European Commission
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ANGELHY

Innovative solutions for design and strengthening of telecommunications and transmission lattice towers using large angles from high strength steel and hybrid techniques of angles with FRP strips

WORK PACKAGE 3 – DELIVERABLE 3.2

Report on experimental tests on closely spaced built-up members

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1 Introduction

Task 3.2 of Work Package WP3 of ANGELHY project includes 16 laboratory tests on closely spaced built-up members fabricated from angle sections. As described in the Deliverable 3.1 [1], three various configurations are tested: "back-to-back connected angles" (BBE tests), "star battened angles with equal sections" (SBE tests) and "star battened angles with unequal sections" (SBU tests). Each specimen is made with two L-shape profiles joint with several packing plates and bolts (M16 10.9 or M12 10.9). They are illustrated in Figure 1.1.

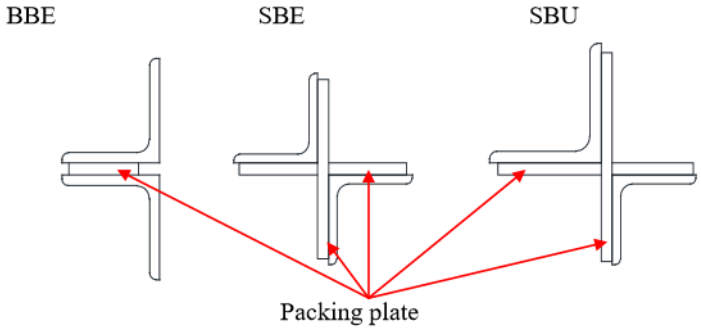


Figure 1.1: Three various configurations.

The details about the experimental campaign including measurements before and during the tests, as well as the test results, are presented in the current report. The test campaign has been carried out in the "Laboratoire de Mécanique des Matériaux et Structures" at University of Liège.

2 Test specifications

The various specimen tests which are carried out during this test campaign are reported in Table 1. The information provided in this section just constitutes so a brief summary of the deliverable 3.1 [1] which describes all the technical specifications for this test campaign.

Table 1: Specimen specifications as reported in deliverable 3.1 [1].

Notation	Cross-section	Member length L (mm)*	Total number of packing plates**	Estimated failure load (kN)	Mid-span displacement for peak load level (mm)
BBE1	2 L 70 x 70 x 7	1200	7	630	1,6
BBE2	2 L 70 x 70 x 7	3600	19	230	34
BBE3	2 L 70 x 70 x 7	2000	4	490	5
BBE4	2 L 70 x 70 x 7	3600	6	220	22
BBE5	2 L 70 x 70 x 7	3600	19	-	-
BBE6	2 L 70 x 70 x 7	3600	6	-	-
SBE1	2 L 60 x 60 x 6	2200	2 x 4	220	15
SBE2	2 L 60 x 60 x 6	3000	2 x 5	130	35
SBE3	2 L 60 x 60 x 6	3000	2 x 4	130	35
SBE4	2 L 60 x 60 x 6	4000	2 x 5	80	70
SBE5	2 L 60 x 60 x 6	3000	2 x 5	-	-
SBE6	2 L 60 x 60 x 6	4000	2 x 5	-	-
SBU1	L 80 x 80 x 8 + L 60 x 60 x 6	2200	2 x 4	260	1,9
SBU2	L 80 x 80 x 8 + L 60 x 60 x 6	3000	2 x 5	200	2,3
SBU3	L 80 x 80 x 8 + L 60 x 60 x 6	3000	2 x 4	200	2,9
SBU4	L 80 x 80 x 8 + L 60 x 60 x 6	4000	2 x 5	140	2,8

It is important to note that the SBU specimens have been delivered to the University of Liège with steel angles L70x70x7 instead of the L80x80x8 planned ones.

The steel grade used for each specimen is S355.

According to deliverable 3.1 [1], all test specimens are to be tested with pinned support conditions at their extremities, except for the BBE specimens in which pinned conditions are to be achieved for bending about strong axis and clamped conditions in the perpendicular directions. These different end conditions are guided by the wish, for the BBE tests, to favour the strong-axis buckling mode of the columns. adapted in order to ensure a failure mode characterised by buckling about the major-axis.

For BBE and SBE tests, the compression force is applied at the centre of gravity of the built-up sections, while it is not the case for SBU tests. End plates are welded at the end of the specimens, which help to position the specimen at its right place in the test machine. Nevertheless, as specified above, the SBU specimens have been delivered with L70x70x7 angles instead of the L80x80x8 … but the positioning of the endplates has not been modified accordingly! Eccentricity measurements are reported in section 4.3.

Various tightening torques have been considered for the bolting of the profiles with the packing plates. The tightening torques are reported in Table 2 here below.

Table 2: Tightening torque used for bolting the steel profiles

Bolt	M16 10.9	M12 10.9
Diameter D (mm)	16	12
f_{ub}(N/mm²)	900	900
A_s(mm²)	157	84,3
Full level pretension $F_{p,CD}$(kN)=0.7xf_{ub}xA_s	98,9	53,1
K factor	0,16	0,16
Tightening torque for 100 % $F_{p,CD}$(N.m)	253,2	102
Tightening torque for 10 % $F_{p,CD}$(N.m)	25,3	10,2

The tightening torque is calculated thanks to the following formula (see notations in Table 2):

$$\text{Tightening torque} = k \cdot D \cdot F_{p,CD}.$$

For some bolts, the tightening torque is calculated considering 100 % of $F_{p,CD}$ (full tightening) while, for others, the tightening torque is calculated considering 10 % of $F_{p,CD}$ (snug tightening). The Table 3 here below gives the tightening torque used for each specimen.

Table 3: Tightening torque for each specimen.

Specimen	Tightening torque (N.m)
BBE1	253
BBE2	253
BBE3	253
BBE4	253
BBE5	25,3
BBE6	25,3
SBE1	102
SBE2	102
SBE3	102
SBE4	102
SBE5	10,2
SBE6	10,2
SBU1	253/102
SBU2	253/102
SBU3	25,3/10,2
SBU4	25,3/10,2

3 Test rig

The SCHENK Hydropuls equipment has been used during this test campaign. This equipment is an hydraulic test rig (servohydraulic machine). The key features of this equipment are:

- Usable height between compression plates (0,5x0,5): from 0,3 to 5,2m ;
- Static force capacity of ± 2500 kN ;

The loading is done by imposed displacements.

(b) General view of the test rig equipment

(a) SBU1 specimen test rig

(c) Connection between compression plates and specimen edge plates

Figure 3.1: General view of the test rig configuration.

The speed of the loading is 3mm in 10 minutes at the beginning of the test. When the load is closing the expected peak load (failure), the speed is reduced to 3mm in 20 minutes in order to avoid any potential dynamic effect.

The measured data are automatically recorded by the control computer.

4 Measurements before and during a test

Before the experiments, the actual dimensions and eccentricity measurements as well as the initial geometrical imperfections of the specimens (out-of straightness) have been measured. These ones are provided in sections 4.1 to 4.3.

Coupons tests were also planned to be realised before the start of the experimental campaign but, as the extra lengths of angles ordered for this purpose have not been delivered together with the specimens, coupons have been extracted from the angles after they have been tested. The measured steel properties are reported for each angle section type in section 4.4.

The measurements achieved during the tests (by means of displacement transducers and strain gauges) are reported in section 4.5.

4.1 Actual dimensions of the cross-sections

The actual geometrical dimensions of each specimen have been measured at 3 points along the member length: 1/4, 1/2 and 3/4 of the total length (L). The performed measurements are reported in Figure 4.1. The mean values of the measurements on BBE specimens are reported in Table 4 below.

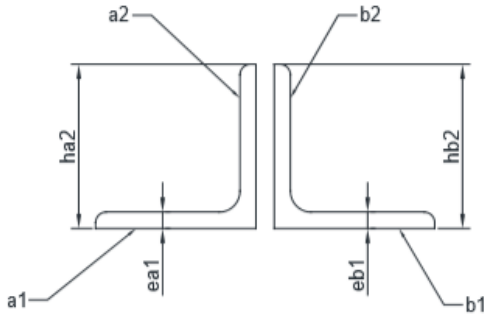


Figure 4.1: Measurements on BBE specimens.

Table 4: Mean values of actual BBE geometrical dimensions.

Specimen	Mean BBE profile geometries			
	ha_2 [mm]	ea_1 [mm]	hb_2 [mm]	eb_1 [mm]
BBE1	70,17	6,77	70,12	6,81
BBE2	69,93	6,86	70,00	6,83
BBE3	69,96	6,82	70,13	6,89
BBE4	69,87	6,82	69,80	6,86
BBE5	69,90	6,83	69,93	6,86
BBE6	69,93	6,84	69,83	6,85

The measurements on SBE specimens are reported in Figure 4.2 and Table 5 below.

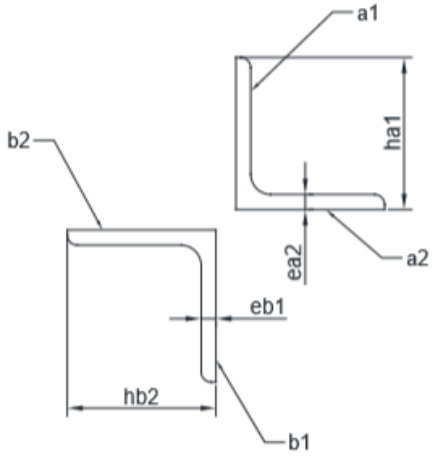


Figure 4.2: Measurements on SBE specimens.

Table 5: Mean values of actual SBE geometrical dimensions.

Specimen	Mean SBE profile geometries			
	ha_1[mm]	ea_2 [mm]	hb_2 [mm]	eb_1 [mm]
SBE1	59,73	5,82	60,40	6,05
SBE2	60,63	6,05	60,53	6,05
SBE3	60,60	6,02	59,80	5,85
SBE4	60,53	5,92	60,57	6,10
SBE5	60,53	6,05	60,87	5,91
SBE6	59,87	6,10	60,57	6,07

Finally, the SBU measurements are reported in Figure 4.3 and Table 6.

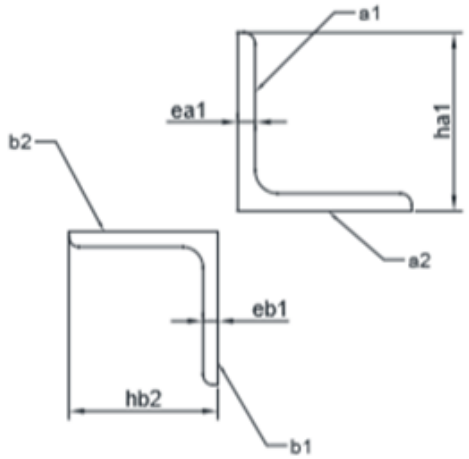


Figure 4.3: Measurements on SBU specimens.

Table 6: Mean values of actual SBU geometrical dimensions.

Specimen	Mean SBU profile geometries			
	ha_1[mm]	ea_1 [mm]	hb_2[mm]	eb_1 [mm]
SBU1	69,87	6,93	59,87	6,03
SBU2	69,93	6,89	60,13	6,07
SBU3	69,90	6,91	60,37	6,01
SBU4	69,93	6,89	59,62	5,88

4.2 Initial Imperfections

Before performing the buckling tests, the geometrical imperfection of each specimen has been measured along its length in order to evaluate its out-of-straightness.

For each geometrical imperfection measurement, the specimen is positioned parallel to a bench equipped with a trolley carrying four laser displacement transducers. The trolley moves along the bench and each of the four laser displacement transducers measures the distance to the specimen. The same process is done with the specimen turned by 90°. This allows to have the initial deformation of the specimen in the two planes. The first measurement point is located at several centimetres from the intersection plan between the profiles and the end-plate. The laser measurement is not continuous but made by successive steps. The measurement step depends on the position of the bolts used to connect the packing plates.

As the chariot supporting the inclinometer was moving onto a horizontal guiding bar, a small rotation of the metric system was created. Moreover, the column wasn't perfectly parallel to the set-up. The first correction to achieve concerns, therefore, the non-parallelism and the rotation of the metric system. Laser measurements have to be corrected by using the following formula:

Laser measurement 1: Mesure 1 - Reference + 2,2 x Inclino
Laser measurement 2: Mesure 2 - Reference + 2,0 x Inclino
Laser measurement 3: Mesure 3 - Reference + 1,2 x Inclino
Laser measurement 4: Mesure 4 - Reference + 0,7 x Inclino

The geometric imperfection curves are reported for each specimen detail in Annex B. For each individual laser measurement, the measured imperfections are reported on the Y axis and the displacements of the trolley on the X axis; then these curves are rotated and shifted so that the y values (member imperfections) equal zero at the two extremities of the element (more explanation about this shift is provided below). Finally, for each of these curves, the ratio between the maximum laser measurement F and the length travelled by the vehicle along the member is evaluated.

Figure 4.4 and Figure 4.5 show the configurations and the details of the measurement system.

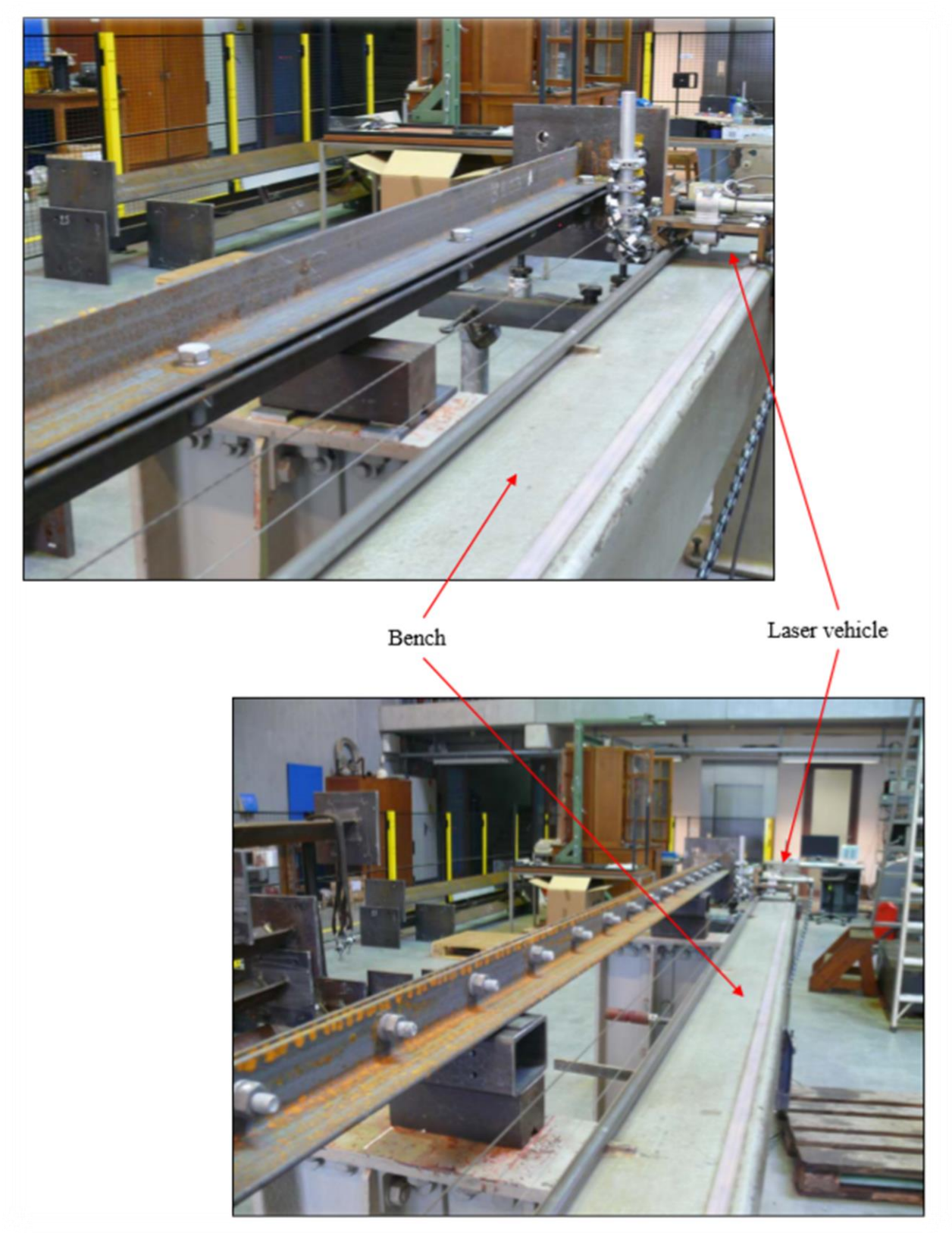


Figure 4.4: Configurations and details of the measurement system.

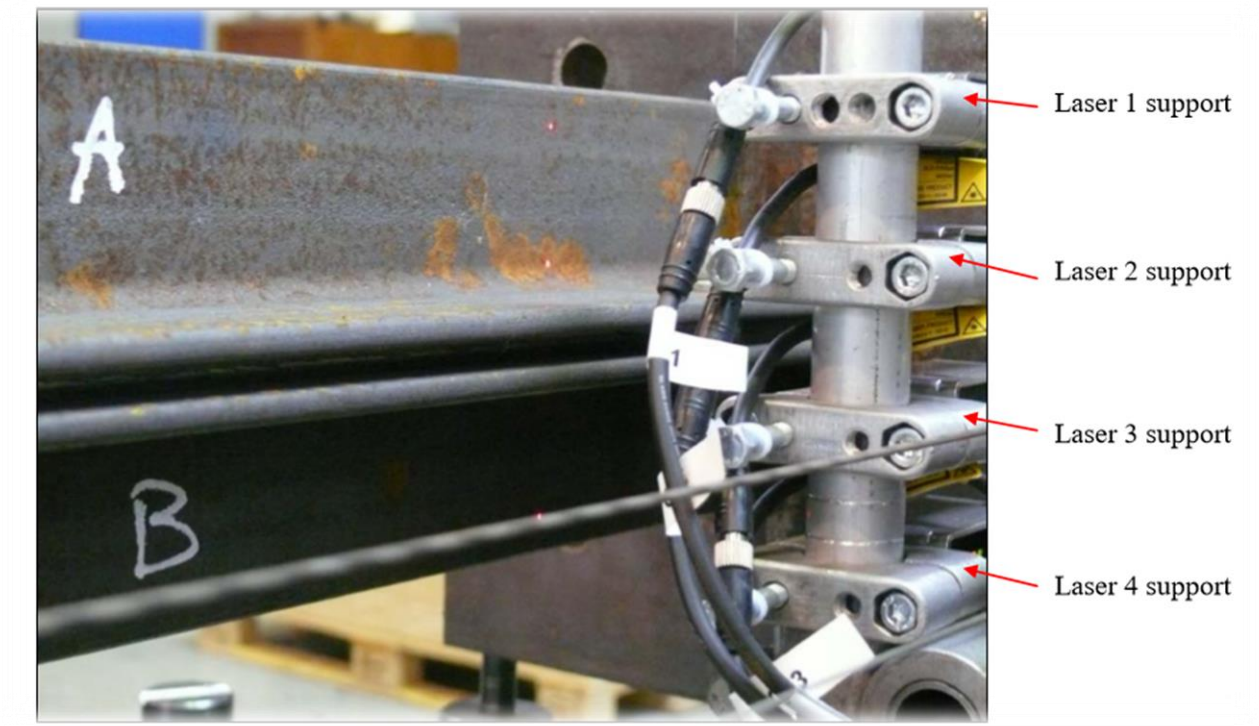
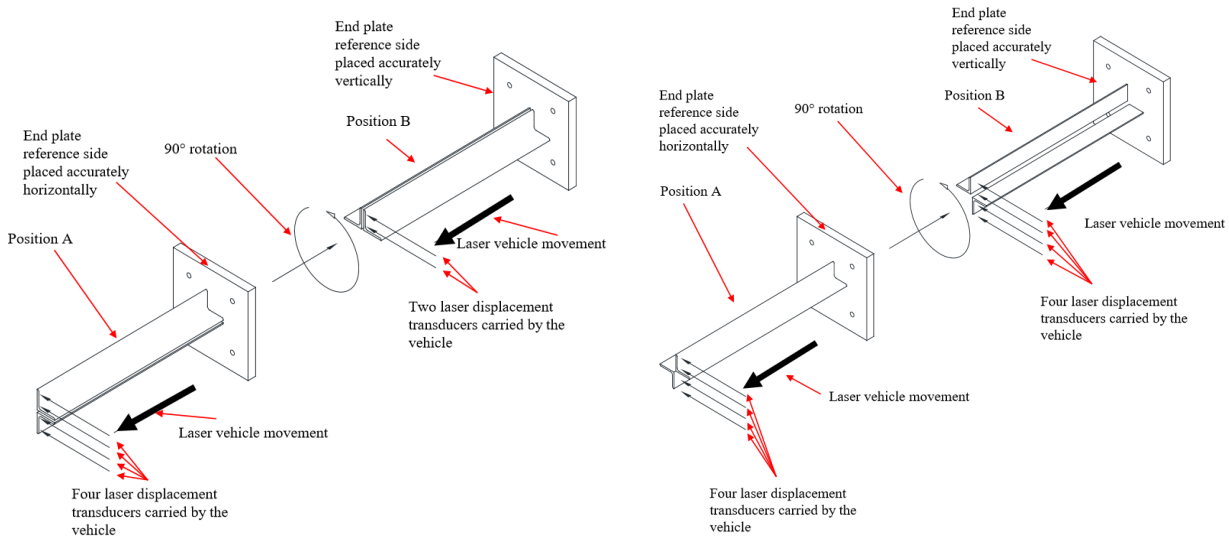


Figure 4.5: Laser supports of the measurement system.

The initial imperfections of each specimen have been measured in two perpendicular planes, in agreement with the illustrations in Figure 4.6: Initial imperfection measurement details for each specimen category.



(a) BBE specimens (b) SBE/SBU specimens

Figure 4.6: Initial imperfection measurement details for each specimen category.

As explained above, the first correction brought to the raw laser measurement values concerns the non parallelism and the rotation of the metric system (the specimens and the bench axis are not perfectly parallel). The second correction consists in ensuring a zero imperfection at the extremities of the column length. The initial imperfections finally obtained for the BBE1 specimen are illustrated, as an example, in Figure 4.7.

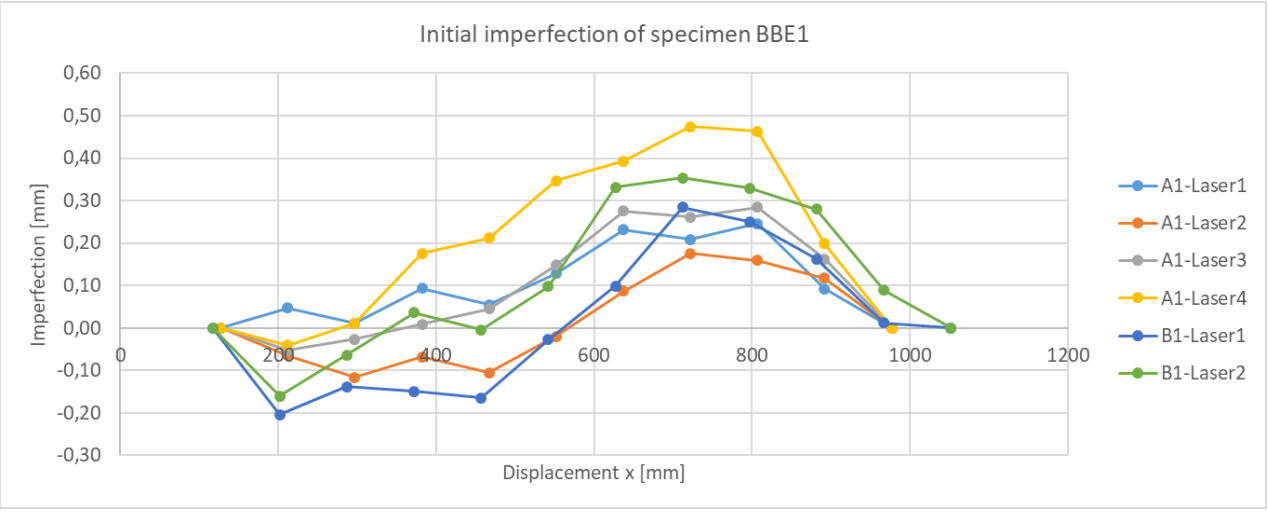


Figure 4.7: Initial imperfection of BBE1.

It is important to note that the shift of the curves is imposed by the fact that the first and last laser measurements location cannot be exactly performed at the extremities of the column (no possibility of access resulting from the presence of the welded endplates). To overpass this difficulty, it is reasonably assumed that the member is straight and without any imperfection in the small zones lying in between the column extremities and the sections where the first and last measurements are performed. The measurements of the initial imperfections are reported in graphs in Annex B for each specimen.

The values of the initial geometric imperfection measurements are reported in Table 7.

Table 7: Initial geometric imperfection measurements for each specimen.

Initial geometric imperfections									
Specimen	Position	Length (mm)	First measure location (mm)	Measurement Step (mm)	Laser Transducers used	F/L Laser 1	F/L Laser 2	F/L Laser 3	F/L Laser 4
BBE1	A	1200	127	85	1-2-3-4	0,00029	0,00021	0,00034	0,00056
	B		117	85	1-2	0,00030	0,00038	/	/
BBE2	A	3600	123	108	1-2-3-4	0,00033	0,00030	0,00019	0,00028
	B		121	108	1-2	0,00038	0,00034	/	/
BBE3	A	2000	118	125	1-2-3-4	0,00029	0,00020	0,00021	0,00031
	B		121	125	1-2	0,00025	0,00028	/	/
BBE4	A	3600	119	115	1-2-3-4	0,00038	0,00030	0,00017	0,00020
	B		114	115	1-2	0,00038	0,00036	/	/
BBE5	A	3600	125	108	1-2-3-4	0,00033	0,00038	0,00041	0,00038
	B		125	108	1-2	0,00014	0,00021	/	/
BBE6	A	3600	115	115	1-2-3-4	0,00044	0,00050	0,00048	0,00053
	B		114	115	1-2	0,00048	0,00047	/	/

SBE1	A	2200	183	265	1-2-3-4	0,00011	0,00023	0,00023	0,00035
	B		176	265	1-2-3-4	0,00031	0,00010	0,00013	0,00029
SBE2	A	3000	179	240	1-2-3-4	0,00038	0,00042	0,00036	0,00043
	B		171	240	1-2-3-4	0,00017	0,00010	0,00019	0,00015
SBE3	A	3000	176	240	1-2-3-4	0,00060	0,00057	0,00017	0,00017
	B		185	240	1-2-3-4	0,00018	0,00020	0,00023	0,00023
SBE4	A	4000	172	240	1-2-3-4	0,00052	0,00051	0,00041	0,00035
	B		180	240	1-2-3-4	0,00036	0,00038	0,00053	0,00055
SBE5	A	3000	175	240	1-2-3-4	0,00016	0,00010	0,00011	0,00024
	B		170	240	1-2-3-4	0,00032	0,00023	0,00022	0,00016
SBE6	A	4000	175	240	1-2-3-4	0,00044	0,00050	0,00048	0,00053
	B		170	240	1-2-3-4	0,00076	0,00078	0,00076	0,00090

SBU1	A	2200	241	215	1-2-3-4	0,00123	0,00124	0,00128	0,00126
	B		240	215	1-2-3-4	0,01200	0,01300	0,01610	0,01470
SBU2	A	3000	239	230	1-2-3-4	0,00075	0,00080	0,00076	0,00076
	B		242	230	1-2-3-4	0,00035	0,00028	0,00064	0,00031
SBU3	A	3000	231	230	1-2-3-4	0,00024	0,00036	0,00036	0,00043
	B		216	230	1-2-3-4	0,00024	0,00019	0,00026	0,00018
SBU4	A	4000	212	235	1-2-3-4	0,00123	0,00124	0,00128	0,00126
	B		219	235	1-2-3-4	0,00120	0,00130	0,00161	0,00147

The measurement system described in this subsection is similar to the one used for the experimental campaign concerning the compression tests on large angle columns in high strength steels, which is included in WP2 of the ANGELHY project [2].

4.3 Eccentricity measurements on edge plates

Some measurements have been performed on all specimen in order to verify the exact position of each specimen on its end supporting plates and so to identify a possible eccentricity at which the compression force would be applied in the testing machine. Figure 4.8, Figure 4.9 and Figure 4.10 indicate the various performed measurements for each specimen category.

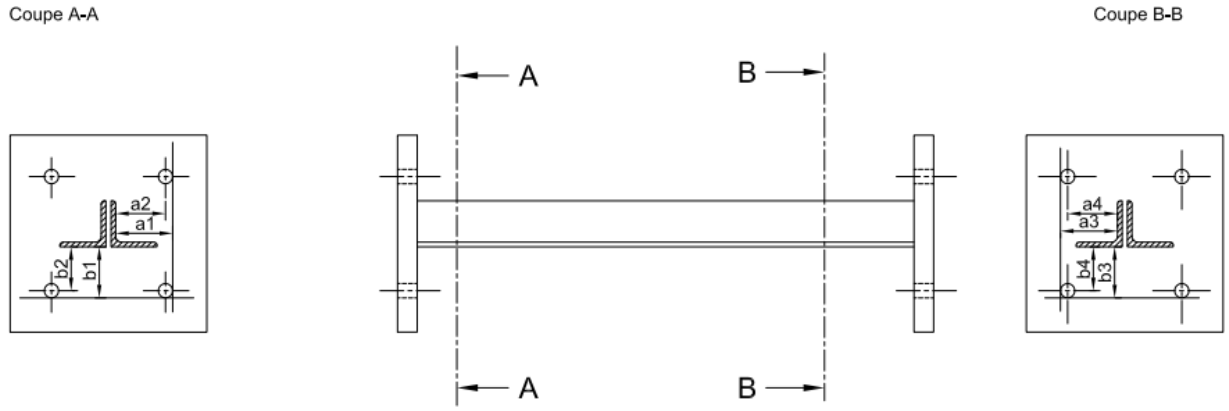


Figure 4.8: Eccentricity measurements on BBE specimens

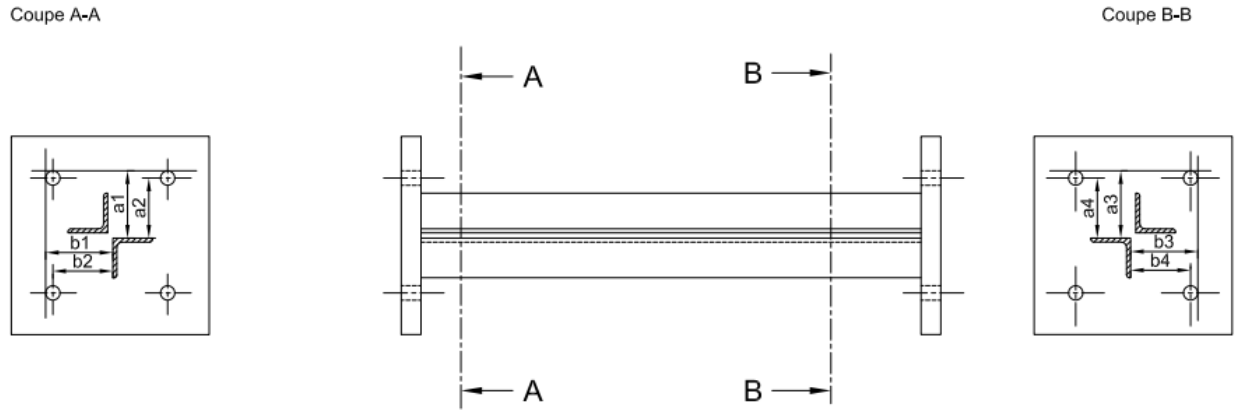


Figure 4.9: Eccentricity measurements on SBE specimens

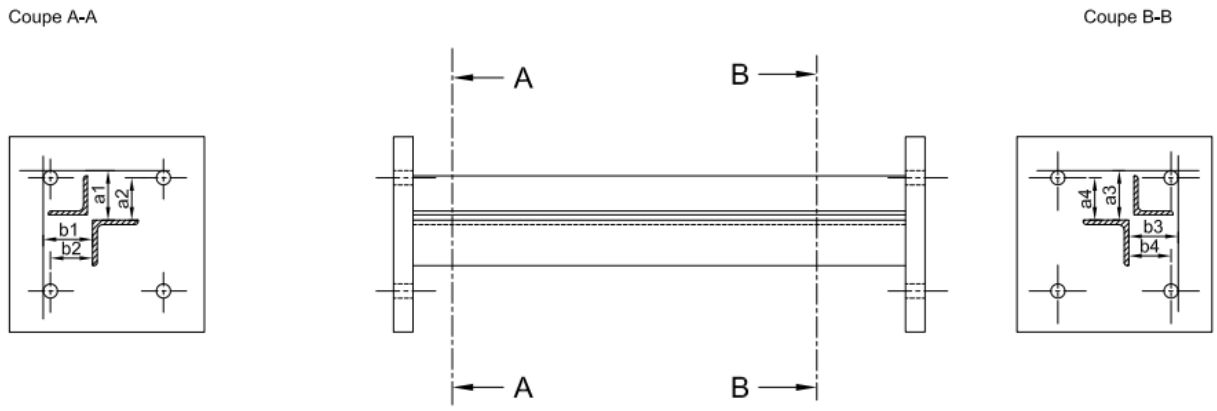


Figure 4.10: Eccentricity measurements on SBU specimens

The initially planned (nominal) values and the measured ones are reported in Table 8. As a reminder, the measurements have been performed with L70x70x7 instead of L80x80x8 steel angles for SBU specimens.

Table 8: Eccentricity measurements on each specimen categories.

Nominal values								
	Bottom plate				Upper plate			
Specimen	a1 (mm)	a2 (mm)	b1 (mm)	b2 (mm)	a3 (mm)	a4 (mm)	b3 (mm)	b4 (mm)
SBE	102	91	102	91	102	91	102	91
SBU	76	65	76	65	76	65	76	65
BBE	87	76	78	67	87	76	78	67
Lab measurements								
	Bottom plate				Upper plate			
Specimen	a1 (mm)	a2 (mm)	b1 (mm)	b2 (mm)	a3 (mm)	a4 (mm)	b3 (mm)	b4 (mm)
SBE1	101	90	102,2	91,2	103,4	92,4	104	93
SBE2	102,4	91,4	103	92	100,3	89,3	103,8	92,8
SBE3	101,6	90,6	102	91	104,1	93,1	102,1	91,1
SBE4	104,1	93,1	101,7	90,7	101	90	103,2	92,2
SBE5	101,3	90,3	103,7	92,7	103,2	92,2	103,6	92,6
SBE6	102,6	91,6	102,8	91,8	100,5	89,5	102,3	91,3
SBU1	75,1	64,1	77	66	75,5	64,5	75,5	64,5
SBU2	75,8	64,8	73,6	62,6	73,9	62,9	73,5	62,5
SBU3	74,4	63,4	79,2	68,2	77,1	66,1	75,8	64,8
SBU4	76,5	65,5	73,8	62,8	75,7	64,7	76,3	65,3
BBE1	86	75	77,6	66,6	85,3	74,3	77	66
BBE2	86,3	75,3	77,2	66,2	86,4	75,4	77,3	66,3
BBE3	87,6	76,6	77,7	66,7	82,8	71,8	77,4	66,4
BBE4	89,1	78,1	78,4	67,4	87,6	76,6	78,5	67,5
BBE5	87	76	79	68	86,8	75,8	77,5	66,5
BBE6	87,6	76,6	77,6	66,6	89,1	78,1	77,9	66,9

4.4 Material properties

Coupon tests have been performed in accordance with ISO 6892-1:2016 [3]. Figure 4.11 shows the strain – stress curve obtained from one coupon test and the characteristic values for each intented measurements are reported in Table 9.

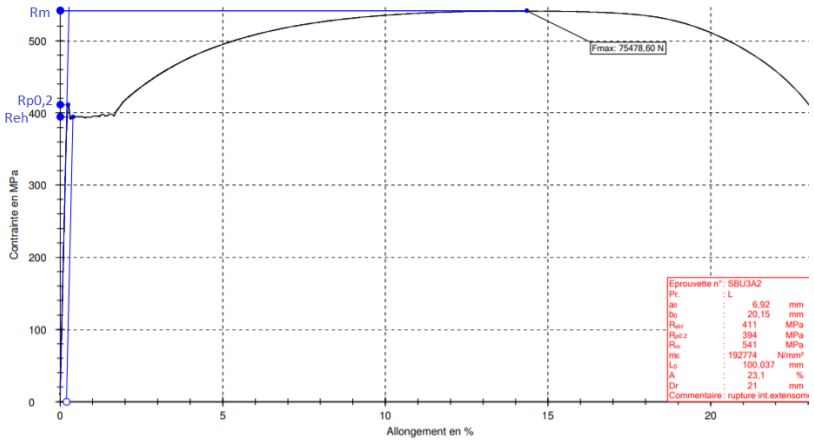


Figure 4.11: Stress-strain curve of SBU3 specimen.

The characteristic values reported in Table 9 below are the following ones:

- E is the Young's modulus [MPa];
- R_{eh} is the apparent yield strength [MPa];
- $R_{p0,2}$ is the offset yield point taken as the stress at which 0.2% plastic deformation occurs [MPa];
- R_m is the ultimate load [MPa];

Mean values are provided while there were two measurement by section leg. However, all data are detailed in Annex C.

Table 9: Coupon test's results.

N° specimen	Section leg	Angle section	E [MPa]	R_{eh} [MPa]	$R_{p0.2}$ [MPa]	R_m[MPa]
BBE2	A	L70x70x7	208056	418,0	398,0	548,0
	B	L70x70x7	204928	419,0	394,0	547,0
BBE6	A	L70x70x7	213086	405,5	392,0	542,5
SBE4	A	L60x60x6	206703	485,0	444,5	545,5
	B	L60x60x6	208742.5	476,5	443,0	536,5
SBE6	A	L60x60x6	206329.5	479,0	444,5	542,5
SBU3	A	L70x70x7	199047.5	414,5	393,5	542,0
SBU4	A	L70x70x7	206991	416,0	392,5	542,5
	B	L60x60x6	205092.5	479,5	445,0	535,0

As mentioned in section 1 concerning the test specifications, the closely spaced built-up members are fabricated by using two types of angle sections, namely: L60x60x6 and L70x70x7. These have been produced in the same time. Therefore, the yield strength can be reported by steel angle sections. Table 10 reports the mean values of the material properties for each angle section.

Table 10: Angle section material properties

Angle section	E [MPa]	R_{eh} [MPa]	$R_{p0.2}$ [MPa]	R_m[MPa]
L60x60x6	206716,9	480,0	444,2	539,9
L70x70x7	206421,7	414,6	394,0	544,4

These values are reported in Annex B for each specimen depending on the used angle section.

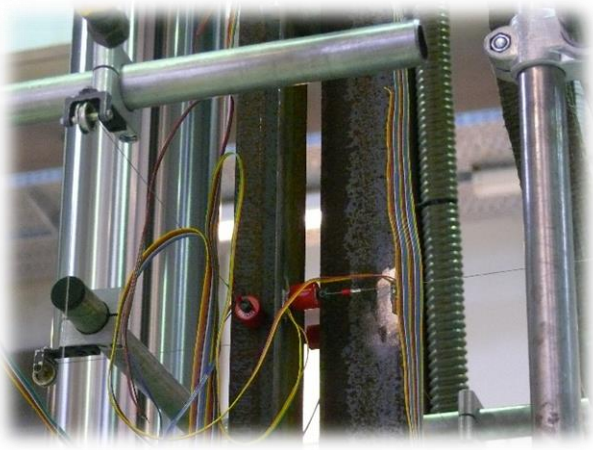
4.5 Measurements during the test

During each test, it has been decided to measure various properties, namely:

- horizontal displacements at mid-height in four cross-section locations (by means of displacements transducers) ;
- strains at 3 various heights, namely L/4, L/2 and 3L/4, in four cross-section locations (by means of strain gauges).

These measurement devices are shown in Figure 4.12 below.

(b) General view of test rig with the with the measurement devices

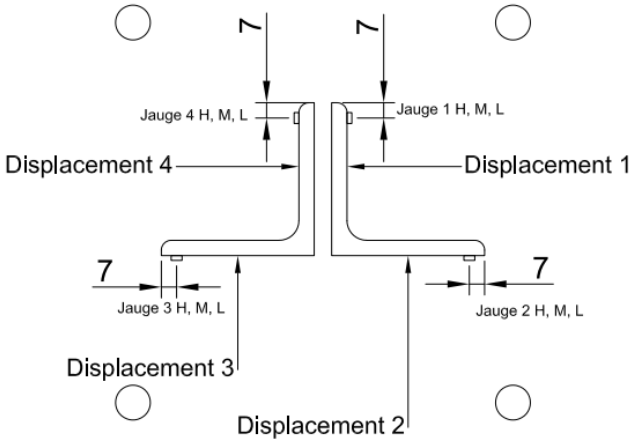


(a) Connection of displacement transducers

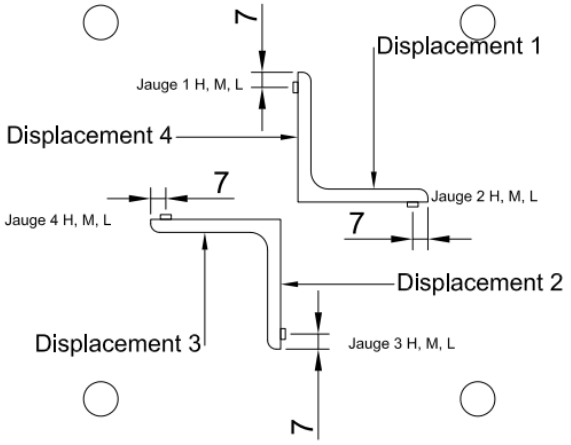
(c) Strain gage measurement

Figure 4.12: General overview of the performed measurements during the tests.

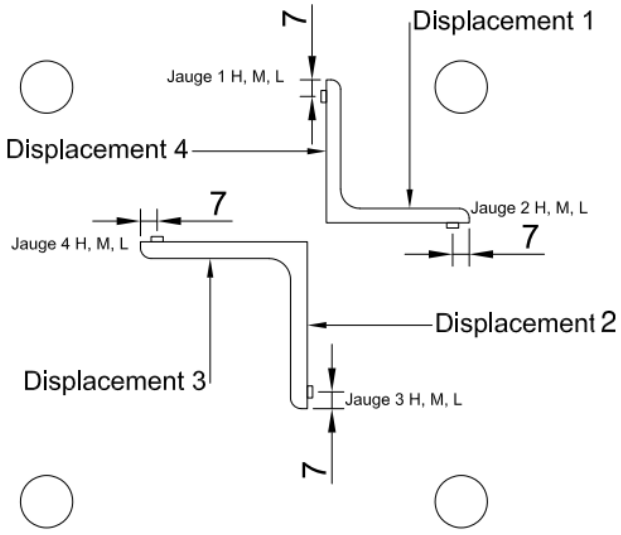
The displacement transducers and the strain gages are displayed differently according to the specimen category. The following Figure 4.13 indicates the location adopted for each specimen category.



(a) BBE specimens



(b) SBE specimens



(c) SBU specimens

Figure 4.13: Locations of the strain gages and displacement transducers for the different types of specimen.

During one of the first tests, a sudden slip occurred. It has then been decided to unload the specimen until roughly 20% of the compression load before re-increasing it further. When the load is closing the expected peak load (failure), the speed is reduced to 3mm in 20 minutes as mentioned in section 3.

5 Results

The aim of this deliverable 3.2 is to only describe the test campaign. Therefore, no post-numerical simulations are reported at this stage.

Annex B has been drafted in such a way that all main results are included for each individual test, so allowing its "stand-alone" use, if necessary. The tests are reported category by category, specifying the following data:

- geometrical measurements;
- material properties;
- number of plates/ bolts and tightening torque applied;
- initial imperfections;
- picture of the specimen right after the test;
- load transducer measurements;
- strain gage measurements.

6 Conclusion

All the tests specified for WP3.2 in the Technical Annex of the RFCS ANGELHY project have been performed at the Laboratory of Materials & Structures at Liège University.

The present document and its annexes gathers all the results of the various measurements and therefore constitutes the "Deliverable 3.2" of the ANGELHY project.

References

[1] A. Bureau, A. Beyer, *Work Package 3 - Deliverable 3.1: Technical specifications for laboratory tests,* Saint Aubin.

[2] Marios-zois Bezas, J-F. Demonceau, J-P. Jaspart, M. Verstraete, *Work Package 2 - Deliverable 2.1: Report about the compression tests on large angle columns in high stregth steel,* Liège.

[3] ISO 6892-1, *Metallic materials - Tensile testing - Part 1: Method of test at room temperature,* Brussels : Comité Européen de normalisation (CEN), 2016.

Annex A

Annex A includes the drawing details of the different types of specimen.

A1. Plan of BBE specimens

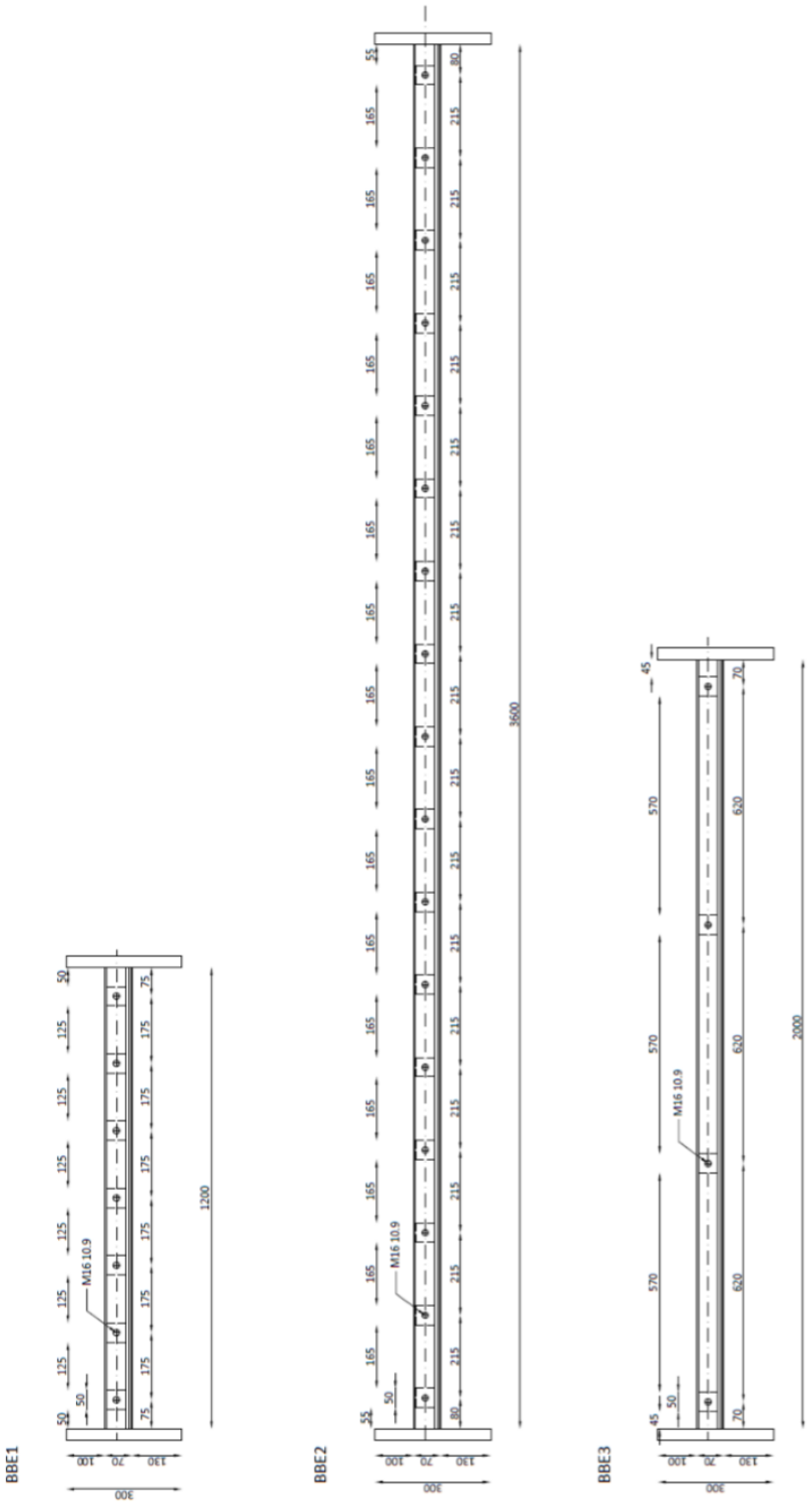


Figure A.1: BBE specimens BBE1 to BBE3 – global view

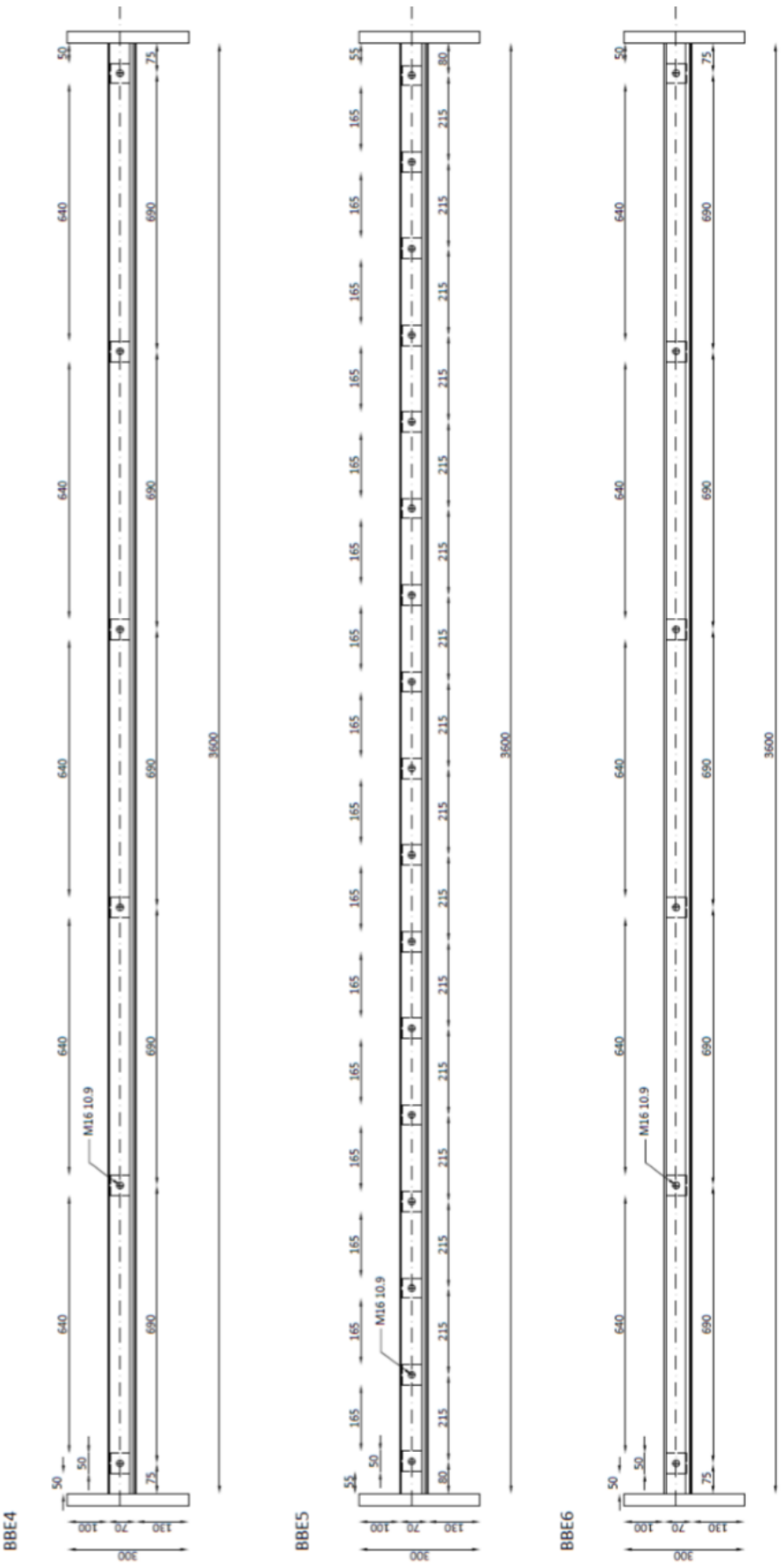


Figure A.2: BBE specimens BBE4 to BBE6 – global view

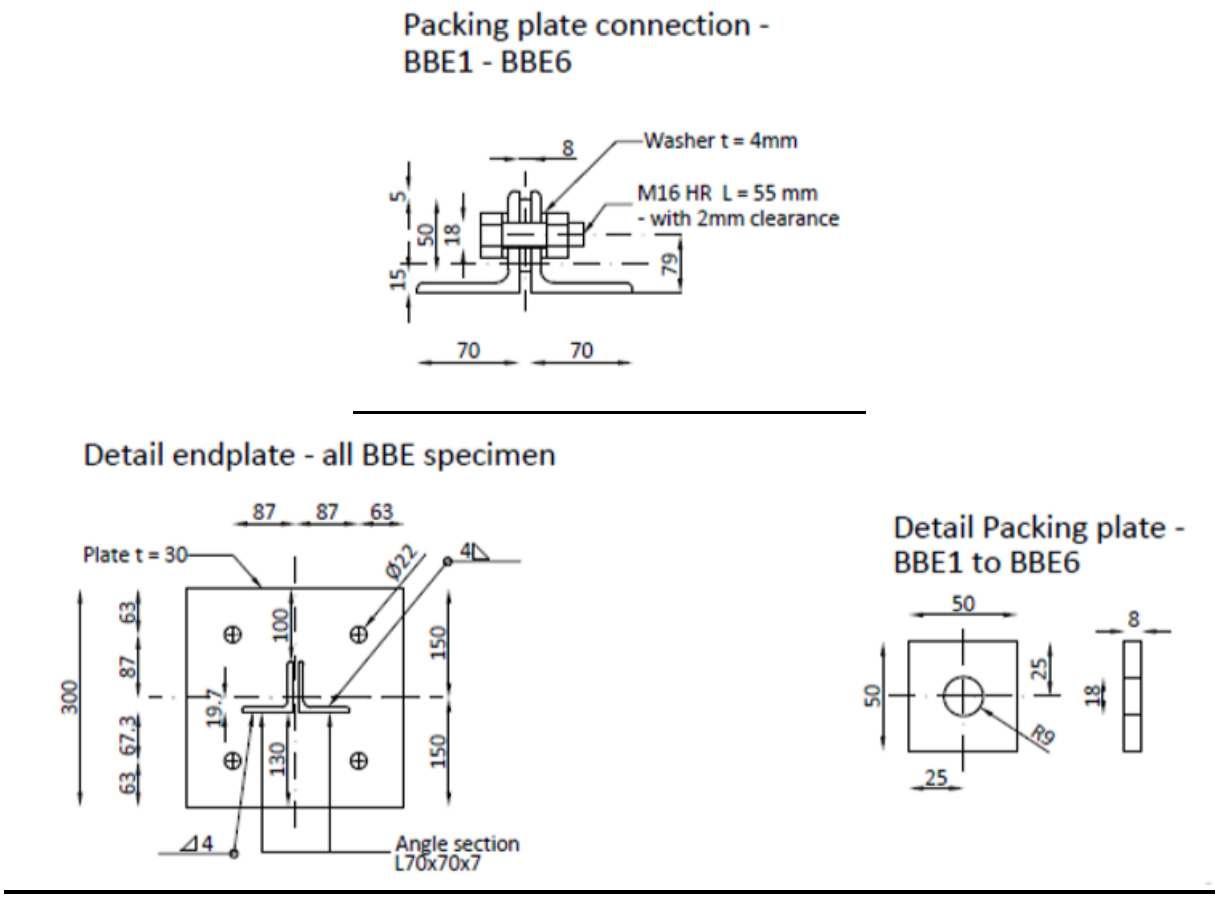


Figure A.3: BBE specimens-details

A2. Plan of SBE specimens

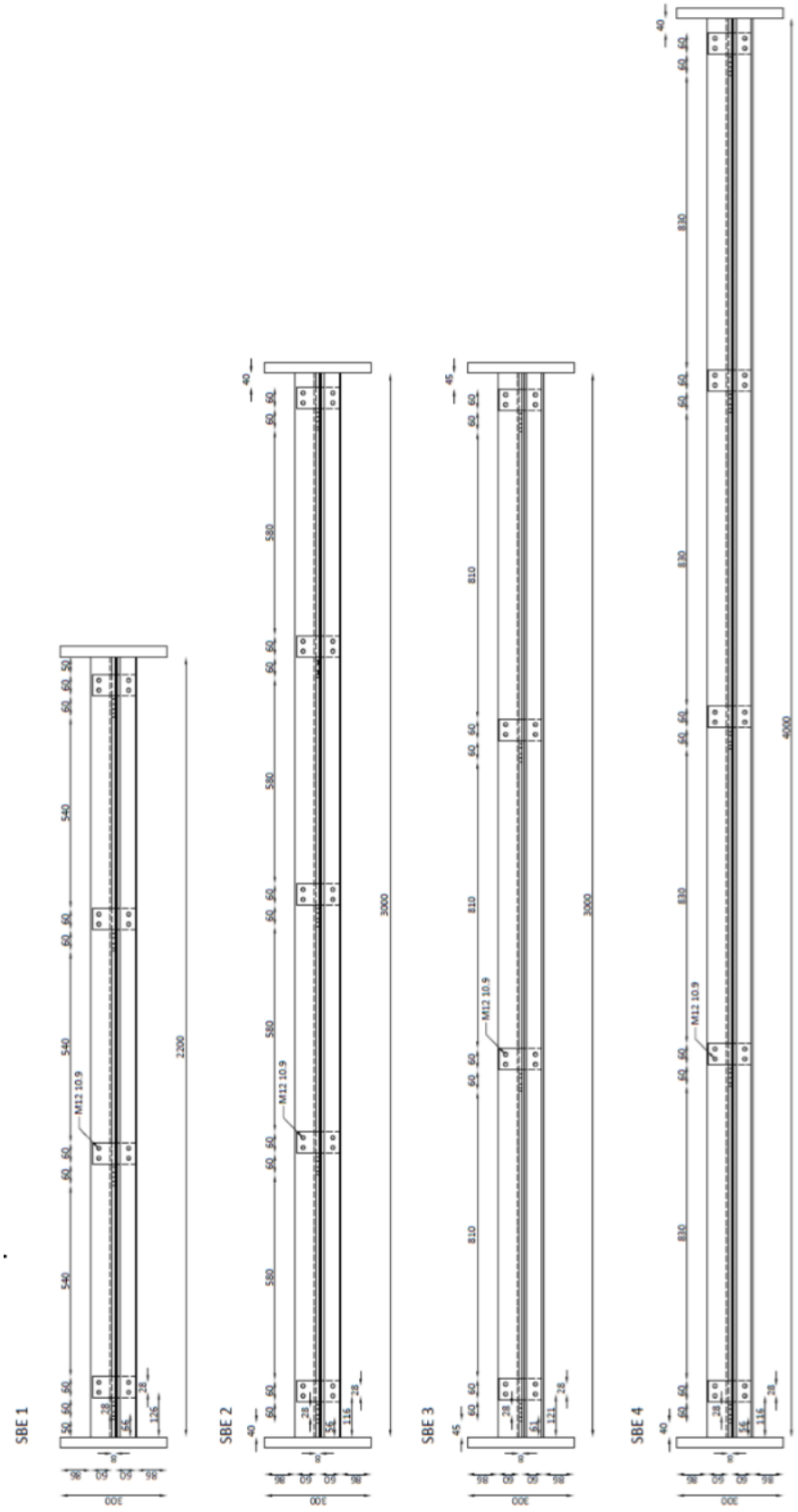


Figure A.4: SBE specimens SBE1 to SBE4 – global view

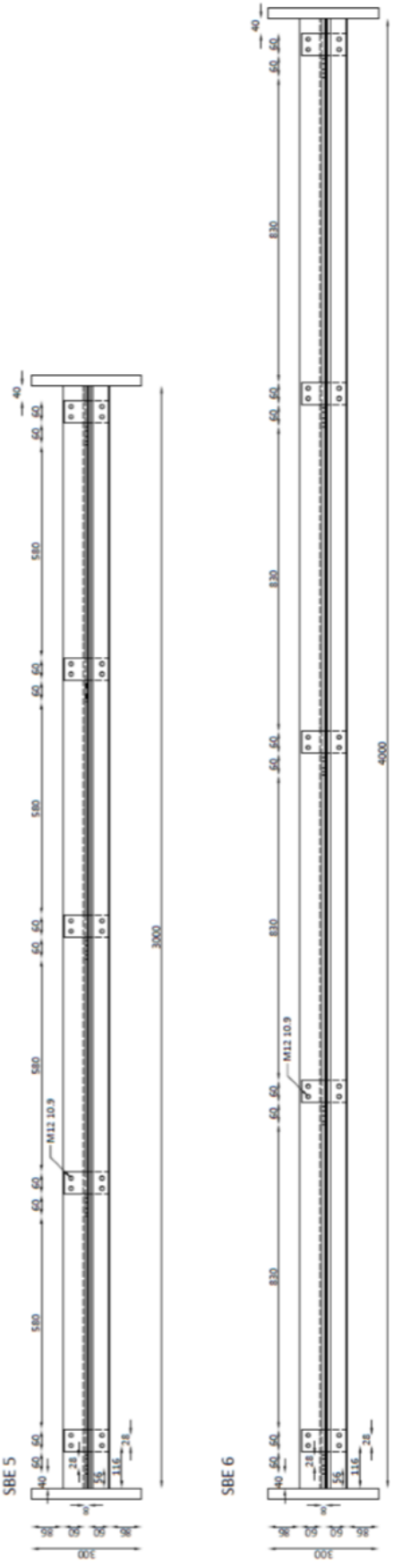


Figure A.5: SBE specimens SBE5 to SBE6 – global view

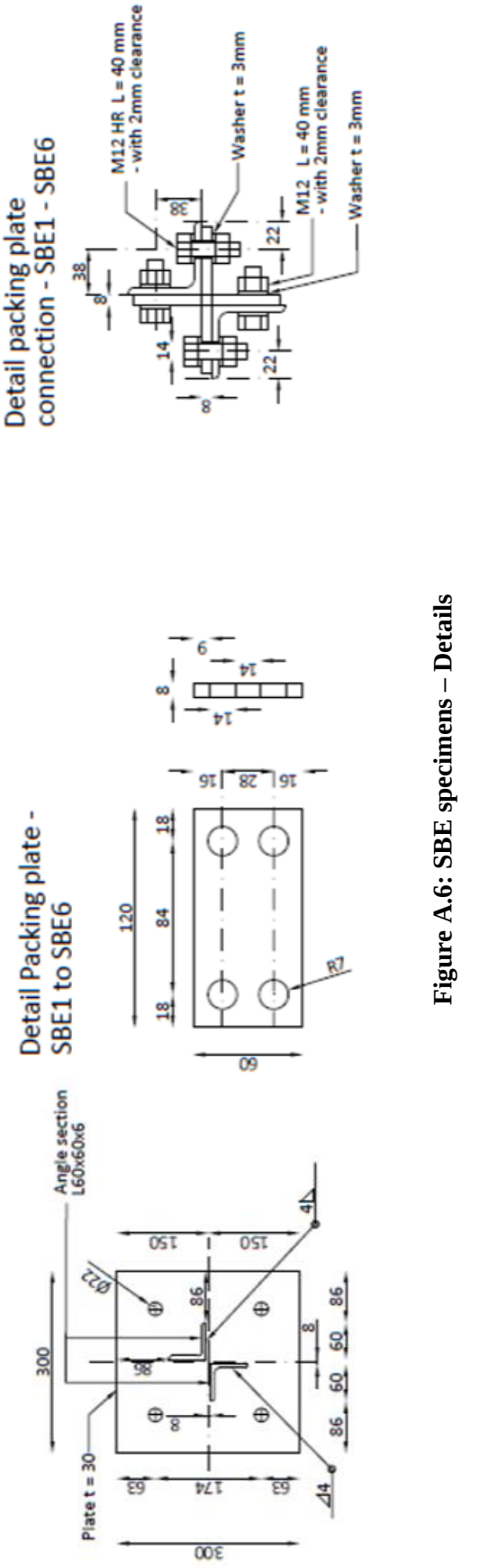


Figure A.6: SBE specimens – Details

A3. Plan of SBU specimens

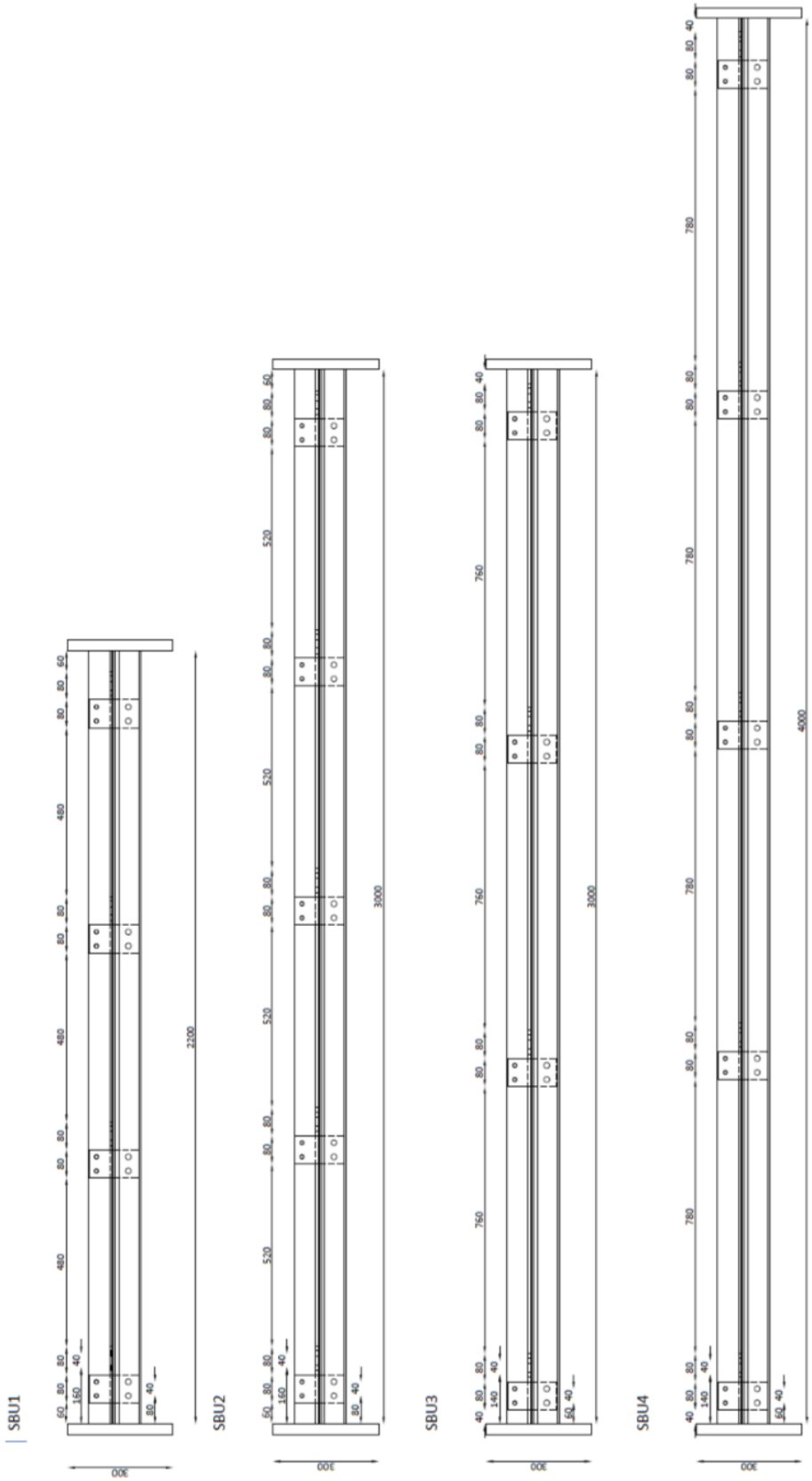


Figure A.7: SBU specimens SBU1 to SBU4 – global view

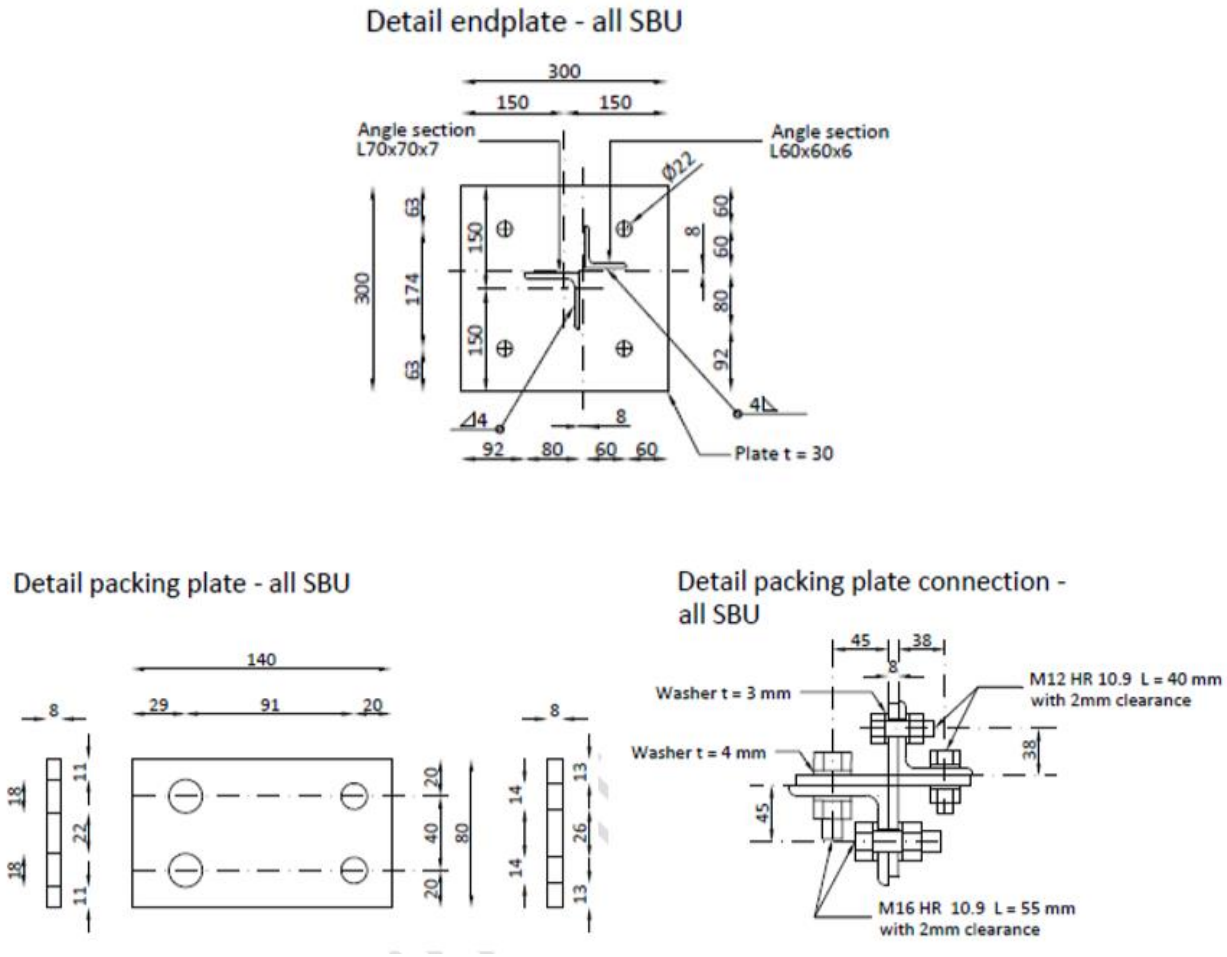


Figure A.8: SBU specimens-details

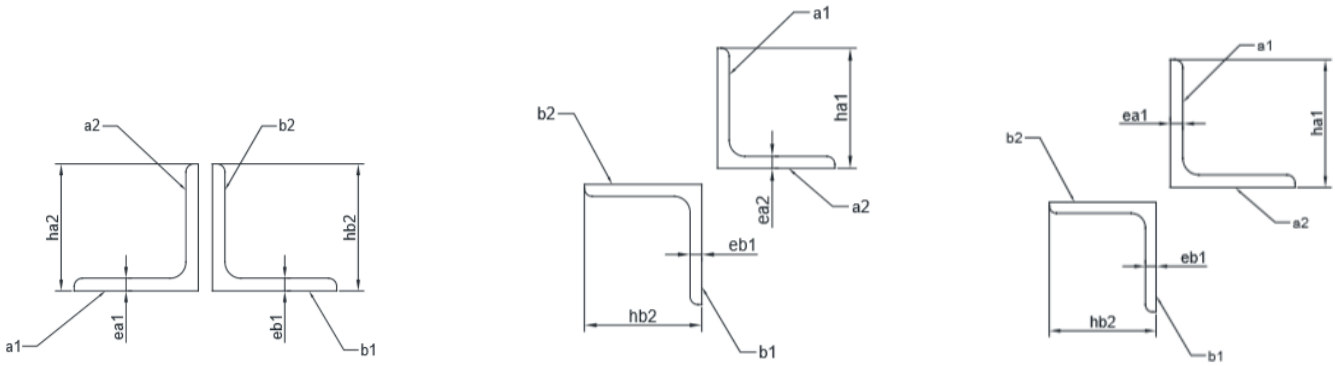
Annex B

Annex B includes the details as well as the results (initial imperfections, load-displacements curves, strain gages) of the experimental test carried out on each specimen. First measure point location for initial imperfection measurements, geometrical measurements, eccentricity measurements, tightening torque values, displacement captors and strain gauge positions are detailed in the chapter 2: "Preparation of the test-Measurements before and during a test" of the current report.

B0. Symbols and definitions

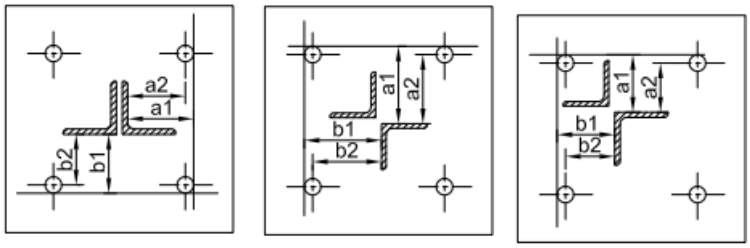
The symbols that are used in graphs and tables of the current annex, are summarized below:

ha_1	is the width of leg 1 (Face A) of the cross-section;
ea_1	is the thickness of leg 1 (Face A) of the cross-section;
hb_2	is the width of leg 2 (Face B) of the cross-section;
eb_1	is the thickness of leg 1 (Face B) of the cross-section;
ha_2	is the width of leg 2 (Face A) of the cross-section;
ea_2	is the thickness of leg 2 (Face A) of the cross-section;
a_1, a_2, b_1, b_2	is the eccentricity measurements on the bottom plate;
a_3, a_4, b_3, b_4	is the eccentricity measurements on the bottom plate;
L	is the length of the specimen i between the gusset plates;
$L_{crit,major-axis}$	is the critical (buckling) length about major-axis of the BBE specimen i containing the gusset plates;
$L_{crit,minor-axis}$	is the critical (buckling) length about major-axis of the BBE specimen i containing the gusset plates;
L_{crit}	is the critical (buckling) length of the SBE/SBU specimen i containing the gusset plates;
f_y	is the actual yielding stress (limit of elasticity value);
A1-Laser j	is the imperfection measurement by the laser j in position A for specimen i;
B1-Laser j	is the imperfection measurement by the laser j in position B for specimen i;
M1	is the first displacement measured at mid – height for specimen i
M2	is the second displacement measured at mid – height for specimen i
M3	is the third displacement measured at mid – height for specimen i
M4	is the fourth displacement measured at mid – height for specimen i
SnHj	is the strain gage at 3/4L in position j for specimen i
SnMj	is the strain gage at L/2 in position j for specimen i
SnLj	is the strain gage at L/4 in position j for specimen i

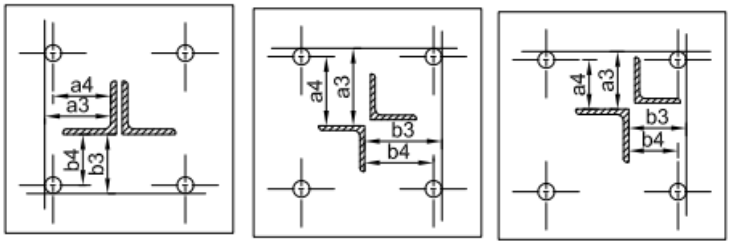


BBE specimens *SBE specimens* *SBU specimens*

Figure B.1: Geometrical measurements on specimens

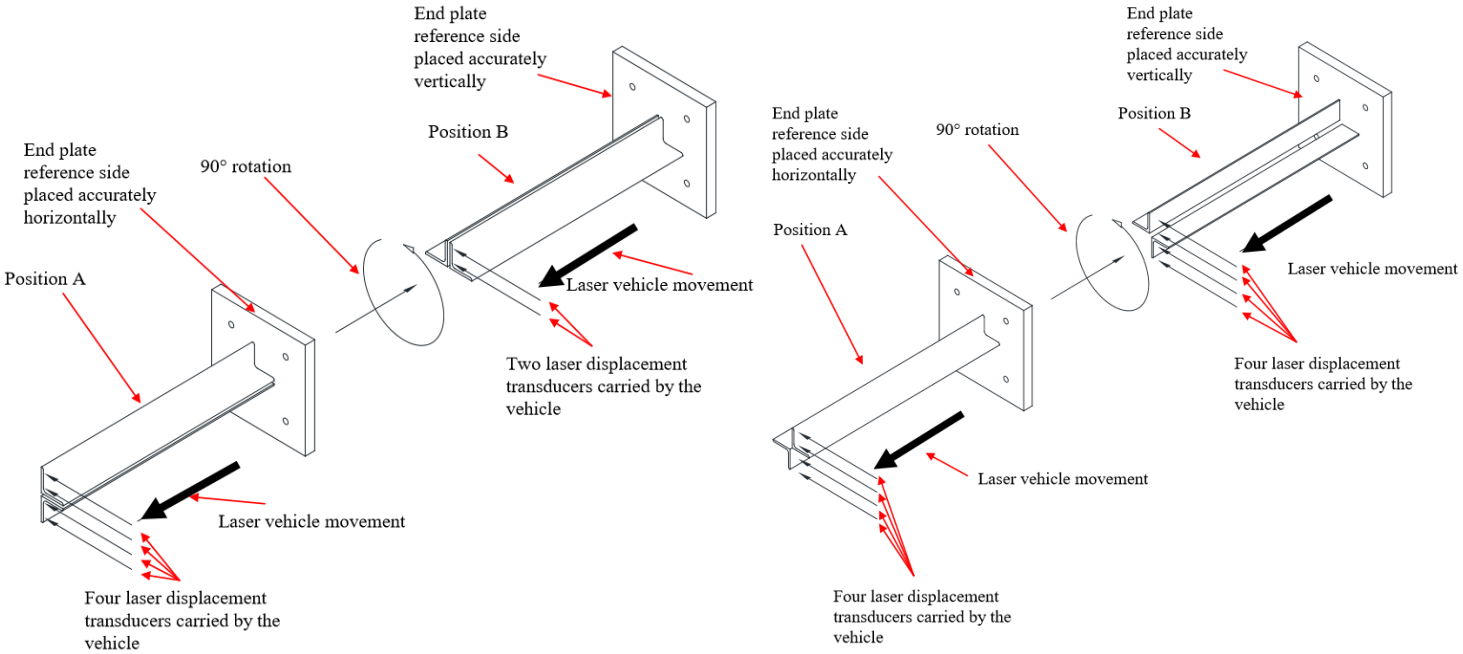


(a) Coupe A-A: Bottom plate



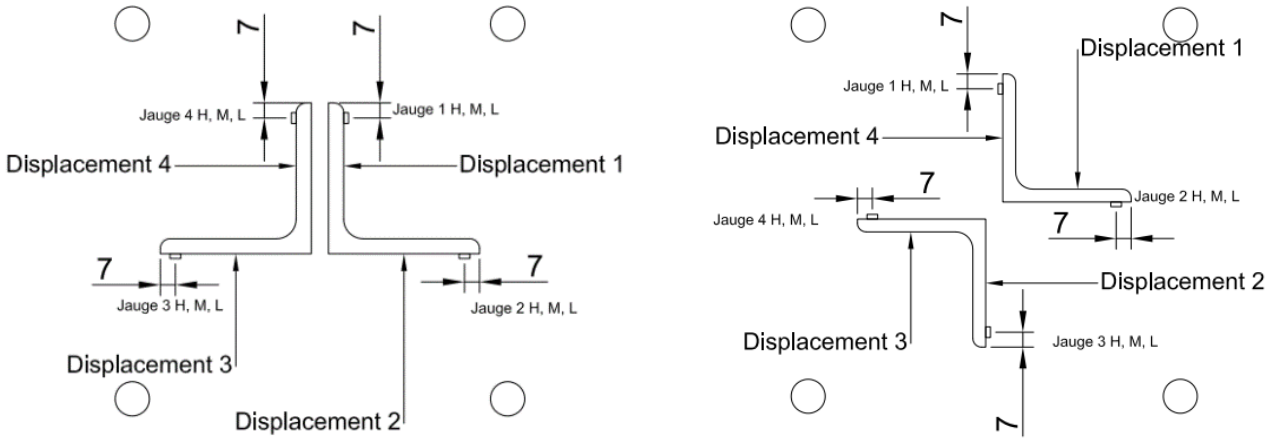
(b) Coupe B-B: Upper plate

Figure B.2: Eccentricity measurements on edge plates



BBE specimens *SBE/SBU specimens*

Figure B.3: Laser locations for imperfection measurements.



BBE specimens *SBE/SBU specimens*

Figure B.4: Strain gages and displacement measure locations.

B1. Specimen BBE1

ID of specimen: BBE1	
Date of testing	10/02/2020
Type of specimen	Back to back connected angles
Mean actual dimensions	
Cross-section	2 L70x70x7
ha_2 [mm]	70,17
ea_1 [mm]	6,77
hb_2 [mm]	70,12
eb_1 [mm]	6,81
a_1 / a_2 [mm]	86 / 75
b_1 / b_2 [mm]	77,6 / 66,6
a_3 / a_4 [mm]	85,3 / 74,3
b_3 / b_4 [mm]	77 / 66
L [mm]	1200
$L_{crit,\ major\text{-}axis}$ [mm]	1260
$L_{crit,\ minor\text{-}axis}$ [mm]	630
Tightening torque [Nm]	253
Total number of packing plates	7
Total number of bolts for packing plate connection	7 M16 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	414,6
Actual f_u [Mpa]	544,4
Response	
Ultimate resistance [kN]	687,56
Comments	Failure occured close to the cross-section resistance

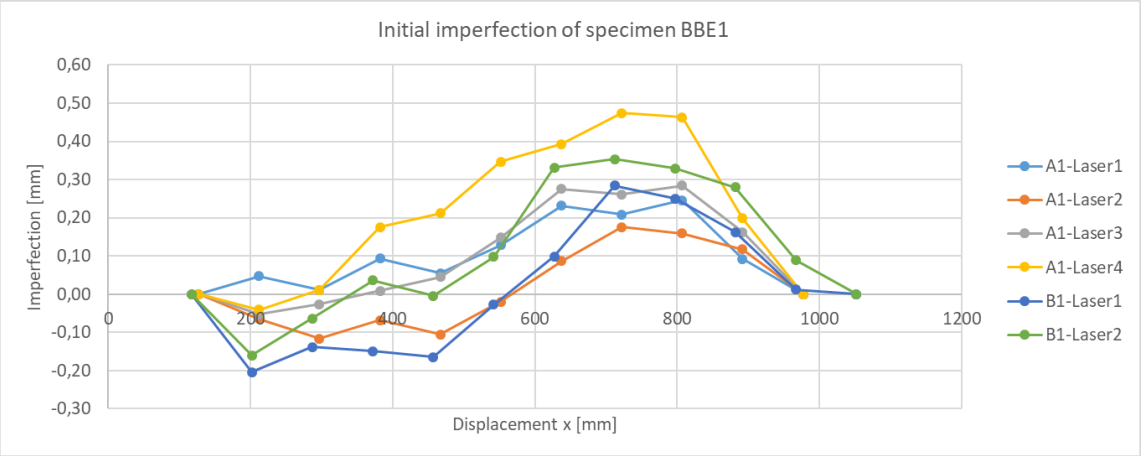


Figure B.5: Initial imperfections along specimen BBE1

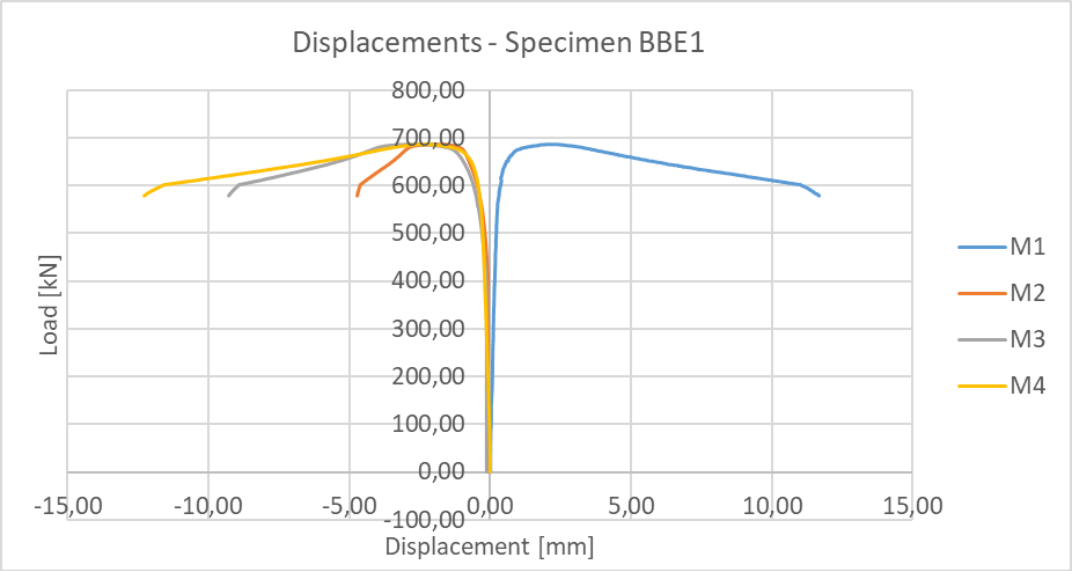


Figure B.6: Displacements along the principal axis, at mid-height, for specimen BBE1

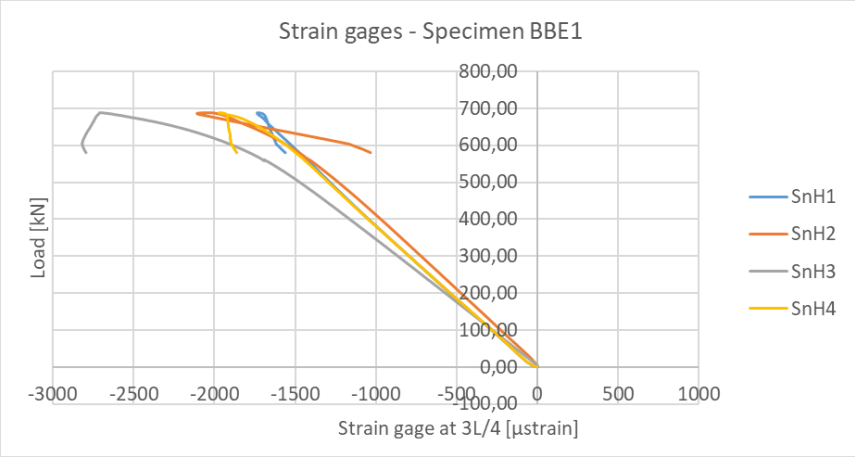


Figure B.7: Measurements of strain gages at 3/4L on specimen BBE1

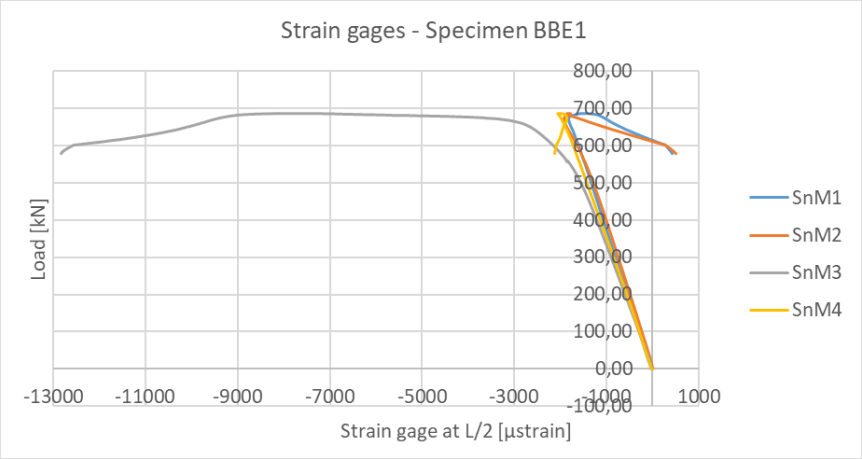


Figure B.8: Measurements of strain gages at L/2 on specimen BBE1

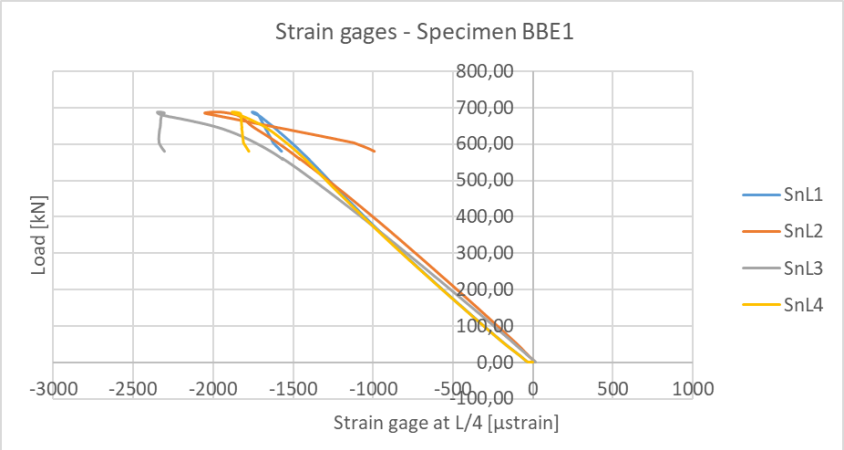
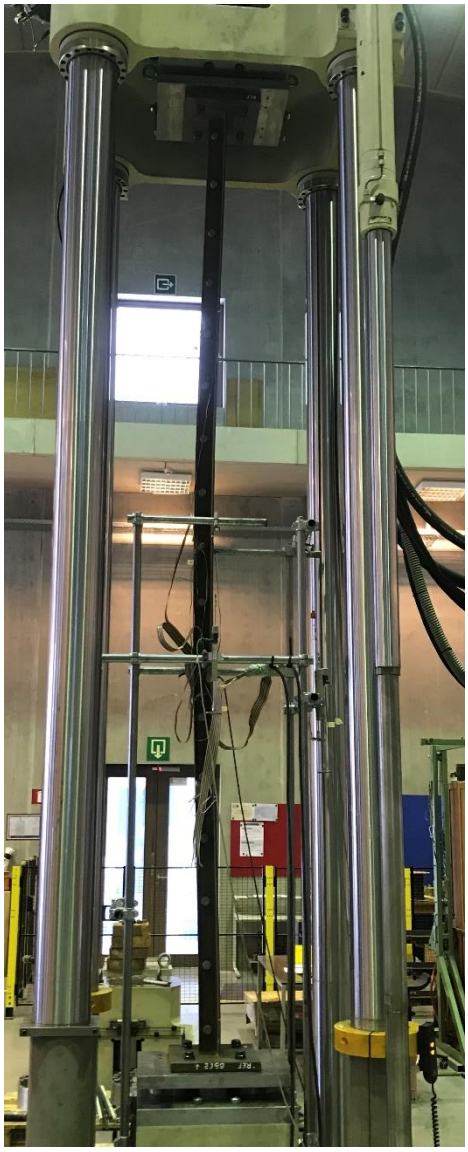


Figure B.9: Measurements of strain gages at L/4 on specimen BBE1

B2. Specimen BBE2

ID of specimen: BBE2	
Date of testing	27/02/2020
Type of specimen	Back to back connected angles
Mean actual dimensions	
Cross-section	2 L70x70x7
ha_2 [mm]	69,93
ea_1 [mm]	6,86
hb_2 [mm]	70
eb_1 [mm]	6,83
a_1 / a_2 [mm]	86,3 / 75,3
b_1 / b_2 [mm]	77,2 / 66,2
a_3 / a_4 [mm]	86,4 / 75,4
b_3 / b_4 [mm]	77,3 / 66,3
L [mm]	3600
$L_{crit,\ major\text{-}axis}$ [mm]	3660
$L_{crit,\ minor\text{-}axis}$ [mm]	1830
Tightening torque [Nm]	253
Total number of packing plates	19
Total number of bolts for packing plate connection	19 M16 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	414,6
Actual f_u [Mpa]	544,4
Response	
Ultimate resistance [kN]	485,36
Comments	Bifurcation around weak axis and no flexural buckling around strong axis as expected !



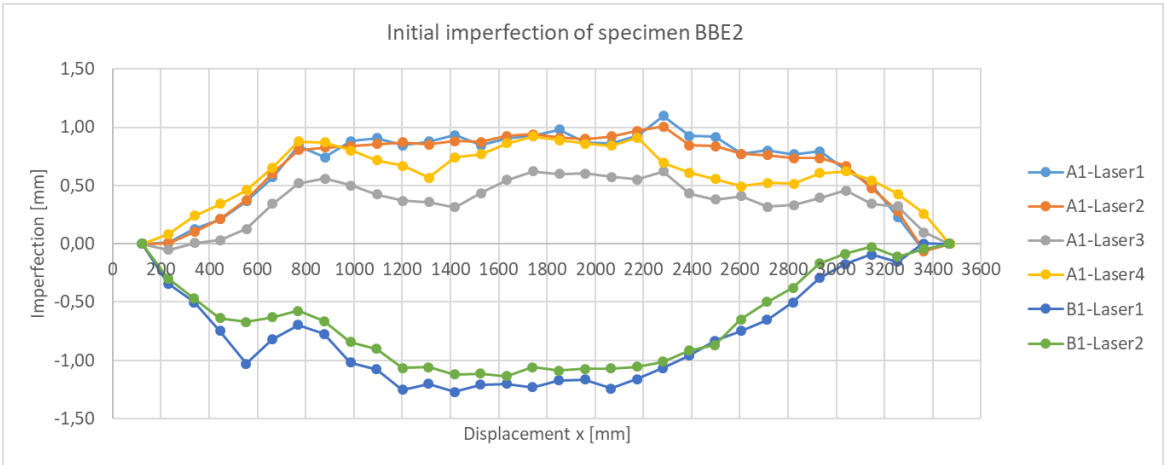


Figure B.10: Initial imperfections along specimen BBE2

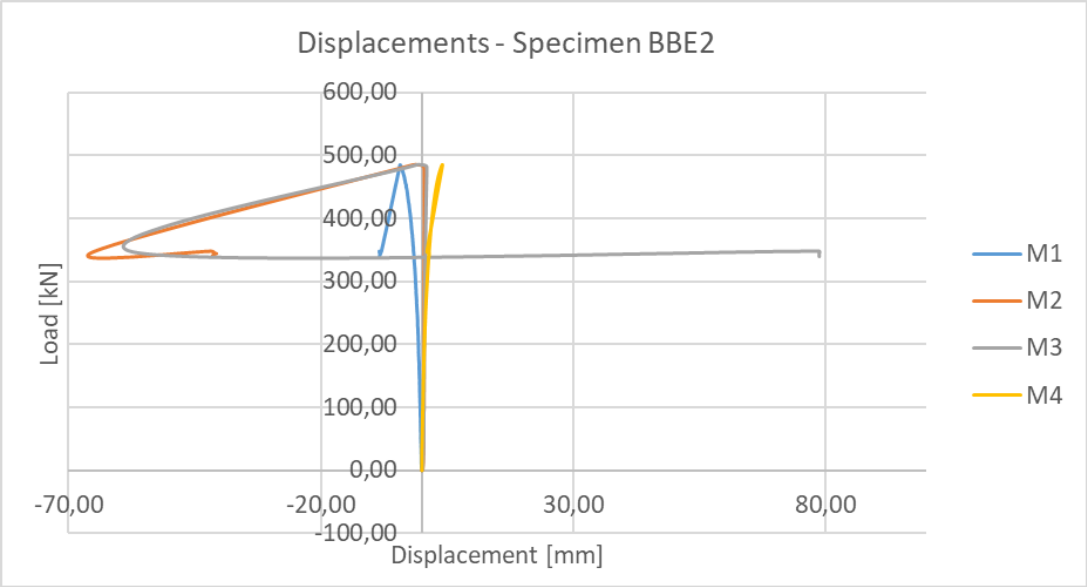


Figure B.11: Displacements along the principal axis, at mid-height, for specimen BBE2

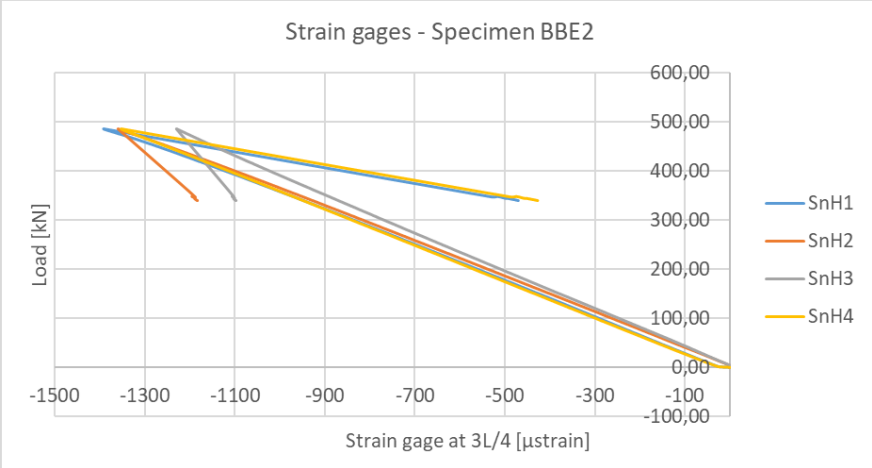


Figure B.12: Measurements of strain gages at 3/4L on specimen BBE2

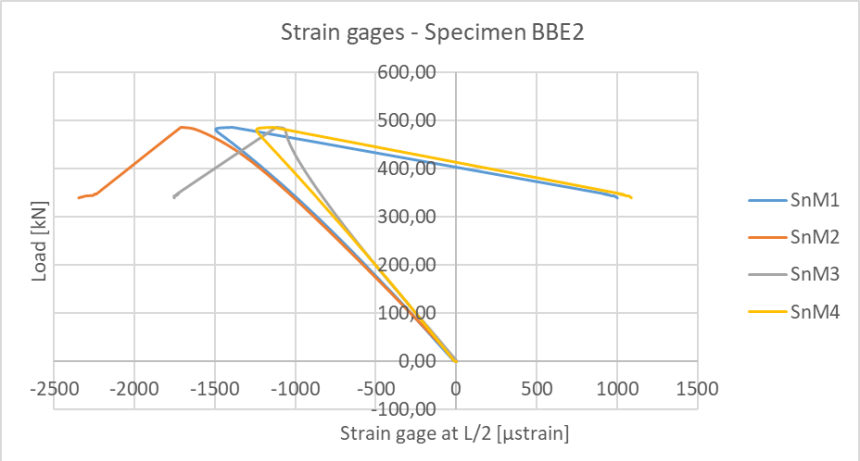


Figure B.13: Measurements of strain gages at L/2 on specimen BBE2

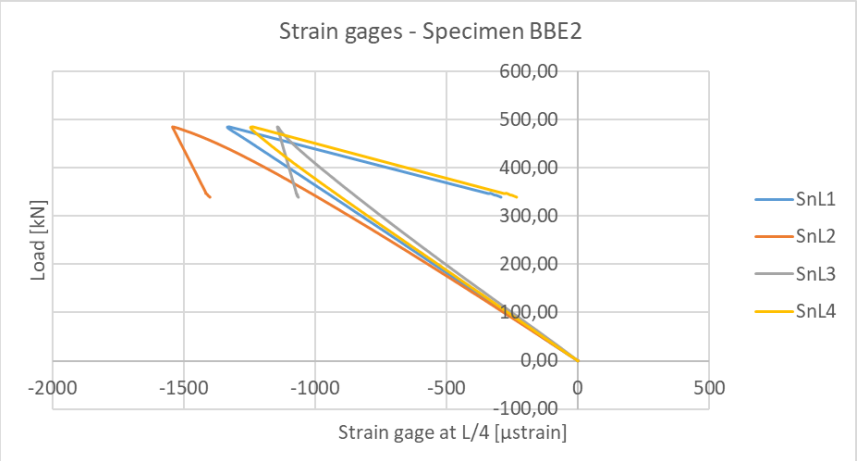


Figure B.14: Measurements of strain gages at L/4 on specimen BBE2

B3. Specimen BBE3

ID of specimen: BBE3	
Date of testing	18/02/2020
Type of specimen	Back to back connected angles
Mean actual dimensions	
Cross-section	2 L70x70x7
ha_2 [mm]	69,96
ea_1 [mm]	6,82
hb_2 [mm]	70,13
eb_1 [mm]	6,89
a_1 / a_2 [mm]	87,6 / 76,6
b_1 / b_2 [mm]	77,7 / 66,7
a_3 / a_4 [mm]	82,8 / 71,8
b_3 / b_4 [mm]	77,4 / 66,4
L [mm]	2000
$L_{crit,\ major\text{-}axis}$ [mm]	2060
$L_{crit,\ minor\text{-}axis}$ [mm]	1030
Tightening torque [Nm]	253
Total number of packing plates	4
Total number of bolts for packing plate connection	4 M16 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	414,6
Actual f_u [Mpa]	544,4
Response	
Ultimate resistance [kN]	601,61
Comments	Buckling occured around the strong axis as expected

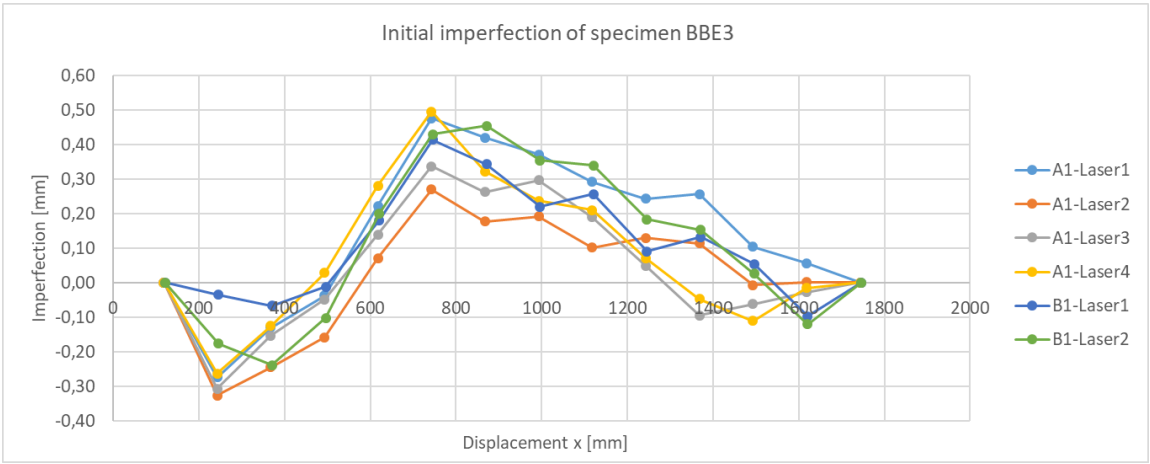


Figure B.15: Initial imperfections along specimen BBE3

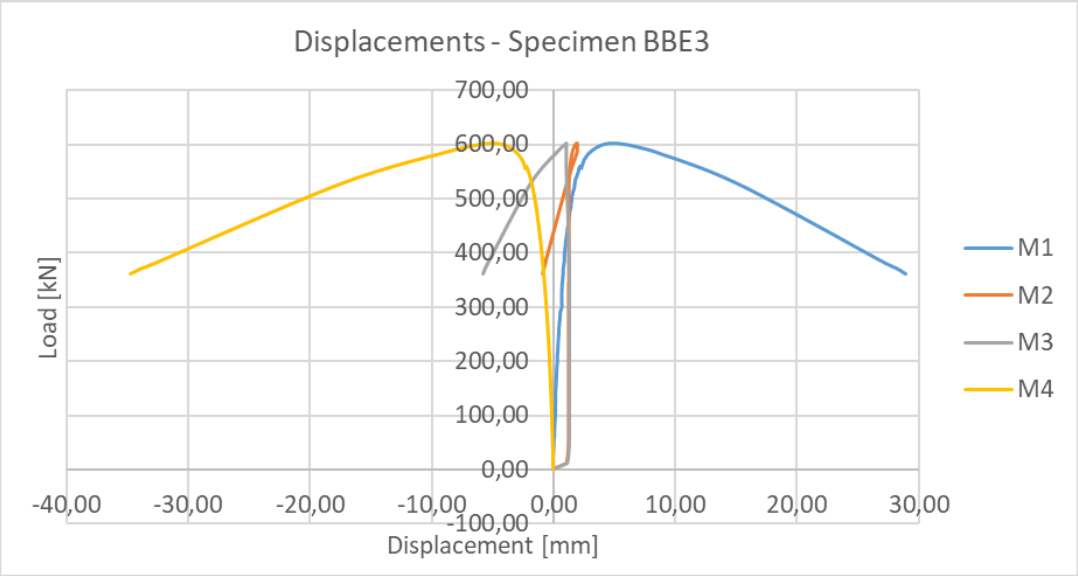


Figure B.16: Displacements along the principal axis, at mid-height, for specimen BBE3

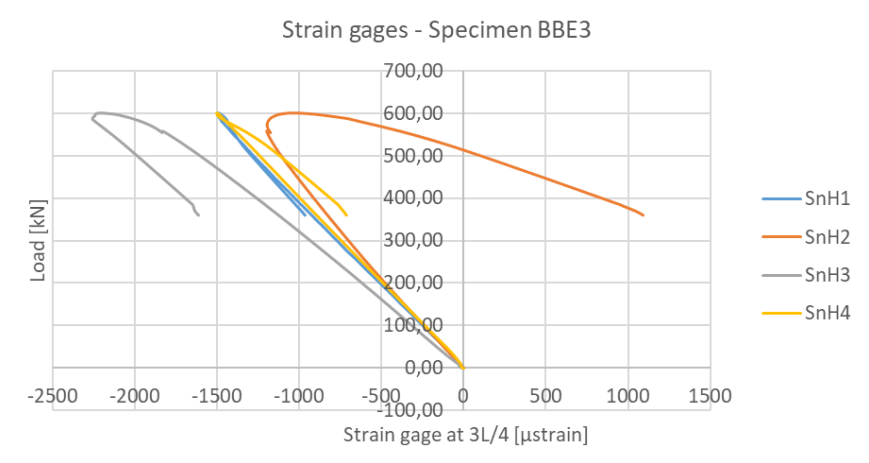


Figure B.17: Measurements of strain gages at 3/4L on specimen BBE3

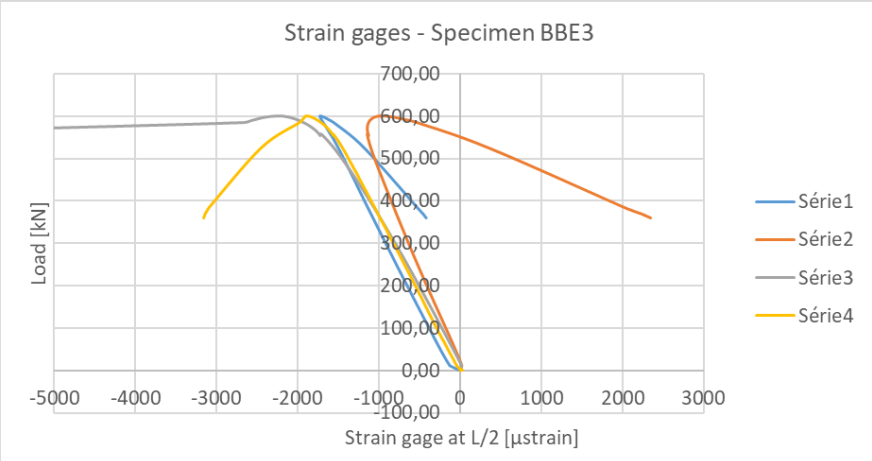


Figure B.18: Measurements of strain gages at L/2 on specimen BBE3

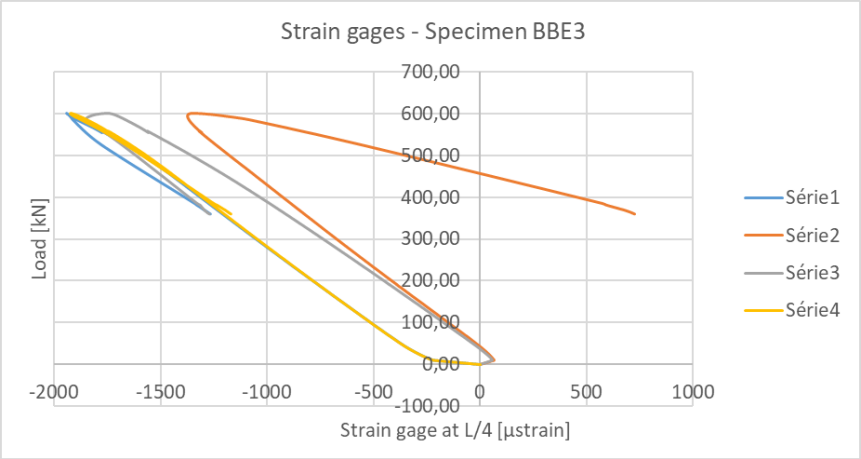


Figure B.19: Measurements of strain gages at L/4 on specimen BBE3

B4. Specimen BBE4

ID of specimen: BBE4	
Date of testing	03/03/2020
Type of specimen	Back to back connected angles
Mean actual dimensions	
Cross-section	2 L70x70x7
ha_2 [mm]	69,87
ea_1 [mm]	6,82
hb_2 [mm]	69,8
eb_1 [mm]	6,86
a_1 / a_2 [mm]	89,1 / 78,1
b_1 / b_2 [mm]	78,4 / 67,4
a_3 / a_4 [mm]	87,6 / 76,6
b_3 / b_4 [mm]	78,5 / 67,5
L [mm]	3600
$L_{crit,\ major\text{-}axis}$ [mm]	3660
$L_{crit,\ minor\text{-}axis}$ [mm]	1830
Tightening torque [Nm]	253
Total number of packing plates	6
Total number of bolts for packing plate connection	6 M16 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	414,6
Actual f_u [Mpa]	544,4
Response	
Ultimate resistance [kN]	311,68
Comments	Buckling occured around the strong axis as expected

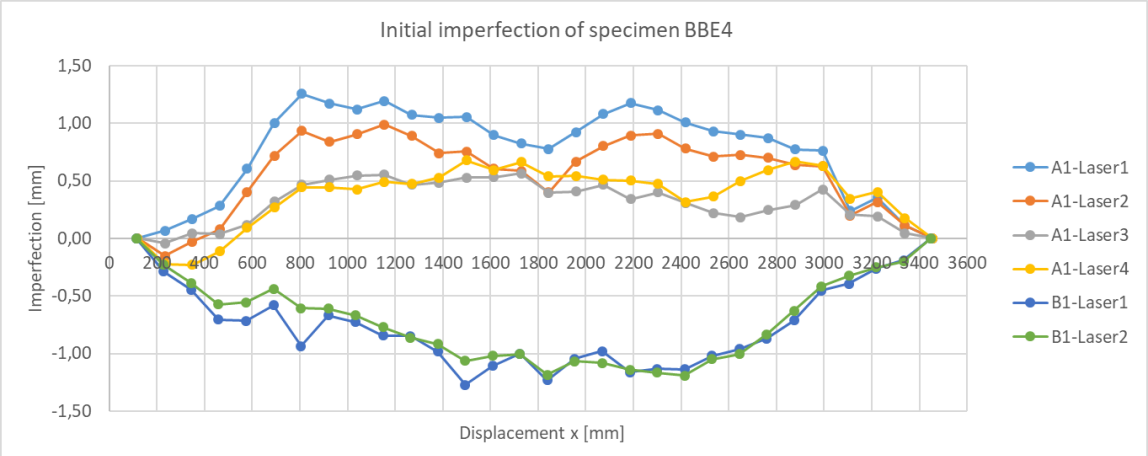


Figure B.20: Initial imperfections along specimen BBE4

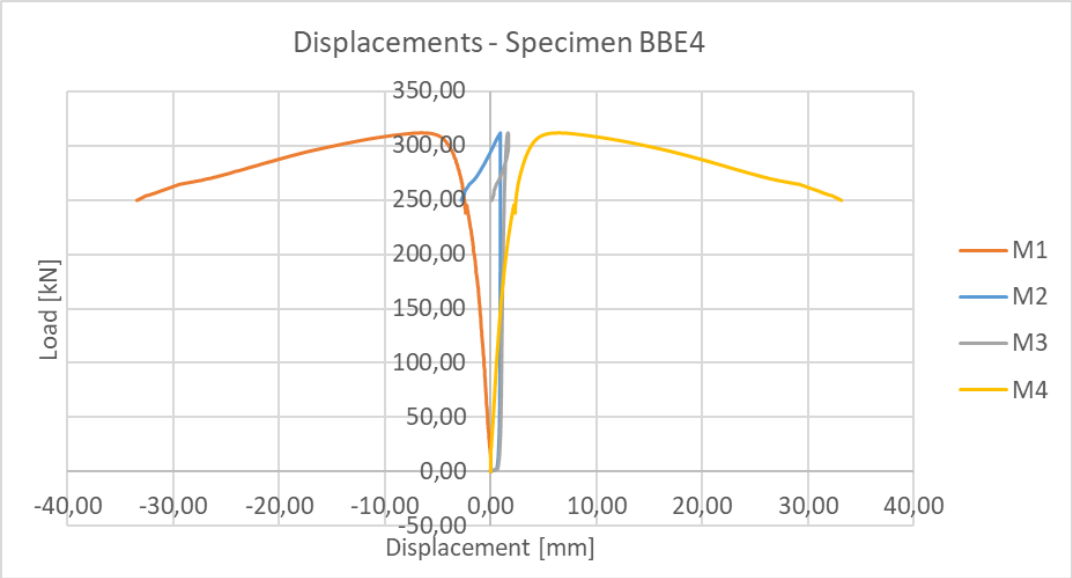


Figure B.21: Displacements along the principal axis, at mid-height, for specimen BBE4

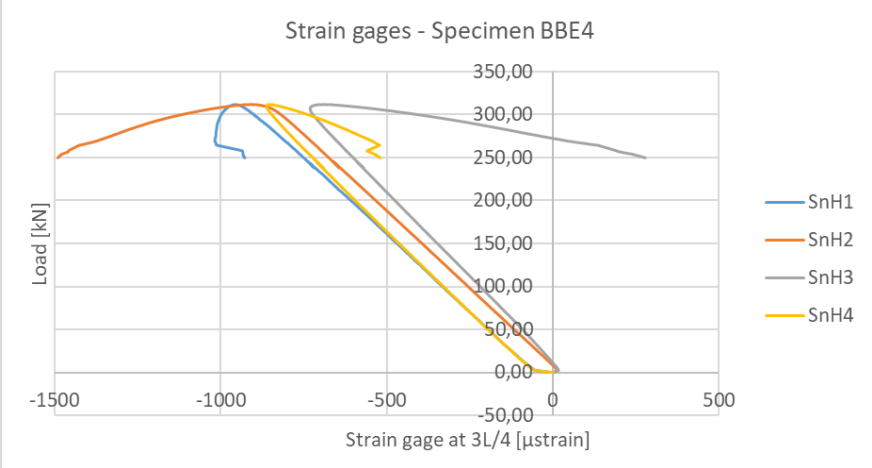


Figure B.22: Measurements of strain gages at 3/4L on specimen BBE4

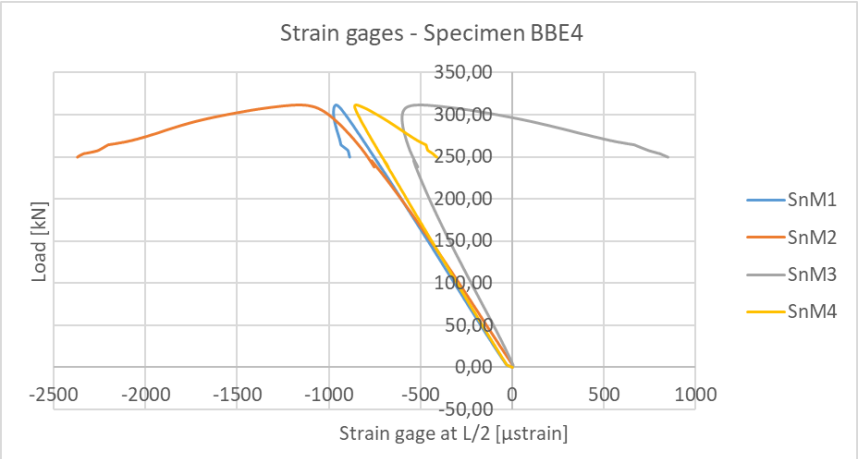


Figure B.23: Measurements of strain gages at L/2 on specimen BBE4

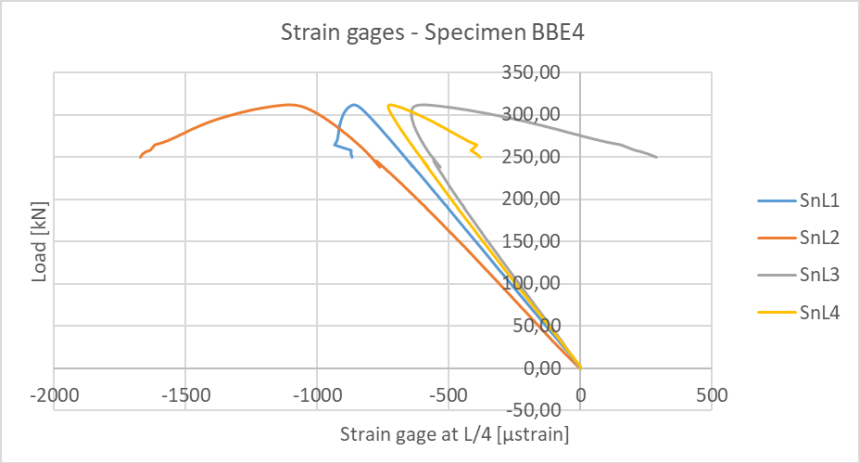


Figure B.24: Measurements of strain gages at L/4 on specimen BBE4

B5. Specimen BBE5

ID of specimen: BBE5	
Date of testing	17/03/2020
Type of specimen	Back to back connected angles
Mean actual dimensions	
Cross-section	2 L70x70x7
ha_2 [mm]	69,9
ea_1 [mm]	6,83
hb_2 [mm]	69,93
eb_1 [mm]	6,86
a_1 / a_2 [mm]	87 / 76
b_1 / b_2 [mm]	79 / 68
a_3 / a_4 [mm]	86,8 / 75,8
b_3 / b_4 [mm]	77,5 / 66,5
L [mm]	3600
$L_{crit,\ major\text{-}axis}$ [mm]	3660
$L_{crit,\ minor\text{-}axis}$ [mm]	1830
Tightening torque [Nm]	25,3
Total number of packing plates	19
Total number of bolts for packing plate connection	19 M16 10.9
Level of bolt pretension [%]	10
Material	S 355
Actual f_y [Mpa]	414,6
Actual f_u [Mpa]	544,4
Response	
Ultimate resistance [kN]	423,32
Comments	Buckling around minor-axis and no flexural buckling around major-axis as expected !

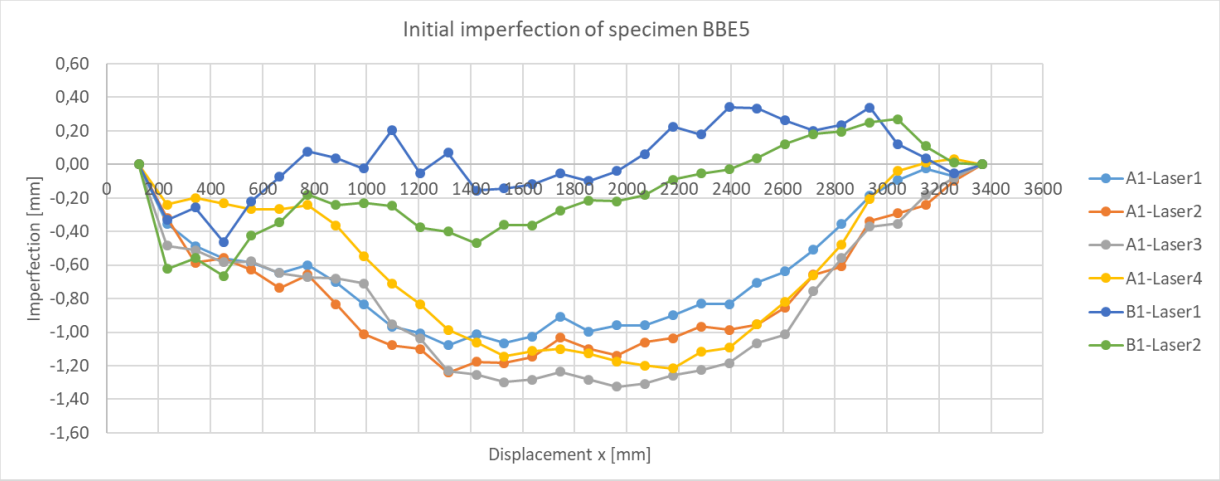


Figure B.25: Initial imperfections along specimen BBE5

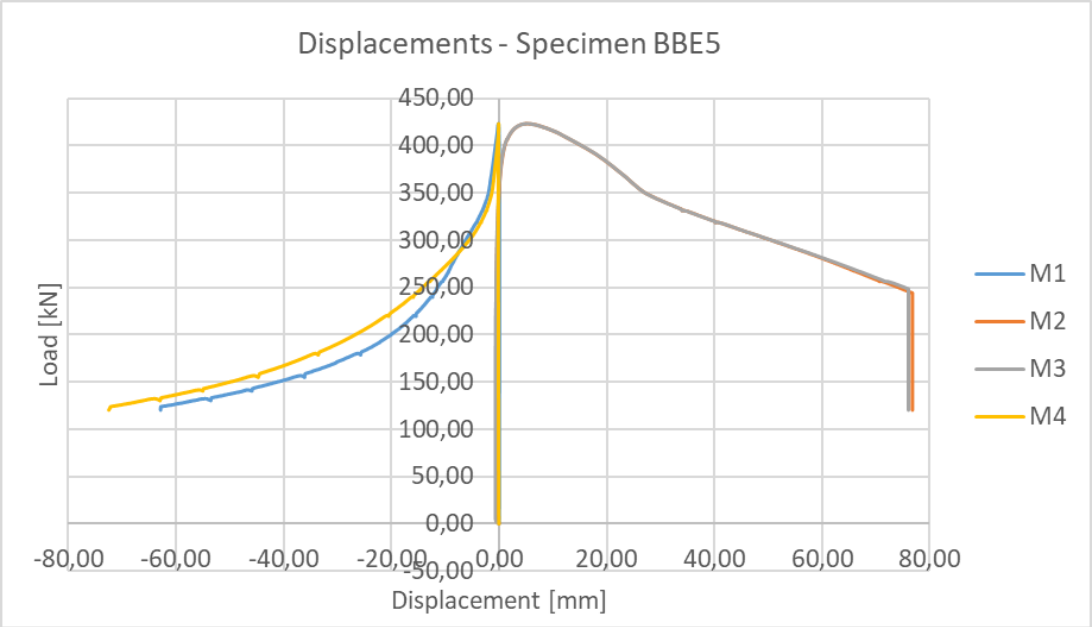


Figure B.26: Displacements along the principal axis, at mid-height, for specimen BBE5

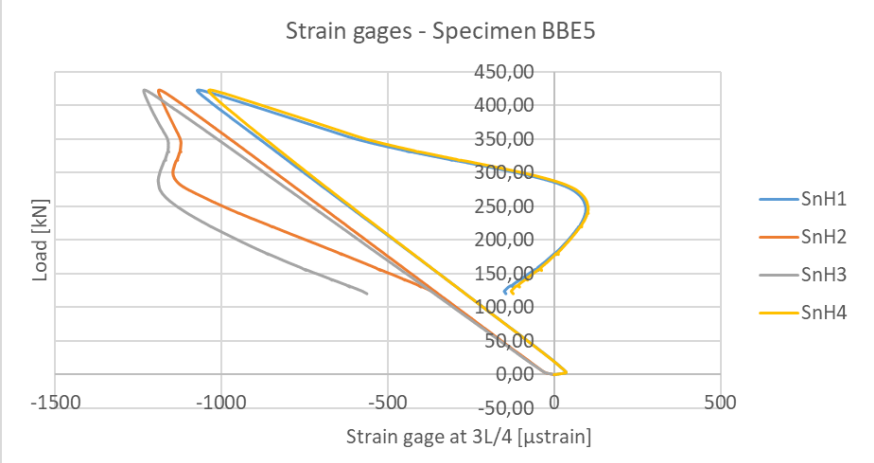


Figure B.27: Measurements of strain gages at 3/4L on specimen BBE5

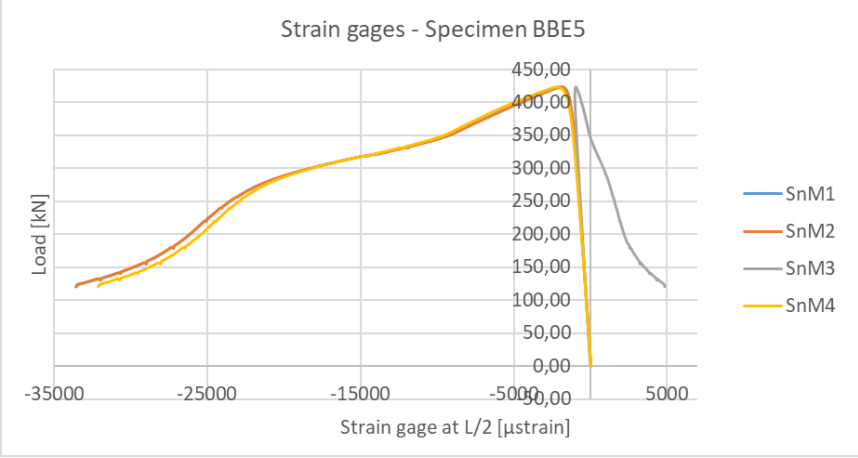


Figure B.28: Measurements of strain gages at L/2 on specimen BBE5

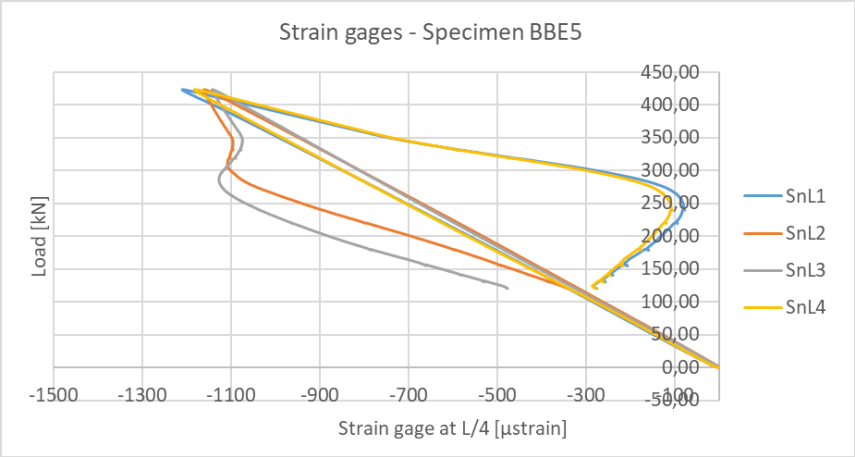


Figure B.29: Measurements of strain gages at L/4 on specimen BBE5

B6. Specimen BBE6

ID of specimen: BBE6	
Date of testing	13/03/2020
Type of specimen	Back to back connected angles
Mean actual dimensions	
Cross-section	2 L70x70x7
ha_2 [mm]	69,93
ea_1 [mm]	6,84
hb_2 [mm]	69,83
eb_1 [mm]	6,85
a_1 / a_2 [mm]	87,6 / 76,6
b_1 / b_2 [mm]	77,6 / 66,6
a_3 / a_4 [mm]	89,1 / 78,1
b_3 / b_4 [mm]	77,9 / 66,9
L [mm]	3600
$L_{crit,\ major\text{-}axis}$ [mm]	3660
$L_{crit,\ minor\text{-}axis}$ [mm]	1830
Tightening torque [Nm]	25,3
Total number of packing plates	6
Total number of bolts for packing plate connection	6 M16 10.9
Level of bolt pretension [%]	10
Material	S 355
Actual f_y [Mpa]	414,6
Actual f_u [Mpa]	544,4
Response	
Ultimate resistance [kN]	382,78
Comments	Buckling occured around minor-axis first !

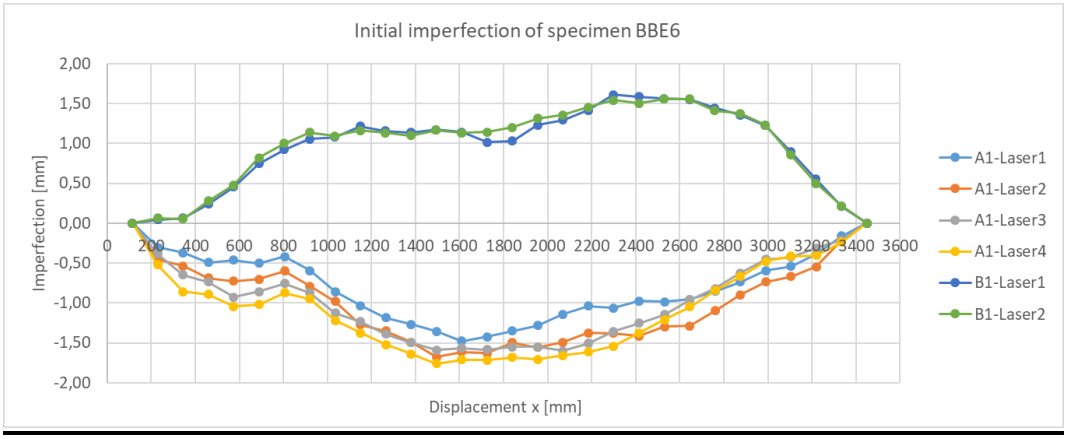


Figure B.30: Initial imperfections along specimen BBE6

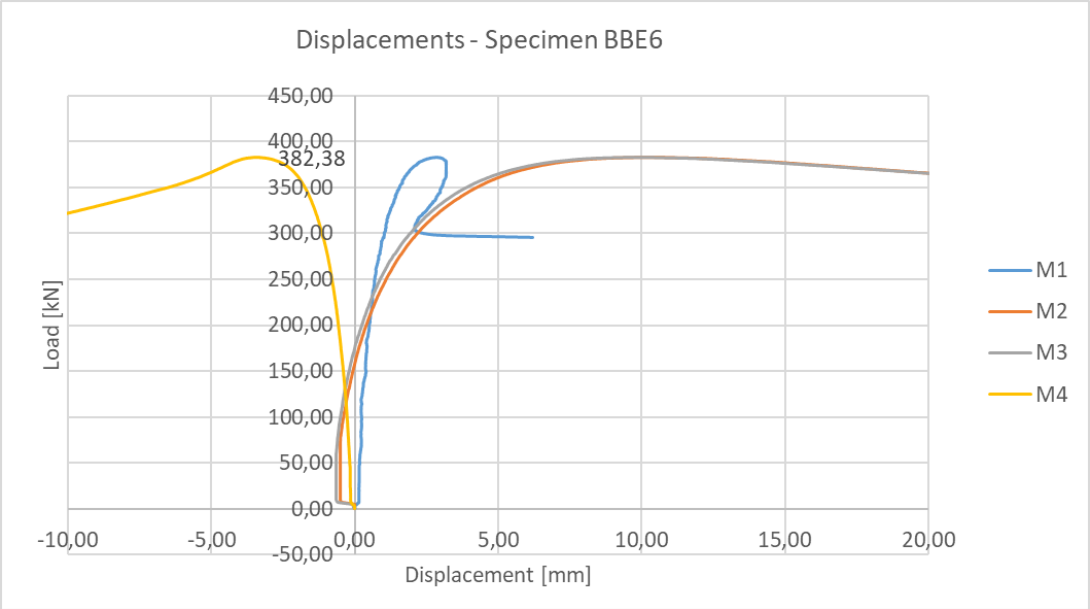


Figure B.31: Displacements along the principal axis, at mid-height, for specimen BBE6

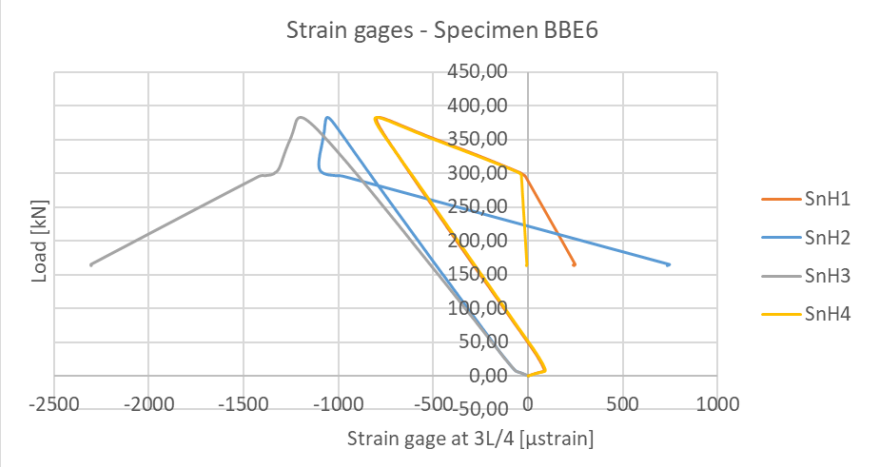


Figure B.32: Measurements of strain gages at 3/4L on specimen BBE6

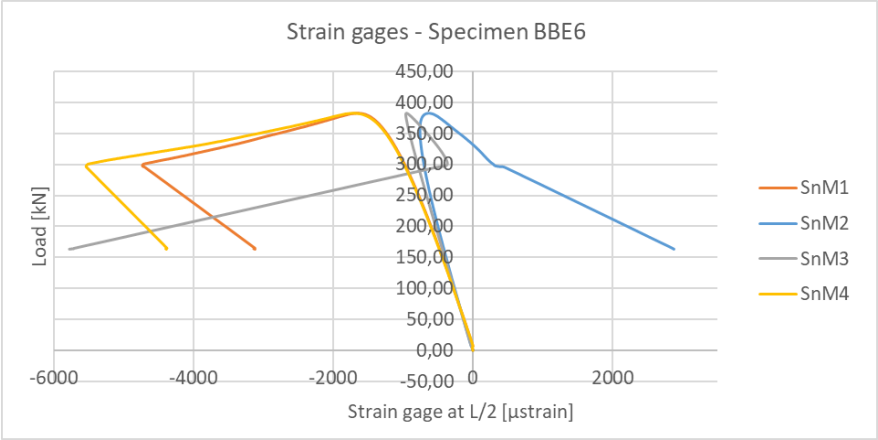


Figure B.33: Measurements of strain gages at L/2 on specimen BBE6

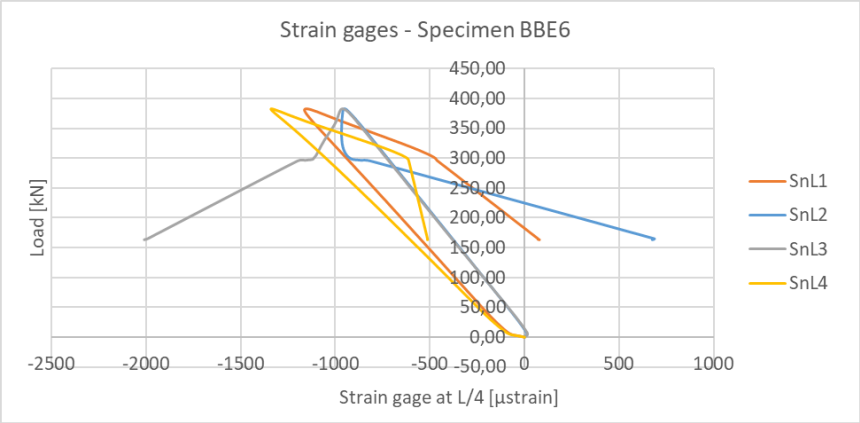


Figure B.34: Measurements of strain gages at L/4 on specimen BBE6

B7. Specimen SBE1

ID of specimen: SBE1	
Date of testing	10/01/2020
Type of specimen	Star battened angles with equal sections
Mean actual dimensions	
Cross-section	2 L60x60x6
ha_1 [mm]	59,73
ea_2 [mm]	5,82
hb_2 [mm]	60,4
eb_1 [mm]	6,05
a_1 / a_2 [mm]	101 / 90
b_1 / b_2 [mm]	102,2 / 91,2
a_3 / a_4 [mm]	103,4 / 92,4
b_3 / b_4 [mm]	104 / 93
L [mm]	2200
L_{crit} [mm]	2260
Tightening torque [Nm]	102
Total number of packing plates	2x4
Total number of bolts for packing plate connection	32 M12 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	480,0
Actual f_u [Mpa]	539,9
Response	
Ultimate resistance [kN]	346,83
Comments	Instability occured close to bifurcation

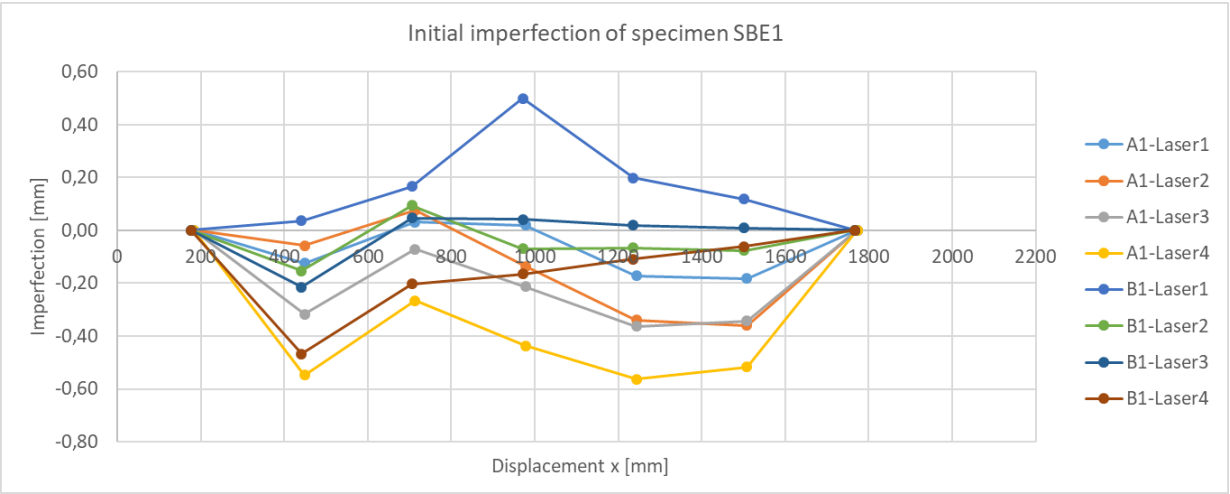


Figure B.35: Initial imperfections along specimen SBE1

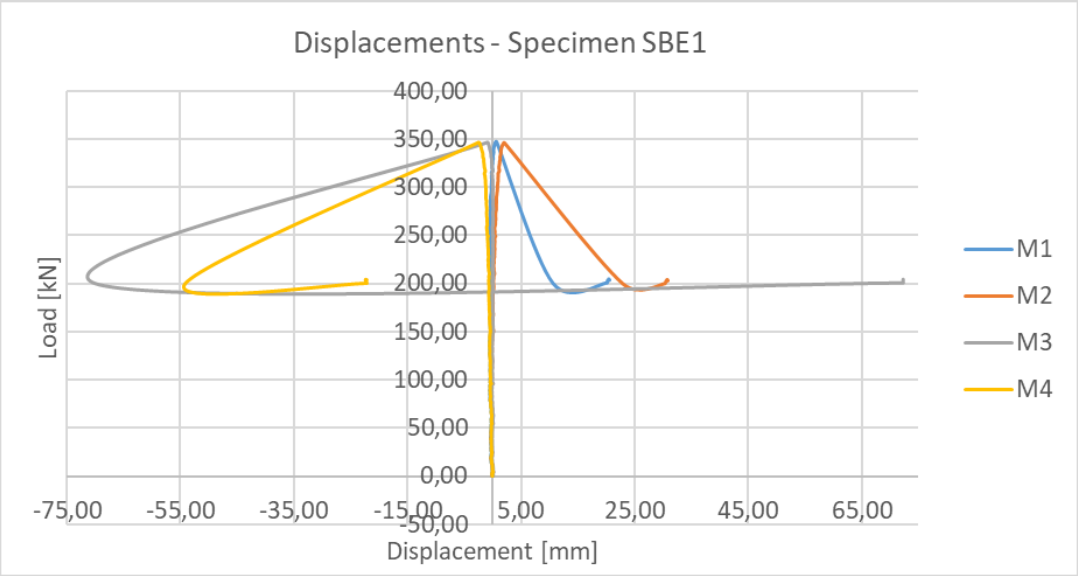


Figure B.36: Displacements along the principal axis, at mid-height, for specimen SBE1

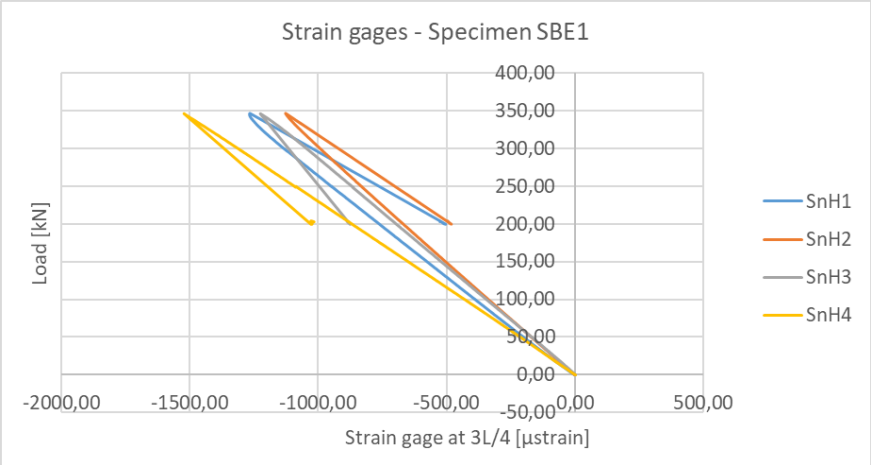


Figure B.37: Measurements of strain gages at 3/4L on specimen SBE1

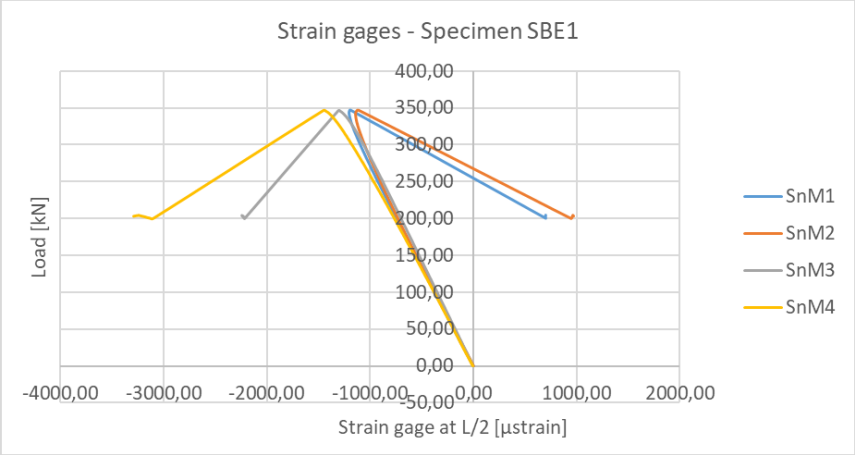


Figure B.38: Measurements of strain gages at L/2 on specimen SBE1

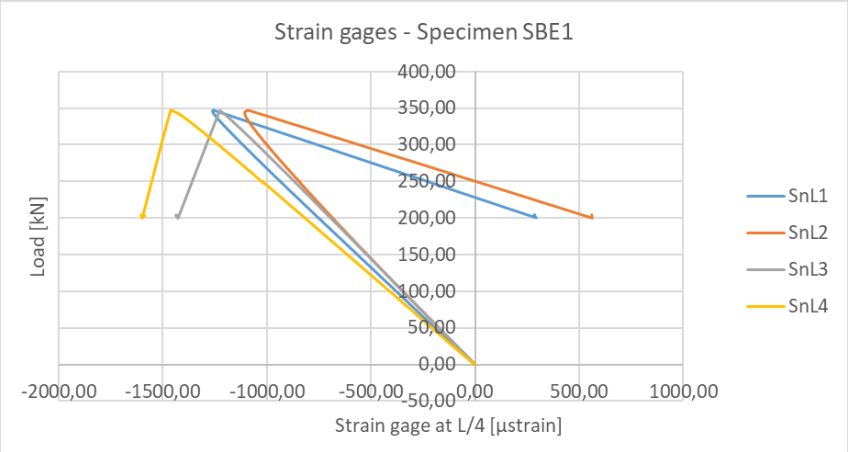
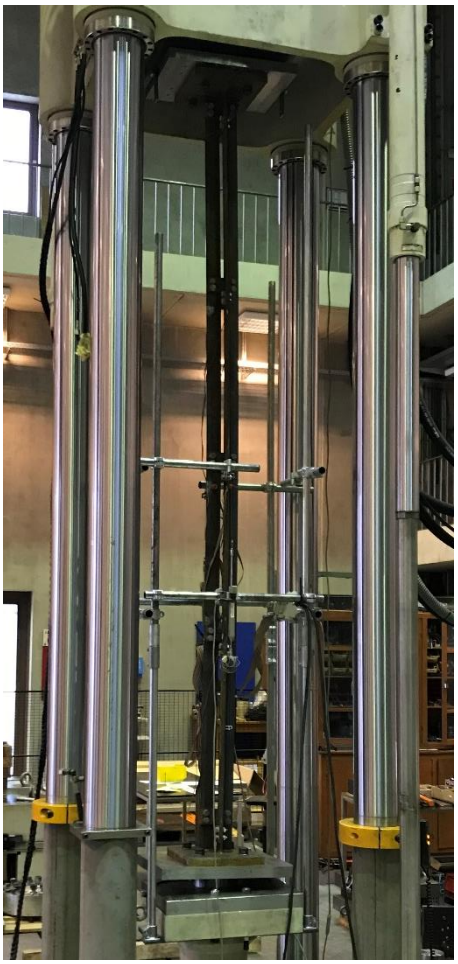


Figure B.39: Measurements of strain gages at L/4 on specimen SBE1

B8. Specimen SBE2

ID of specimen: SBE2	
Date of testing	27/01/2020
Type of specimen	Star battened angles with equal sections
Mean actual dimensions	
Cross-section	2 L60x60x6
ha_1 [mm]	60,63
ea_2 [mm]	6,05
hb_2 [mm]	60,53
eb_1 [mm]	6,05
a_1 / a_2 [mm]	102,4 / 91,4
b_1 / b_2 [mm]	103 / 92
a_3 / a_4 [mm]	100,3 / 89,3
b_3 / b_4 [mm]	103,8 / 92,8
L [mm]	3000
L_{crit} [mm]	3060
Tightening torque [Nm]	102
Total number of packing plates	2x5
Total number of bolts for packing plate connection	40 M12 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	480,0
Actual f_u [Mpa]	539,9
Response	
Ultimate resistance [kN]	296,32
Comments	Instability occured close to bifurcation



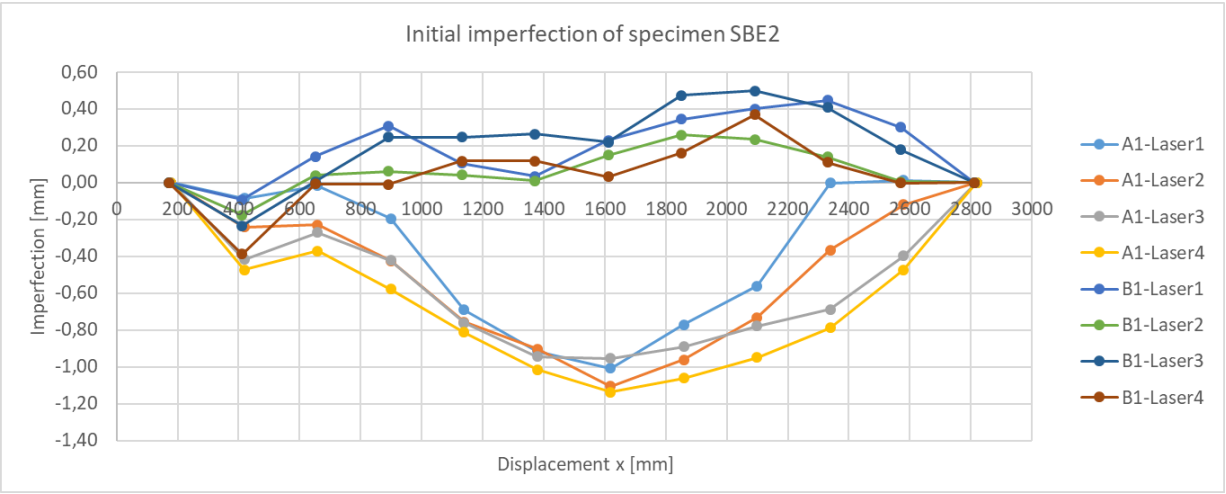


Figure B.40: Initial imperfections along specimen SBE2

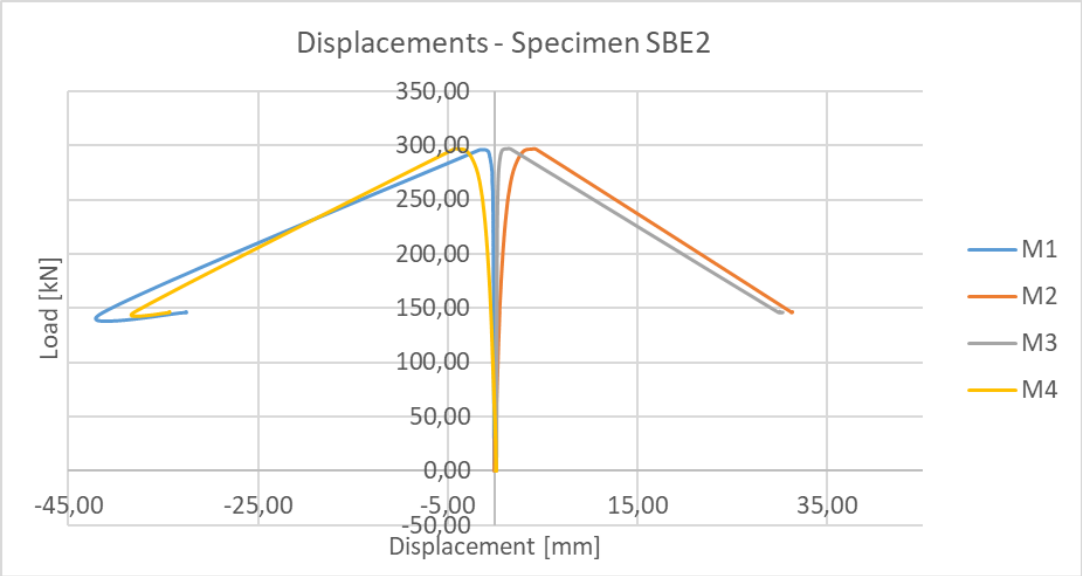


Figure B.41: Displacements along the principal axis, at mid-height, for specimen SBE2

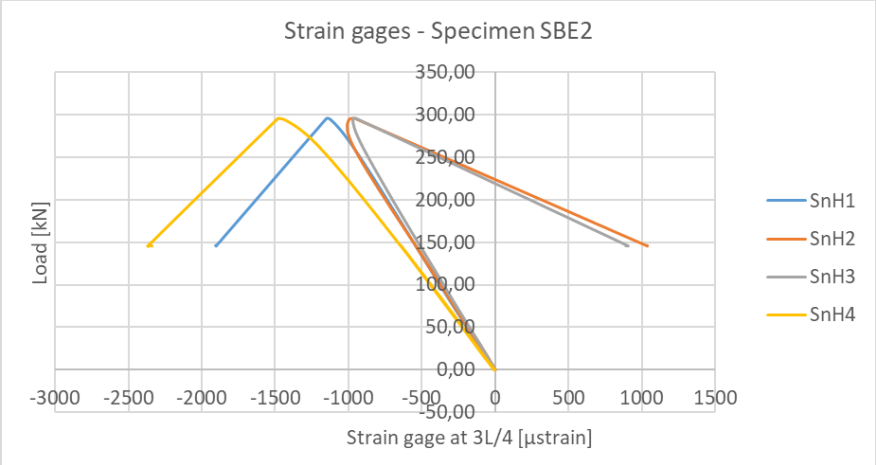


Figure B.42: Measurements of strain gages at 3/4L on specimen SBE2

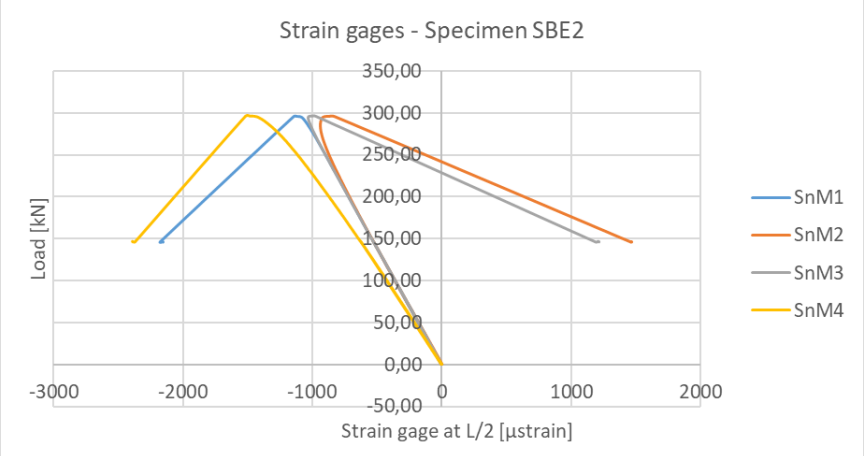


Figure B.43: Measurements of strain gages at L/2 on specimen SBE2

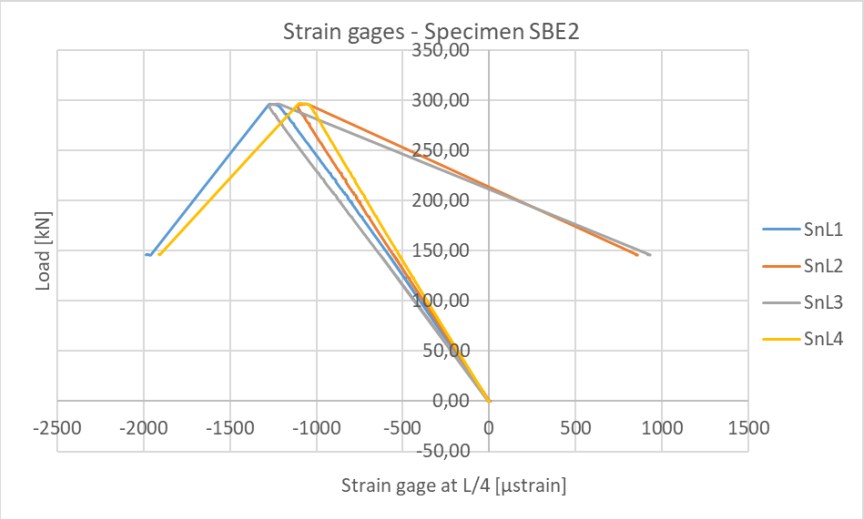


Figure B.44: Measurements of strain gages at L/4 on specimen SBE2

B9. Specimen SBE3

ID of specimen: SBE3	
Date of testing	22/01/2020
Type of specimen	Star battened angles with equal sections
Mean actual dimensions	
Cross-section	2 L60x60x6
ha_1 [mm]	60,6
ea_2 [mm]	6,02
hb_2 [mm]	59,8
eb_1 [mm]	5,85
a_1 / a_2 [mm]	101,6 / 90,6
b_1 / b_2 [mm]	102 / 91
a_3 / a_4 [mm]	104,1 / 93,1
b_3 / b_4 [mm]	102,1 / 91,1
L [mm]	3000
L_{crit} [mm]	3060
Tightening torque [Nm]	102
Total number of packing plates	2x4
Total number of bolts for packing plate connection	32 M12 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	480,0
Actual f_u [Mpa]	539,9
Response	
Ultimate resistance [kN]	283,10
Comments	Instability occured close to bifurcation

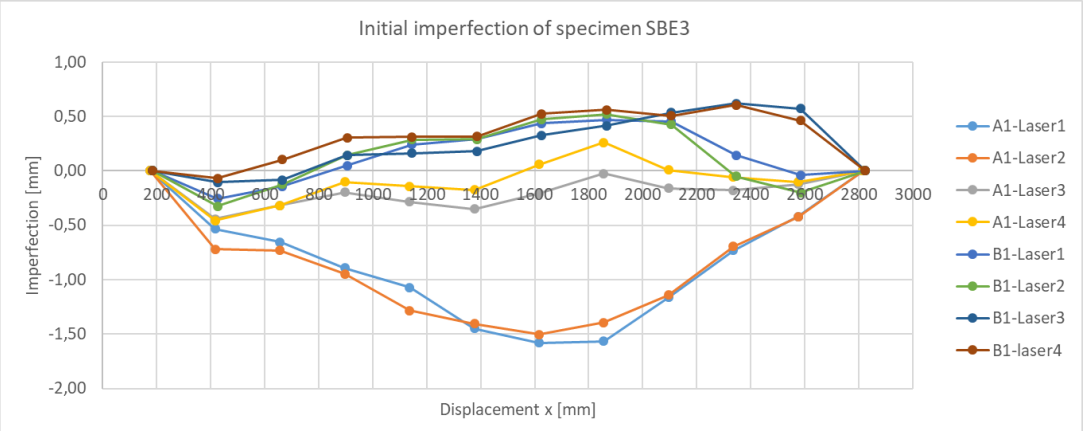


Figure B.45: Initial imperfections along specimen SBE3

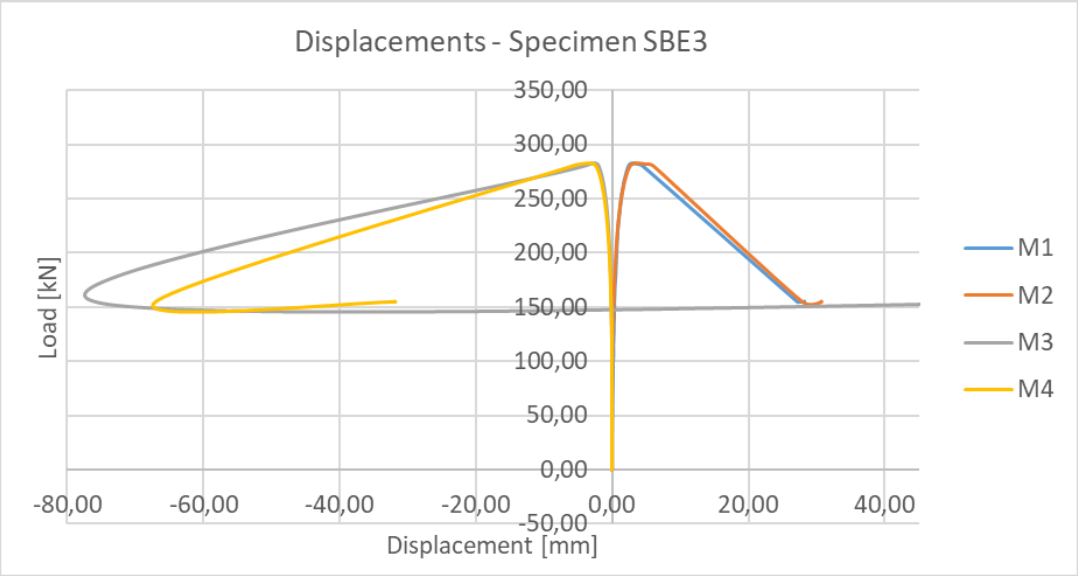


Figure B.46: Displacements along the principal axis, at mid-height, for specimen SBE3

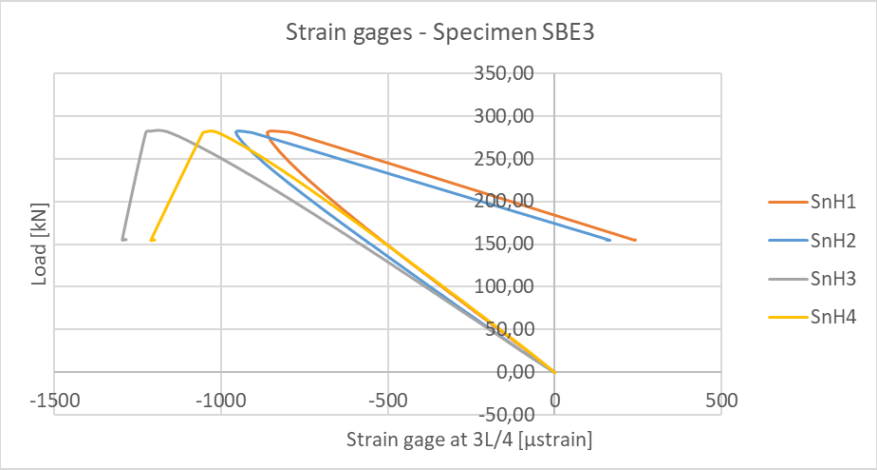


Figure B.47: Measurements of strain gages at 3/4L on specimen SBE3

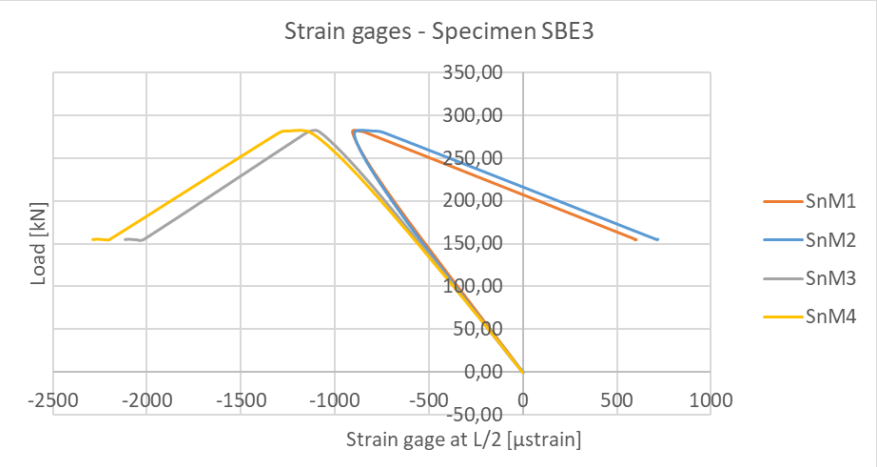


Figure B.48: Measurements of strain gages at L/2 on specimen SBE3

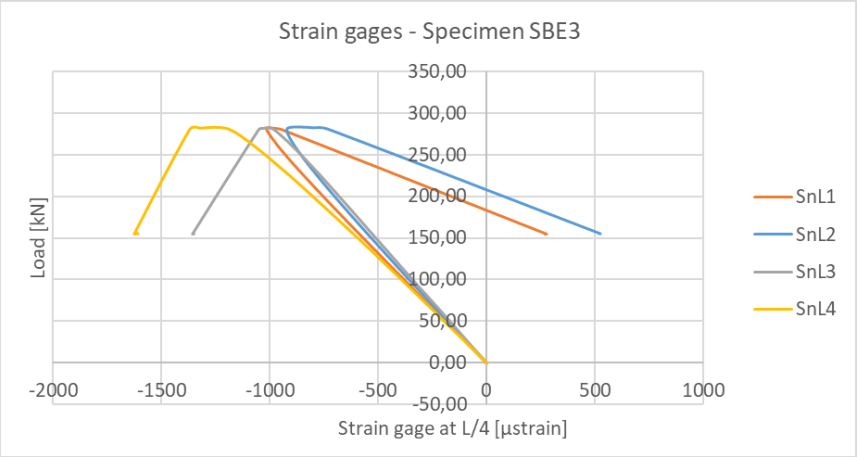


Figure B.49: Measurements of strain gages at L/4 on specimen SBE3

B10. Specimen SBE4

ID of specimen: SBE4	
Date of testing	03/02/2020
Type of specimen	Star battened angles with equal sections
Mean actual dimensions	
Cross-section	2 L60x60x6
ha_1 [mm]	60,53
ea_2 [mm]	5,92
hb_2 [mm]	60,57
eb_1 [mm]	6,1
a_1 / a_2 [mm]	104,1 / 93,1
b_1 / b_2 [mm]	101,7 / 90,7
a_3 / a_4 [mm]	101 / 90
b_3 / b_4 [mm]	103,2 / 92,2
L [mm]	4000
L_{crit} [mm]	4060
Tightening torque [Nm]	102
Total number of packing plates	2x5
Total number of bolts for packing plate connection	40 M12 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	480,0
Actual f_u [Mpa]	539,9
Response	
Ultimate resistance [kN]	127,41
Comments	/

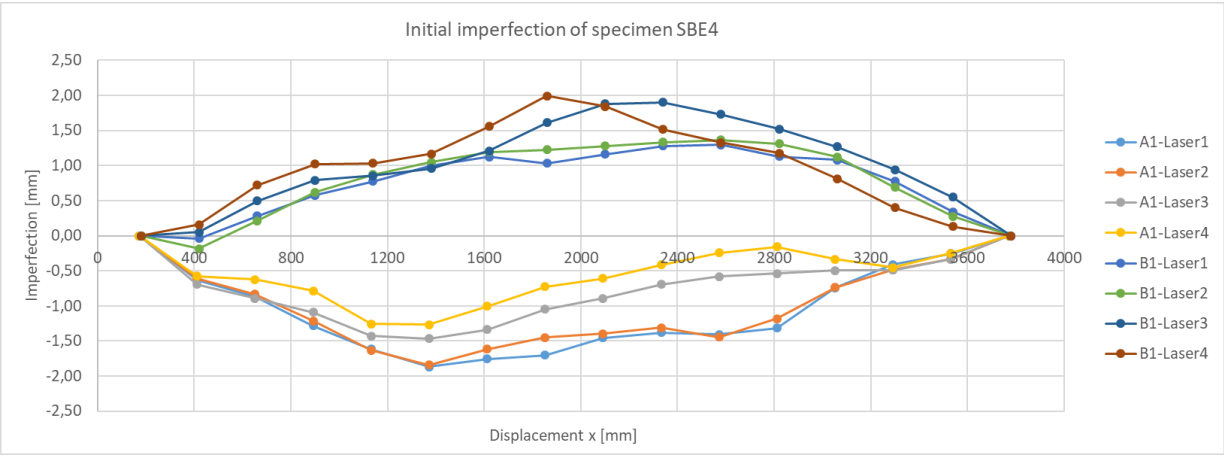


Figure B.50: Initial imperfections along specimen SBE4

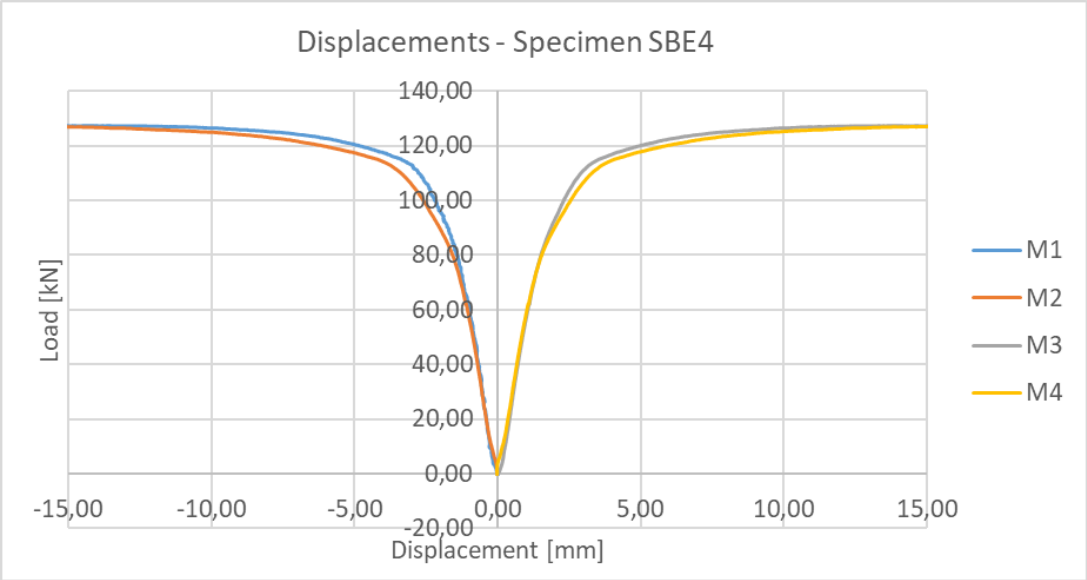


Figure B.51: Displacements along the principal axis, at mid-height, for specimen SBE4

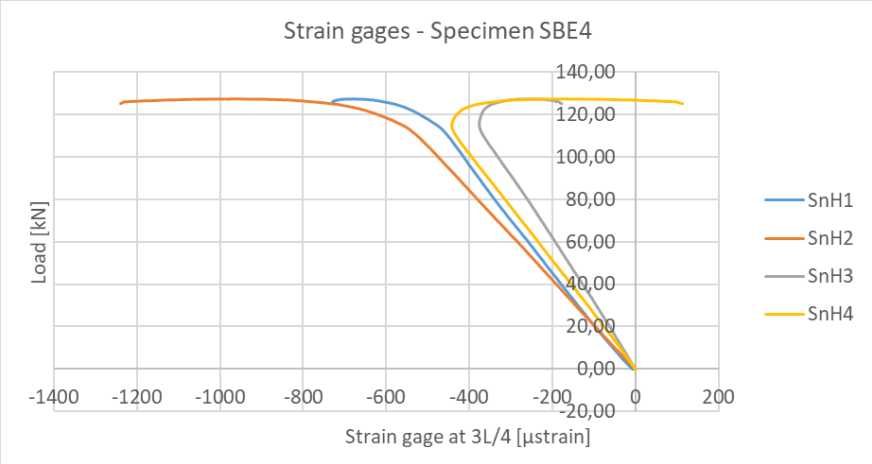


Figure B.52: Measurements of strain gages at 3/4L on specimen SBE4

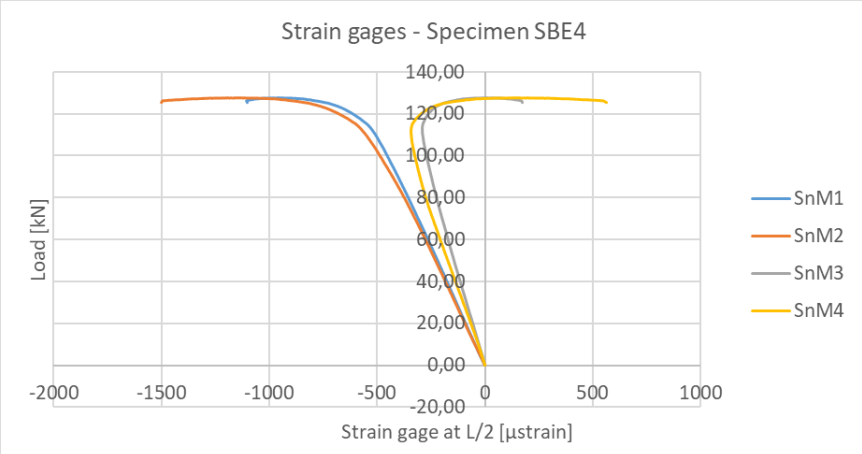


Figure B.53: Measurements of strain gages at L/2 on specimen SBE4

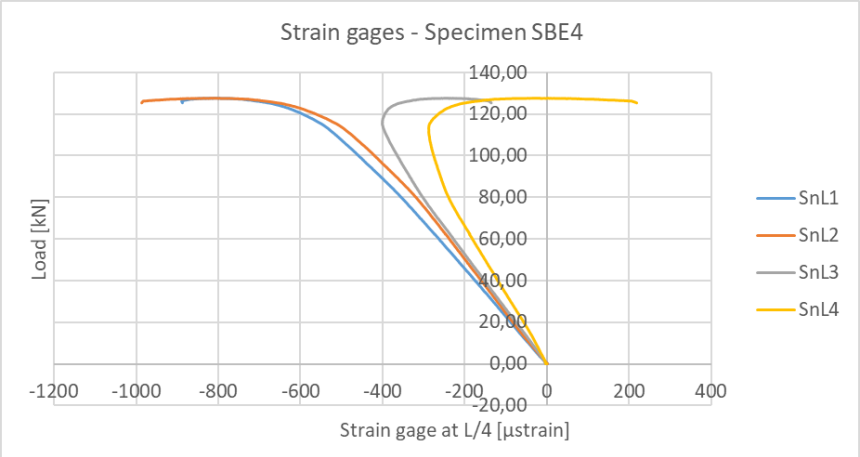


Figure B.54: Measurements of strain gages at L/4 on specimen SBE4

B11. Specimen SBE5

ID of specimen: SBE5	
Date of testing	27/01/2020
Type of specimen	Star battened angles with equal sections
Mean actual dimensions	
Cross-section	2 L60x60x6
ha_1 [mm]	60,53
ea_2 [mm]	6,05
hb_2 [mm]	60,87
eb_1 [mm]	5,91
a_1 / a_2 [mm]	101,3 / 90,3
b_1 / b_2 [mm]	103,7 / 92,7
a_3 / a_4 [mm]	103,2 / 92,2
b_3 / b_4 [mm]	103,6 / 92,6
L [mm]	3000
L_{crit} [mm]	3060
Tightening torque [Nm]	10,2
Total number of packing plates	2x5
Total number of bolts for packing plate connection	40 M12 10.9
Level of bolt pretension [%]	10
Material	S 355
Actual f_y [Mpa]	480,0
Actual f_u [Mpa]	539,9
Response	
Ultimate resistance [kN]	251,92
Comments	Instability occured close to bifurcation

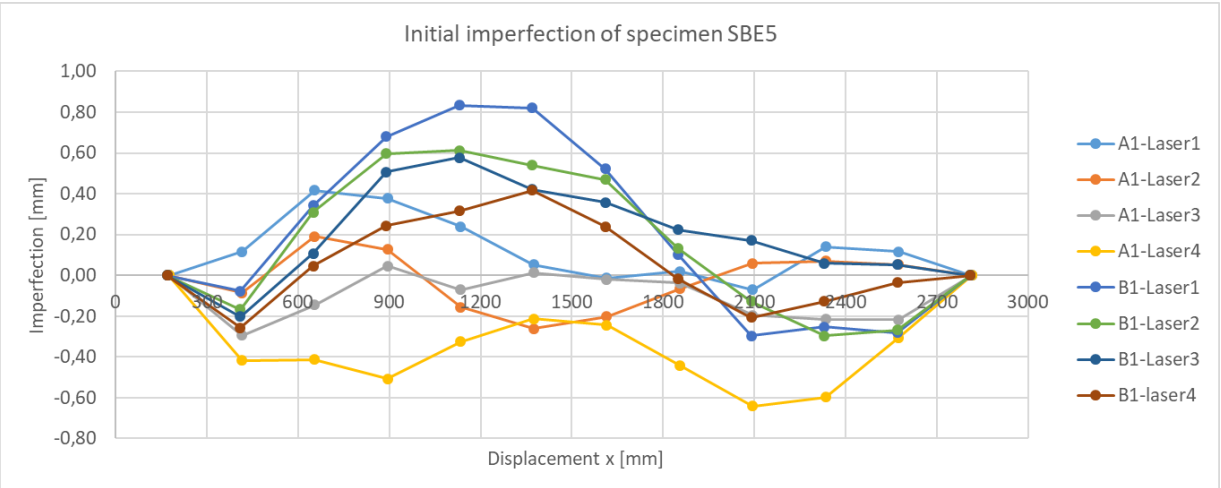


Figure B.55: Initial imperfections along specimen SBE5

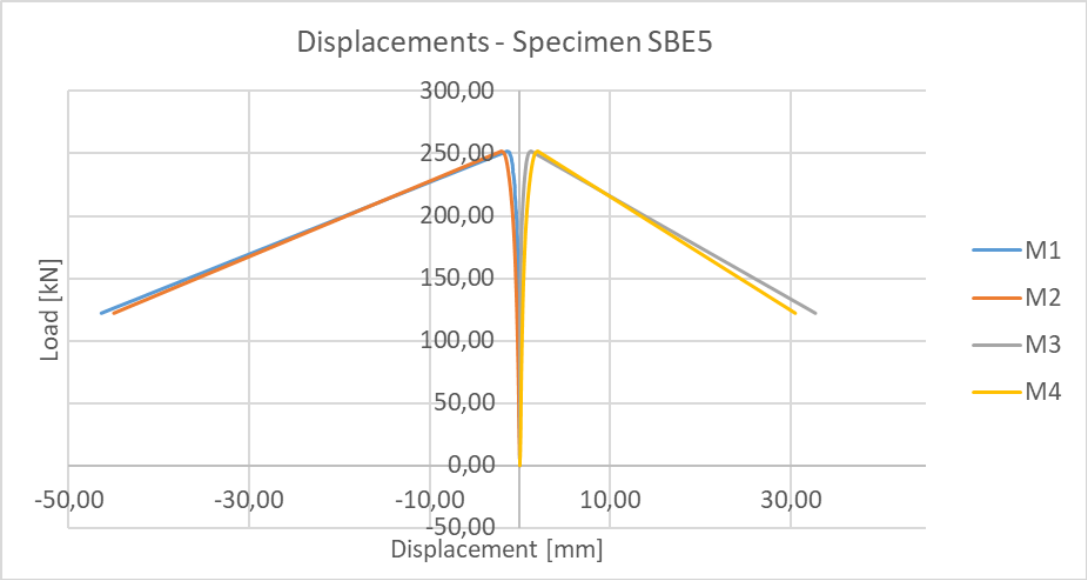


Figure B.56: Displacements along the principal axis, at mid-height, for specimen SBE5

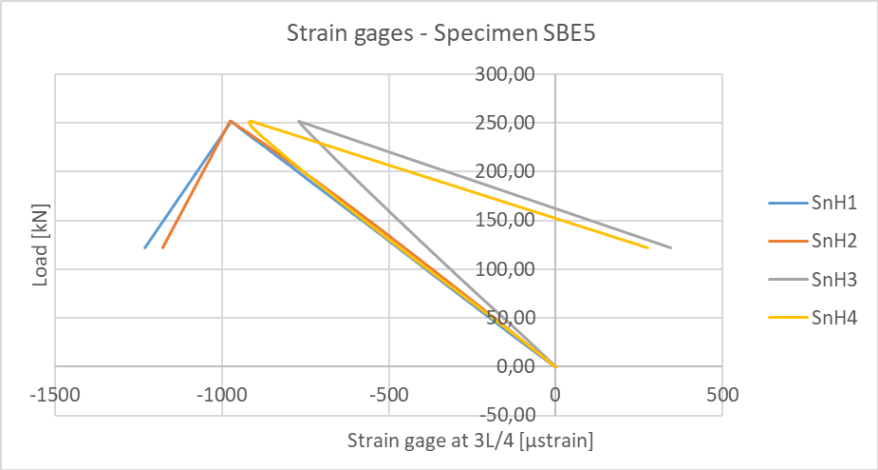


Figure B.57: Measurements of strain gages at 3/4L on specimen SBE5

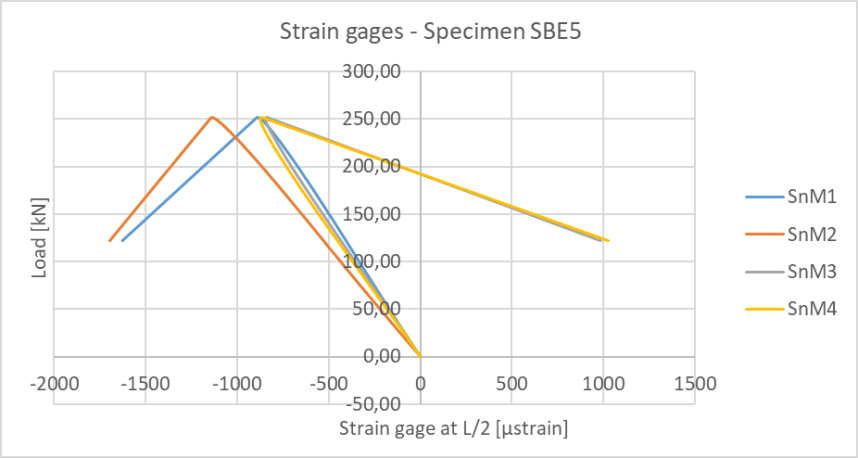


Figure B.58: Measurements of strain gages at L/2 on specimen SBE5

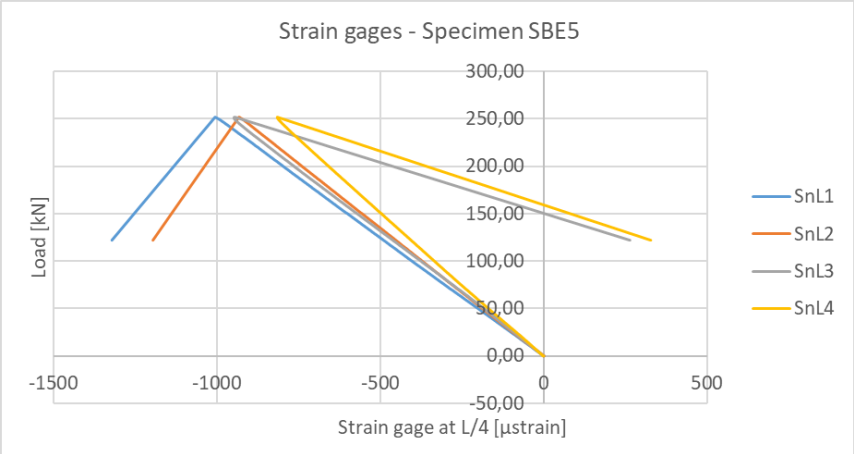


Figure B.59: Measurements of strain gages at L/4 on specimen SBE5

B12. Specimen SBE6

ID of specimen: SBE6	
Date of testing	30/01/2020
Type of specimen	Star battened angles with equal sections
Mean actual dimensions	
Cross-section	2 L60x60x6
ha_1 [mm]	59,87
ea_2 [mm]	6,1
hb_2 [mm]	60,57
eb_1 [mm]	6,07
a_1 / a_2 [mm]	102,6 / 91,6
b_1 / b_2 [mm]	102,8 / 91,8
a_3 / a_4 [mm]	100,5 / 89,5
b_3 / b_4 [mm]	102,3 / 91,3
L [mm]	4000
L_{crit} [mm]	4060
Tightening torque [Nm]	10,2
Total number of packing plates	2x5
Total number of bolts for packing plate connection	40 M12 10.9
Level of bolt pretension [%]	10
Material	S 355
Actual f_y [Mpa]	480,0
Actual f_u [Mpa]	539,9
Response	
Ultimate resistance [kN]	81,47
Comments	Peak load close to the predicted one

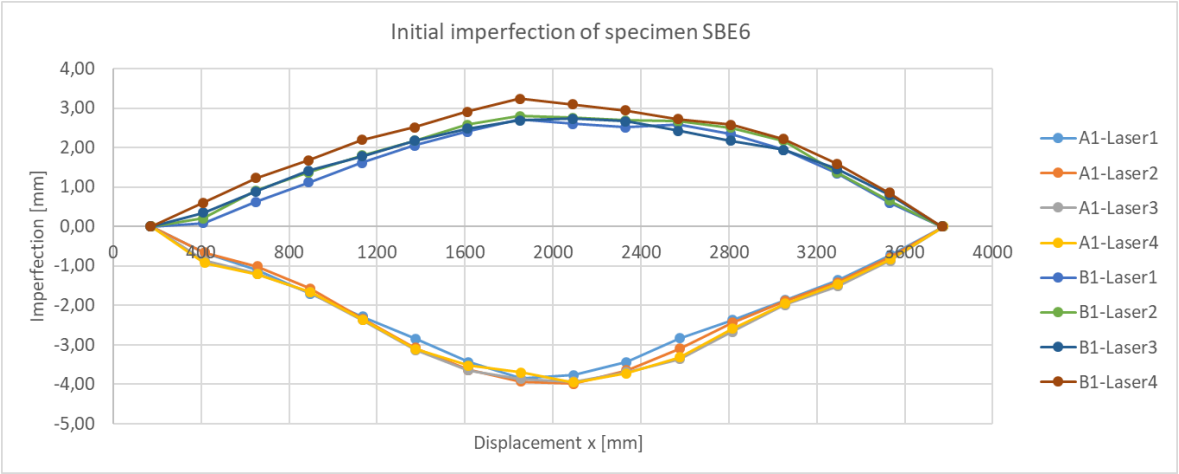


Figure B.60: Initial imperfections along specimen SBE6

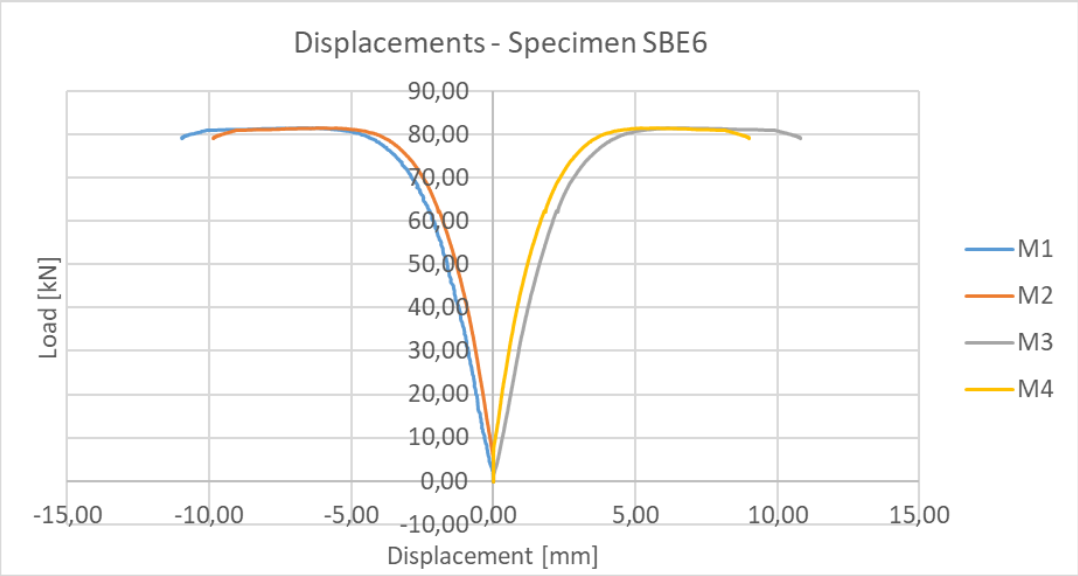


Figure B.61: Displacements along the principal axis, at mid-height, for specimen SBE6

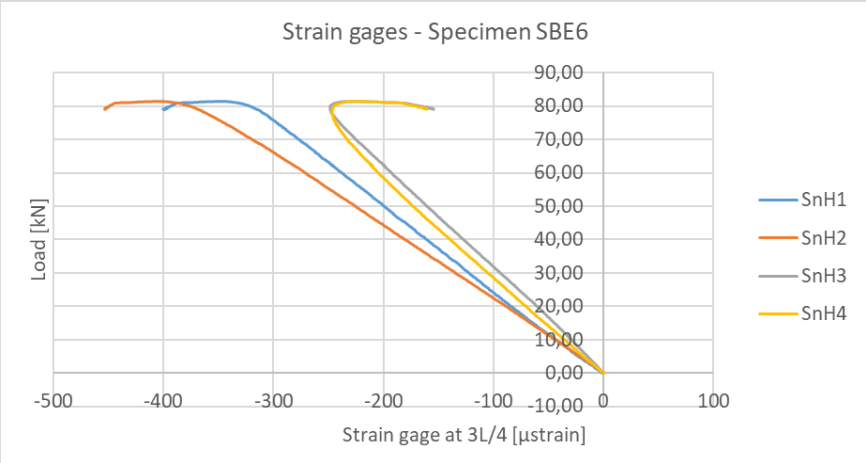


Figure B.62: Measurements of strain gages at 3/4L on specimen SBE6

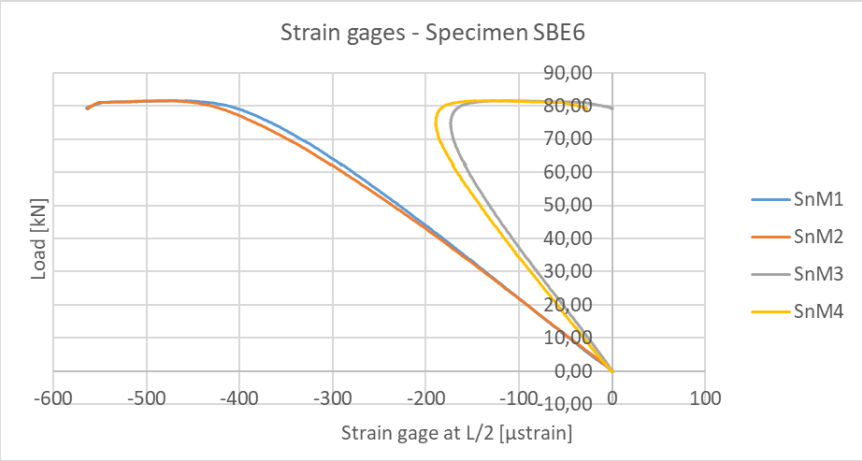


Figure B.63: Measurements of strain gages at L/2 on specimen SBE6

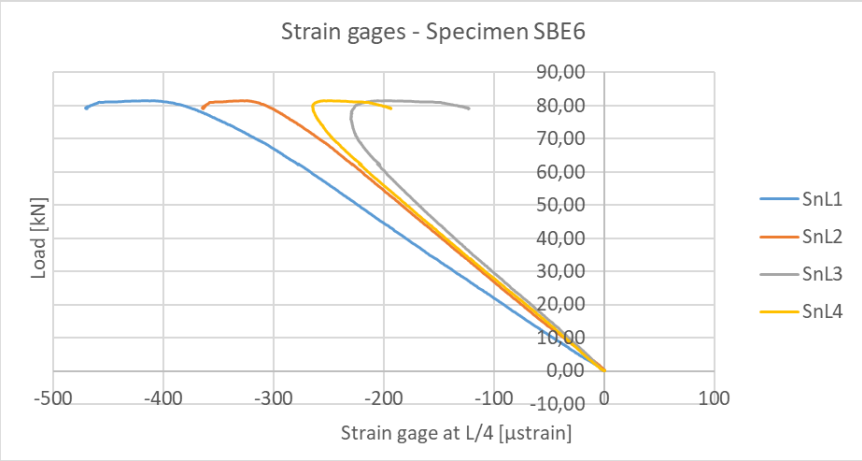


Figure B.64: Measurements of strain gages at L/4 on specimen SBE6

B1. Specimen SBU1

ID of specimen: SBU1	
Date of testing	07/01/2020
Type of specimen	Star battened angles with unequal sections
Mean actual dimensions	
Cross-section	L70x70x7 + L60x60x6
ha_1 [mm]	69,87
ea_1 [mm]	6,93
hb_2 [mm]	59,87
eb_1 [mm]	6,03
a_1 / a_2 [mm]	75,1 / 64,1
b_1 / b_2 [mm]	77 / 66
a_3 / a_4 [mm]	75,5 / 64,5
b_3 / b_4 [mm]	75,5 / 64,5
L [mm]	2200
L_{crit} [mm]	2260
Tightening torque [Nm]	253/102
Total number of packing plates	2x4
Total number of bolts for packing plate connection	16 M16 10.9 16 M12 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	414,6 / 480,0
Actual f_u [Mpa]	544,4 / 539,9
Response	
Ultimate resistance [kN]	231,97
Comments	Classical flexural buckling occured close to the predicted load. One slip occured during the test.

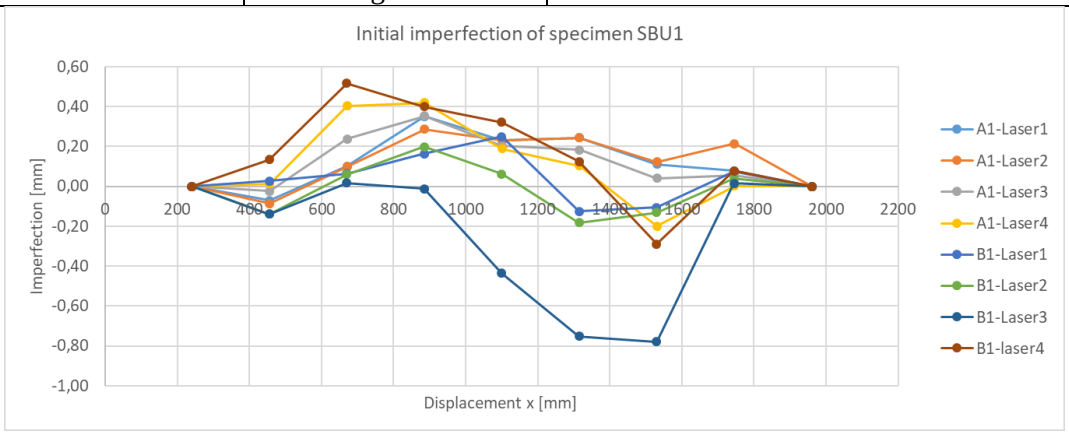


Figure B.65: Initial imperfections along specimen SBU1

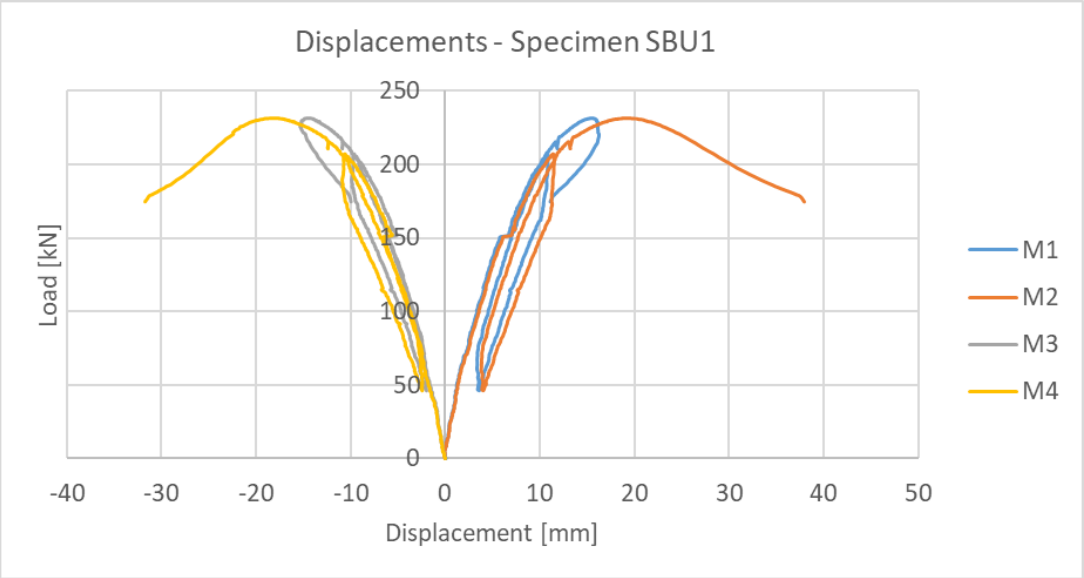


Figure B.66: Displacements along the principal axis, at mid-height, for specimen SBU1

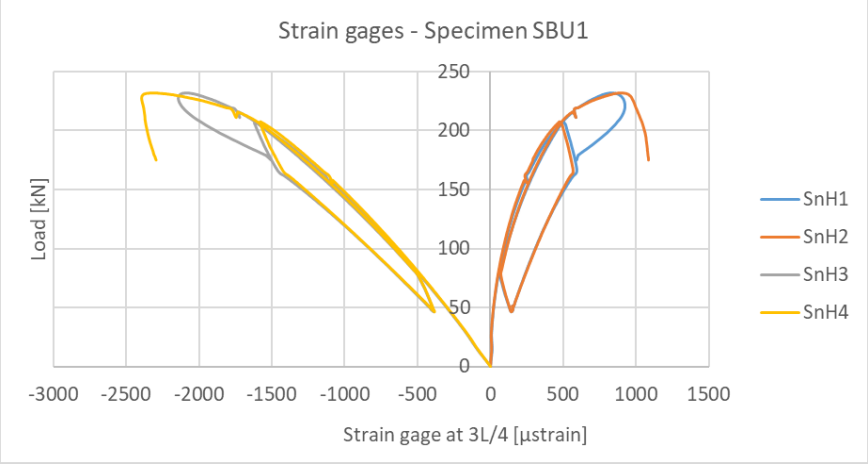


Figure B.67: Measurements of strain gages at 3/4L on specimen SBU1

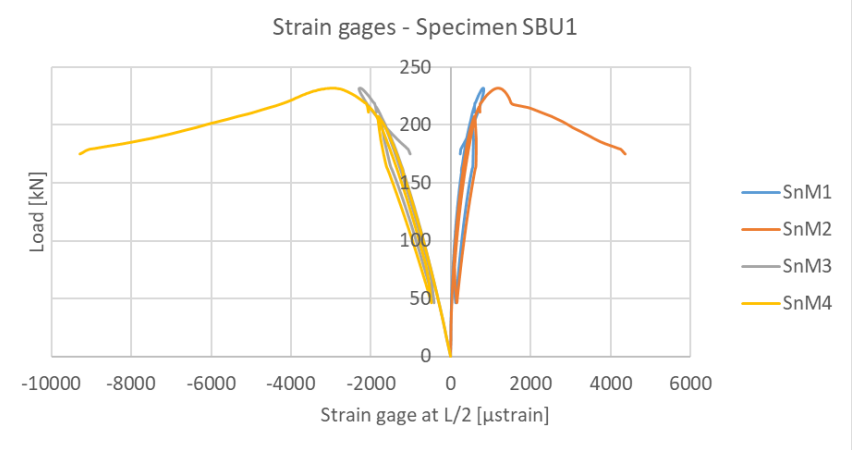


Figure B.68: Measurements of strain gages at L/2 on specimen SBU1

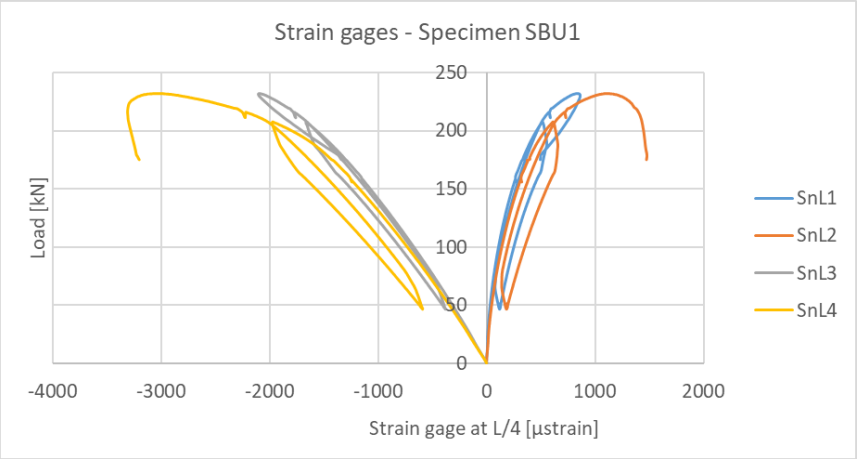


Figure B.69: Measurements of strain gages at L/4 on specimen SBU1

B14. Specimen SBU2

ID of specimen: SBU2	
Date of testing	16/01/2020
Type of specimen	Star battened angles with unequal sections
Mean actual dimensions	
Cross-section	L70x70x7 + L60x60x6
ha_1 [mm]	69,93
ea_1 [mm]	6,89
hb_2 [mm]	60,13
eb_1 [mm]	6,07
a_1 / a_2 [mm]	75,8 / 64,8
b_1 / b_2 [mm]	73,6 / 62,6
a_3 / a_4 [mm]	73,9 / 62,9
b_3 / b_4 [mm]	73,5 / 62,5
L [mm]	3000
L_{crit} [mm]	3060
Tightening torque [Nm]	253/102
Total number of packing plates	2x5
Total number of bolts for packing plate connection	20 M16 10.9 20 M12 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	414,6 / 480,0
Actual f_u [Mpa]	544,4 / 539,9
Response	
Ultimate resistance [kN]	168,26
Comments	Classical flexural buckling occured close to the predicted load

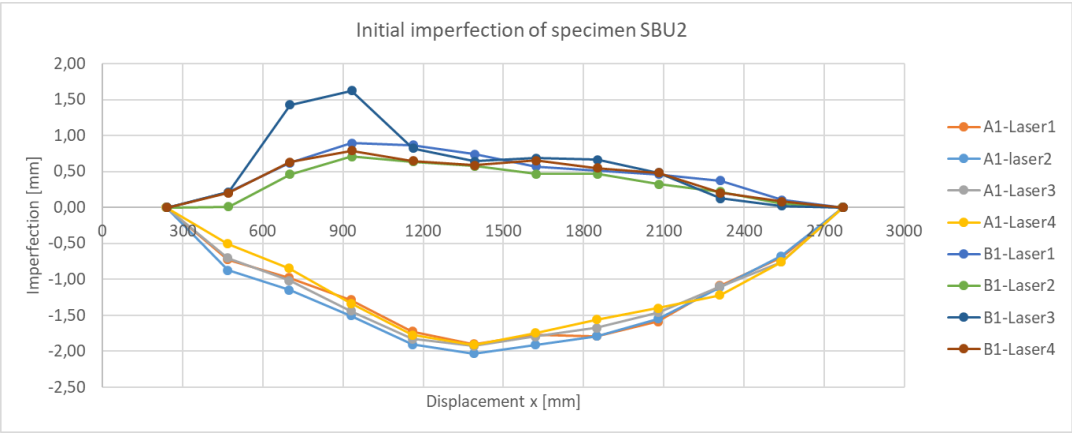


Figure B.70: Initial imperfections along specimen SBU2

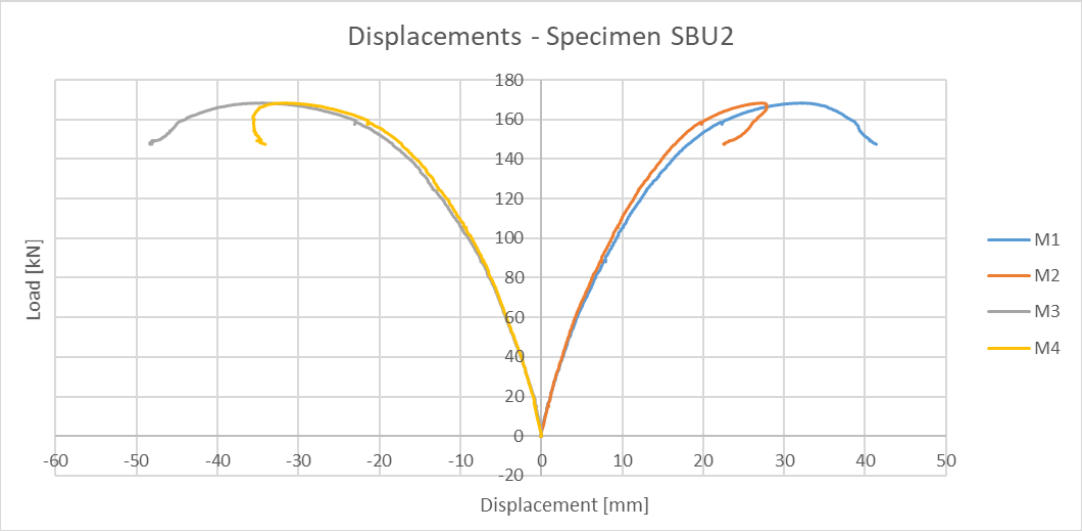


Figure B.71: Displacements along the principal axis, at mid-height, for specimen SBU2

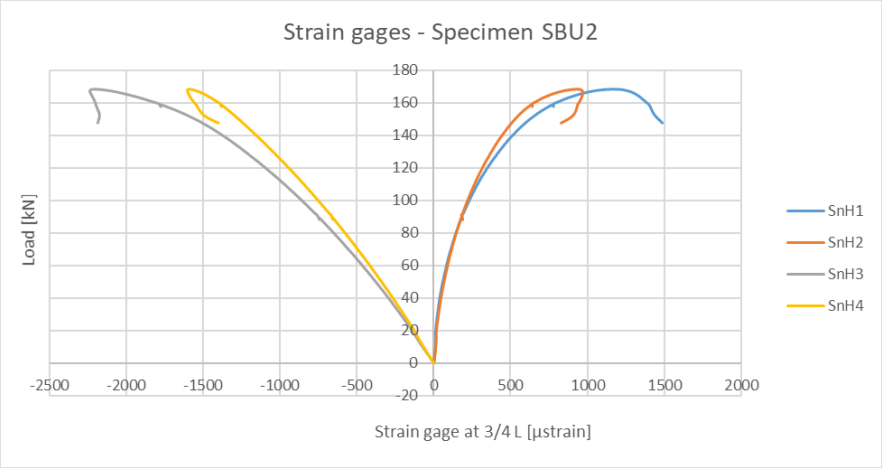


Figure B.72: Measurements of strain gages at 3/4L on specimen SBU2

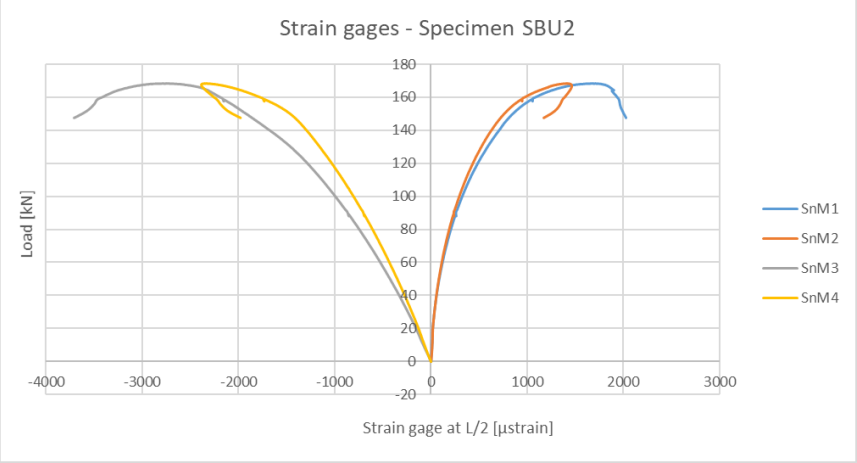


Figure B.73: Measurements of strain gages at L/2 on specimen SBU2

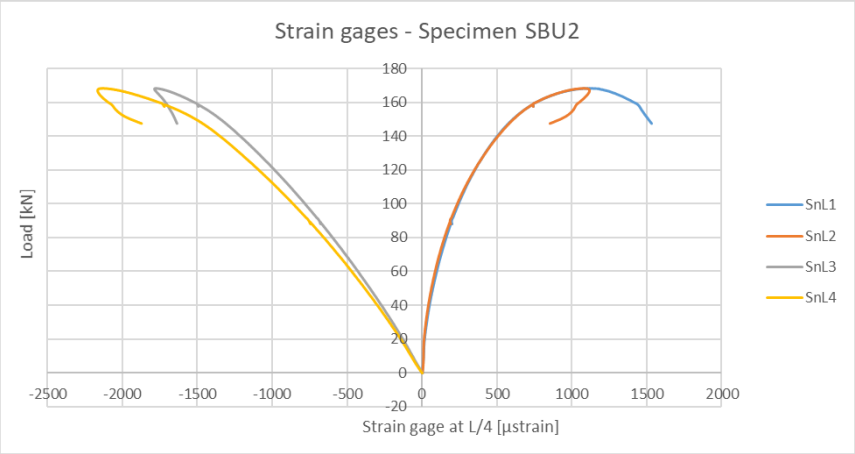


Figure B.74: Measurements of strain gages at L/4 on specimen SBU2

B15. Specimen SBU3

ID of specimen: SBU3	
Date of testing	21/01/2020
Type of specimen	Star battened angles with unequal sections
Mean actual dimensions	
Cross-section	L70x70x7 + L60x60x6
ha_1 [mm]	69,9
ea_1 [mm]	6,91
hb_2 [mm]	60,37
eb_1 [mm]	6,01
a_1 / a_2 [mm]	74,4 / 63,4
b_1 / b_2 [mm]	79,2 / 68,2
a_3 / a_4 [mm]	77,1 / 66,1
b_3 / b_4 [mm]	75,8 / 64,8
L [mm]	3000
L_{crit} [mm]	3060
Tightening torque [Nm]	25,3/10,2
Total number of packing plates	2x4
Total number of bolts for packing plate connection	16 M16 10.9 16 M12 10.9
Level of bolt pretension [%]	10
Material	S 355
Actual f_y [Mpa]	414,6 / 480,0
Actual f_u [Mpa]	544,4 / 539,9
Response	
Ultimate resistance [kN]	152,54
Comments	Classical flexural buckling occured but with wrong support conditions Be careful : Rotation fixed at bottom hinge

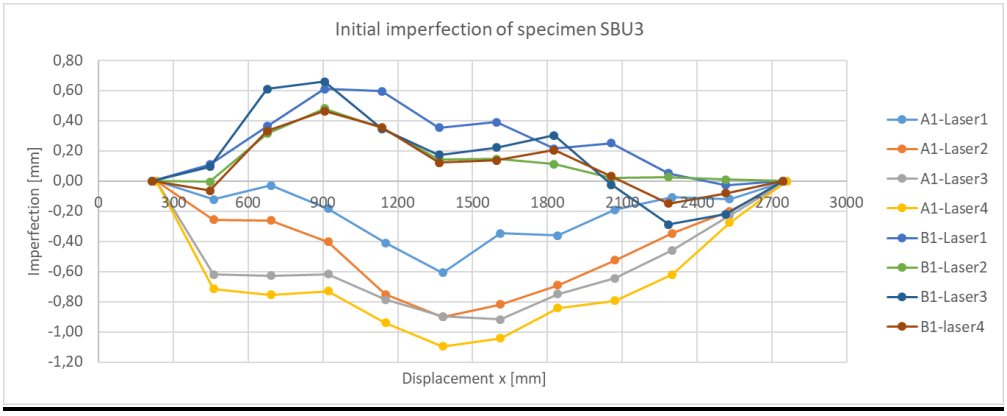


Figure B.75: Initial imperfections along specimen SBU3

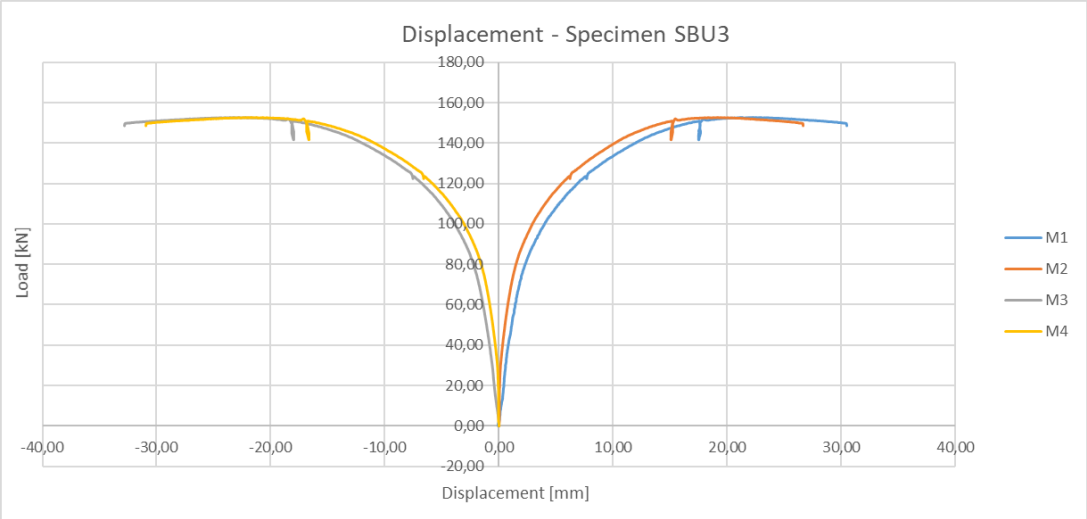


Figure B.76: Displacements along the principal axis, at mid-height, for specimen SBU3

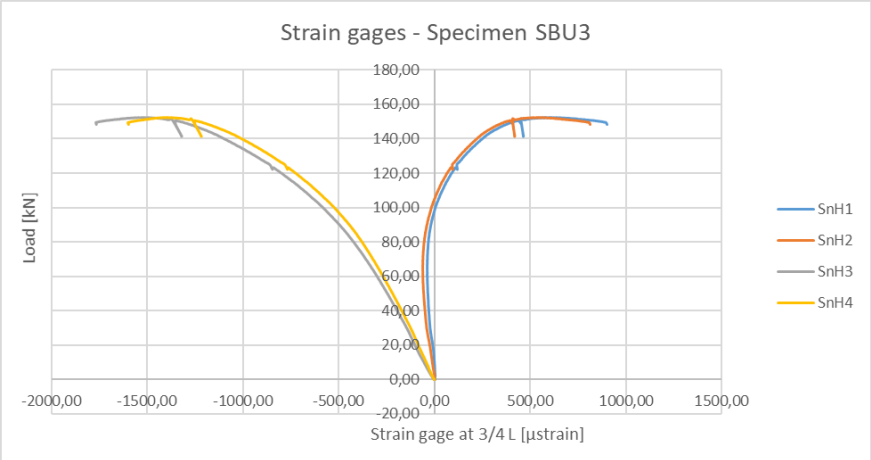


Figure B.77: Measurements of strain gages at 3/4L on specimen SBU3

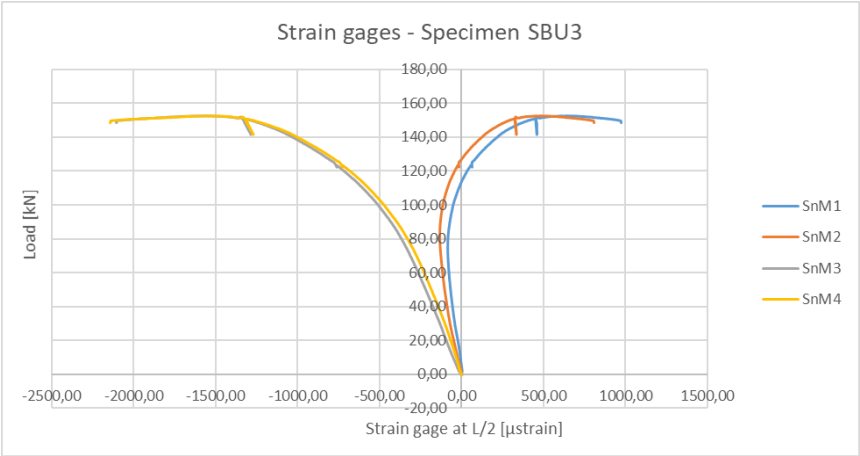


Figure B.78: Measurements of strain gages at L/2 on specimen SBU3

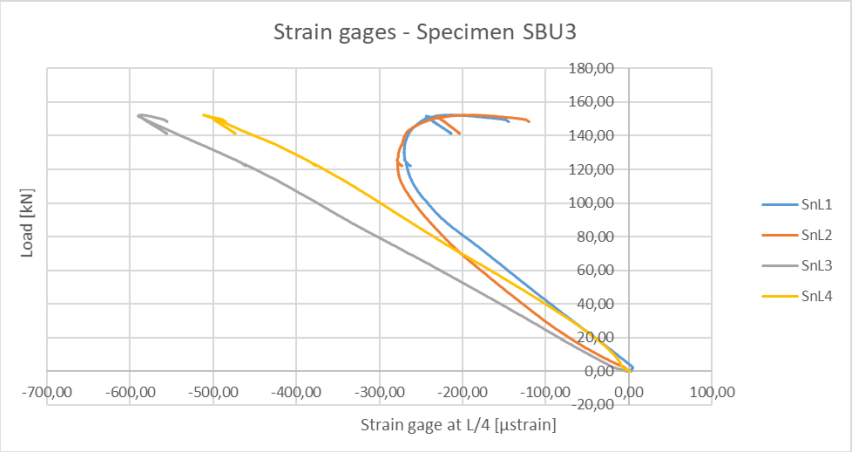


Figure B.79: Measurements of strain gages at L/4 on specimen SBU3

B16. Specimen SBU4

ID of specimen: SBU4	
Date of testing	04/02/2020
Type of specimen	Star battened angles with unequal sections
Mean actual dimensions	
Cross-section	L70x70x7 + L60x60x6
ha_1 [mm]	69,93
ea_1 [mm]	6,89
hb_2 [mm]	59,62
eb_1 [mm]	5,88
a_1 / a_2 [mm]	76,5 / 65,5
b_1 / b_2 [mm]	73,8 / 62,8
a_3 / a_4 [mm]	75,7 / 64,7
b_3 / b_4 [mm]	76,3 / 65,3
L [mm]	4000
L_{crit} [mm]	4060
Tightening torque [Nm]	25,3/10,2
Total number of packing plates	2x5
Total number of bolts for packing plate connection	20 M16 10.9 20 M12 10.9
Level of bolt pretension [%]	10
Material	S 355
Actual f_y [Mpa]	414,6 / 480,0
Actual f_u [Mpa]	544,4 / 539,9
Response	
Ultimate resistance [kN]	84,68
Comments	Classical flexural buckling occured

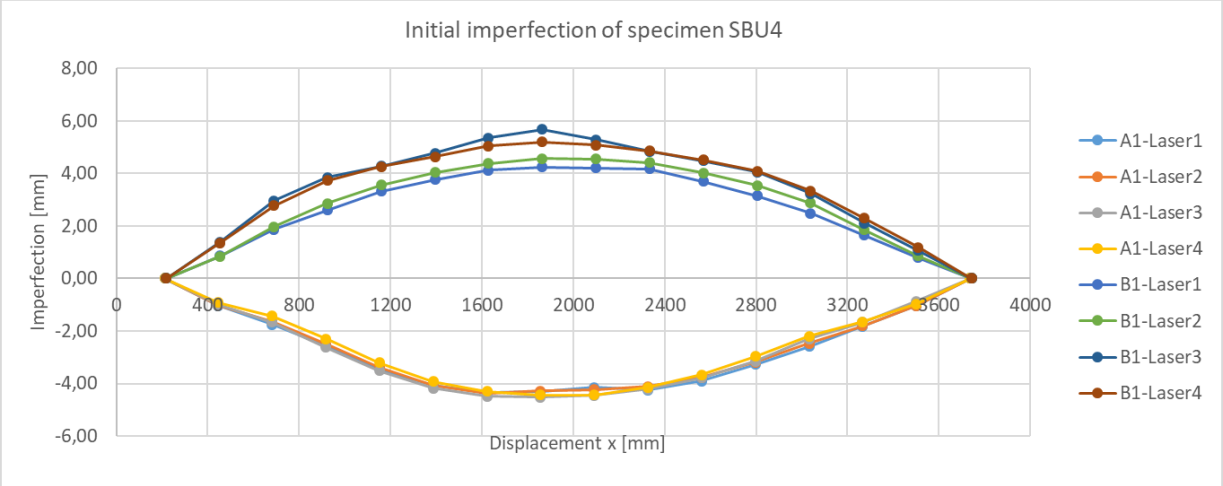


Figure B.80: Initial imperfections along specimen SBU4

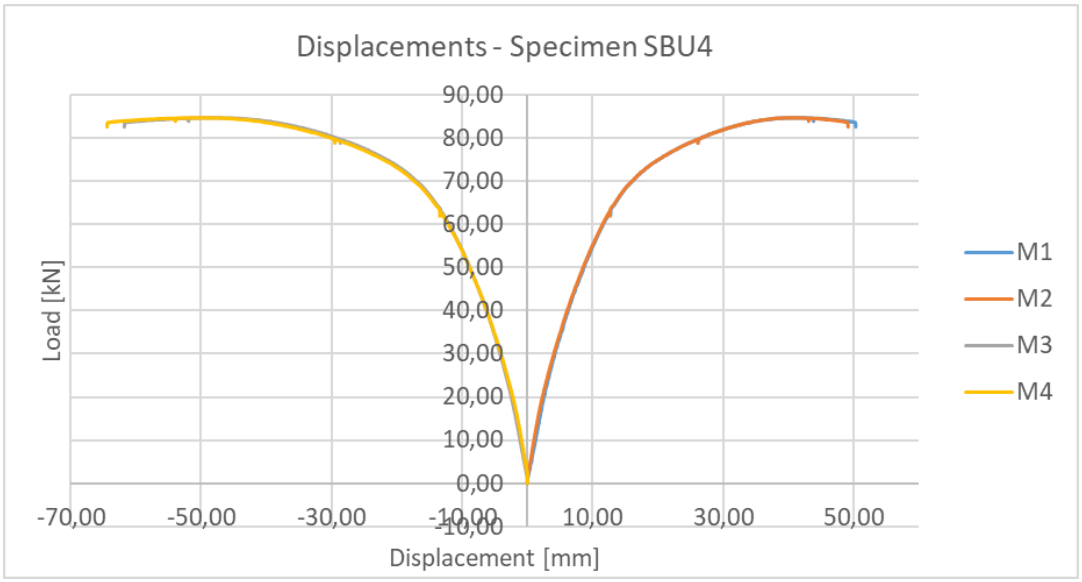


Figure B.81: Displacements along the principal axis, at mid-height, for specimen SBU4

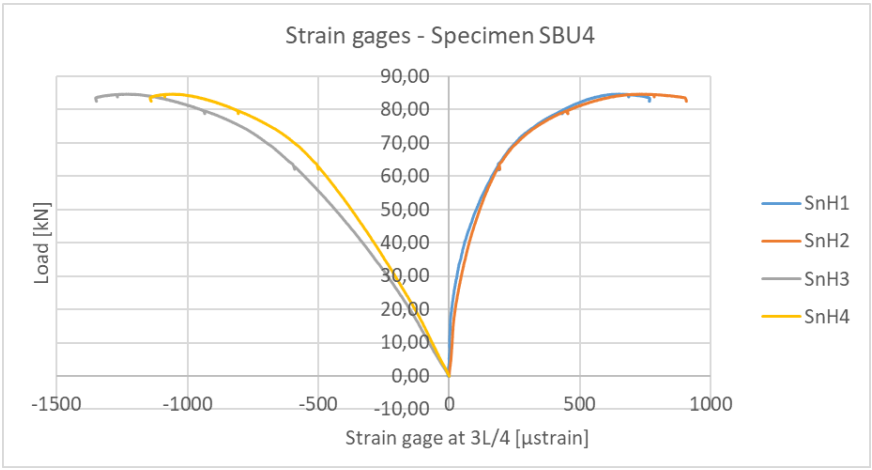


Figure B.82: Measurements of strain gages at 3/4L on specimen SBU4

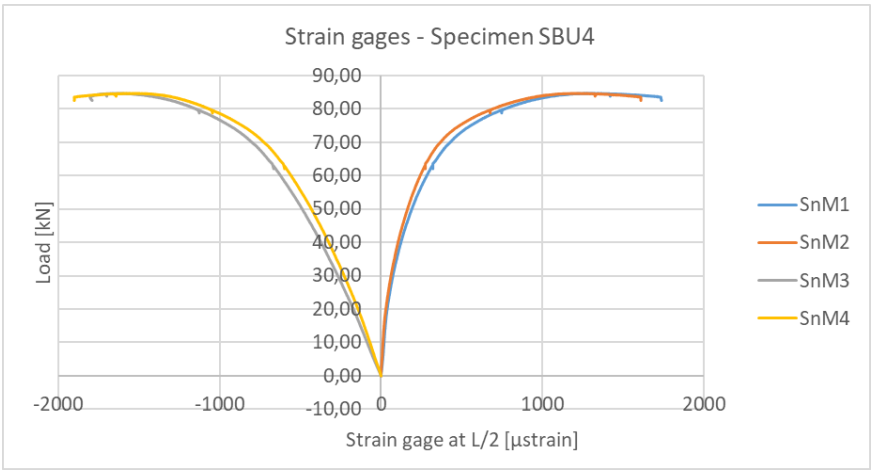


Figure B.83: Measurements of strain gages at L/2 on specimen SBU4

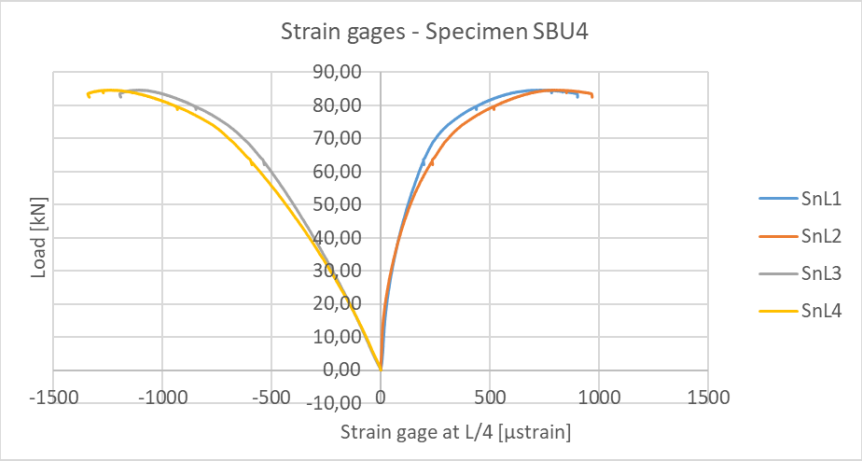


Figure B.84: Measurements of strain gages at L/4 on specimen SBU4

Annex C

Annex C includes details concerning coupon tests. These detail values are reported in Table 11 below.

Table 11: Coupon test's results.

Nr	Eprouvette n°	Pr.	a_0 mm	b_0 mm	L_0 mm	R_{eH} MPa	$R_{p0.2}$ MPa	Fmax N	R_m MPa	m_E N/mm²	A %	Dr mm	Commentaire
1	SBU3A2	L	6,92	20,15	100,037	411	394	75478,60	541	192774	23,1	21	rupture int.extensometre
2	SBU3A1	L	6,95	21,05	100,016	418	393	79413,59	543	205321	25,1	45	rupture int.extensometre
3	SBU4B2	L	6,11	20	100,019	488	444	64800,33	530	199021	25,6	35	rupture int.extensometre
4	SBU4B1	L	5,85	20,9	100,010	471	446	66052,41	540	211164	23,2	40	rupture int.extensometre
5	SBU4A2	L	6,96	19,84	100,015	419	393	74519,34	540	207057	26,1	45	rupture int.extensometre
6	SBU4A1	L	6,85	20,85	99,993	413	392	77802,10	545	206925	25,0	50	rupture int.extensometre
7	SBE6A2	L	5,98	19,81	100,020	473	440	63502,36	536	206014	23,6	50	rupture int.extensometre
8	SBE6A1	L	6,05	20,81	100,014	485	449	69090,47	549	206645	23,4	45	rupture int.extensometre
9	SBE4B2	L	6,03	19,86	100,019	475	443	64041,95	535	208060	24,5	42	rupture int.extensometre
10	SBE4B1	L	5,86	20,77	100,010	478	443	65512,27	538	209425	23,7	40	rupture int.extensometre
11	SBE4A2	L	6,1	20,13	100,018	489	446	66945,87	545	206296	23,3	30	rupture int.extensometre
12	SBE4A1	L	5,9	20,75	100,015	481	443	66897,99	546	207110	23,6	25	rupture int.extensometre
13	BBE6A2	L	6,86	20,22	100,011	402	392	75327,78	543	205772	26,7	55	rupture int.extensometre
14	BBE6A1	L	6,91	20,82	100,005	409	392	77912,55	542	220400	25,0	37	rupture int.extensometre
15	BBE2B	L	6,87	20,85	100,011	419	394	78393,43	547	204928	25,1	60	rupture int.extensometre
16	BBE2A	L	6,89	20,96	100,017	418	398	79148,14	548	208056	25,1	40	rupture int.extensometre