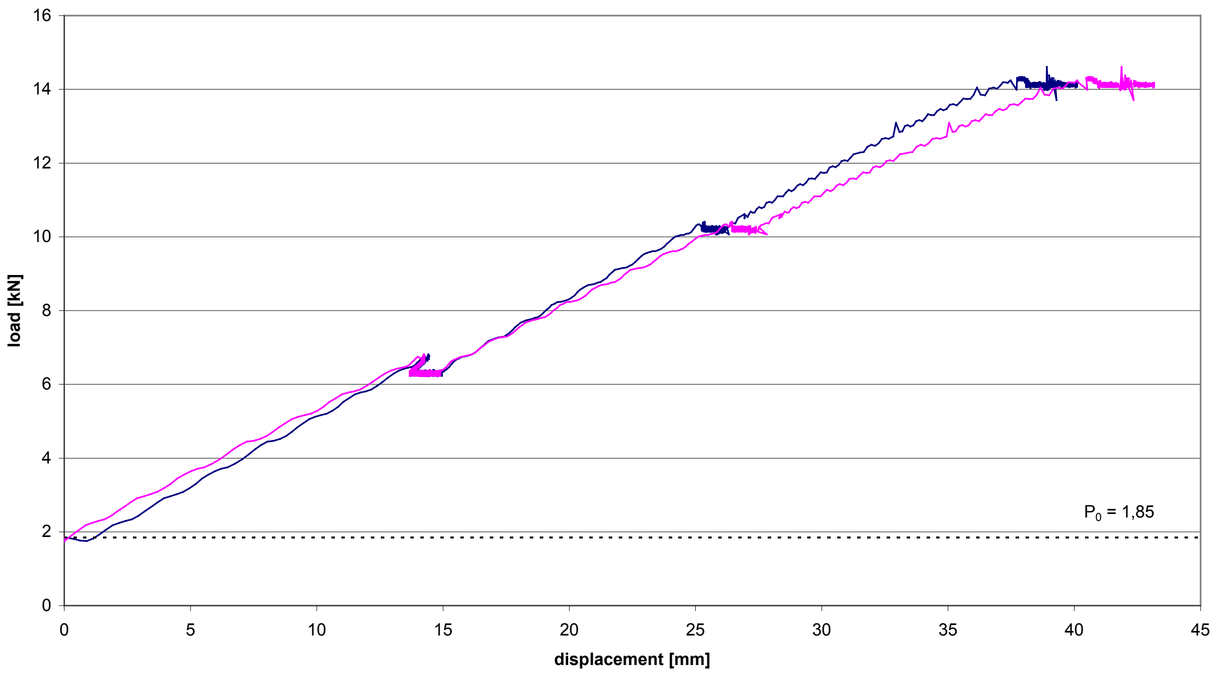

Test 19, q = 0,9 kN/m²
Load case wind suction
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,08
0,06
0,04
0,02
0,00
-0,02
-0,04
-0,06
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12


Test 19, q = 1,45 kN/m²
Load case wind suction
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,05
0,04
0,03
0,02
0,01
0,00
-0,01
-0,02
-0,03
-0,04
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,12


Test 19, q = 2,01 kN/m²
Load case wind suction
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,04
0,03
0,02
0,01
0,00
-0,01
-0,02
-0,03
-0,04
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04


Test 19
Load case wind suction
Thyssen roof
Facing material: steel (t_o = 0,5 mm; t_u = 0,4 mm)
Core material: PUR (d = 40 mm)
purlin: IPE 160
l_s = 3,5 m
torsional moment [kNm/m]
rotation [rad]
0,08
0,06
0,04
0,02
0,00
-0,02
-0,04
-0,06
-0,12
-0,10
-0,08
-0,06
-0,04
-0,02
0,00
0,02
0,04
0,06
0,08
0,10
0,12

Test 19


16
14
12
10
8
6
4
2
0
load [kN]
0
5
10
15
20
25
30
35
40
45
displacement [mm]
P0 = 1,85

6 Determination of the material properties

6.1 Mechanical properties of the metallic surface layers

After test performance, specimens for tensile tests according to DIN EN 10002-1 were worked out from the slightly stressed ranges of upper and lower surface layer at each tested type of element. The performance of tensile tests for determining the mechanical properties of surface layers was done on a universal testing machine of the Versuchsanstalt für Stahl, Holz und Steine of the University of Karlsruhe. For the determination of the yield strength $R_{eH}/R_{p0,2}$ and the tensile strength $R_{m,}$ the core thicknesses determined on the specimens were used. The mean values of the results are listed in Tab. 3.

No.		t_K [mm]	$R_{eH}/R_{p0,2}$ [N/mm²]	R_m [N/mm²]
01	positive	0,541	441	441
	negative	0,538	431	439
02	GFRP, see chapter 6.2			
03	positive	0,651	207	231
	negative	0,644	204	227
04a	positive	0,659	219	241
	negative	0,512	200	233
04b	see No. 04a			
05	positive	0,597	437	433
	negative	0,546	426	419
06	see No. 07			
07	positive	0,479	389	433
		0,495[1)]	410[1)]	423[1)]
	negative	0,485	430	437
		0,495[1)]	410[1)]	423[1)]
08	see No. 07			
09	positive	0,476	374	435
	negative	0,458	375	427
10	see No. 09			
11	see No. 01			
12	positive	0,478	408	439
	negative	0,381	424	441
13	see No. 12			
14	see No. 05			
16	see No. 12			
16k	see No. 12			
17	see No. 05			
18k	see No. 12			
18ok	see No. 12			
19	see No. 12			

[1)] Results of the tests performed by the manufacturer

Tab. 3: Mechanical properties of the metallic surface layers

6.2 Mechanical properties of the GFRP surface layers

Specimens for tensile tests according to DIN EN ISO 527-4 were worked out from samples taken form the batches used for the tests on torsional restraint. The performance of tensile tests for determining the mechanical properties of surface layers was done on a universal testing machine of the Versuchsanstalt für Stahl, Holz und Steine of the University of Karlsruhe. For the determination of the tensile strength $R_{m,}$ the thicknesses determined on the specimens were used. The mean values of the results are listed in Tab. 4.

No.	t	R_m	$E_{F,c}$	$E_{F,t}$
	[mm]	[N/mm²]	[N/mm²]	[N/mm²]
02	1,83	63	7582	7432

Tab. 4: Mechanical properties of the GFRP surface layers

In addition, tension/compression tests with a test device according to Gehring [3] were performed on GFRP facings for determining the modulus under compression and tensile loading. The values are listed in Tab. 4.

6.3 Mechanical properties of the core layer

The mechanical properties were determined according to [N3]. The determination of the compression strength f_{Cc} β_z, the tensile strength f_{Ct}, the shear strength f_{Cv}, the density ρ, as well as the appropriate shear, compression and tensile module values G_C, E_{Cc} and E_{Ct} was realized on at least three specimens. For the compression and tensile tests, specimens with the dimension 100 m 100 x thickness of the element were taken from panels not used for the tests on torsional restraint. The analysis of the modulus of elasticity E_C was realised as mean value from the compression and tensile module of a specimen pair. The mean values of the results are listed in Tab. 5 and Tab. 6.

No.	f_{Cv}	f_{Cc}	f_{Ct}	ρ
	[N/mm²]	[N/mm²]	[N/mm²]	[kg/m³]
01	0,142	0,177	0,145	-
	-	0,169 1)	-	-
02	0,124	0,165	0,253	-
	-	0,143 1)	-	-
03	0,123	0,111	0,189	-
04a	0,130	0,106	0,153	-
04b	see No. 04a			
05	0,039	0,107	0,049	-
06	see No. 07			
07	0,144	0,149	0,088	-
	0,14 1)	0,151 1)	0,114 1)	37,8 1)
08	see No. 07			
09	0,146	0,107	0,101	-
	0,16 1)	0,151 1)	0,102 1)	145 1)
10	see No. 09			
11	see No. 01			
12	0,111	0,156	0,049	-
	0,17 1)	0,150 1)	0,099 1)	43,6 1)
13	see No. 12			
14	see No. 05			
16	see No. 12			
16k	see No. 12			
17	see No. 05			
18k	see No. 12			
18ok	see No. 12			
19	see No. 12			

1) Results of the tests performed by the manufacturer

Tab. 5: Mechanical properties of the core layer – strength and density

No.	G_C	E_{Cc}	E_{Ct}	E_C
	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]
01	5,15	4,14	4,92	4,53
	-	4,69[1)]	-	-
02	4,75	3,25	6,31	4,78
	-	3,65[1)]	-	-
03	3,62	1,58	4,40	2,99
04a	3,46	1,79	3,61	2,70
04b	see No. 04a			
05	3,26	4,43	3,69	4,06
06	see No. 07			
07	4,54	3,03	3,18	3,11
	3,59[1)]	3,99[1)]	5,43[1)]	4,71[1)]
08	see No. 07			
09	15,77	6,36	7,07	6,72
	16,24[1)]	7,70[1)]	24,9[1)]	16,3[1)]
10	see No. 09			
11	see No. 01			
12	7,83	2,75	2,46	2,61
	4,33[1)]	2,77[1)]	7,88[1)]	5,32[1)]
13	see No. 12			
14	see No. 05			
16	see No. 12			
16k	see No. 12			
17	see No. 05			
18k	see No. 12			
18ok	see No. 12			
19	see No. 12			
[1)] Results of the tests performed by the manufacturer				

Tab. 6: Mechanical properties of the core layer - module

7 Summary

WP 3 of the EASIE project deals with the application of sandwich panels for stiffening of buildings and building components and in addition as a replacement for the load transferring substructure. D3.2-part 1the results of the experimental tests on stabilisation of beams by torsional restraint are presented. The evaluation of the results can be found in deliverable D3.3 – part 1. Deliverable D3.3 – part 1 is also dealing with the numerical calculations and the derivation of a design concept.

8 References

[1] Dürr, M. 2008. Die Stabilisierung biegedrillknickgefährdeter Träger durch Sandwichelemente und Trapezbleche. Karlsruhe: Berichte der Versuchsanstalt für Stahl, Holz und Steine der Universität Fridericiana in Karlsruhe, 5. Folge Heft 17.

[2] Lindner,J., Gregul, T.: Drehbettungswerte für Dacheindeckungen mit unterlegter Wärmedämmung. Stahlbau 58 (1989), S. 173-179.

[3] Gehring, A. 2008. Beurteilung der Eignung von metallischem Band und Blech zum Walzprofilieren. Karlsruhe: Berichte der Versuchsanstalt für Stahl, Holz und Steine der Universität Fridericiana in Karlsruhe, 5. Folge Heft 19.

[4] Preliminary European Recommendations for the Testing and Design of Fastenings for Sandwich Panels: ECCS - European Convention for constructional steelwork, TWG 7.9 Sandwich panels and related structures & CIB - International Council for Research and Innovation in Building Construction, W056 Lightweight Constructions. Brussels/Rotterdam 2009.

[N1] DIN 18800-2:2008-11: Stahlbauten – Teil 2: Stabilitätsfälle – Knicken von Stäben und Stabwerken (Steel structures - Part 2: Stability - Buckling of bars and skeletal structures)

[N2] EN 1933-1-3:2006: Eurocode 3: Design of steel structures - Part 1-3: General rules - Supplementary rules for cold-formed members and sheeting

[N3] EN 14509:2006: Self-supporting double skin metal faced insulating panels - Factory made products - Specifications