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Tampere University of Technology. Department of Civil Engineering. Structural Engineering.
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**Test Report, End Plate Joints of Steel Tubes, Strong Axis
Bending**



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TEST REPORT, END PLATE JOINTS OF STEEL TUBES, STRONG AXIS BENDING

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Appendix

1. Introduction

The most novel European standards for the design of steel EN 1993-1-8 (2005) and aluminum EN 1999-1-1 (2007) joints includes the component method to define the stiffness and to check ductility and resistance of different joints. The component method is very generic and it can be used for the design of many kinds of joints. This is true, if the structural behaviors of all the components appearing in the joints are known.

The standards do not cover the design of a very frequently used joint of rectangular tubular members. The design rules for the extended end plate joints are missing. The “extended” means: The bolts are locating outside the edge-lines of the cross-section. This situation is demonstrated in Figure 1.1.

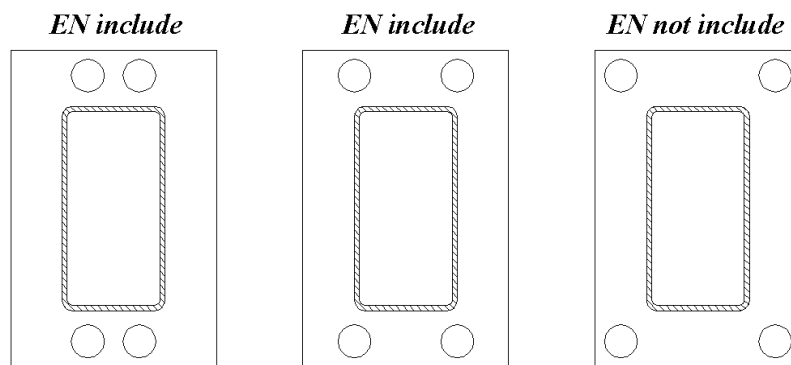


Figure 1.1. End plate joints.

There exist many cases where the rectangular tubular members are joined with these kinds of extended end plates and bolts to other members. One example is the base bolt joint. The splices of tubular members (beams, columns, chords, braces) are also frequently used. They can also joint beams to columns using blind bolts in these joints, and metal members to concrete or other materials using e.g. injection bolts. The joined members can be made of steel or aluminum.

If some bolt of the extended end plate joint is in tension, then it is essential to know the corresponding yield mechanism near this bolt. If this mechanism is known, then it is possible to develop the component for the component method of EN 1993-1-8 or EN 1999-1-1 to describe the behavior of this tension component. The tension component may act as individual or in group. Both situations should be considered, if they may realize, and the most critical situation is used in the design.

In (Wheeler et al., 2008) are given test results and design rules for the extended end plate joints of steel splice joints. In (Wald et al., 2000) and (Laine, 2007) are given the yield mechanisms for the base bolt joints using extended steel end plates. In (Wald et al., 2000) and (Laine, 2007) are given the verifications using the finite element models. No test results are in those two references. The differences between these joints are such that in splice joints the prying forces are active and in base bolt joints typically not. The activation of the prying forces depends on the elongation length of the bolt in tension. The referred mechanisms are described in Figure 1.2.

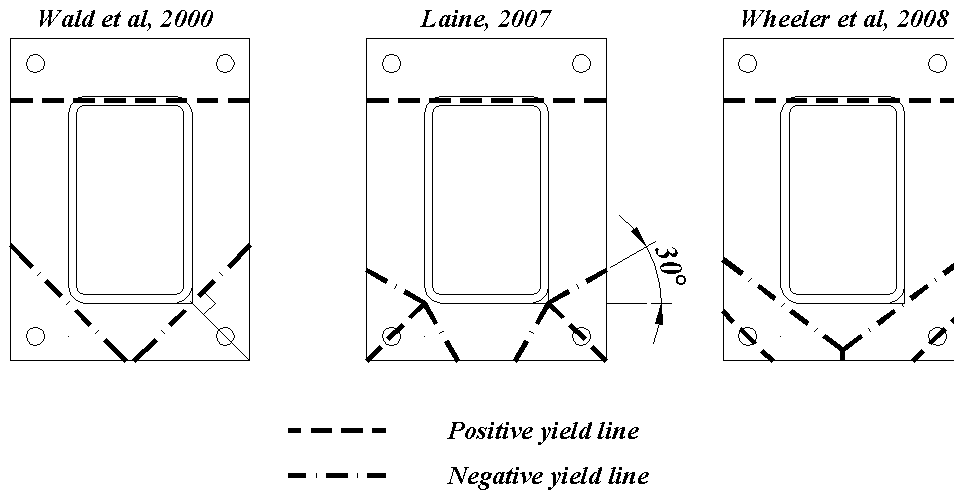


Figure 1.2. Yield line mechanisms.

The scope of this entire research is to derive and proof the proper yield mechanism for the tensile component of the extended end plate joint for tubular members. In this report steel joints are dealt. Both cases with and without prying forces should be considered. At this stage the bending around the strong axis is considered. The results of (Wheeler et al., 2008) are available for the splice joints.

In the base bolt joints the elongation length $8d$ is supposed for the base bolts in tension in EN 1993-1-8, where d is the diameter of the bolt. The $8d$ rule is based on an old US study of base bolt joints (Salmon, Shenker, 1956). In this report the tests results are given where the base bolt elongations are imitated using the steel tubes of the lengths about $8d$ around the tensile bolts. In further studies the analysis of the results will be given.

Tests were done for the bolt layouts included in the standard EN 1993-1-8 (see Figure 1.1) to get the reference resistances. The similar joints with the same end plate and member properties, but using the bolt layouts not included in the standard (see Figure 1.1) were the new cases of interest.

Nine tests are reported in this report. The tests were done using three different end plate thicknesses and three different bolt locations (see Figure 1.1). Other properties of test beams were the same in all tests. For the smallest end plate thickness the prying effect was estimated to be active and for others not.

The test specimen were made by Rautaruukki Oyj and they were assembled in the laboratory. Tests were done in May 2008 in the laboratory of Structural Engineering in Tampere University of Technology (TUT), Tampere, Finland. Test arrangements, measured tests results and moment-rotation relationships based on the tests are given in this report.

2. Test arrangements and measuring

2.1. Specimens and materials

The tests consisted of nine beam tests with the joint under consideration at the middle. The spans of all beams were 1 m. There were three end plate thicknesses and three bolt locations at the joints meaning totally 9 tests. Other properties of the test specimen were the same in the tests. The beams were made of rectangular cold formed cross-sections typed as CFRHS 250x150x10 (cold formed rectangular hollow section) and the material grade of the tubes was S355J2H.

One specimen consisted of two parts ready made in the steel factory. One part consisted of the rectangular tube and plates at the both ends. At the support was welded a steel plate PL20x290x170 to the tube and at the joint under consideration the plates 390x290 were butt welded to the tube as shown in Fig 2.1. The thicknesses of these joint plates were 10, 15 and 20 mm and the steel grade of all the plates was S355K2+N (EN 10025-2:2004).

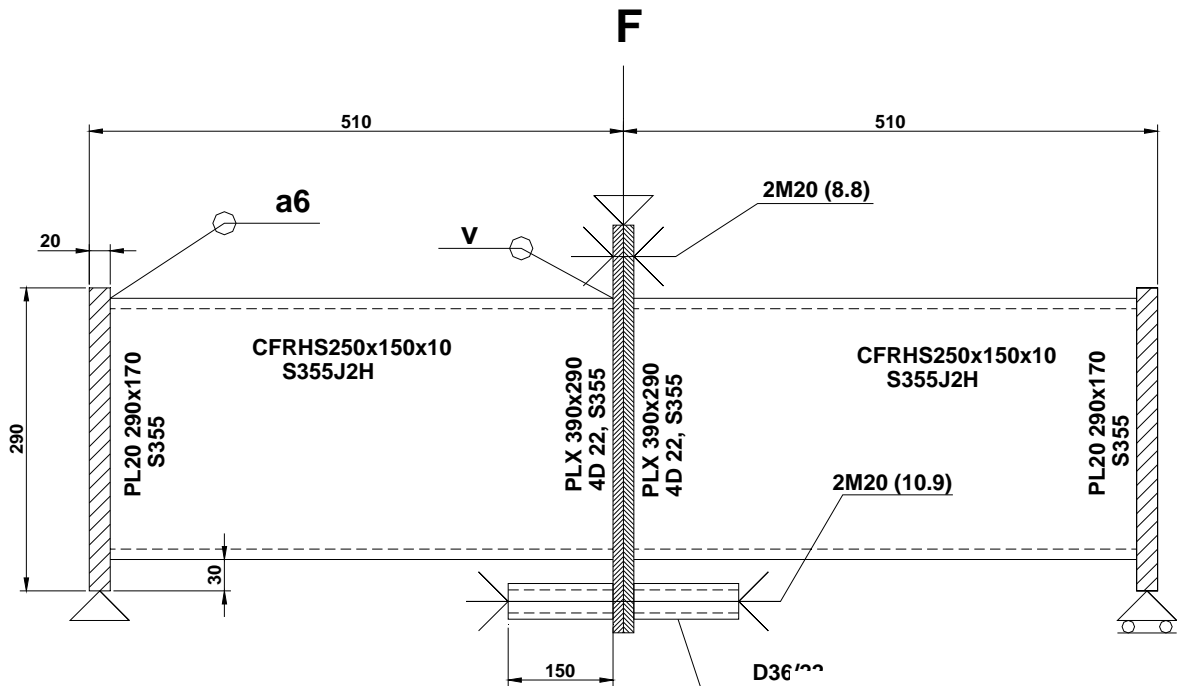


Figure 2.1. Test arrangement.

The end plates at the upper part of the mid joint were connected using two hexagonal full tread galvanized M20x80 grade 8.8 bolts (SFS EN ISO 4017). The bottom parts were connected using two M20x500 grade 10.9 threaded round bars. These bars went through round two tubular bars (S235) of the length 150 mm. The outer diameters of these tubes were 36,1 mm and the wall thickness 7,1 mm. These tubes imitate the elongation lengths of bolts in the base bolt joints ($8 \times 20 = 160$ mm).

The nuts with the height 15,2 mm were used at the joint. The washers at the upper part were 3 mm thick and at the bottom part 5 mm thick, both were round (SFS-EN ISO 7093-1).

The end plates included holes made in the steel factory and the diameters were 22 mm according to (SFS 3898). The locations of the holes at the joints are presented in Fig 2.2.

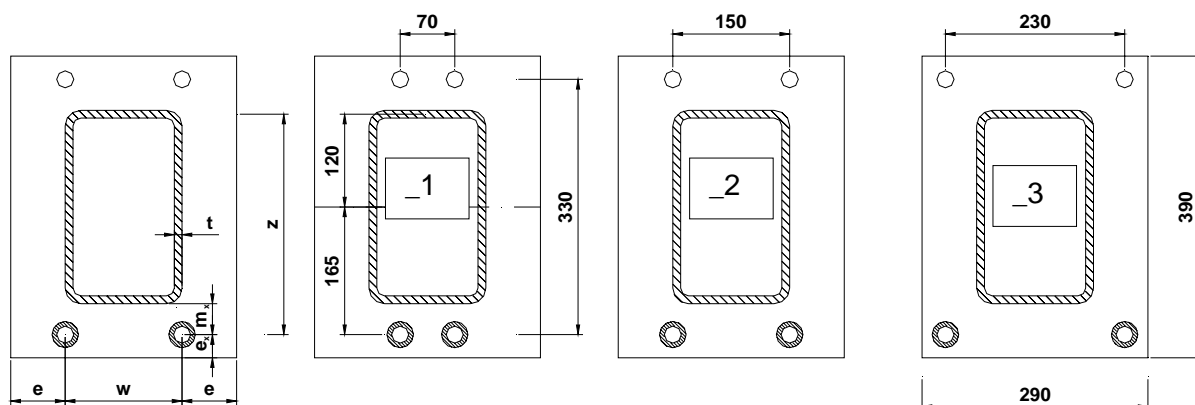


Figure 2.2. Bolt layouts and notations.

The torque moment of 23 Nm was adapted to the bolts and to the threaded bars using a calibrated tool.

The measured properties and nominal dimensions of the joint plates are given in Table 2.1. The notations of the dimensions are shown in Fig. 2.2. The plate thickness is t_p . The specimen code includes the thickness of the end plate and the location code of the bolts, as shown in Fig. 2.2. The yield strengths and the tensile strengths of the end plates were measured by the steel fabricator using their normal quality control system.

Table 2.1. Properties of the end plates

Specimen code	Yield strength	Tensile strength	Plate nominal dimensions [mm]				
	R_{eH} [MPa]	R_m [MPa]	t_p	w	e	e_x	m_x
10_1	421	540	10	70	110	30	40
10_2	421	540	10	150	70	30	40
10_3	421	540	10	230	30	30	40
15_1	429	556	15	70	110	30	40
15_2	429	556	15	150	70	30	40
15_3	429	556	15	230	30	30	40
20_1	401	534	20	70	110	30	40
20_2	401	534	20	150	70	30	40
20_3	401	534	20	230	30	30	40

The ultimate tension resistances of the threaded bars were measured in TUT laboratory to be $F_u = 280$ kN (mean of three tests), meaning the tensile stress $280000/245 = 1143$ MPa using the stress area 245 mm^2 for M20. The measured yield force for the bar was 255 kN ending up to the stress $255000/245 = 1041$ MPa.

2.2. Testing

Tests were done using a hydraulic 5 MN testing apparatus of the laboratory. Test arrangement is shown in Fig 2.3. The rolling end of the beam was resting on a plate locating above three round bars. The fixed end of the beam was resting above one round bar. The load was transferred with the force control to the mid joint via a steel plate.



Figure 2.3. Testing equipments.

The first load cycle was done up to the jack loads given in Table 2.2. After reaching this load, the load was removed. The load speed was 5 kN/min and loading was stopped for about 5 minutes to complete the slide caliber measurements. After this first cycle the specimen were loaded with the same loading scheme up to the ultimate load.

Table 2.2. First cycle.

Specimen Code	10_1	10_2	10_3	15_1	15_2	15_3	20_1	20_2	20_3
Max.jack load at the first cycle [kN]	52,0	49,0	52,0	99,7	100,3	100,7	149,4	149,7	149,1

2.3. Measurements

The vertical displacements at the loading point were measured at the top of the beam with four electronic displacement transducers numbered as 4, 5, 6, and 7. The vertical displacements were measured at the supports using the transducers 11 and 12 as shown in Figs. 2.4 – 2.6. The jack force and the displacements were observed and stored every 5 seconds.

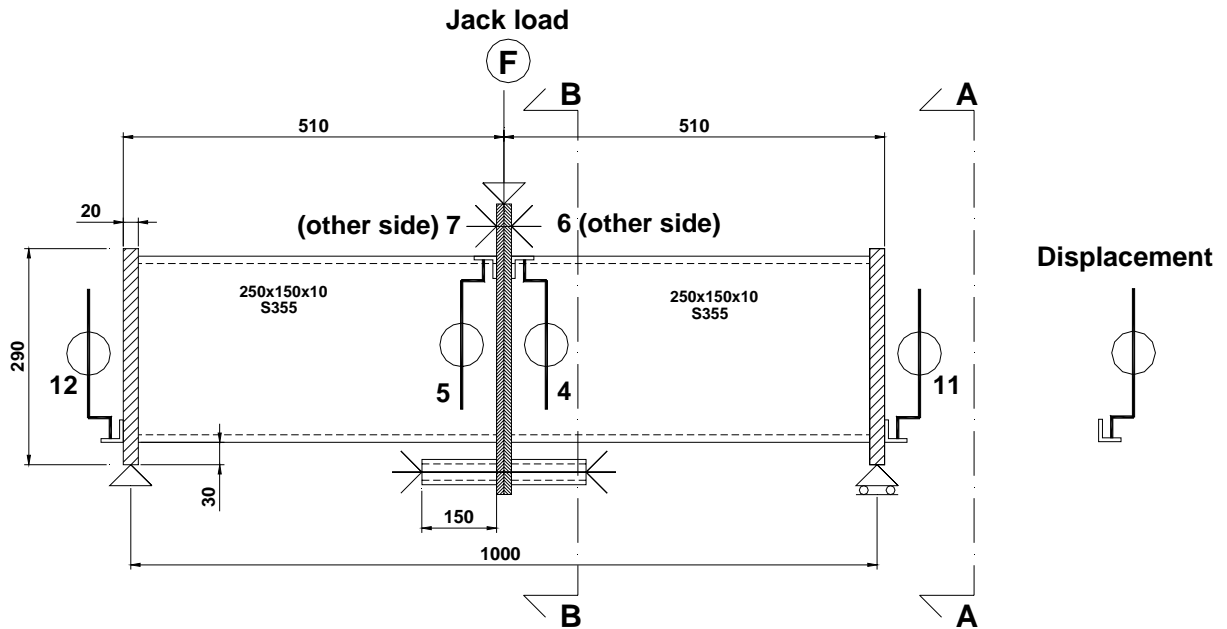


Figure 2.4. Displacement transducers 4 – 6, 11 and 12.

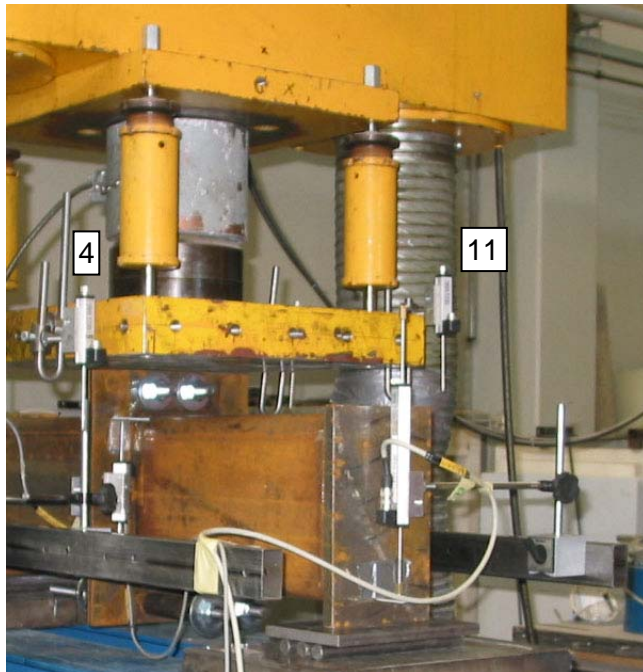
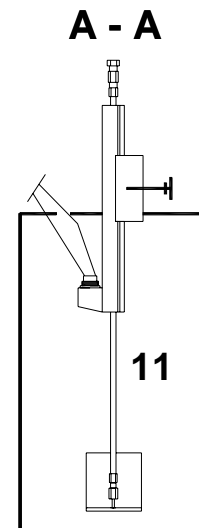


Figure 2.5. Detail A.



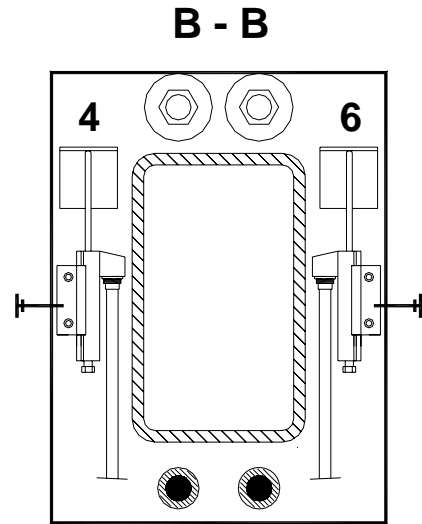
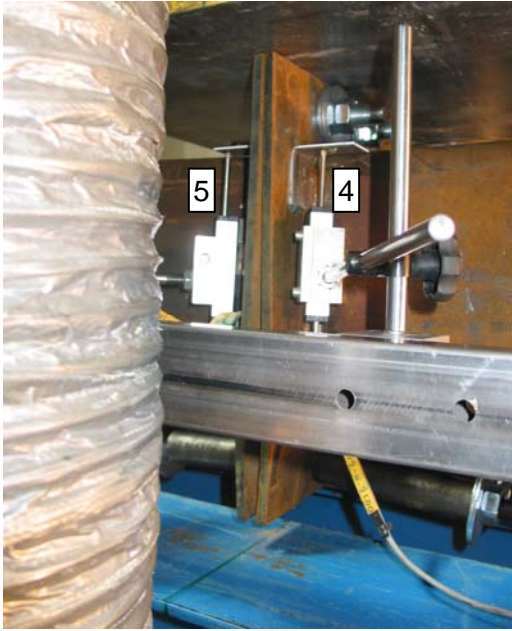


Figure 2.6. Detail B.

The horizontal displacements between the outer surfaces of the end plates were measured manually using a slide caliper at points 1 – 6 as shown in Fig. 2.7.

Looking direction: same as in B-B

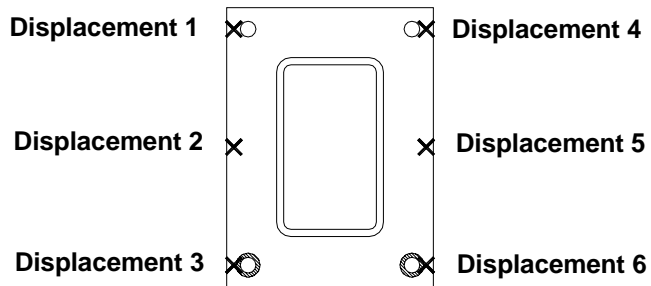


Figure 2.7. Relative horizontal displacement measurement points.

2.4. Test results

2.4.1. Test 10_1

The ultimate load in this test was 253,4 kN and the mean vertical displacement at the mid point was then 13,9 mm. The specimen after the test is shown in Fig. 2.8.



Figure 2.8. Specimen 10_1 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.9. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.3.

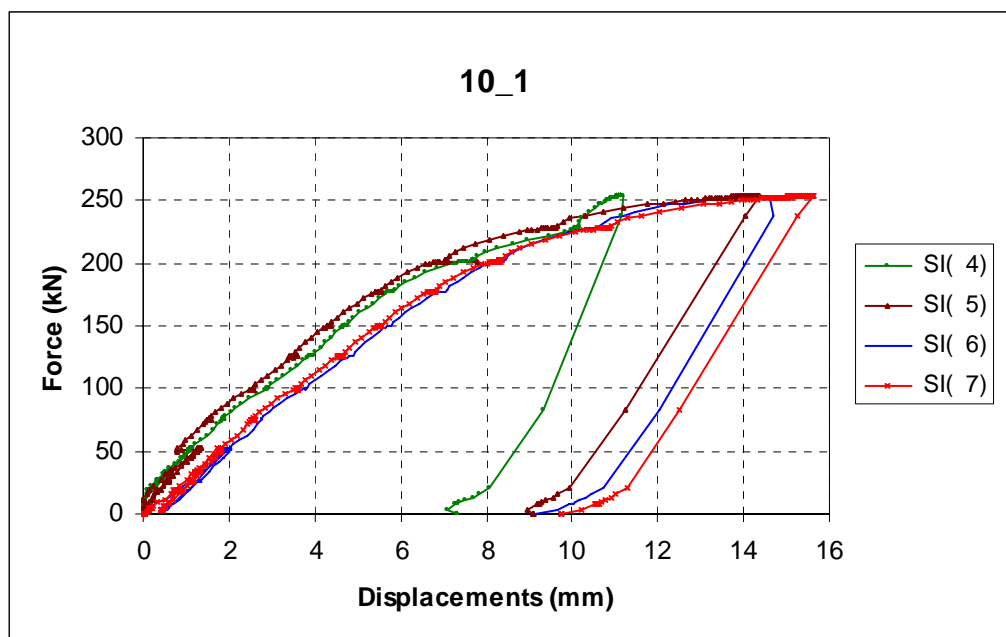


Figure 2.9. Jack load versus measured displacements for 10_1.

Table 2.3. Displacements at the ultimate jack load for 10_1.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
10_1	253,4	11,2	14,3	14,6	15,6	13,9

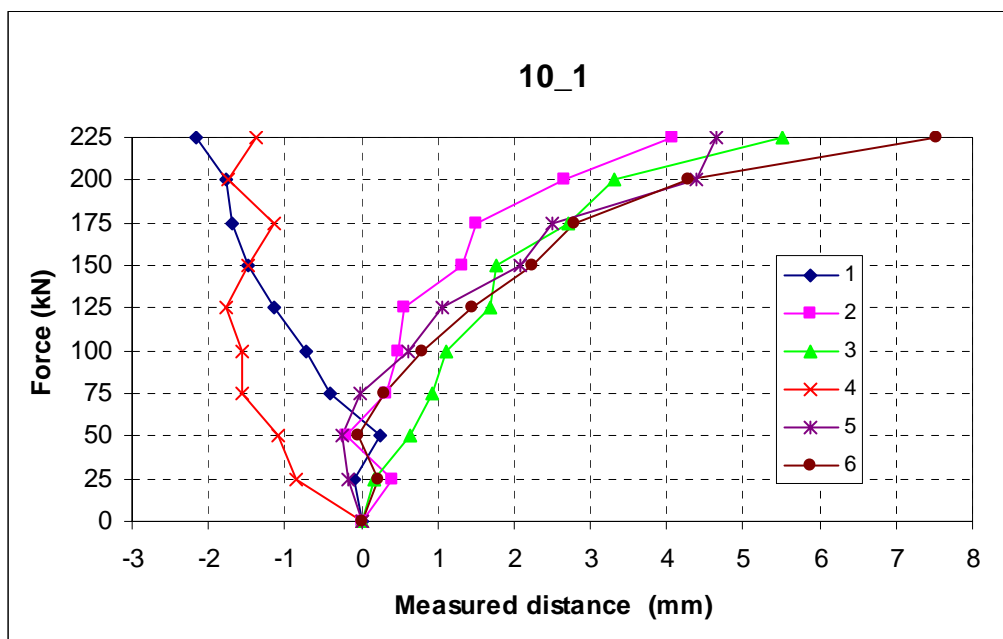


Figure 2.10. Jack load versus slide caliber results for 10_1.

The results for the slide caliber measurements are given in Fig. 2.10 and in Table 2.4.

Table 2.4. Slide caliber results for 10_1.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
10_1	25	-0,09	0,41	0,17	-0,85	-0,17	0,21
	50	0,26	-0,20	0,63	-1,08	-0,24	-0,05
	75	-0,40	0,32	0,92	-1,55	-0,02	0,29
	100	-0,71	0,49	1,11	-1,57	0,62	0,81
	125	-1,13	0,57	1,69	-1,77	1,06	1,46
	150	-1,47	1,33	1,77	-1,49	2,09	2,23
	175	-1,70	1,51	2,71	-1,15	2,50	2,78
	200	-1,78	2,66	3,32	-1,75	4,38	4,28
225	-2,17	4,07	5,50	-1,80	4,64	7,54	

It can be seen from the slide caliber measurement results at the points 1 and 2 (negative displacements) that the initial torque of the bolts at the upper part was not enough to assure the full contact between the end plates at the mid joint.

2.4.2. Test 10_2

The ultimate load in this test was 230,8 kN and the mean vertical displacement at the mid point was then 16,7 mm. The specimen after the test is shown in Fig. 2.11.



Figure 2.11. Specimen 10_2 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.12. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.5.

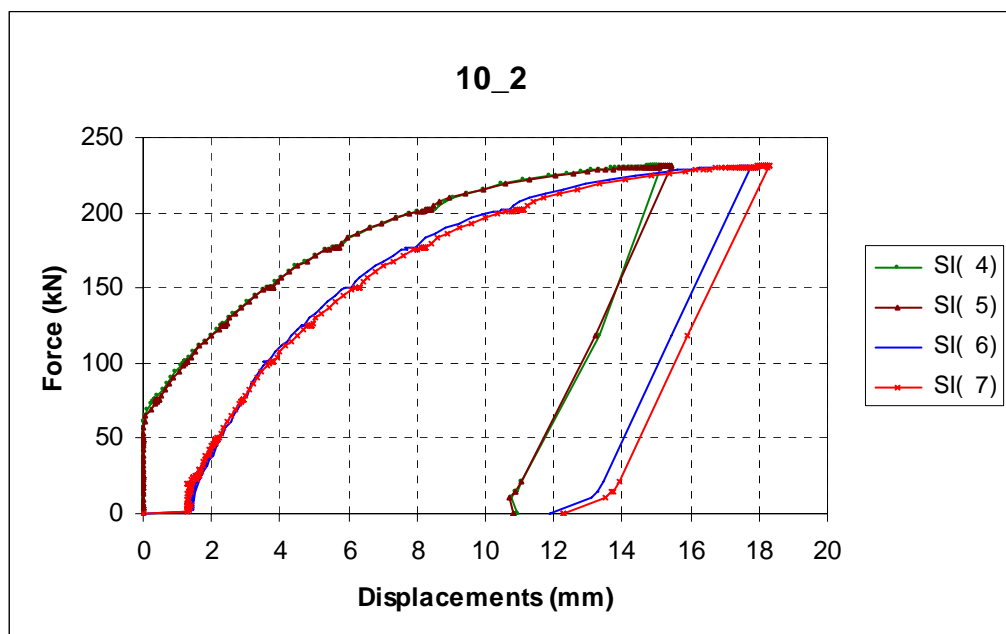


Figure 2.12. Jack load versus measured displacements for 10_2.

Table 2.5. Displacements at the ultimate jack load for 10_2.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
10_2	230,8	15,1	15,5	17,8	18,3	16,7

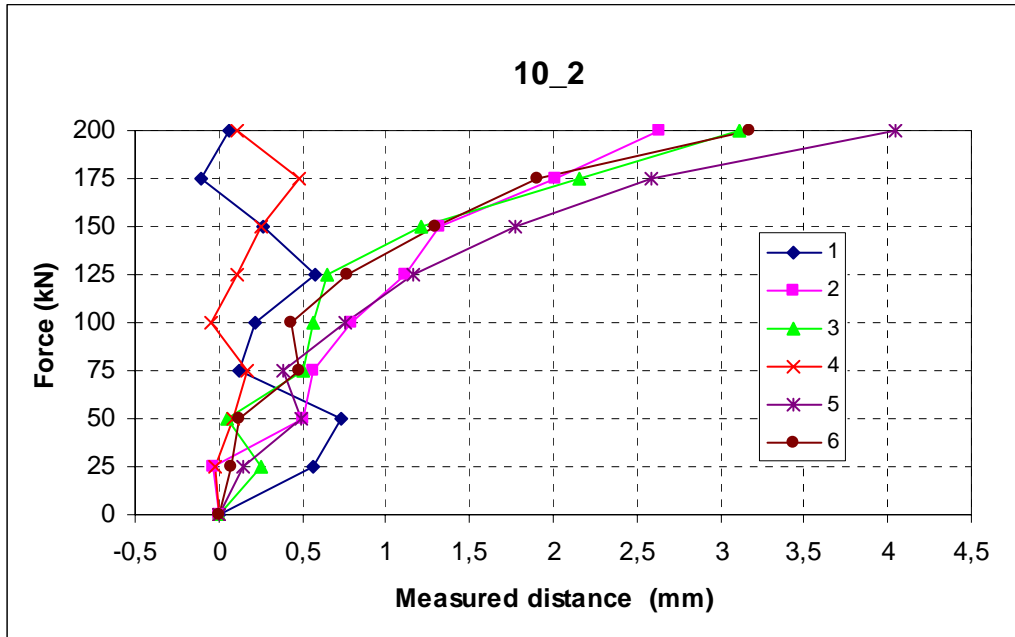


Figure 2.13. Jack load versus slide caliber results for 10_2.

The results for the slide caliber measurements are given in Fig. 2.13 and in Table 2.6.

Table 2.6. Slide caliber results for 10_2.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
10_2	25	0,56	-0,03	0,25	-0,02	0,15	0,07
	50	0,73	0,50	0,05	0,09	0,49	0,12
	75	0,12	0,56	0,51	0,17	0,39	0,48
	100	0,22	0,79	0,57	-0,04	0,76	0,43
	125	0,58	1,11	0,65	0,11	1,16	0,77
	150	0,26	1,32	1,21	0,25	1,77	1,29
	175	-0,10	2,01	2,15	0,48	2,59	1,90
	200	0,06	2,63	3,11	0,11	4,05	3,17

2.4.3. Test 10_3

The ultimate load in this test was 151,8 kN and the mean vertical displacement at the mid point was then 13,7 mm. The specimen after the test is shown in Fig. 2.14.



Figure 2.14. Specimen 10_3 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.15. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.7.

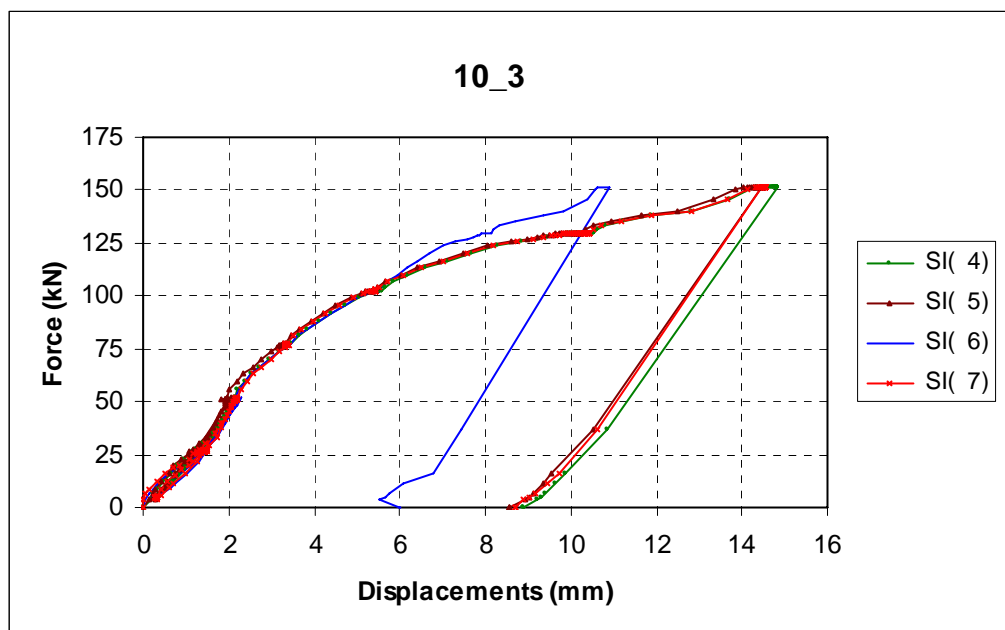


Figure 2.15. Jack load versus measured displacements for 10_3.

Table 2.7. Displacements at the ultimate jack load for 10_3.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
10_3	151,8	14,9	14,5	10,9	14,5	13,7

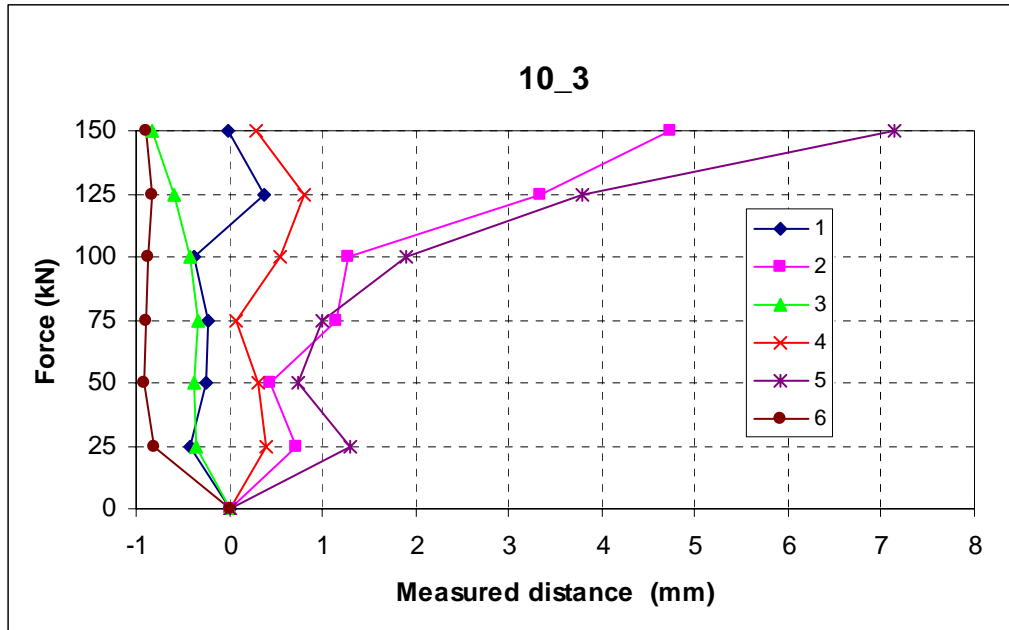


Figure 2.16. Jack load versus slide caliber results for 10_3.

The results for the slide caliber measurements are given in Fig. 2.16 and in Table 2.8.

Table 2.8. Slide caliber results for 10_3.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
10_3	25	-0,42	0,71	-0,35	0,39	1,30	-0,81
	50	-0,25	0,44	-0,38	0,31	0,73	-0,91
	75	-0,23	1,15	-0,34	0,08	1,00	-0,90
	100	-0,38	1,27	-0,42	0,54	1,91	-0,87
	125	0,38	3,34	-0,59	0,81	3,80	-0,83
	150	-0,02	4,74	-0,82	0,28	7,15	-0,90

2.4.4. Test 15_1

The ultimate load in this test was 428,0 kN and the mean vertical displacement at the mid point was then 14,5 mm. The specimen after the test is shown in Fig. 2.17.



Figure 2.17. Specimen 15_1 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.18. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.9.

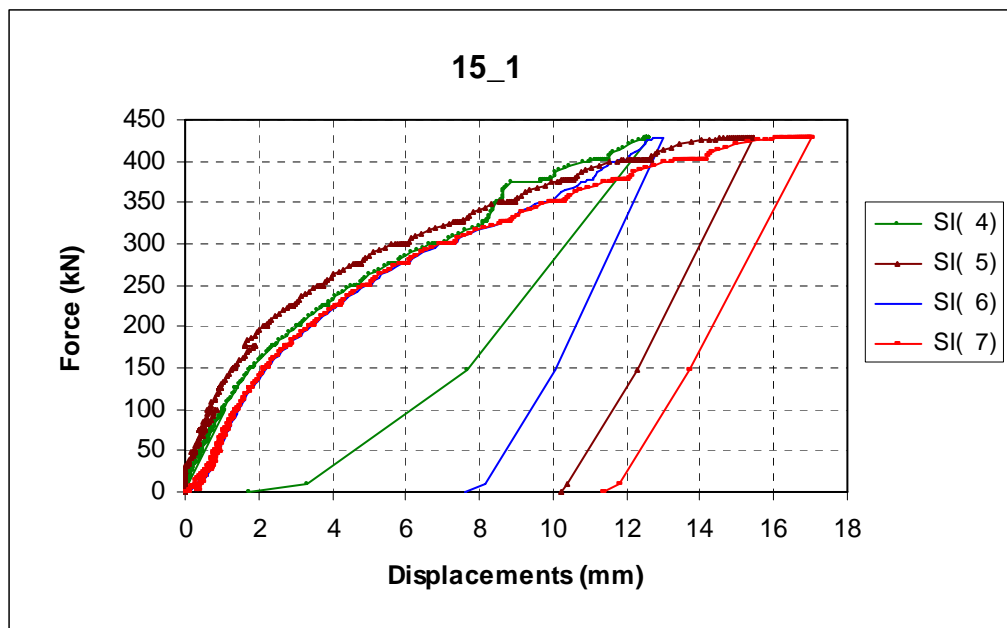


Figure 2.18. Jack load versus measured displacements for 15_1.

Table 2.9. Displacements at the ultimate jack load for 15_1.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
15_1	428,0	12,6	15,4	13,0	17,0	14,5

The results for the slide caliber measurements are given in Fig. 2.19 and in Table 2.10.

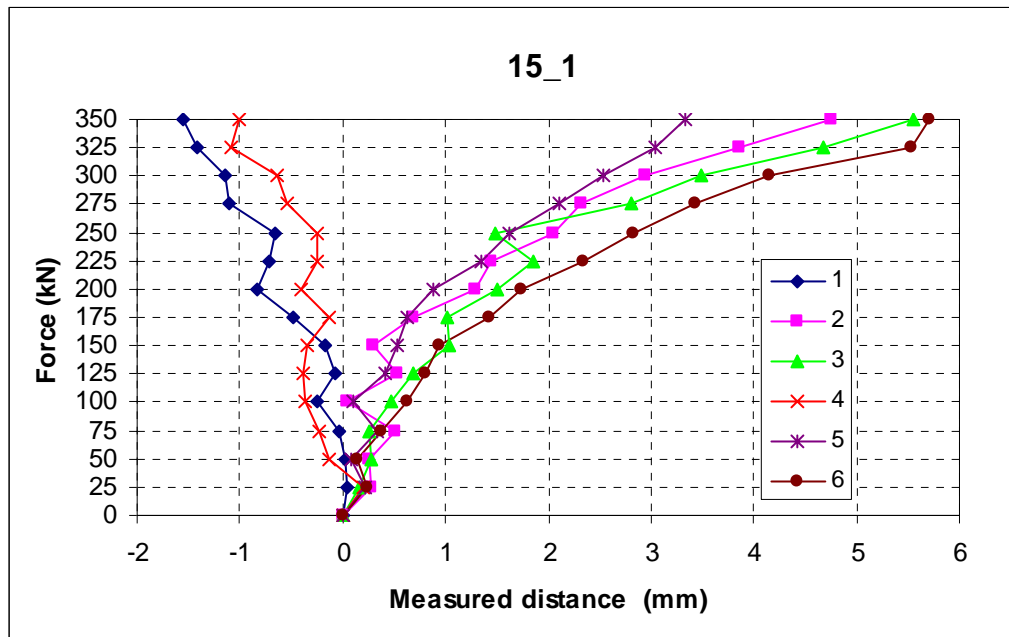


Figure 2.19. Jack load versus slide caliber results for 15_1.

Table 2.10. Slide caliber results for 15_1.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
15_1	25	0,04	0,27	0,16	0,20	0,22	0,24
	50	0,03	0,25	0,27	-0,14	0,09	0,14
	75	-0,04	0,51	0,26	-0,22	0,34	0,38
	100	-0,24	0,04	0,47	-0,37	0,10	0,62
	125	-0,08	0,53	0,68	-0,38	0,41	0,81
	150	-0,18	0,29	1,03	-0,34	0,53	0,93
	175	-0,49	0,68	1,01	-0,14	0,62	1,43
	200	-0,84	1,28	1,51	-0,41	0,88	1,74
	225	-0,71	1,44	1,86	-0,24	1,35	2,35
	250	-0,65	2,04	1,48	-0,25	1,62	2,83
	275	-1,11	2,32	2,80	-0,54	2,11	3,43
	300	-1,14	2,95	3,48	-0,64	2,53	4,16
	325	-1,41	3,86	4,67	-1,08	3,05	5,54
	350	-1,55	4,75	5,55	-1,01	3,34	5,71

2.4.5. Test 15_2

The ultimate load in this test was 399,3 kN and the mean vertical displacement at the mid point was then 13,3 mm. The specimen after the test is shown in Fig. 2.20.



Figure 2.20. Specimen 15_2 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.21. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.11.

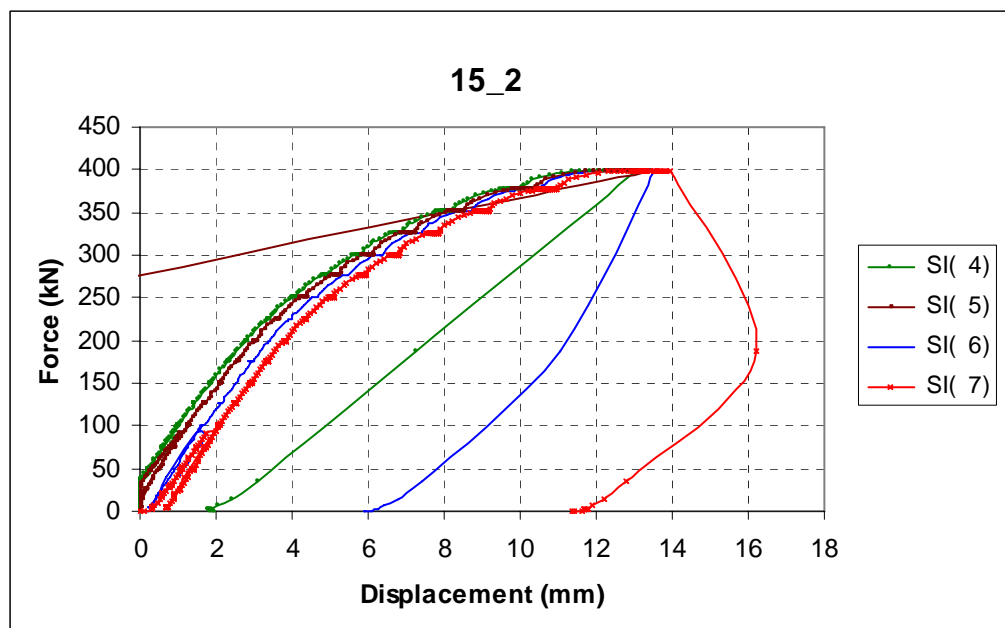


Figure 2.21. Jack load versus measured displacements for 15_2.

Table 2.11. Displacements at the ultimate jack load for 15_2.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
15_2	399,3	12,9	13,2	13,4	13,8	13,3

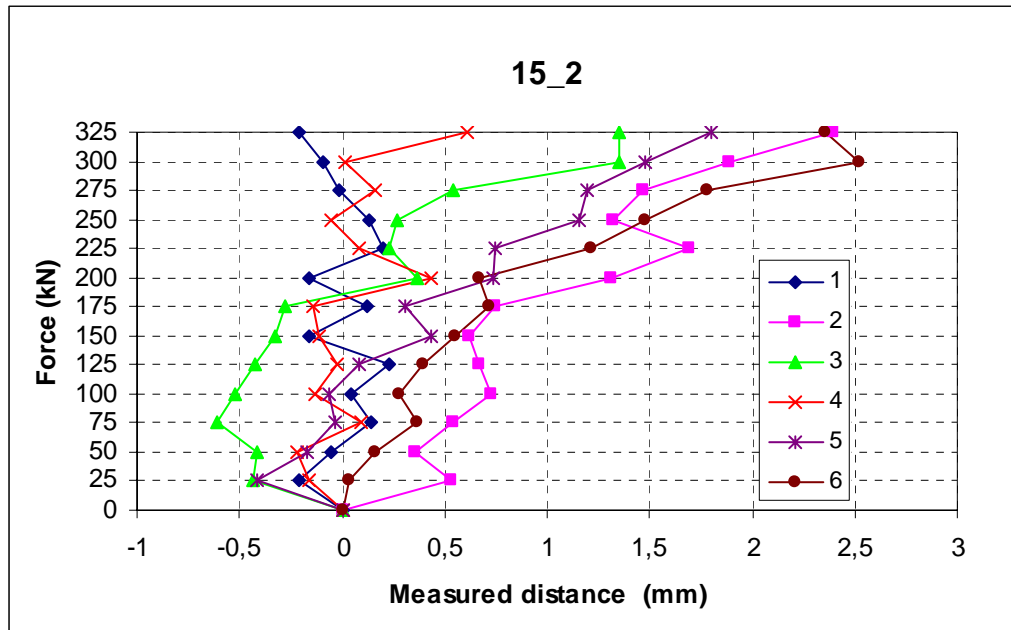


Figure 2.22. Jack load versus slide caliber results for 15_2.

The results for the slide caliber measurements are given in Fig. 2.22 and in Table 2.12.

Table 2.12. Slide caliber results for 15_2.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
15_2	25	-0,21	0,53	-0,43	-0,16	-0,41	0,03
	50	-0,05	0,36	-0,41	-0,22	-0,17	0,16
	75	0,14	0,54	-0,61	0,09	-0,03	0,37
	100	0,04	0,73	-0,52	-0,13	-0,06	0,28
	125	0,23	0,67	-0,42	-0,02	0,08	0,40
	150	-0,16	0,62	-0,33	-0,11	0,43	0,55
	175	0,12	0,75	-0,28	-0,14	0,31	0,72
	200	-0,16	1,31	0,37	0,43	0,74	0,67
	225	0,20	1,69	0,23	0,08	0,75	1,21
	250	0,13	1,32	0,27	-0,05	1,16	1,48
	275	-0,01	1,47	0,54	0,16	1,20	1,78
	300	-0,09	1,89	1,35	0,01	1,48	2,52
325	-0,21	2,40	1,35	0,61	1,80	2,36	

2.4.6. Test 15_3

The ultimate load in this test was 304,6 kN and the mean vertical displacement at the mid point was then 16,5 mm. The specimen after the test is shown in Fig. 2.23.

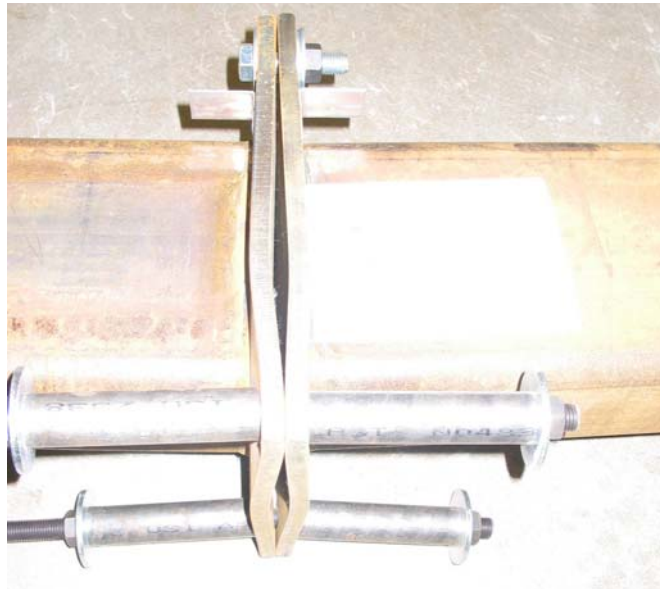


Figure 2.23. Specimen 15_3 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.24. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.13.

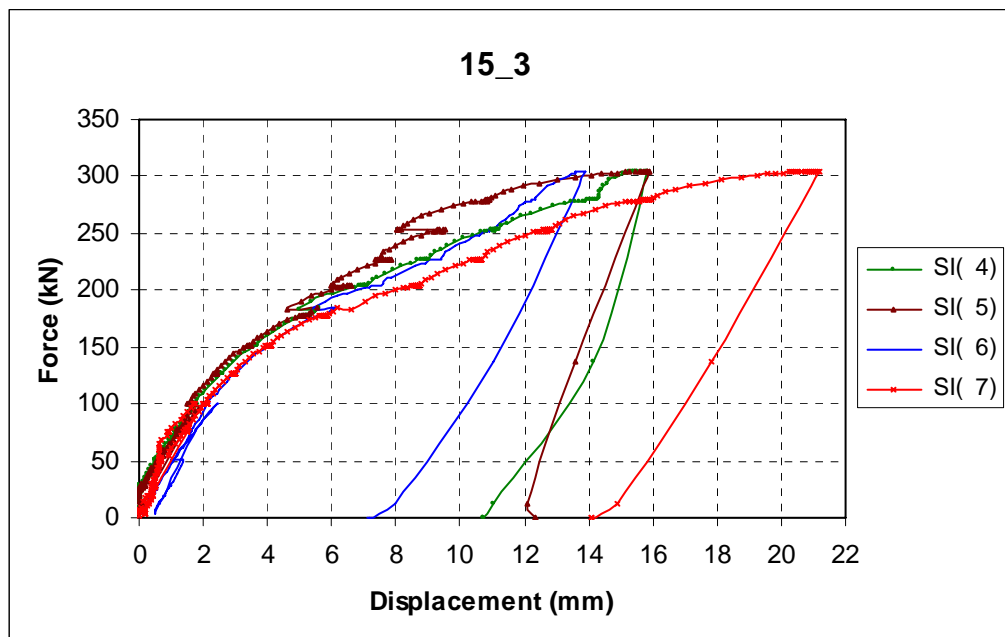


Figure 2.24. Jack load versus measured displacements for 15_3.

Table 2.13. Displacements at the ultimate jack load for 15_3.

Specimen Code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
15_3	304,6	115,8	15,9	13,9	21,2	16,5

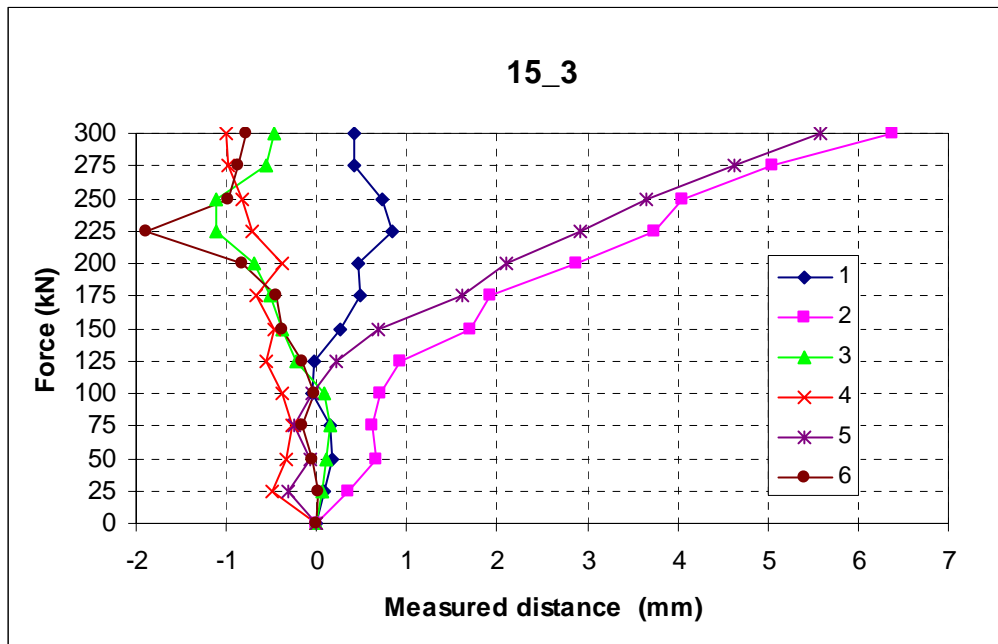


Figure 2.25. Jack load versus slide caliber results for 15_3.

The results for the slide caliber measurements are given in Fig. 2.25 and in Table 2.14.

Table 2.14. Slide caliber results for 15_3.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
15_3	25	0,09	0,35	0,07	-0,49	-0,32	0,01
	50	0,18	0,67	0,10	-0,33	-0,08	-0,06
	75	0,15	0,62	0,16	-0,26	-0,25	-0,17
	100	-0,05	0,71	0,08	-0,39	-0,04	-0,03
	125	-0,03	0,93	-0,22	-0,56	0,21	-0,17
	150	0,27	1,70	-0,39	-0,48	0,69	-0,39
	175	0,49	1,92	-0,51	-0,67	1,62	-0,45
	200	0,46	2,88	-0,69	-0,39	2,11	-0,83
	225	0,83	3,75	-1,12	-0,72	2,92	-1,90
	250	0,73	4,06	-1,11	-0,82	3,66	-0,97
	275	0,42	5,06	-0,57	-0,98	4,63	-0,88
	300	0,41	6,39	-0,46	-1,00	5,59	-0,79

2.4.7. Test 20_1

The ultimate load in this test was 550,9 kN and the mean vertical displacement at the mid point was then 12,1 mm. The specimen after the test is shown in Fig. 2.26.



Figure 2.26. Specimen 15_3 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.27. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.15.

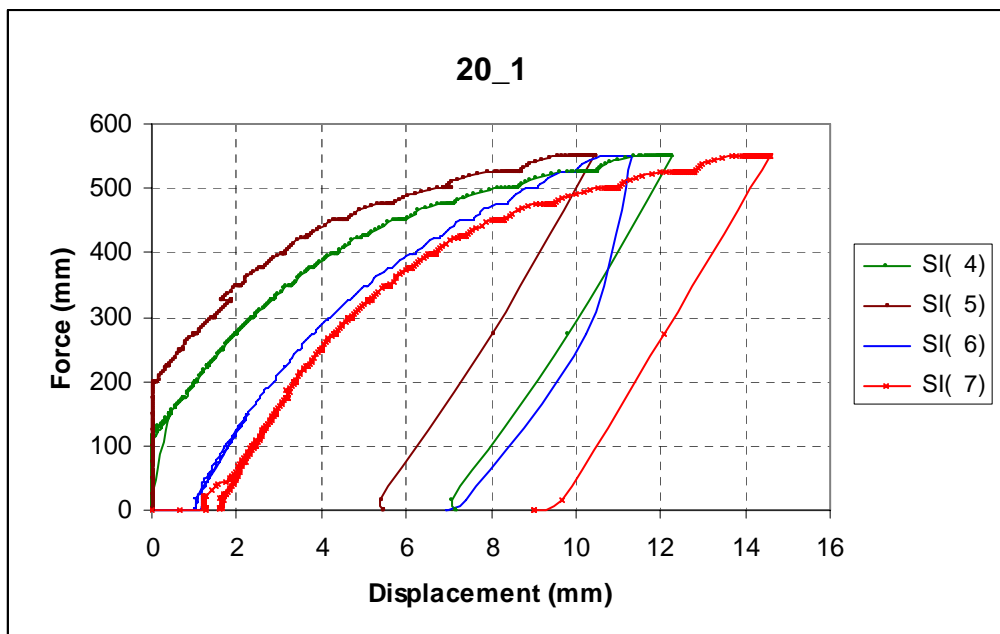


Figure 2.27. Jack load versus measured displacements for 20_1.

Table 2.15. Displacements at the ultimate jack load for 20_1.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
20_1	550,9	12,3	10,4	11,3	14,6	12,1

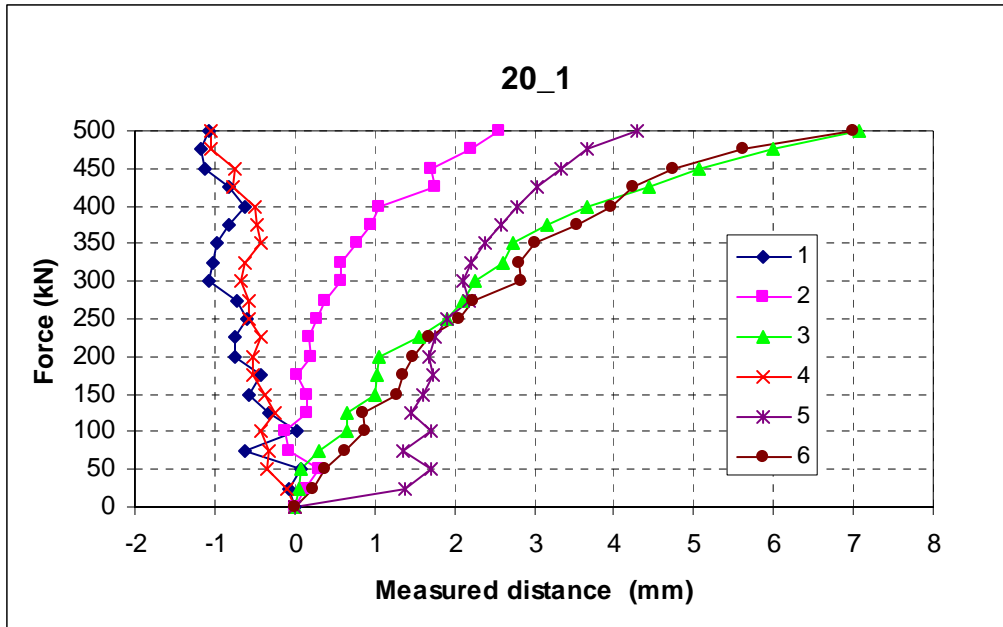


Figure 2.28. Jack load versus slide calibrator results for 20_1

The results for the slide calibrator measurements are given in Fig. 2.28 and in Table 2.16.

Table 2.16. Slide caliber results for 20_1.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
20_1	25	-0,07	0,14	0,05	-0,10	1,38	0,23
	50	0,07	0,31	0,08	-0,35	1,71	0,38
	75	-0,61	-0,06	0,31	-0,32	1,37	0,63
	100	0,03	-0,12	0,65	-0,42	1,72	0,88
	125	-0,33	0,15	0,65	-0,25	1,45	0,85
	150	-0,57	0,16	1,00	-0,36	1,61	1,28
	175	-0,41	0,04	1,03	-0,51	1,73	1,36
	200	-0,74	0,20	1,05	-0,52	1,69	1,49
	225	-0,75	0,19	1,55	-0,42	1,75	1,69
	250	-0,59	0,27	1,90	-0,58	1,92	2,05
	275	-0,73	0,38	2,11	-0,57	2,19	2,23
	300	-1,07	0,57	2,27	-0,66	2,10	2,83
	325	-1,03	0,59	2,61	-0,62	2,22	2,82
	350	-0,98	0,77	2,73	-0,42	2,38	3,01
	375	-0,82	0,96	3,16	-0,46	2,59	3,54
	400	-0,61	1,06	3,67	-0,50	2,78	3,96
	425	-0,82	1,77	4,45	-0,77	3,04	4,24
	450	-1,13	1,70	5,06	-0,75	3,34	4,74
475	-1,18	2,20	5,99	-1,04	3,66	5,62	
500	-1,08	2,55	7,07	-1,05	4,28	7,00	

2.4.8. Test 20_2

The ultimate load in this test was 502,1 kN and the mean vertical displacement at the mid point was then 10,0 mm. The specimen after the test is shown in Fig. 2.29.



Figure 2.29. Specimen 20_2 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.30. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.17.

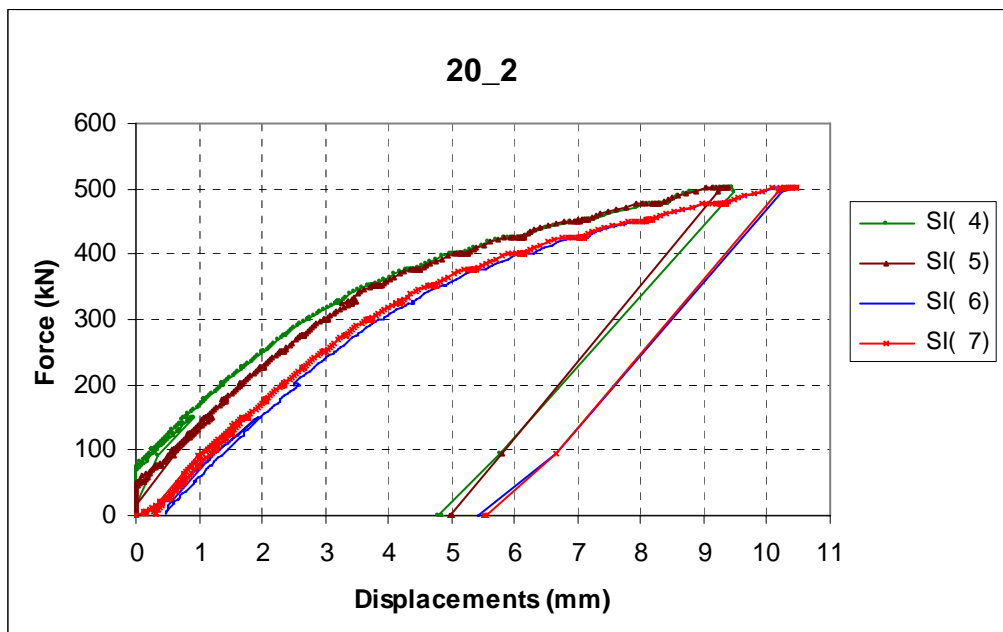


Figure 2.30. Jack load versus measured displacements for 20_2.

Table 2.17. Displacements at the ultimate jack load for 20_2.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
20_2	502,1	9,5	9,4	10,5	10,5	10,0

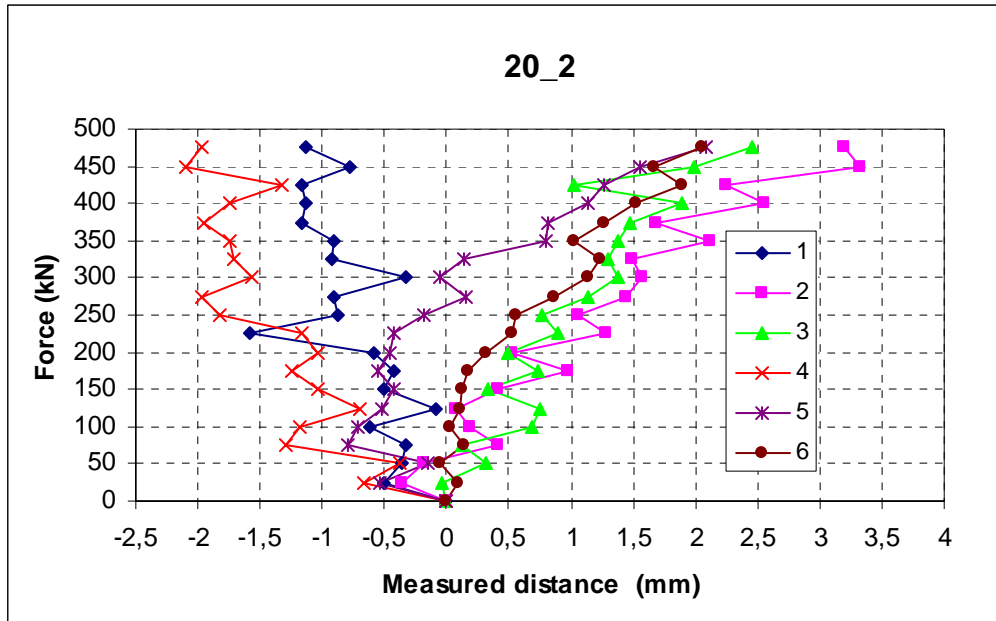


Figure 2.31. Jack load versus slide caliber results for 20_2.

The results for the slide caliber measurements are given in Fig. 2.31 and in Table 2.18.

Table 2.18. Slide caliber results for 20_2.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
20_2	25	-0,50	-0,36	-0,04	-0,67	-0,54	0,09
	50	-0,36	-0,19	0,31	-0,37	-0,15	-0,05
	75	-0,33	0,41	0,13	-1,29	-0,79	0,14
	100	-0,61	0,18	0,69	-1,18	-0,72	0,02
	125	-0,08	0,08	0,75	-0,69	-0,52	0,10
	150	-0,50	0,42	0,33	-1,04	-0,42	0,13
	175	-0,43	0,98	0,74	-1,24	-0,56	0,17
	200	-0,58	0,52	0,50	-1,04	-0,46	0,31
	225	-1,59	1,28	0,90	-1,17	-0,42	0,53
	250	-0,87	1,05	0,76	-1,82	-0,19	0,55
	275	-0,90	1,44	1,14	-1,97	0,15	0,86
	300	-0,32	1,57	1,37	-1,57	-0,05	1,13
	325	-0,93	1,49	1,29	-1,71	0,14	1,23
	350	-0,90	2,11	1,37	-1,75	0,80	1,02
	375	-1,17	1,69	1,48	-1,96	0,81	1,26
	400	-1,13	2,56	1,90	-1,74	1,14	1,52
	425	-1,17	2,25	1,02	-1,32	1,26	1,89
450	-0,78	3,32	1,99	-2,10	1,55	1,66	
475	-1,14	3,19	2,46	-1,97	2,09	2,06	

2.4.9. Test 20_3

The ultimate load in this test was 452,5 kN and the mean vertical displacement at the mid point was then 17,4 mm. The specimen after the test is shown in Fig. 2.32.



Figure 2.32. Specimen 20_3 after the test.

The displacements at the measuring points 4 – 7 are shown in Fig. 2.33. The measured support displacements are extracted from these. The displacements at the ultimate load are given in Table 2.19.

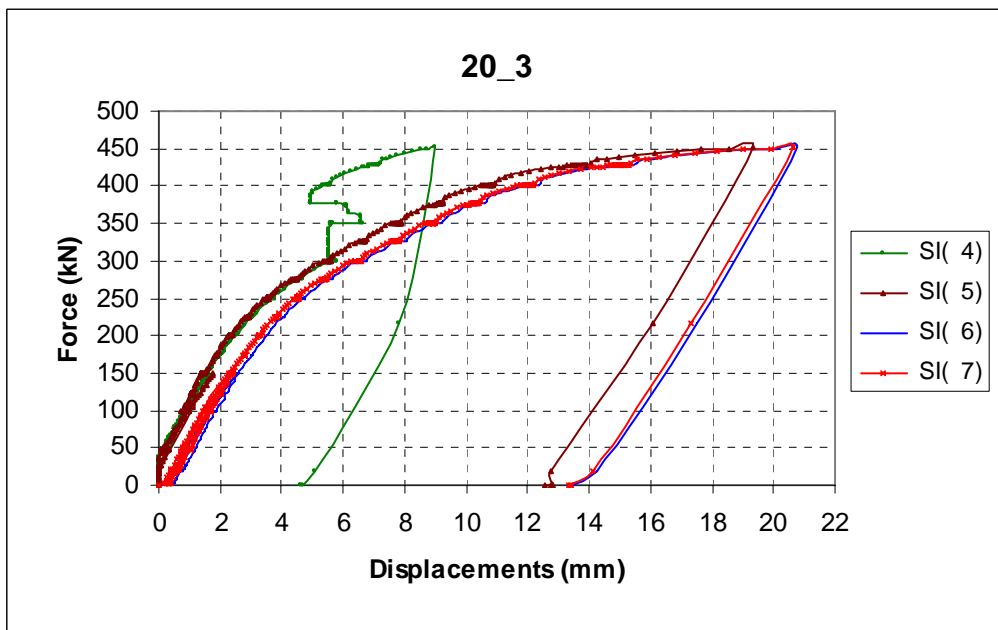


Figure 2.33. Jack load versus measured displacements for 20_3.

Table 2.19. Displacements at the ultimate jack load for 20_3.

Specimen code	Ultimate jack load [kN]	SI(4) [mm]	SI(5) [mm]	SI(6) [mm]	SI(7) [mm]	Average (4,5,6,7) [mm]
20_3	452,5	9,0	19,3	20,8	20,7	17,4

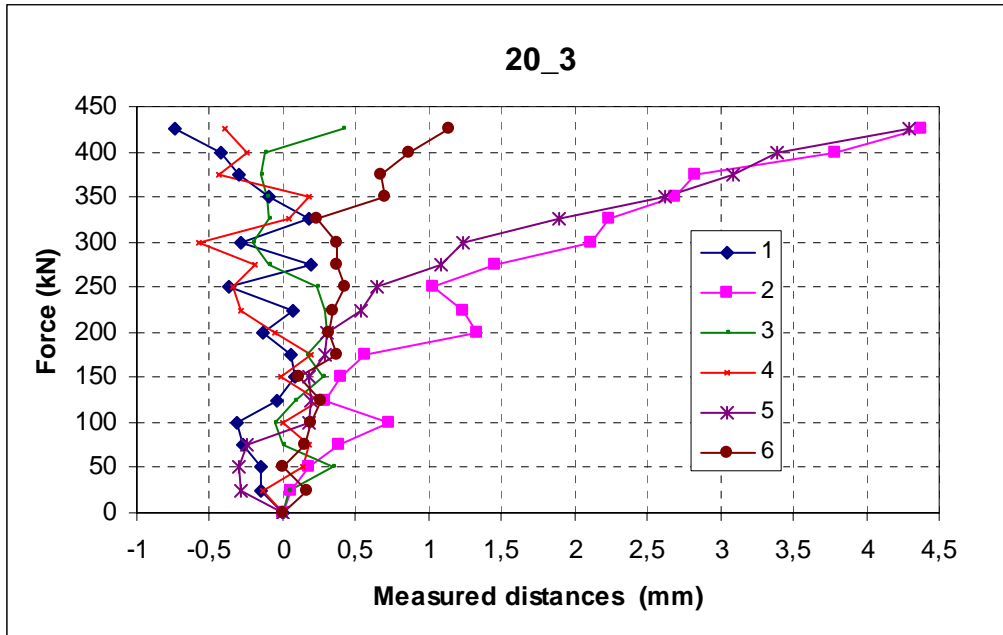


Figure 2.34. Jack load versus slide caliber results for 20_3.

The results for the slide caliber measurements are given in Fig. 2.34 and in Table 2.20.

Table 2.20. Slide caliber results for 20_3.

Specimen code	Jack load F [kN]	1 [mm]	2 [mm]	3 [mm]	4 [mm]	5 [mm]	6 [mm]
20_3	25	-0,15	0,06	0,04	-0,13	-0,29	0,16
	50	-0,15	0,18	0,34	0,14	-0,30	0
	75	-0,27	0,39	0	0,18	-0,25	0,15
	100	-0,31	0,73	-0,06	0	0,18	0,20
	125	-0,04	0,29	0,09	0,25	0,20	0,26
	150	0,09	0,40	0,28	-0,01	0,18	0,11
	175	0,06	0,56	0,17	0,20	0,29	0,37
	200	-0,13	1,33	0,30	-0,06	0,30	0,32
	225	0,07	1,23	0,29	-0,28	0,53	0,35
	250	-0,37	1,03	0,23	-0,34	0,65	0,42
	275	0,19	1,45	-0,09	-0,19	1,09	0,37
	300	-0,28	2,12	-0,21	-0,57	1,24	0,37
	325	0,18	2,24	-0,09	0,04	1,89	0,23
	350	-0,09	2,69	-0,11	0,18	2,62	0,70
	375	-0,30	2,83	-0,15	-0,44	3,09	0,67
	400	-0,43	3,79	-0,12	-0,25	3,39	0,87
425	-0,74	4,38	0,41	-0,39	4,30	1,14	

3. Analysis of the test results

3.1. Effect of bolt pretension

The bolt pretension force is [6]:

$$F_M = \frac{2 \cdot M_A}{1,155 \cdot \mu_G \cdot d_2 + \mu_K \cdot D_{km} + \frac{P}{\pi}} = \frac{2 \cdot 23}{1,155 \cdot 0,14 \cdot 18,2 + 0,14 \cdot 26 + \frac{2,5}{\pi}} = 6,2 \text{ kN} \quad (3.1)$$

$$D_{km} = \frac{d_K + D_B}{2} = \frac{30 + 22}{2} = 26 \text{ mm} \quad (3.2)$$

where:

M_A is the bolt installation torque [Nm],

μ_G is the coefficient of friction of screw thread,

μ_K is the coefficient of friction of screw (nut) surfaces,

d_2 is the edge diameter [mm],

D_{km} is the mean screw diameter [mm]

P is the bolt pitch.

It can be seen, that the used installation torque 23 Nm means very small force to the bolt and this force is ignored when analyzing the results.

3.2. Moment-rotation relationships based on tests

The bending moment of the joint is in this case

$$M_j = \frac{F \cdot L}{4} \quad (3.3)$$

where

F is the jack load and,

L is the span of the beam.

The rotation φ of the joint can be calculated based on the measured deflections. The measured deflection at the mid span of the beam is $\delta_{measured}$. The deflection due to the bending of the elastic beam at the mid span is

$$\delta_{beam} = \frac{F \cdot L^3}{48 \cdot E \cdot I} \quad (3.4)$$

where

E is the elastic modulus of the beam,

I is the moment of inertia of the beam.

The elastic modulus and the moment of inertia of the beam cross-section CFRHS250x150x10 are

$$\begin{aligned} W_{el} &= 500 \text{ cm}^3, \\ I &= 6259 \text{ cm}^4. \end{aligned} \tag{3.5}$$

The elastic moment of the beam is using the nominal yield strength 355 MPa

$$M_{el} = 355 \cdot 0,500 = 177 \text{ kNm} \Rightarrow F_{el} = 4 \cdot M_{el} / L = 710 \text{ kN}. \tag{3.6}$$

All the jack loads were well below this value, meaning that the tube of the beam behaved elastically in all the tests.

The deflection due to the local joint displacements can be calculated as follows

$$\delta_{joint} = \delta_{measured} - \delta_{beam} \tag{3.7}$$

The rotation φ of the joint due to this displacement is:

$$\frac{\varphi}{2} \cdot \frac{L}{2} = \delta_{joint} \Rightarrow \varphi = \frac{4 \cdot \delta_{joint}}{L} \tag{3.8}$$

These and the corresponding calculated bending moments of the joint (Eq. (3.3)) M_j are given in the following figures.

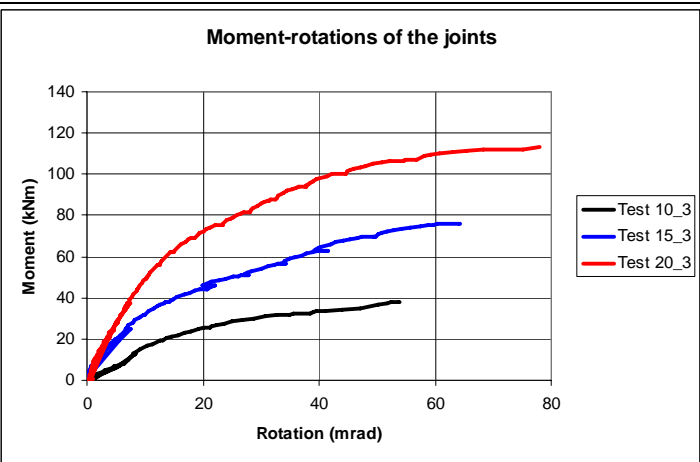
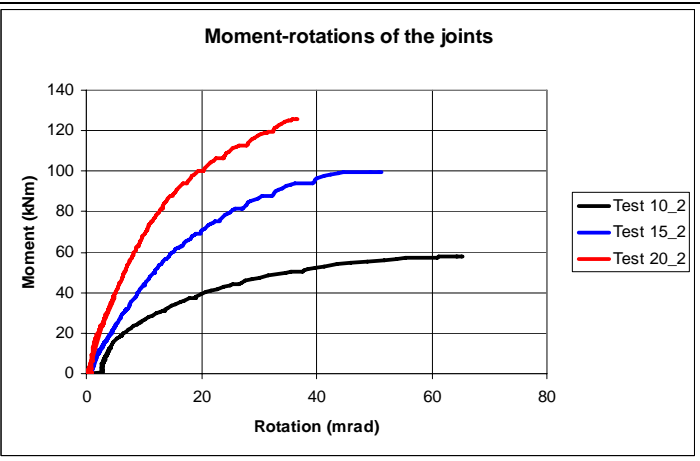
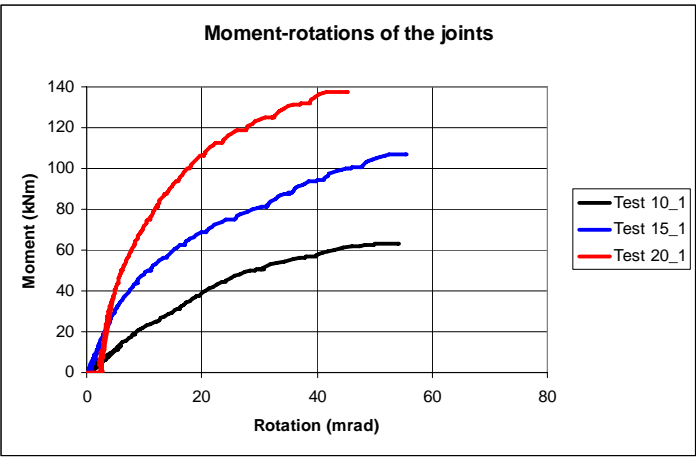
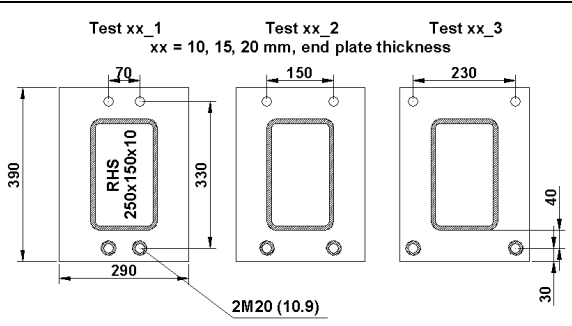


Figure 3.1. Measured joint moment – rotation relationships

It can be seen, that the joints with the indexes _1 had the largest bending resistances in every cases and the joints with the indexes _3 had the smallest resistances. The rotations of the joints were over 35 mrad in every case.

4. References

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Appendix 7(19)

Miki	aika	m.aika	VO(1)	SI(2)	SI(4)	SI(5)	SI(6)	SI(7)	SI(11)	SI(12)
521	2600	0,6	-401,78	-22,21	-13,28	-14,41	-13,86	-15,90	1,77	1,78
522	2605	0,61	-401,80	-22,21	-13,28	-14,41	-13,86	-15,90	1,77	1,78
523	2610	0,61	-402,26	-22,22	-13,28	-14,43	-13,87	-15,90	1,77	1,78
524	2615	0,61	-405,44	-22,27	-13,31	-14,47	-13,87	-15,96	1,77	1,79
525	2620	0,6	-408,54	-22,36	-13,35	-14,54	-13,92	-16,03	1,76	1,79
526	2625	0,6	-411,59	-22,47	-13,43	-14,62	-14,00	-16,10	1,76	1,79
527	2630	0,6	-414,43	-22,62	-13,55	-14,78	-14,11	-16,25	1,75	1,79
528	2635,1	0,6	-417,23	-22,86	-13,69	-14,99	-14,20	-16,48	1,75	1,81
529	2640,1	0,6	-420,14	-23,12	-13,83	-15,23	-14,27	-16,74	1,74	1,83
530	2645,1	0,6	-423,08	-23,45	-13,98	-15,52	-14,29	-17,04	1,73	1,83
531	2650	0,61	-425,61	-23,77	-14,12	-15,82	-14,36	-17,35	1,72	1,83
532	2655	0,61	-426,44	-23,99	-14,22	-16,03	-14,43	-17,55	1,71	1,82
533	2660	0,6	-426,90	-24,16	-14,25	-16,18	-14,44	-17,71	1,71	1,82
534	2665	0,6	-427,25	-24,27	-14,26	-16,28	-14,47	-17,80	1,70	1,81
535	2670	0,6	-427,34	-24,37	-14,27	-16,38	-14,49	-17,69	1,70	1,81
536	2675	0,61	-427,42	-24,45	-14,28	-16,47	-14,50	-17,97	1,70	1,81
537	2680	0,61	-427,56	-24,52	-14,29	-16,52	-14,52	-18,03	1,70	1,81
538	2685	0,61	-427,65	-24,57	-14,31	-16,58	-14,53	-18,09	1,69	1,80
539	2690	0,6	-427,65	-24,62	-14,31	-16,62	-14,53	-18,15	1,69	1,80
540	2695	0,6	-427,69	-24,67	-14,30	-16,66	-14,54	-18,19	1,69	1,80
541	2700	0,6	-427,75	-24,71	-14,30	-16,70	-14,55	-18,23	1,69	1,80
542	2705	0,61	-427,73	-24,76	-14,30	-16,73	-14,56	-18,26	1,69	1,80
543	2710	0,61	-427,77	-24,79	-14,29	-16,75	-14,57	-18,30	1,69	1,80
544	2715	0,6	-427,85	-24,82	-14,29	-16,79	-14,57	-18,34	1,69	1,80
545	2720	0,6	-427,86	-24,85	-14,29	-16,82	-14,57	-18,36	1,68	1,80
546	2725	0,6	-427,88	-24,87	-14,29	-16,84	-14,58	-18,38	1,68	1,80
547	2730	0,61	-427,88	-24,90	-14,29	-16,87	-14,58	-18,41	1,68	1,79
548	2735	0,61	-427,90	-24,93	-14,29	-16,89	-14,58	-18,43	1,68	1,79
549	2740	0,61	-427,93	-24,95	-14,29	-16,91	-14,59	-18,45	1,68	1,79
550	2745	0,6	-428,02	-24,97	-14,29	-16,93	-14,59	-18,48	1,68	1,79
551	2750	0,6	-427,91	-24,99	-14,30	-16,96	-14,60	-18,49	1,68	1,79
552	2755	0,6	-427,90	-25,01	-14,30	-16,97	-14,61	-18,50	1,68	1,79
553	2760	0,61	-427,98	-25,03	-14,30	-16,99	-14,61	-18,52	1,68	1,79
554	2765	0,61	-427,90	-25,05	-14,30	-17,01	-14,62	-18,54	1,68	1,79
555	2770	0,6	-428,12	-25,07	-14,30	-17,02	-14,63	-18,56	1,68	1,79
556	2775	0,6	-427,99	-25,08	-14,30	-17,03	-14,63	-18,58	1,68	1,78
557	2780	0,6	-427,99	-25,10	-14,30	-17,04	-14,63	-18,58	1,68	1,78
558	2785	0,6	-428,00	-25,11	-14,31	-17,06	-14,64	-18,60	1,68	1,77
559	2790,1	0,6	-428,00	-25,13	-14,31	-17,07	-14,64	-18,62	1,68	1,77
560	2795,1	0,6	-428,00	-25,15	-14,31	-17,09	-14,64	-18,62	1,68	1,77
561	2800	0,61	-427,99	-25,16	-14,31	-17,09	-14,65	-18,64	1,68	1,77
562	2805	0,61	-428,02	-25,17	-14,31	-17,11	-14,65	-18,66	1,68	1,77
563	2810	0,61	-428,04	-25,19	-14,31	-17,12	-14,65	-18,67	1,67	1,77
564	2815	0,6	-428,03	-25,20	-14,31	-17,13	-14,66	-18,68	1,67	1,77
565	2820	0,6	-428,03	-25,21	-14,31	-17,14	-14,66	-18,69	1,67	1,77
566	2825	0,6	-428,07	-25,22	-14,31	-17,15	-14,66	-18,69	1,67	1,76
567	2830	0,61	-427,99	-25,23	-14,31	-17,15	-14,67	-18,69	1,67	1,76
568	2835	0,61	-428,02	-25,24	-14,31	-17,16	-14,68	-18,71	1,67	1,76
569	2840	0,6	-427,95	-25,25	-14,31	-17,17	-14,68	-18,72	1,67	1,76
570	2845	0,6	-428,00	-25,26	-14,31	-17,18	-14,68	-18,73	1,67	1,76
571	2850	0,6	-427,98	-25,27	-14,31	-17,18	-14,69	-18,74	1,67	1,76
572	2855	0,6	-147,32	-20,90	-8,66	-13,28	-11,08	-14,70	0,92	1,07
573	2860	0,72	-10,80	-15,95	-3,36	-10,43	-8,22	-11,88	0,15	-0,02
574	2865	0,72	0,64	-11,21	-1,04	-9,57	-6,95	-10,68	-0,83	-0,54
575	2870	0,71	0,76	-6,49	-1,04	-9,57	-6,94	-10,67	-0,83	-0,54

Appendix 8(19)

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Table with columns for Miki, aika, m.aika, VOI, SI(2), SI(4), SI(5), SI(6), SI(7), SI(8), SI(11), SI(12), and SI(1). Rows contain numerical data points for various Miki values from 0 to 130.

Appendix 12(19)

Miki	aika	m.aika	VO(1)	SI(2)	SI(4)	SI(5)	SI(6)	SI(7)	SI(11)	SI(12)
261	1300	0,61	-242,37	-18,33	-10,95	-9,32	-11,22	-12,58	1,18	0,99
262	1305	0,61	-245,62	-18,59	-11,19	-9,57	-11,44	-12,83	1,17	0,99
263	1310	0,6	-248,86	-18,88	-11,45	-9,84	-11,63	-13,09	1,16	0,97
264	1315	0,6	-251,10	-19,12	-11,69	-10,06	-11,78	-13,31	1,14	0,97
265	1320	0,6	-251,63	-19,26	-11,82	-10,18	-11,84	-13,43	1,14	0,96
266	1325	0,61	-252,06	-19,35	-11,90	-10,27	-11,88	-13,51	1,13	0,95
267	1330	0,61	-252,45	-19,42	-11,97	-10,33	-11,90	-13,59	1,11	0,94
268	1335	0,6	-252,47	-19,46	-12,01	-10,38	-11,91	-13,64	1,11	0,94
269	1340	0,6	-252,40	-19,50	-12,05	-10,40	-11,93	-13,68	1,11	0,94
270	1345	0,6	-252,35	-19,53	-12,08	-10,43	-11,94	-13,70	1,11	0,94
271	1350	0,6	-252,35	-19,56	-12,10	-10,50	-11,95	-13,72	1,11	0,94
272	1355	0,61	-252,45	-19,58	-12,11	-10,51	-11,97	-13,74	1,11	0,94
273	1360	0,61	-252,46	-19,60	-12,14	-10,54	-11,97	-13,77	1,11	0,94
274	1365	0,6	-252,43	-19,62	-12,15	-9,05	-11,98	-13,80	1,11	0,94
275	1370	0,6	-252,43	-19,64	-12,16	-9,06	-11,98	-13,82	1,10	0,94
276	1375	0,6	-252,54	-19,66	-12,18	-9,07	-11,99	-13,83	1,10	0,94
277	1380	0,61	-252,54	-19,67	-12,19	-9,09	-12,00	-13,84	1,10	0,94
278	1385	0,61	-252,55	-19,68	-12,20	-9,10	-12,02	-13,84	1,10	0,94
279	1390	0,61	-252,66	-19,70	-12,22	-9,11	-12,02	-13,85	1,10	0,94
280	1395	0,6	-253,56	-19,74	-12,25	-9,15	-12,05	-13,89	1,10	0,94
281	1400	0,6	-256,50	-19,84	-12,33	-9,23	-12,16	-13,98	1,10	0,94
282	1405	0,6	-259,16	-19,99	-12,48	-9,36	-12,26	-14,10	1,10	0,94
283	1410,1	0,6	-262,10	-20,20	-12,67	-9,53	-12,40	-14,28	1,09	0,93
284	1415,1	0,6	-264,59	-20,46	-12,92	-9,77	-12,52	-14,55	1,08	0,93
285	1420,1	0,6	-268,08	-20,76	-13,21	-10,06	-12,64	-14,84	1,07	0,92
286	1425	0,61	-271,21	-21,10	-13,52	-10,39	-12,74	-15,17	1,06	0,92
287	1430	0,61	-274,36	-21,47	-13,86	-10,74	-12,84	-15,51	1,03	0,91
288	1435	0,6	-276,81	-21,81	-14,20	-11,06	-12,95	-15,87	1,01	0,90
289	1440	0,6	-277,61	-22,03	-14,40	-11,28	-13,01	-16,09	1,01	0,89
290	1445	0,6	-278,14	-22,20	-14,56	-11,43	-13,05	-16,23	1,00	0,89
291	1450	0,61	-278,38	-22,31	-14,65	-11,55	-13,09	-16,32	0,99	0,84
292	1455	0,61	-278,51	-22,41	-14,75	-11,66	-13,10	-16,41	0,99	0,84
293	1460	0,61	-278,67	-22,48	-14,83	-11,74	-13,11	-16,48	0,98	0,84
294	1465	0,6	-278,78	-22,56	-14,87	-11,81	-13,14	-16,54	0,98	0,84
295	1470	0,6	-278,81	-22,61	-14,94	-11,76	-13,14	-16,60	0,98	0,83
296	1475	0,6	-278,93	-22,67	-14,98	-11,77	-13,15	-16,64	0,97	0,83
297	1480	0,61	-278,95	-22,71	-15,04	-11,82	-13,16	-16,69	0,97	0,83
298	1485	0,61	-279,11	-22,76	-15,06	-11,68	-13,18	-16,73	0,97	0,82
299	1490	0,6	-279,07	-22,79	-15,10	-11,72	-13,18	-16,76	0,97	0,82
300	1495	0,6	-279,09	-22,83	-15,13	-11,74	-13,19	-16,79	0,96	0,82
301	1500	0,6	-279,06	-22,86	-15,14	-11,77	-13,20	-16,81	0,96	0,82
302	1505	0,6	-279,12	-22,88	-15,16	-11,80	-13,20	-16,84	0,96	0,82
303	1510	0,61	-280,76	-22,95	-15,20	-11,86	-13,25	-16,90	0,95	0,81
304	1515	0,61	-283,59	-23,10	-15,21	-11,98	-13,30	-17,04	0,95	0,81
305	1520	0,6	-286,29	-23,32	-15,23	-12,20	-13,39	-17,27	0,95	0,82
306	1525	0,6	-288,83	-23,66	-15,27	-12,49	-13,49	-17,59	0,93	0,82
307	1530	0,6	-291,33	-24,06	-15,31	-12,85	-13,60	-17,99	0,92	0,82
308	1535	0,61	-294,17	-24,55	-15,41	-13,32	-13,74	-18,45	0,88	0,80
309	1540	0,61	-297,03	-25,10	-15,48	-13,83	-13,89	-18,97	0,85	0,78
310	1545	0,6	-299,86	-25,70	-15,62	-14,40	-14,06	-19,54	0,82	0,75
311	1550	0,6	-301,27	-26,20	-15,74	-14,85	-14,19	-20,00	0,79	0,74
312	1555	0,6	-302,07	-26,57	-15,84	-15,18	-14,26	-20,33	0,78	0,74
313	1560	0,6	-302,71	-26,86	-15,91	-15,46	-14,30	-20,60	0,78	0,73
314	1565,1	0,6	-303,08	-27,11	-15,95	-15,68	-14,33	-20,82	0,77	0,73
315	1570,1	0,6	-303,44	-27,30	-16,00	-15,86	-14,36	-21,01	0,76	0,72
316	1575,1	0,6	-303,70	-27,47	-16,05	-16,03	-14,39	-21,02	0,75	0,72
317	1580	0,61	-303,78	-27,62	-16,10	-16,16	-14,41	-21,15	0,74	0,70
318	1585	0,61	-304,11	-27,74	-16,13	-16,27	-14,43	-21,26	0,74	0,70
319	1590	0,6	-304,10	-27,84	-16,15	-16,37	-14,46	-21,36	0,74	0,70
320	1595	0,6	-304,28	-27,94	-16,19	-16,45	-14,48	-21,46	0,73	0,69
321	1600	0,6	-304,34	-28,02	-16,22	-16,53	-14,50	-21,54	0,73	0,69
322	1605	0,61	-304,18	-28,09	-16,23	-16,60	-14,51	-21,60	0,73	0,69
323	1610	0,61	-304,42	-28,17	-16,32	-16,53	-14,52	-21,67	0,72	0,69
324	1615	0,6	-304,45	-28,23	-16,36	-16,42	-14,53	-21,71	0,72	0,68
325	1620	0,6	-304,47	-28,30	-16,48	-16,50	-14,55	-21,79	0,71	0,68
326	1625	0,6	-304,54	-28,35	-16,50	-16,54	-14,55	-21,82	0,71	0,68
327	1630	0,6	-304,56	-28,40	-16,52	-16,59	-14,56	-21,87	0,70	0,67
328	1635	0,61	-137,63	-24,61	-14,47	-13,88	-11,33	-18,16	0,30	0,34
329	1640	0,72	-11,78	-19,54	-10,64	-11,73	-7,61	-14,53	-0,25	-0,53
330	1645	0,71	-0,30	-14,65	-9,56	-11,16	-5,96	-12,91	-1,18	-1,17
331	1650	0,71	-0,19	-9,83	-9,55	-11,16	-5,95	-12,91	-1,18	-1,17

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