

Experimental Testing of Anchoring Devices for Bottom Rail in Partially Anchored Timber Frame Shear Walls With Two-Sided Sheathing

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Abstract

Källsner and Girhammar [1] have presented a new plastic design method for wood-framed shear walls at ultimate limit state. This method allows the designer to calculate the load-carrying capacity of shear walls partially anchored, where the leading stud is not fully anchored against uplift.

The anchorage system of shear walls is provided from anchor bolts and hold downs. Anchor bolts provide horizontal shear continuity between the bottom rail and the foundation. Hold downs are directly connected from the vertical end stud to the foundation. When hold downs are not provided, the bottom row of nails transmits the vertical forces in the sheathing to the bottom rail (instead of the vertical stud) where the anchor bolts will further transmit the forces into the foundation.

Because of the eccentric load transfer, due to forces acting in the same vertical plane, transverse bending is created in the bottom rail and splitting often occurs.

It is important to evaluate this cross-wise bending and to ensure that no brittle failure occur in the bottom rail.

The bottom rail is experimentally studied with respect to two primary failure modes, splitting along the bottom of the bottom rail due to cross-wise bending and splitting along the edge side of the bottom rail due forces perpendicular to the grain from the sheathing-to-framing connections.

The parameters varied are the size of the washer and the orientation of the pith.

The bottom rail was subjected to loading perpendicular to grain through two-sided sheathing.

In this report the different set of series are presented. Five sets were conducted depending on the size of the washer and in each set the pith was placed upwards and downwards.

The tests showed three different failure modes. In addition to the failure modes that the testing program was aimed at, splitting along the bottom or side of the bottom rail, the final failure was also due to plastic bending and withdrawal of the sheathing-to-framing nails.

The results show that the size of the washer has a significant influence on the maximum load and the failure modes. The results show also that the orientation of the pith have a significant influence on the maximum load.

Key words: timber shear walls, partially anchored, sheathing-to-framing joint, bottom rail, cross-wise bending, splitting of bottom surface, splitting of side surface.

Acknowledgements

The experiments of this report were carried out at Umeå University, Sweden, in June 2011.

Bo Källsner and Ulf Arne Girhammar have initiated this study as part of their research work on a plastic design method for partially anchored light-frame shear walls. Per-Anders Daerga has planned the test series. Giuseppe Caprolu has performed the experiment and written the report.

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Introduction

Background

Källsner and Girhammar [1] have presented a new plastic design method for wood-framed shear walls at ultimate limit state. This method allows the designer to calculate the load-carrying capacity of shear walls partially anchored, where the leading stud is not fully anchored against uplift.

The anchorage system of shear walls is provided from anchor bolts and hold downs. Anchor bolts provide horizontal shear continuity between the bottom rail and the foundation. Hold downs are directly connected from the vertical end stud to the foundation. When hold downs are not provided, the bottom row of nails transmits the vertical forces in the sheathing to the bottom rail (instead of the vertical stud) where the anchor bolts will further transmit the forces into the foundation.

Because of the eccentric load transfer, due to forces acting in the same vertical plane, transverse bending is created in the bottom rail and splitting often occurs.

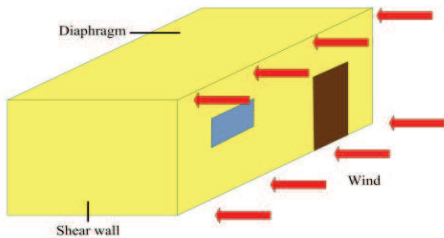
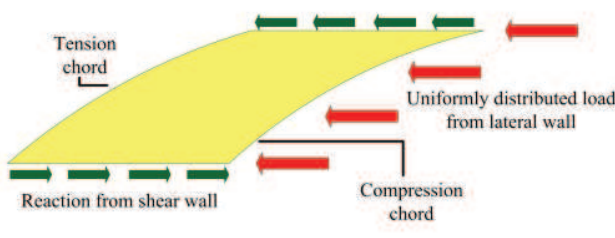
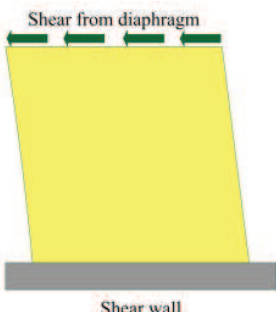
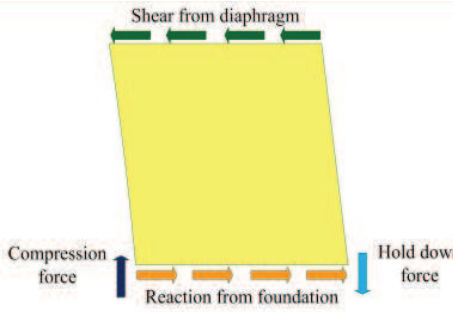
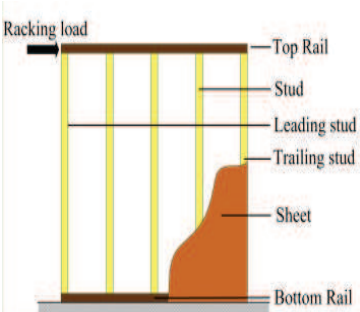
Characteristics of shear walls

A shear wall is an in-plane structural element designed to transmit forces in its own plane. Horizontal roof and floor diaphragms are designed to distribute lateral loads to the shear wall elements, which in turn carry the loads to the foundations. The shear walls are subjected to shear forces at roof level from the roof diaphragm, and resisted by shear and normal reactions at the foundations. Shear walls must be anchored to the foundation to resist uplift forces.

A shear wall in timber construction is a load-bearing wall that is designed to carry racking loads in the plane of the wall (shear loads) in addition to the vertical loads.

The horizontal forces create an overturning moment on the shear wall and therefore create uplift forces on one side and compression on the other side of the wall. The strength of the wall is dependent upon three components: timber frame members, sheathing and fasteners.

Table 1: Behaviour of shear wall

 <p>The lateral wall, considered to be simply supported at roof and foundation, transfer one half of the total wind load to the roof level.</p>	 <p>The diaphragm, acting as a deep horizontal beam, transmits the load to the end shear walls.</p>	
 <p>Load on the shear wall obtained from the diaphragm.</p>	 <p>The shear wall transfers the load to the foundation.</p>	 <p>Details of shear wall.</p>

Details of the bottom rail

The main difference between fully and partially anchored shear walls is the presence in the second case of uplift of the studs of the wall, especially of the leading stud.

In fully anchored shear walls the uplift is prevented by some kind of tying down device at the leading stud. This will result in a concentrate force at the end of the wall. In partially anchored shear walls there are no device between the leading stud and foundation. The uplift is resisted by the sheathing-to-framing joints along the bottom rail. This will result in a distributed force on the bottom rail and there is some uplift of the studs of the wall (*see Figure 1*).

In the latter case the bottom rail will be subject to uplift forces that cause a tension stresses perpendicular to the grain and crosswise bending (*see Figure 1*).

Due these stresses brittle failure of the bottom rail may occur. In order to have the correct distribution of the forces for partially anchored shear walls, brittle failure of the bottom rail should be avoided.

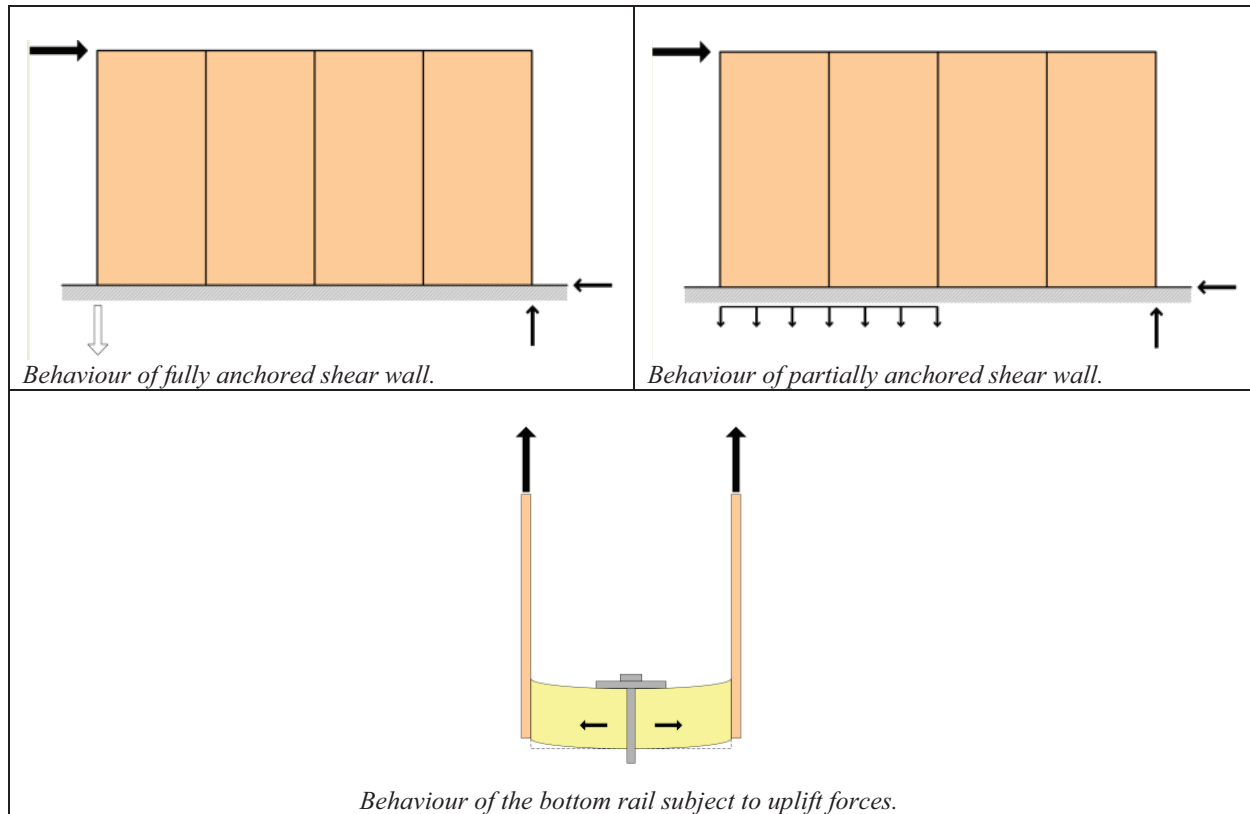


Figure 1: Behaviour of fully and partially anchored shear walls and behaviour of the bottom rail under uplift forces

Aim and scope

The overall study focuses on the study of a new plastic design method [1] of wood-frame shear walls at ultimate limit state. This method allows to calculate the load-carrying capacity of shear wall partially anchored, where the leading stud is not anchored against the uplift.

The aim of this study is to design the bottom rail against forces from sheathing-to-framing joint. The bottom rail should be designed in the ultimate limit state. Both shear force and cross-wise bending, due the absence of hold down, are present in the bottom rail. It is also important to determine the conditions for the bottom rail for the plastic method to work.

This study focuses on double-sided sheathing. Earlier one-sided sheathing was studied [2].

In order to use the plastic method it is necessary to ensure two main conditions: avoid brittle failure of the bottom rail and to ensure a ductile behaviour of the sheathing-to-framing joint.

The scope of this report is to present results of laboratory tests of the bottom rail subjected to uplift forces through sheathing-to-framing joints. Two primary failure modes are in focus, splitting along the bottom of the bottom rail due to cross-wise bending and splitting along the edge side of the bottom rail due forces perpendicular to the grain from the sheathing-to-framing connections.

The bottom rail was subjected to loading perpendicular to grain through two-sided sheathing.

The experimental work was conducted at Umeå University during June 2011.

Test setup and material

Test specimen

The specimens were built with a rail of length 900 mm and with a cross section of 45×120 mm, joined with hardboard sheet of $500 \times 900 \times 8$ mm.

At first it was thought of planing the top and bottom surface of the rail, in order to eliminate any influence of cupping and possible pre-cracking, when tightening the anchor bolts, on the ultimate load. However it was not necessary because the surfaces of the bottom rail were acceptable with regard to flatness.

The rails were kept enclosed in a plastic cover in lab from 29 March 2011 to September 2011. The temperature in lab was about 20° C. They were already cut from the factory, therefore it was impossible to choose rails cut from the same board in order to have rails with the same density.

The specimens were assembled manually. They were usually assembled the evening before the day of testing. Sometime this was not possible (*see Appendix B for a chronological summary of the conduction of the tests*).

Test program

A total of 64 specimens were planned to test but due to a mistake during the testing of Set 1 (*tested with the inclined bars in the lifting device*) it was necessary to repeat that Set and Set 1-BIS was added to the test program and a total of 80 specimens have been tested. The results of Set 1 are still presented in this report.

The table below shows the test program:

Table 2: Test program

Series	Anchor bolt position	Set	Size of washer [mm]	Number of tests	Distance from washer edge to rail edge [mm]
4	Centre 60 mm from sheathing	1	40x40x15	16 ¹⁾	40
		1-BIS	40x40x15	16 ¹⁾	40
		2	60x60x15	16 ¹⁾	30
		3	80x70x15	16 ¹⁾	20
		4	100x70x15	16 ¹⁾	10

¹⁾ 8 specimens with the pith downwards and 8 upwards

Material properties

The following materials were used for the specimens:

- Bottom rail: Spruce (Picea Abis), C24, 45x120 mm;
- Sheathing: Hardboard, C40, 8 mm (wet process fibre board, HB.HLA2, Masonite AB);
- Sheathing-to-timber joints: Annular ringed shank nails, 50x2.1 mm (Duofast, Nordisk Kartro AB). The joints were nailed manually and the holes were pre-drilled, 1.7 mm. Nail spacing was 25 mm or 50 mm. Edge distance was 22.5 mm along the bottom rail;
- Anchor bolt: Ø12 (M12). The holes in the bottom rail were pre-drilled, 13 mm.

Moisture content and density

After each test, material samples were taken from the test specimens (only for the rail). The moisture content and density of the bottom rail were determined according to recommendations of ISO 3130:1975 and ISO 3131:1975 respectively.

The moisture content (ω) was calculated according to the following formula (ISO 3130):

$$\omega = \frac{m_1 - m_0}{m_0} \cdot 100 [\%]$$

where:

- m_1 is the mass of the test piece before the drying [g];
- m_0 is the mass of the test piece after the drying [g].

The density of the bottom rail (ρ) was calculated according to the following formula (ISO 3031):

$$\rho = \frac{m_0}{V_w} \left[\frac{kg}{m^3} \right]$$

where:

- m_0 is the mass of the test piece after the drying [g];
- V_w is the volume of the test piece before the drying [m³, cm³].

The moisture content and density were measured the same day of the test. Sometime due different problems this was not possible and they were measured some days later (*see appendix for a chronological summary of the conduction of the tests*).

Test setup

The bottom rail was fixed to a steel plate simulating the foundation which in turn was welded to a steel structure. The connection between bottom rail and steel plate was made through two anchor bolts. To tighten the bolt a torque moment of 50 Nm was used. A square or rectangular washer of high rigidity was inserted between the bottom rail and the head bolt. Its size and shape varied for the set tested.

A tensile load with a rate of 2 mm/min was applied by a hydraulic piston (static load capacity 100 kN) through two load distribution C steel beams attached to the upper panels by four bolts Ø 16 for each panel (see Figures 2 and 3 for test setup).



Figure 2: Test setup



Figure 3: Test setup, connection panels – lifting device by bolts

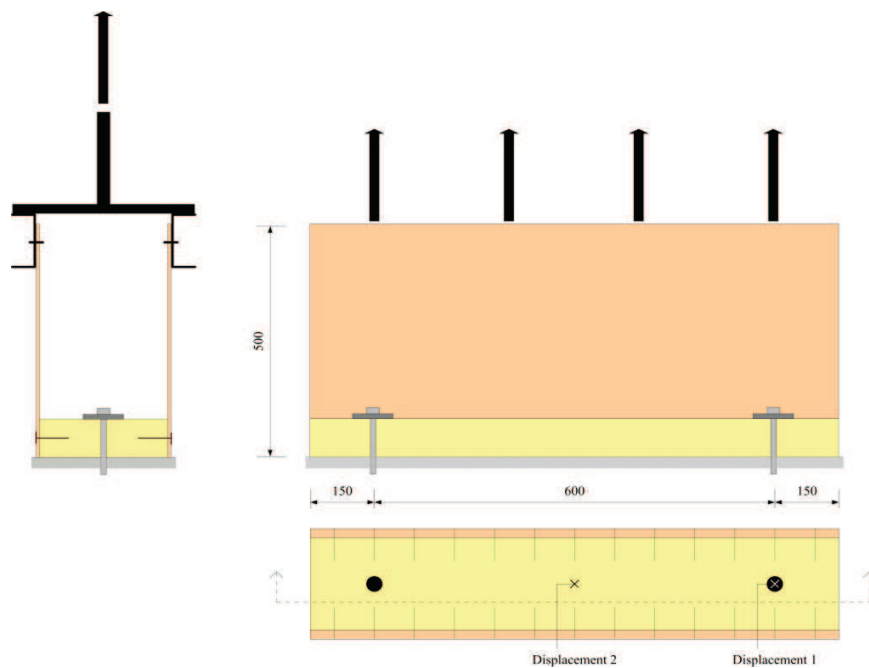


Figure 4: Specimen and test setup

Two displacements were measured using a Linear Voltage Displacement Transducer (LVDT) during the tests. These displacements are called *Displacement 1*, which measured the movement of the washer that was positioned on the upper surface of the washer on the side 1, and *Displacement 2*, which measured as the upward movement of the upper surface of the rail in the line of the anchor bolts in the middle of the distance between the anchor bolts (see Figures 4, 5 and 6).

However the displacement 1 was too small to measure and this has given some problem during recording of data. Plotting the graph load vs. displacement during the post process the line plotted appears disturbed and it is impossible to understand the real curve trend.

The rails are free to rotate during loading, i.e. the inclined bars are removed from the lifting device (see Figure 7 and 8). This provides a well-defined boundary condition. However by mistake Set 1 was tested before cutting the inclined bars and it was retested in Set 1-BIS (see Figure 9 and 10). The results of Set 1 are also presented in this report and compared with Set 1-BIS, in order to evaluate the influence of different boundary conditions.



Figure 5: position of the two LVDT on the upper surface of the bottom rail



Figure 6: position of LVDT recording displacement 1

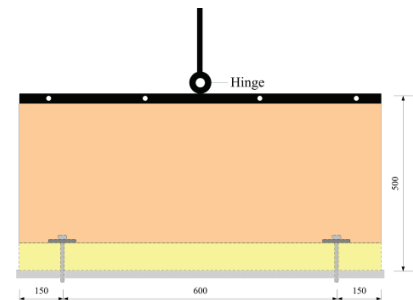


Figure 7: lifting device free to rotate during loading



Figure 8: lifting device free to rotate during loading

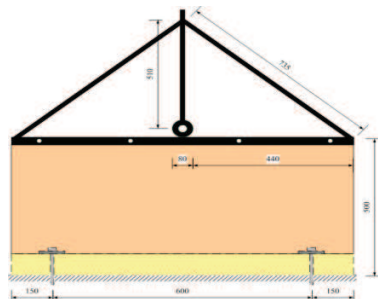


Figure 9: lifting device with inclined bars used for Set 1



Figure 10: lifting device with inclined bars used for Set 1

Test results

The load vs. time and load vs. displacement graphs are displayed for each test in Appendix A. Moreover other data and test results, as well as figures for each test, are displayed. Type of failure;

- Failure load;
- Displacement 1 and 2 at failure (*displacement 1 measured the movement of washer surface on the side 1 in line of the anchor bolt. Displacement 2 measured the upward movement of the upper surface of the rail in the line of the anchor bolts in the middle of the distance between the anchor bolts*);
- Distance from crack to edge, side 1 and 2 (see Figure 11);
- Distance from crack to anchor bolt, side 1 and 2 (see Figure 11);
- Moisture;
- Density.

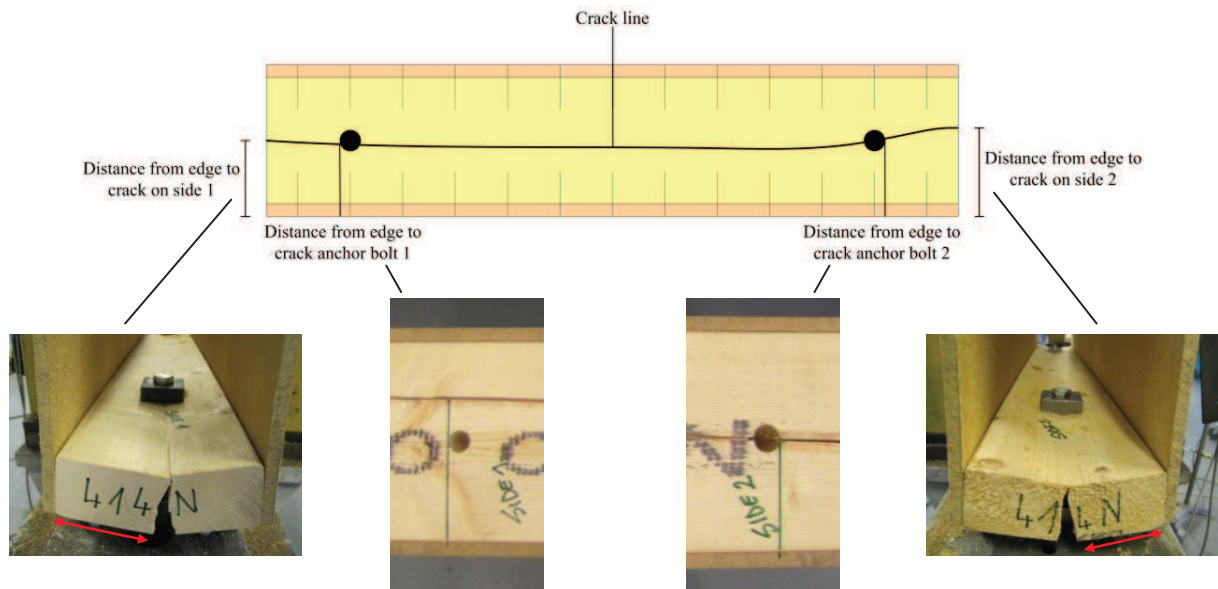


Figure 11: Example of distance between the edge of the bottom rail and crack line on side 1 and 2, and example of distance between the edge of the bottom rail and crack line at anchor bolt position on side 1 and 2

In order to identify the specimen the Swedish convention is used where N means ner (downwards in English) and U means Upp (upwards in English) according to pith orientation.

Failure modes

Different failure modes were found during the tests. They were dependant on the washer size. In total three primary failure modes were observed.

- **Failure mode 1:** failure due to splitting of the underneath side of the bottom rail (see Figure 12);

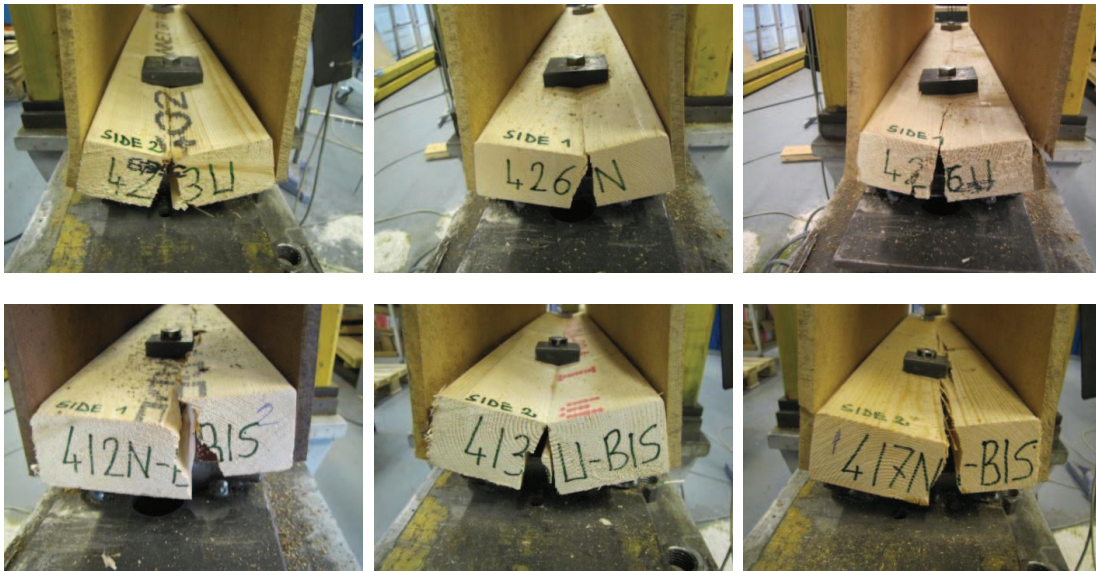


Figure 12: Some example of failure mode 1, splitting of the underneath side of the bottom rail

- **Failure mode 2:** failure due to splitting along the edge side of the bottom rail (see Figure 13);

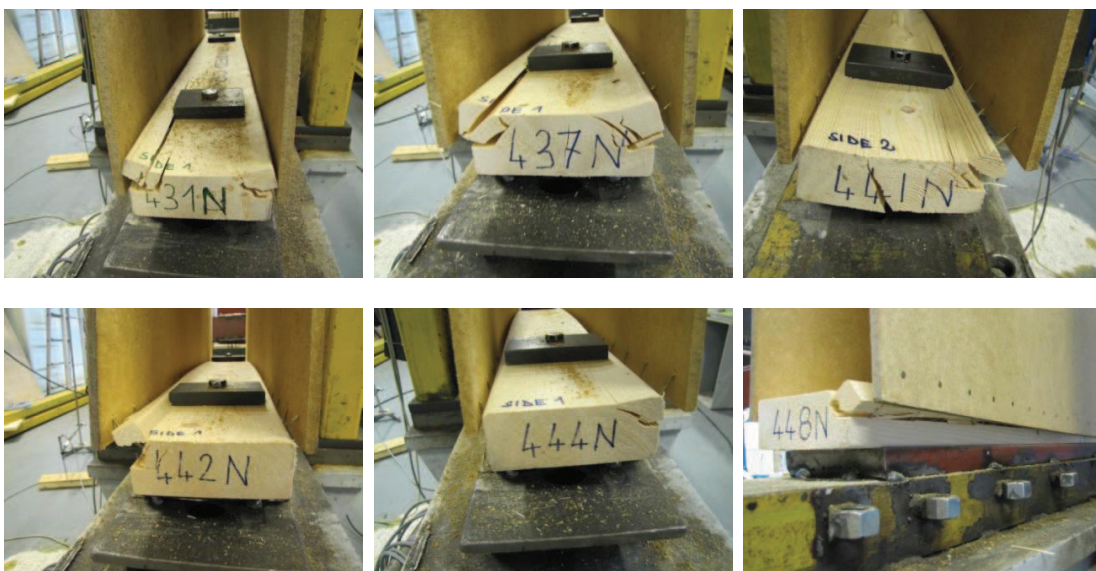


Figure 13: Failure mode 2, splitting along the edge side of the bottom rail

- **Failure mode 3:** failure due to pull-out of nails (see Figure 14);

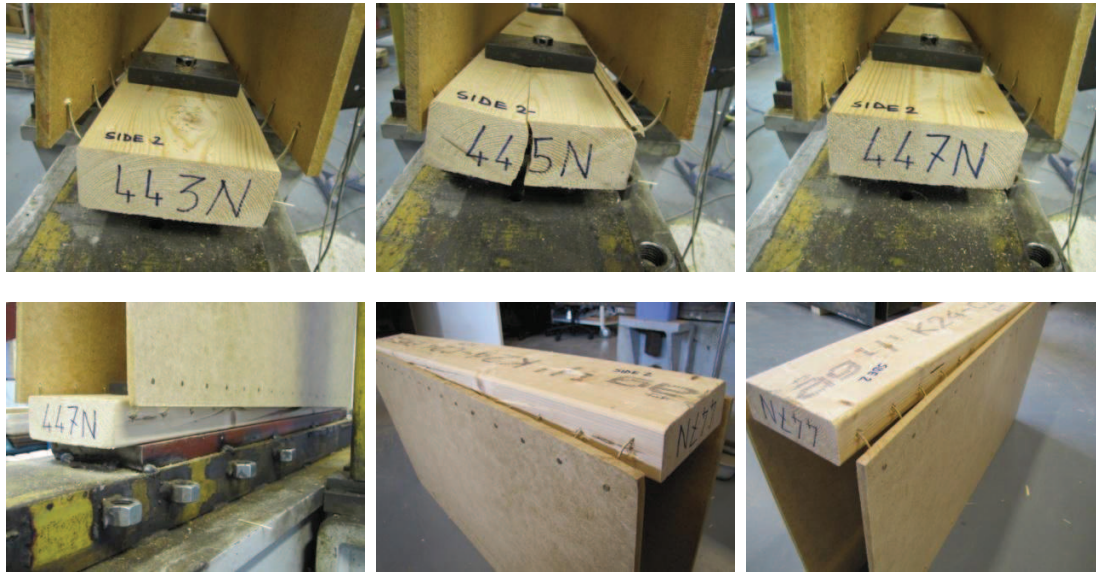


Figure 14: Failure mode 3, pull-out of nails

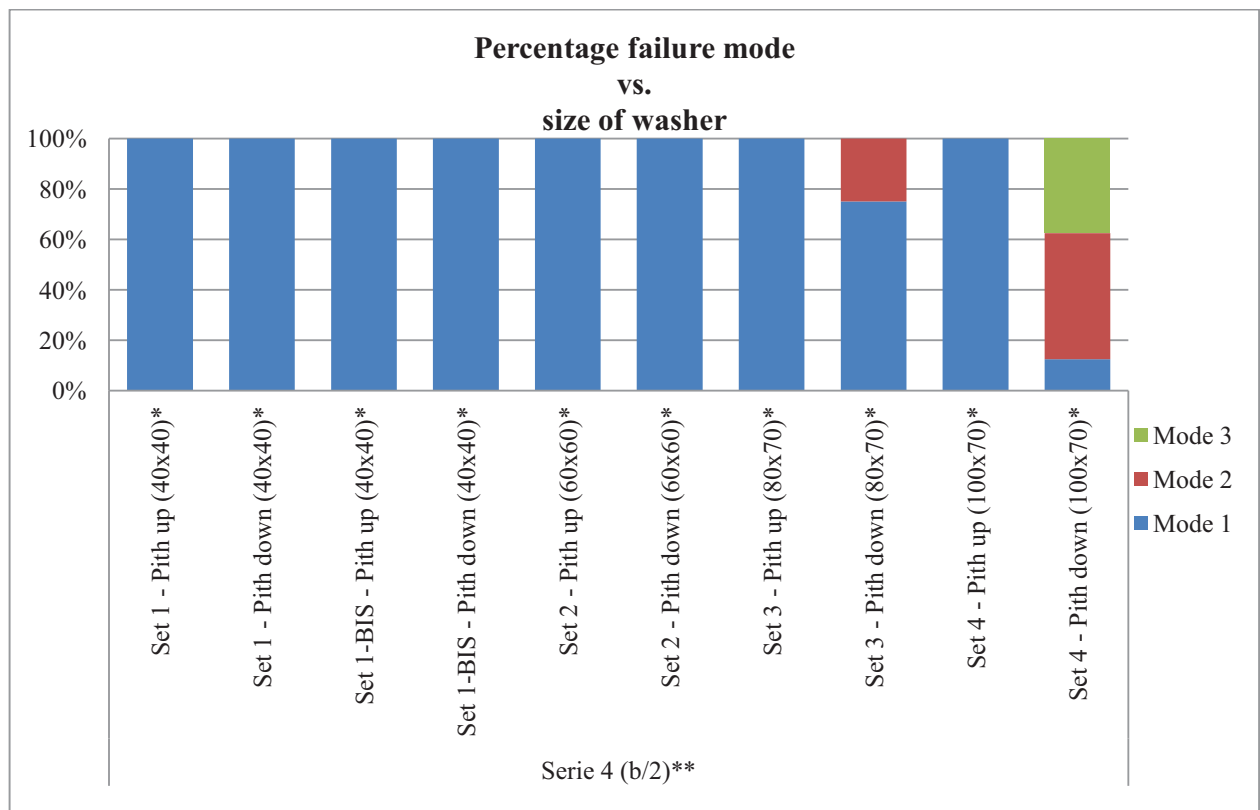


Figure 15: *Size of washer [mm], **Bolt position (where b is the width of the bottom rail, 120 mm). **Failure mode 1:** splitting of the bottom rail; **failure mode 2:** splitting of the bottom rail along the line of the nails between the anchor bolts; **failure mode 3:** pull-out of nails

Load vs. time and load vs. displacement curves

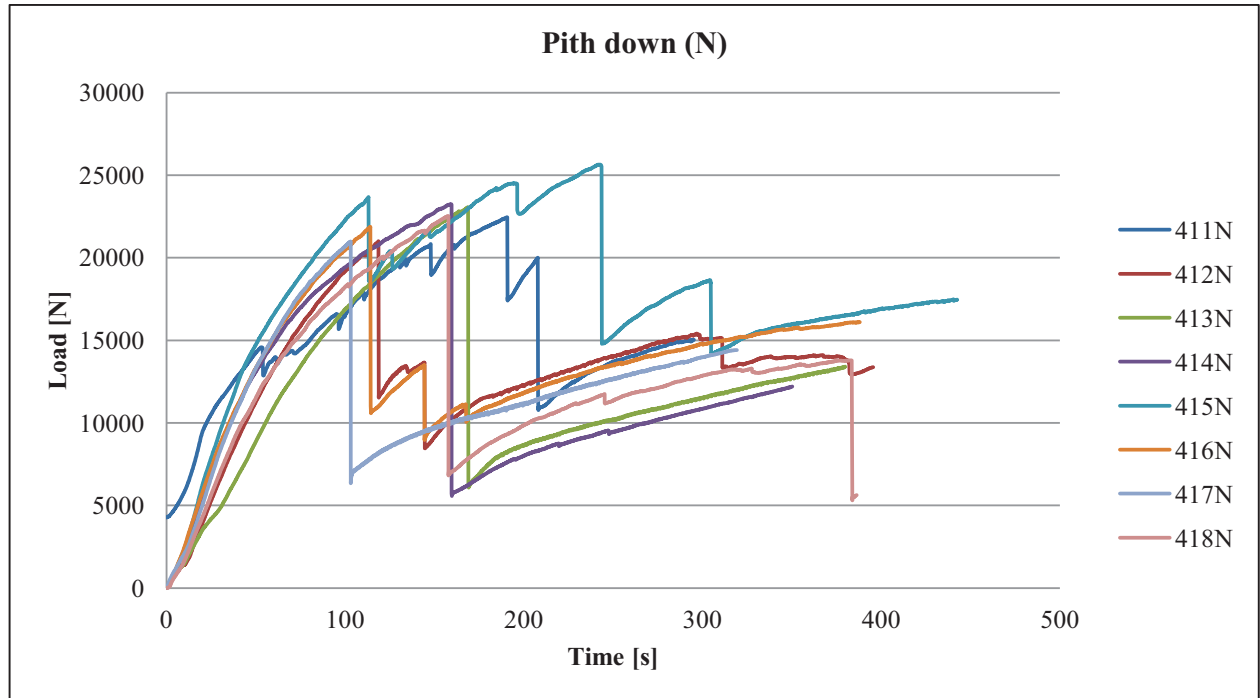


Figure 16: Load vs. time curves for bottom rail with pith down of Series 4 – Set 1.8 failure mode of type 1

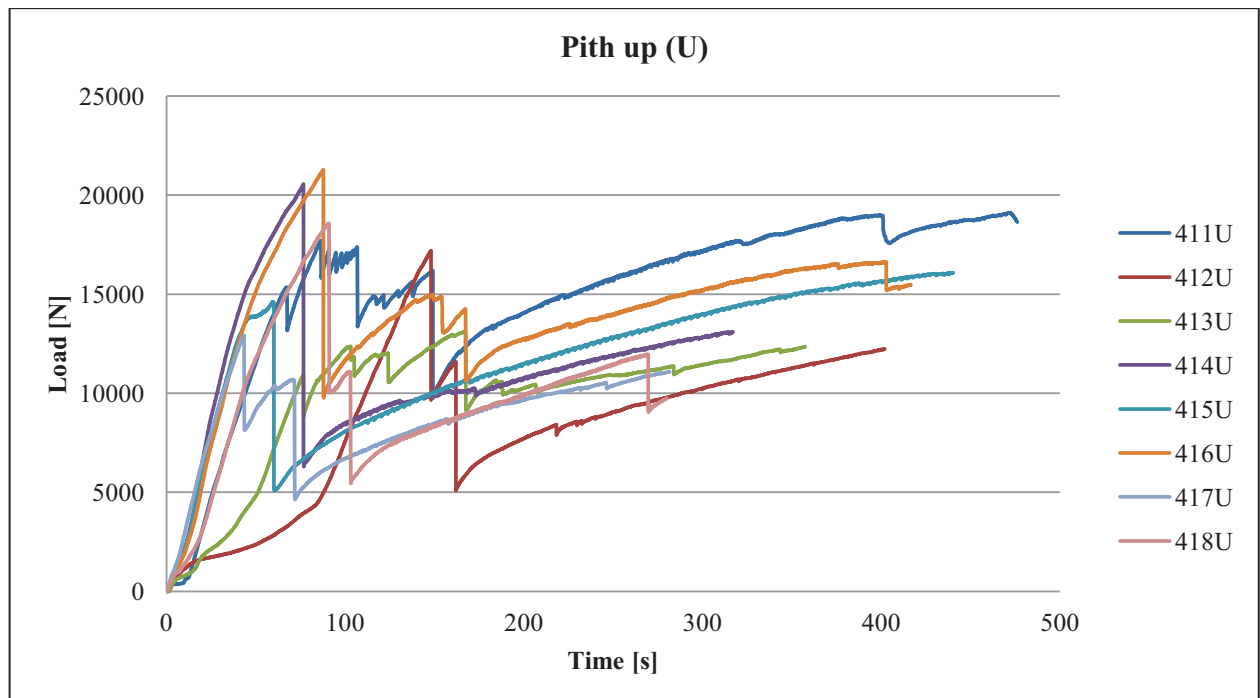


Figure 17: Load vs. time curves for bottom rail with pith up of Series 4 – Set 1.8 failure mode of type 1

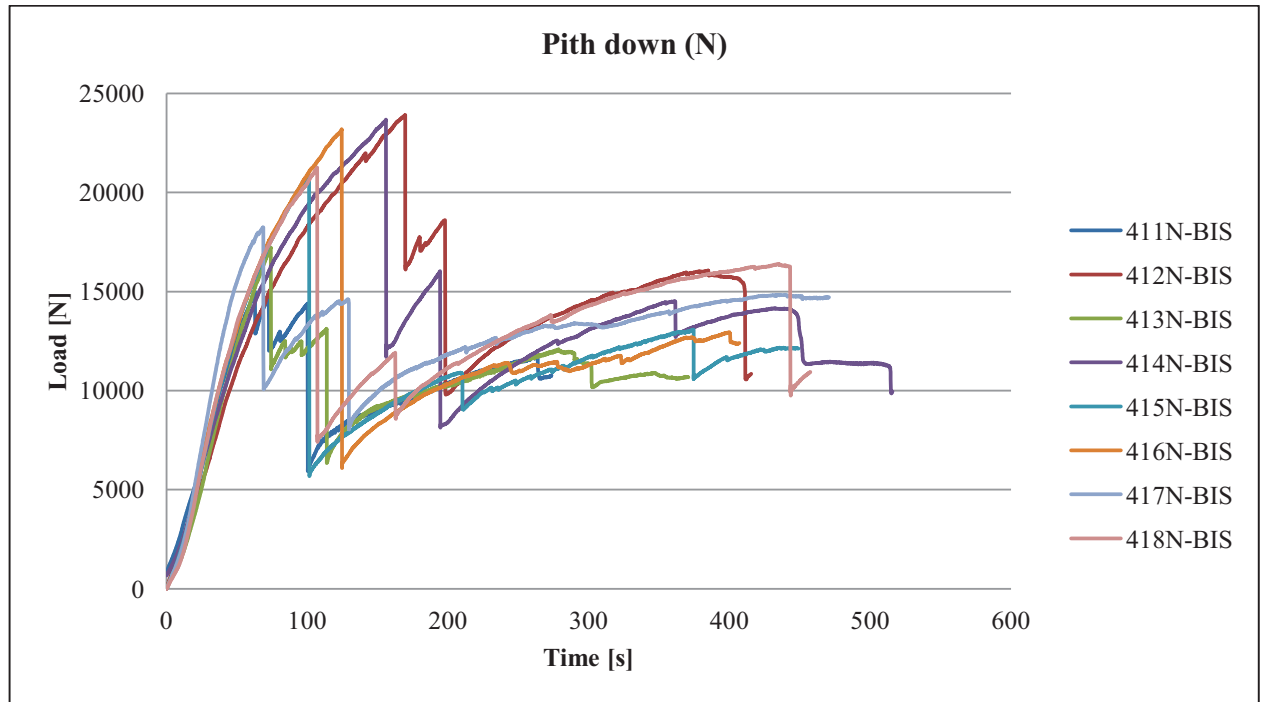


Figure 18: Load vs. time curves of bottom rail with pith down of Series 4 – Set 1-BIS. 8 failure mode of type 1

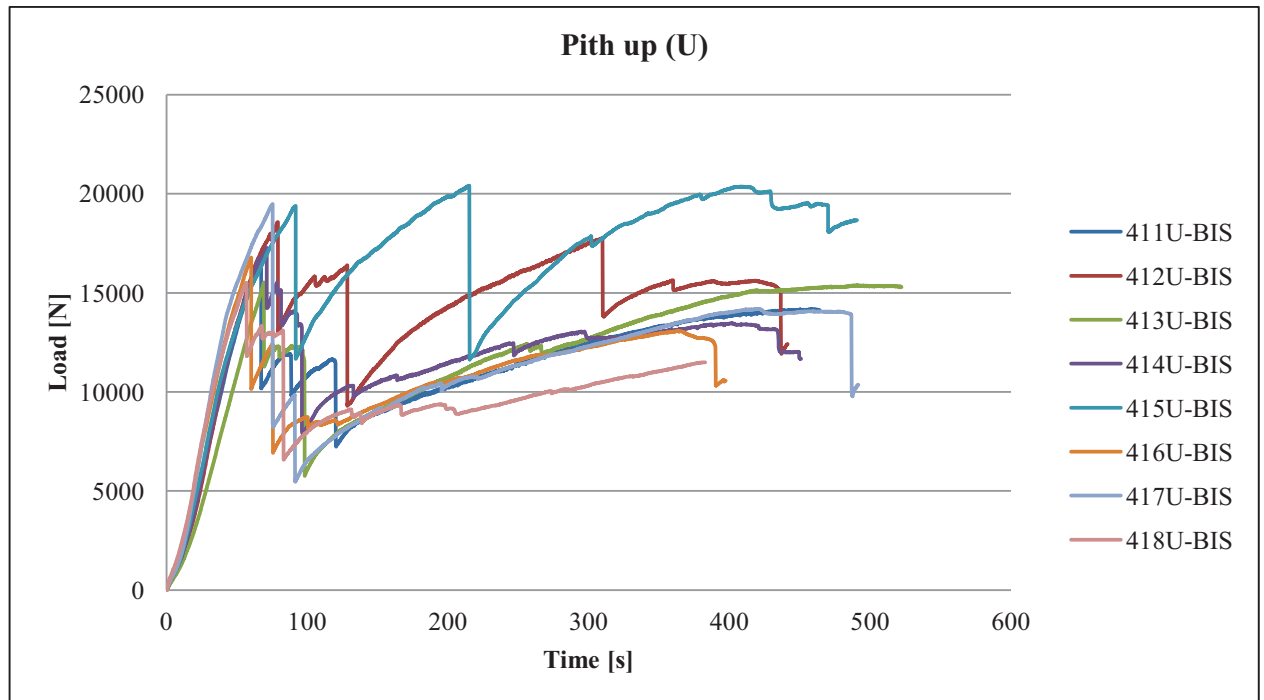


Figure 19: Load vs. time curves of bottom rail with pith up of Series 4 – Set 1-BIS. 8 Failure mode of type 1

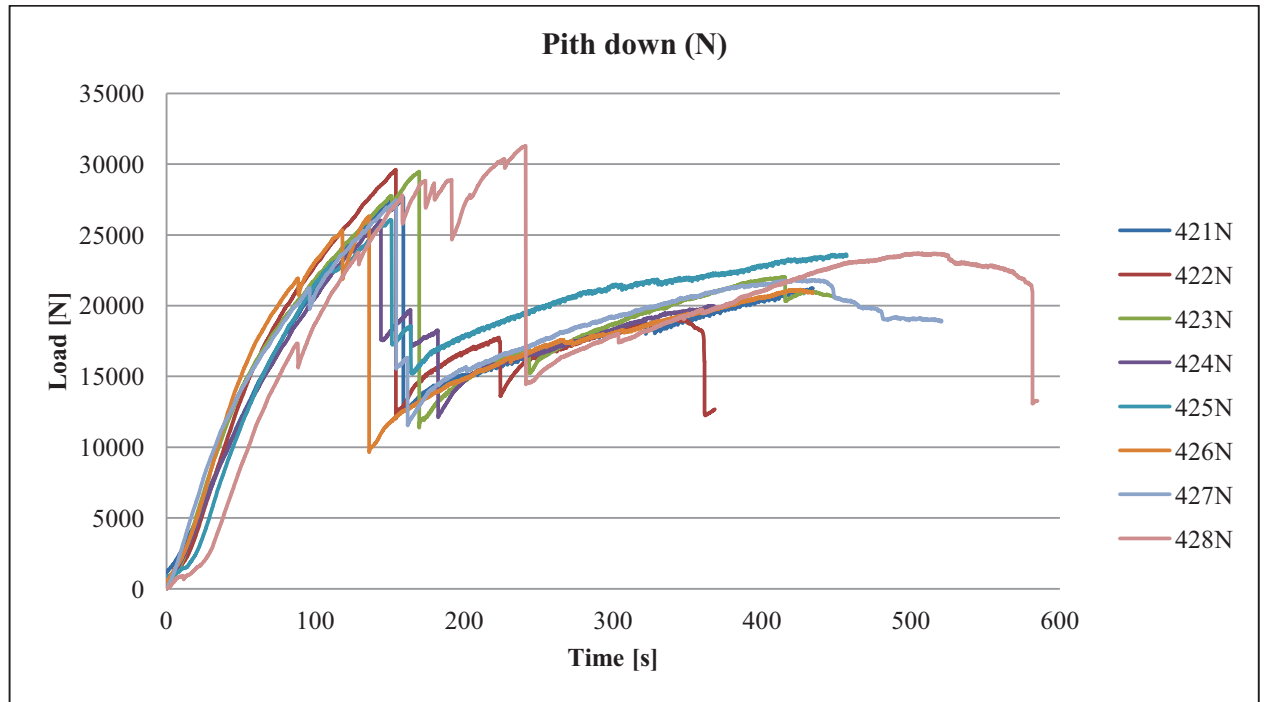


Figure 20: Load vs. time curves of bottom rail with pith down of Series 4 – Set 2. 8 failure mode of type 1

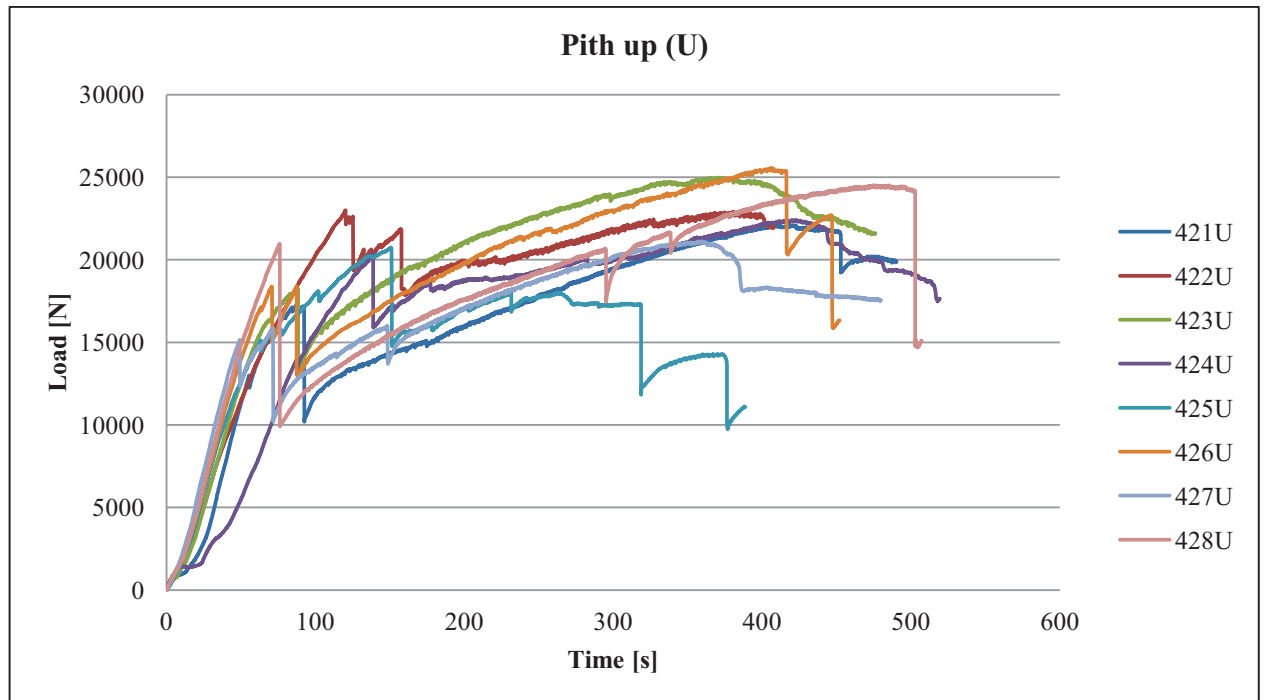


Figure 21: Load vs. time curves of bottom rail with pith up of Series 4 – Set 2. 8 failure mode of type 1

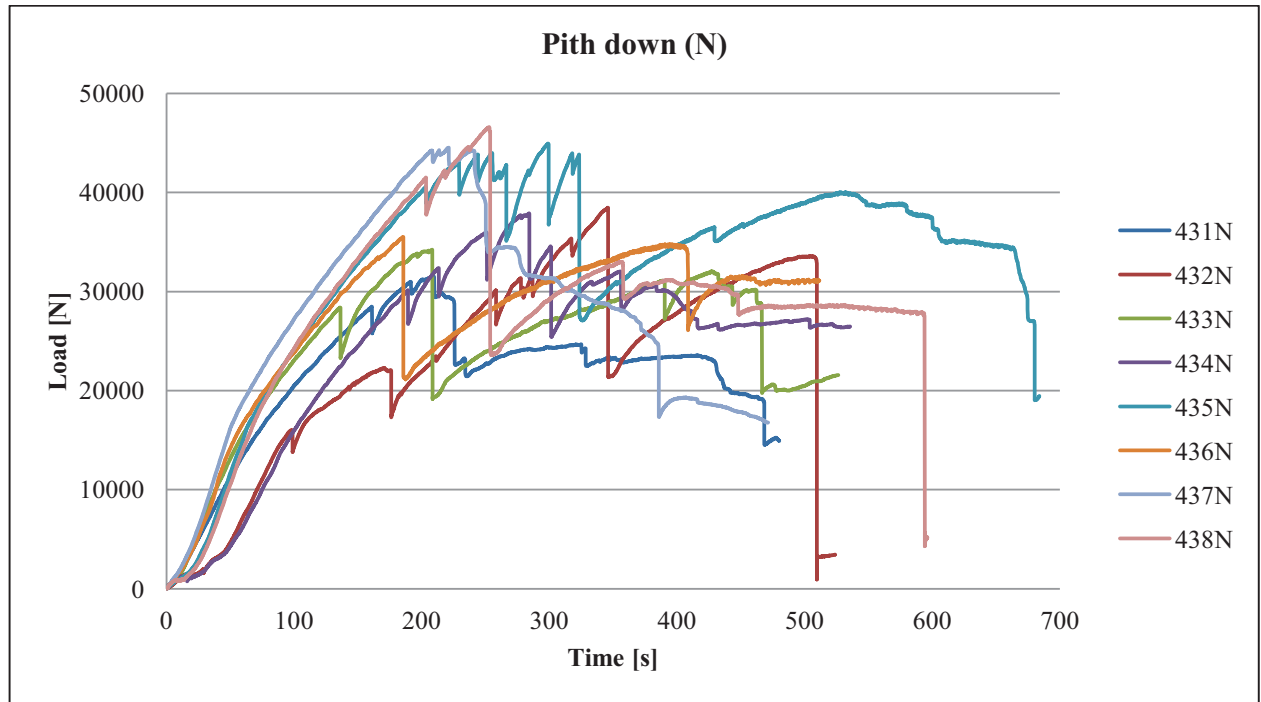


Figure 22: Load vs. time curves of bottom rail with pith down of Series 4 – Set 3. 6 failure mode of type 1 and 2 of type 2

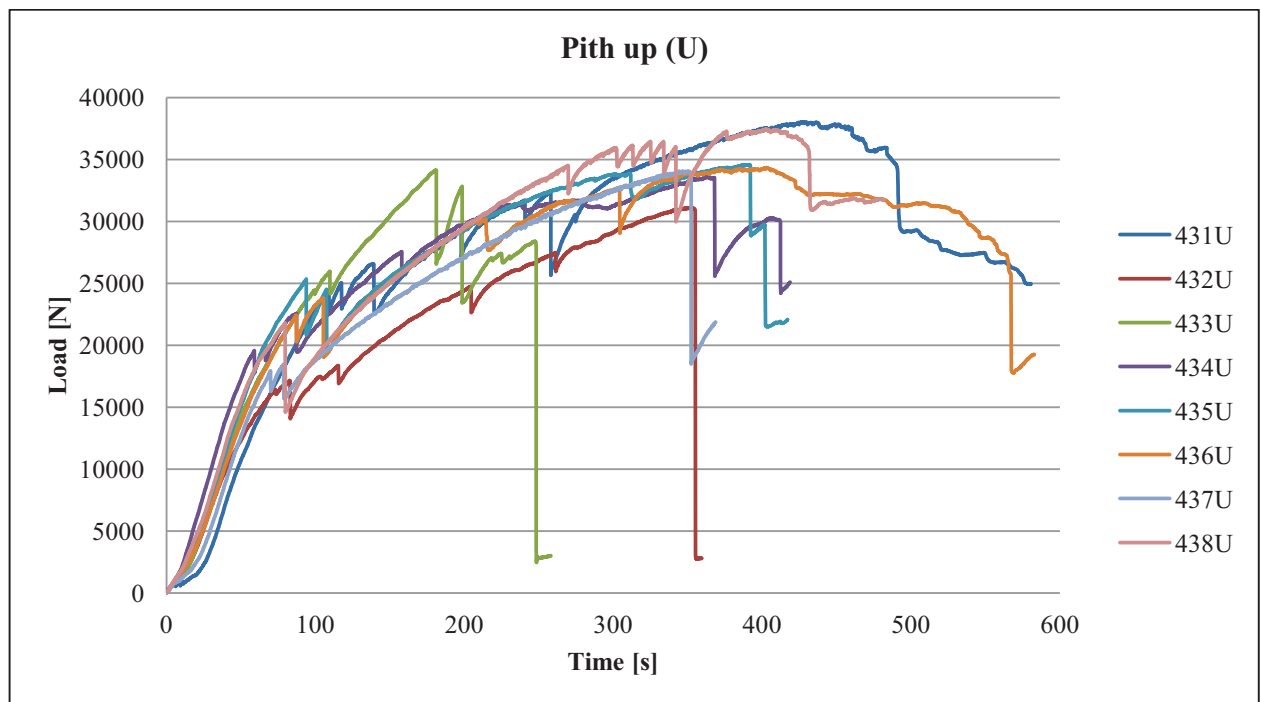


Figure 23: Load vs. time curves of bottom rail with pith up of Series 4 – Set 3. 8 failure mode of type 1

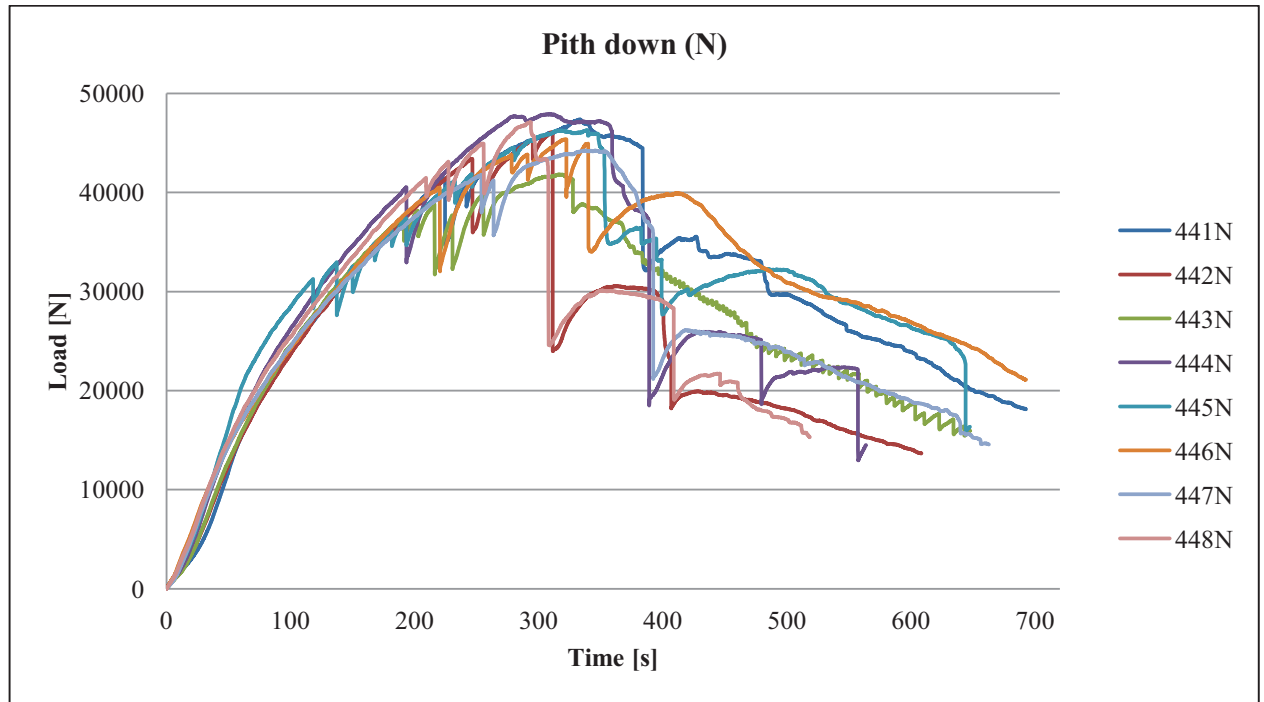


Figure 24: Load vs. time curves of bottom rail with pith down of Series 4 – Set 4. 1 failure mode of type 1, 4 failure mode of type 2 and 3 failure mode of type 3

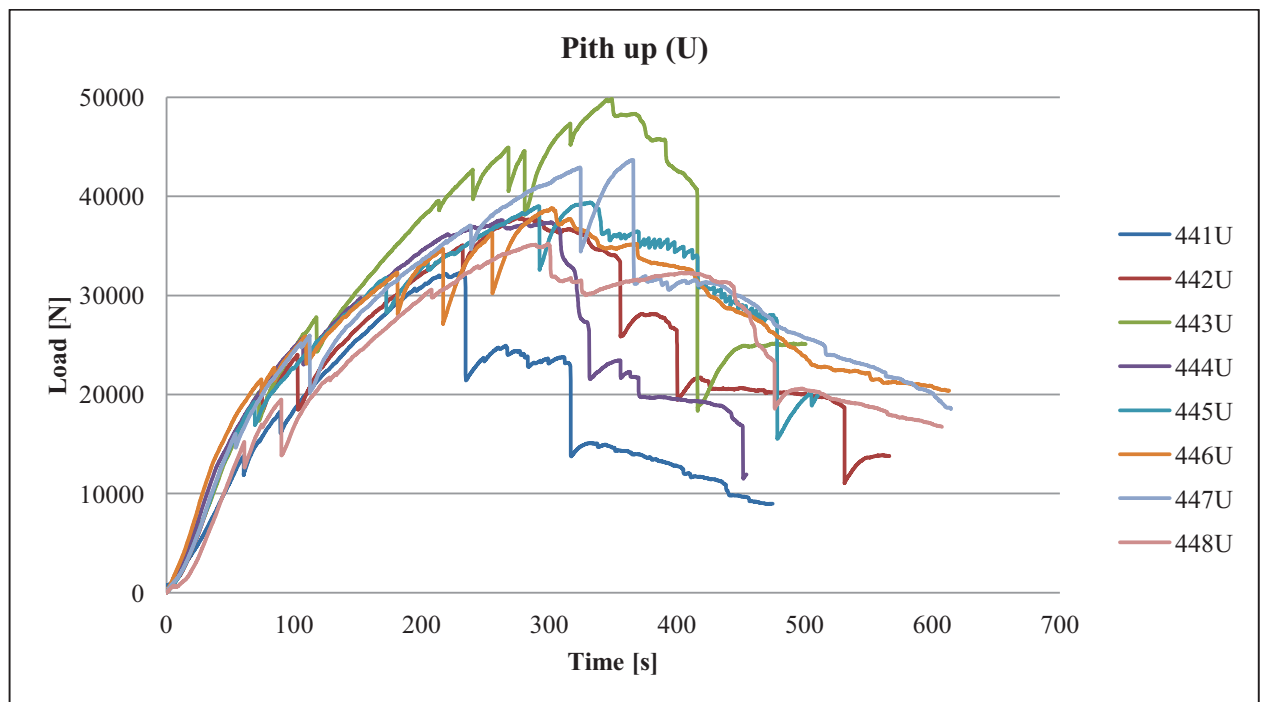


Figure 25: Load vs. time curves of bottom rail with pith up of Series 4 – Set 4. 8 failure mode of type 1 (see Appendix B notes ⁽¹⁾, ⁽²⁾ and ⁽³⁾ about the type of failure of this set)

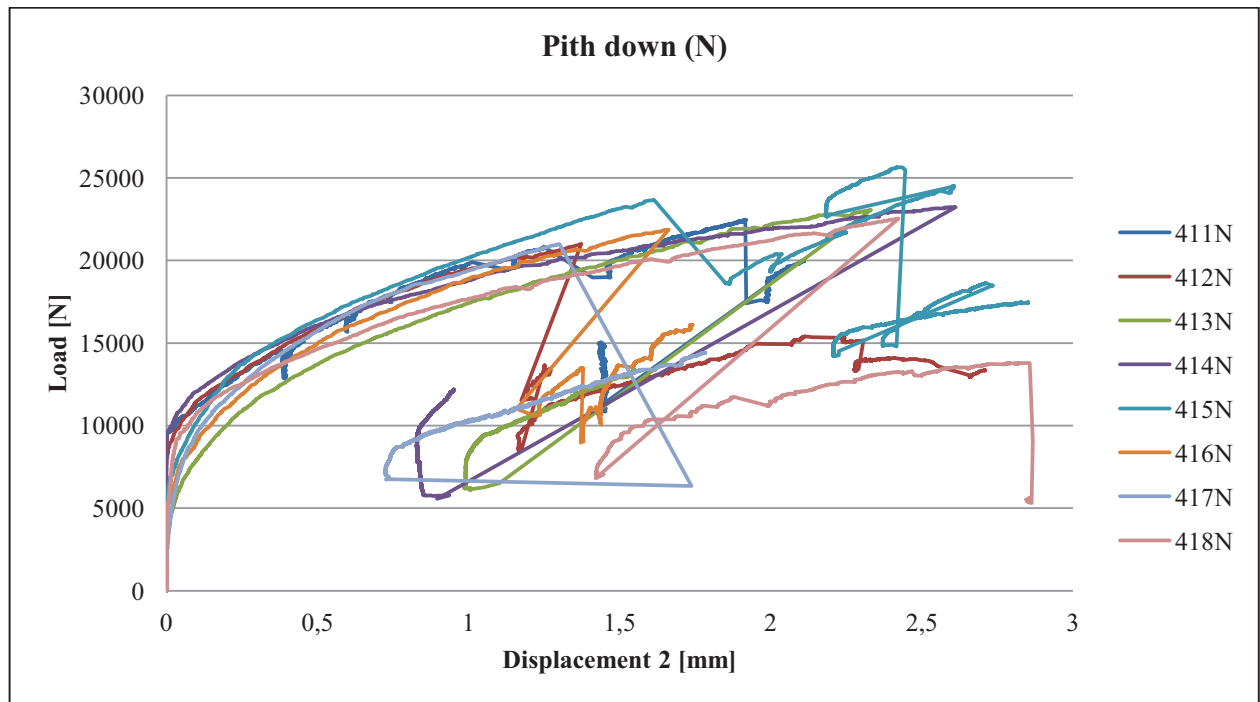


Figure 26: Load vs. displacement curves of bottom rail with pith down of Series 4 – Set 1. 8 failure mode of type 1

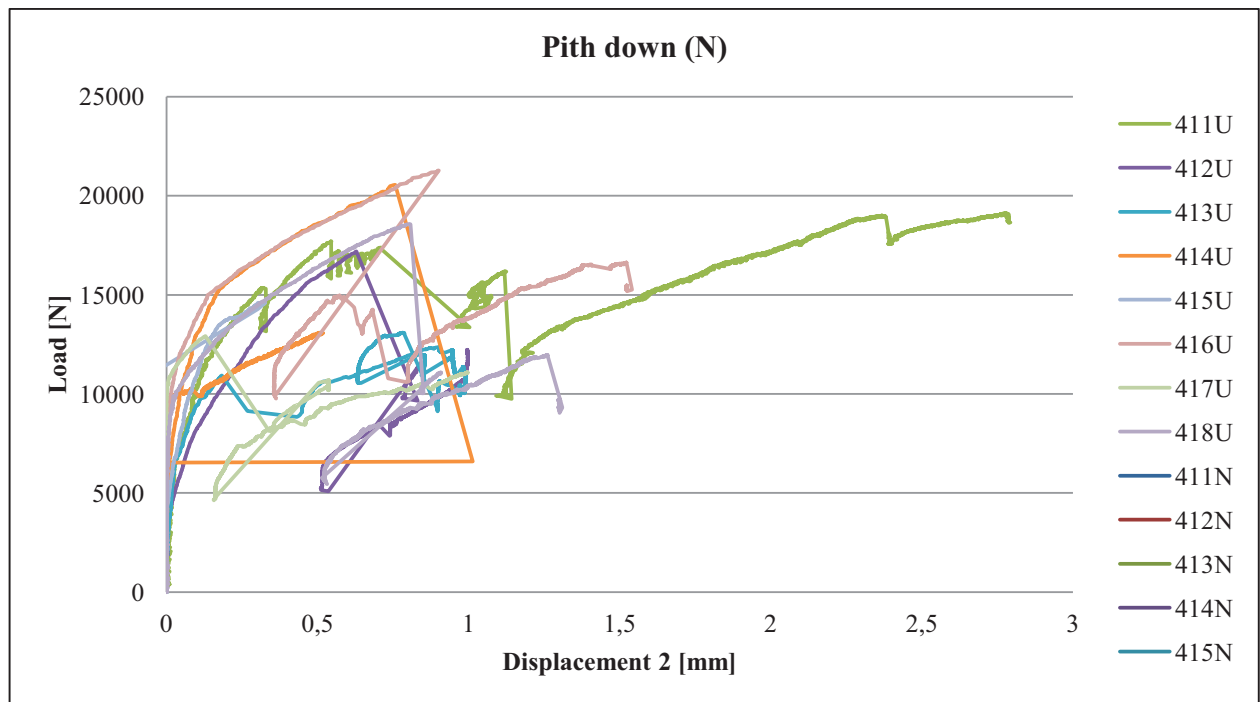


Figure 27: Load vs. displacement curves of bottom rail with pith up of Series 4 – Set 1. 8 failure mode of type 1

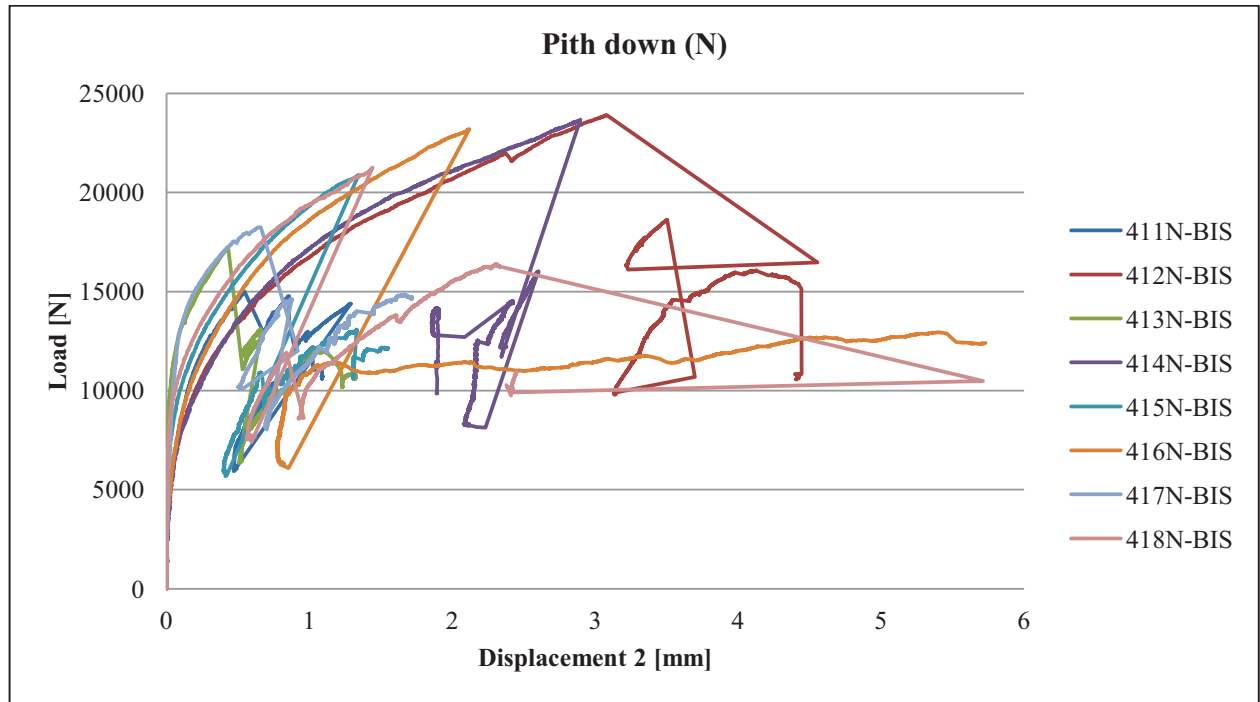


Figure 28: Load vs. displacement curves of bottom rail with pith down of Series 4 – Set 1-BIS. 8 failure mode of type 1

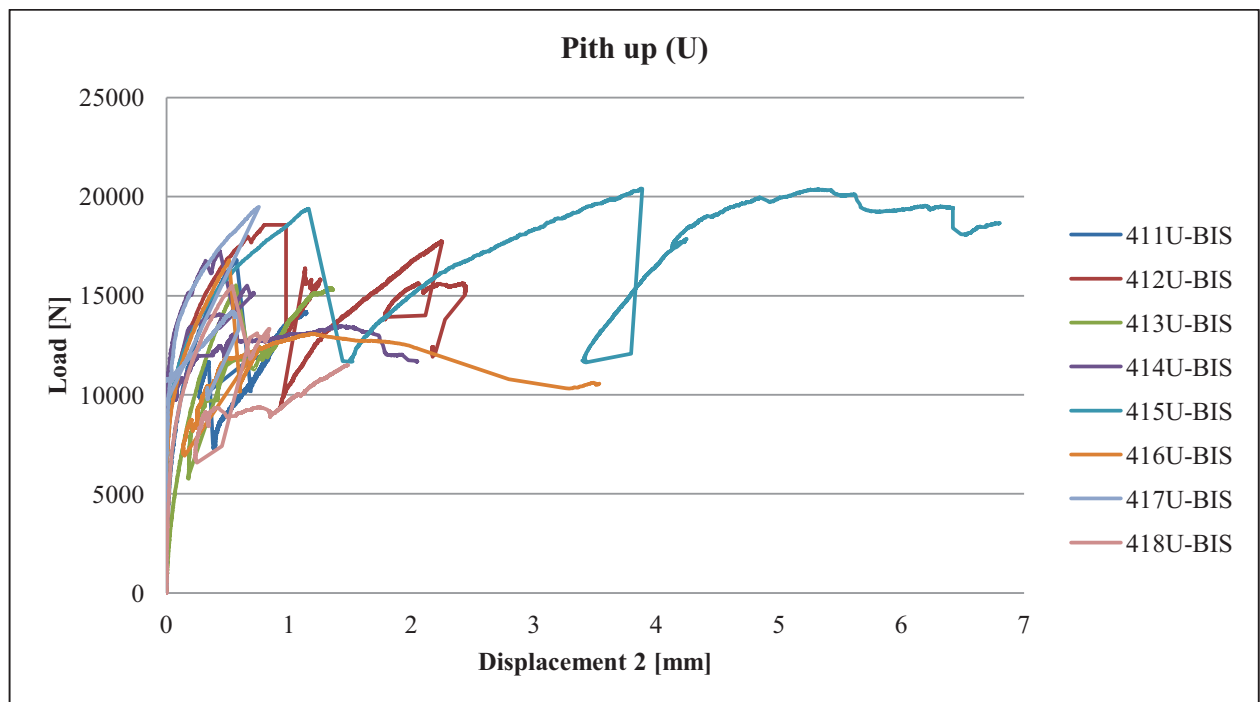


Figure 29: Load vs. displacement curves of bottom rail with pith up of Series 4 – Set 1-BIS. 8 failure mode of type 1

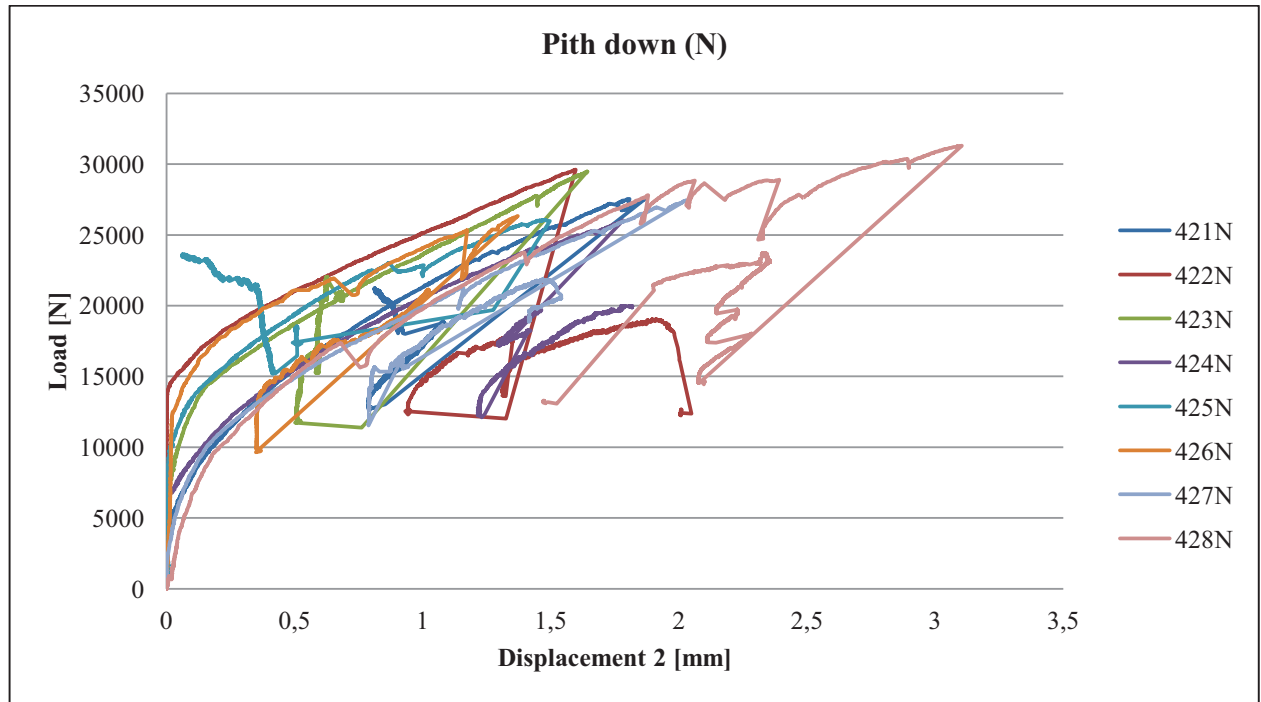


Figure 30: Load vs. displacement curves of bottom rail with pith down of Series 4 – Set 2. 8 failure mode of type 1

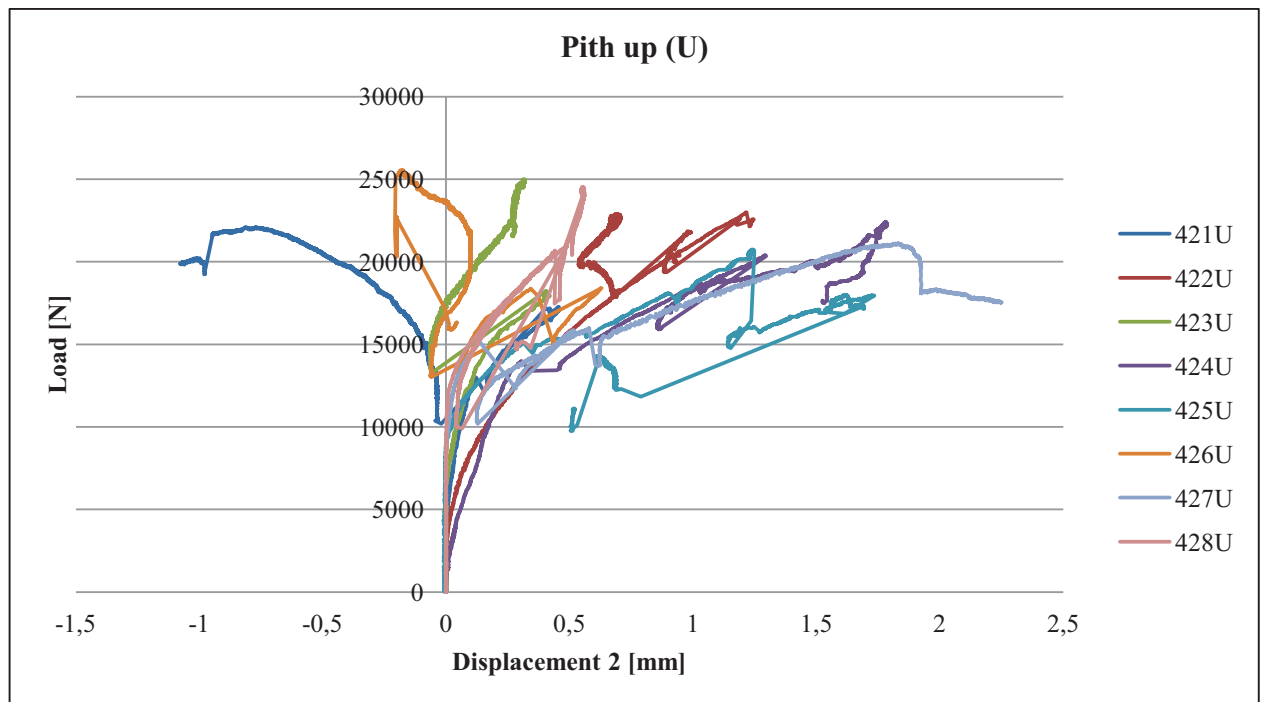


Figure 31: Load vs. displacement curves of bottom rail with pith up of Series 4 – Set 2. 8 failure mode of type 1

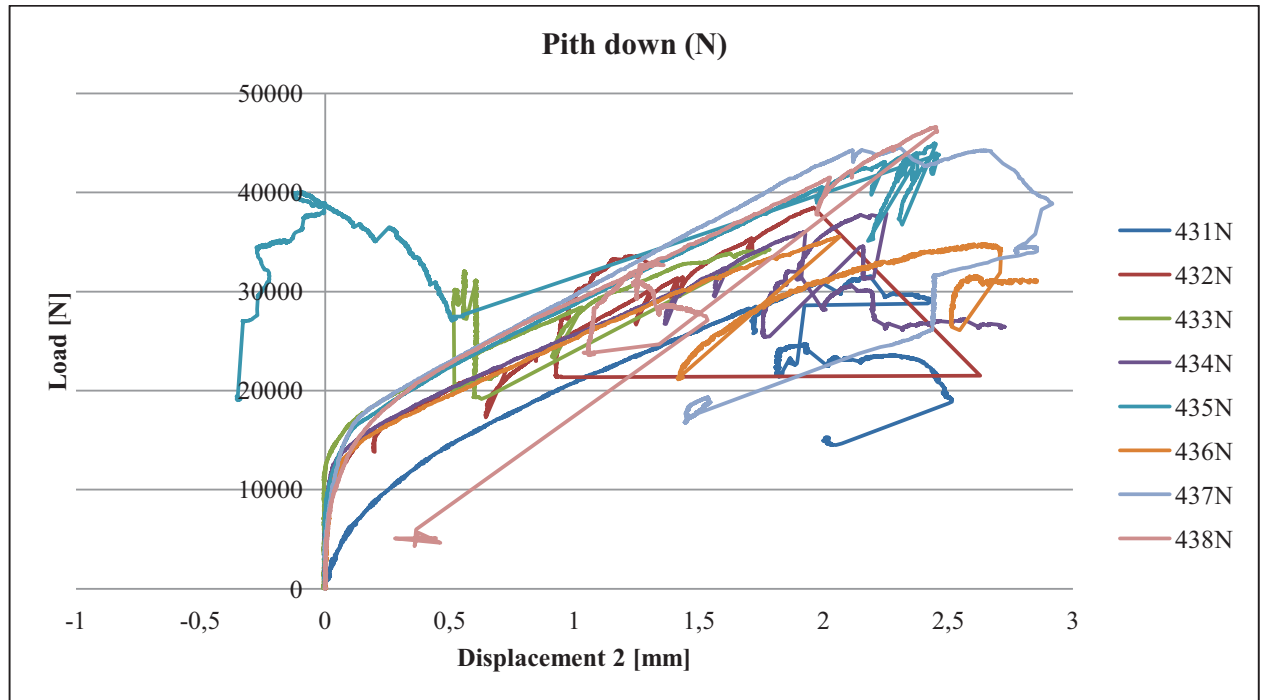


Figure 32: Load vs. displacement curves of bottom rail with pith down of Series 4 – Set 3. 6 failure mode of type 1 and 2 failure mode of type 2

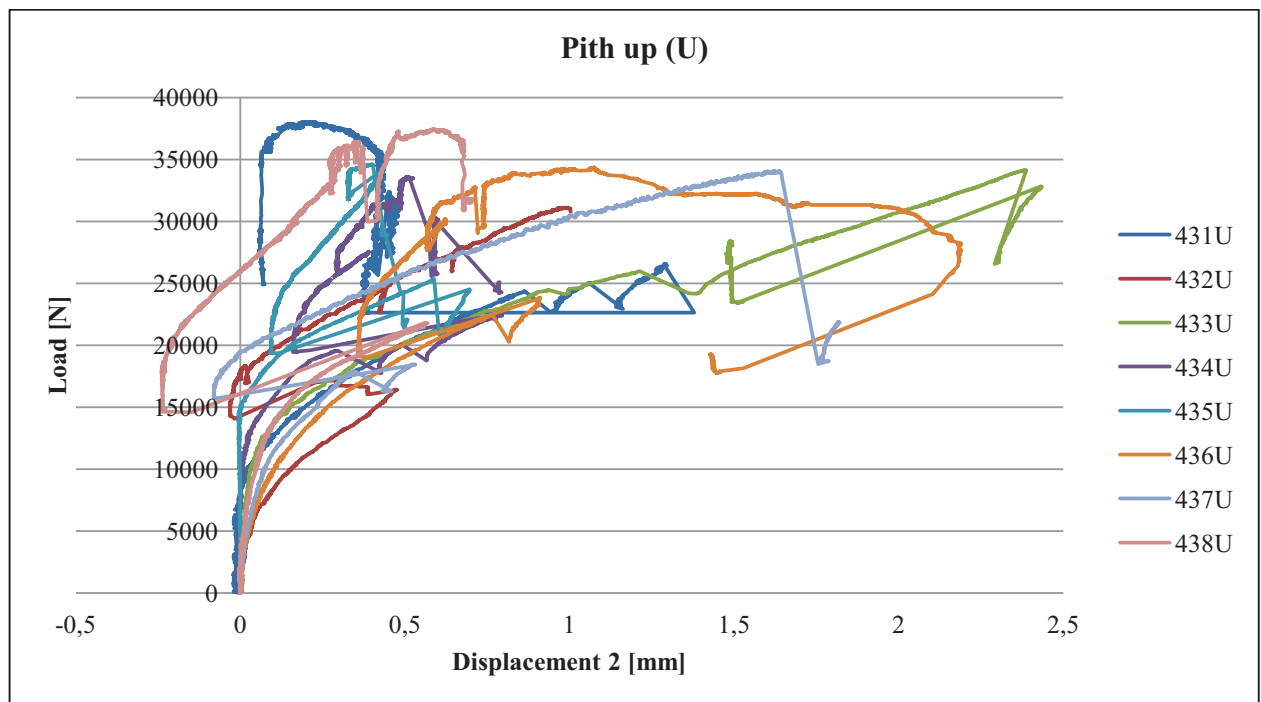


Figure 33: Load vs. displacement curves of bottom rail with pith up of Series 4 – Set 3. 8 failure mode of type 1

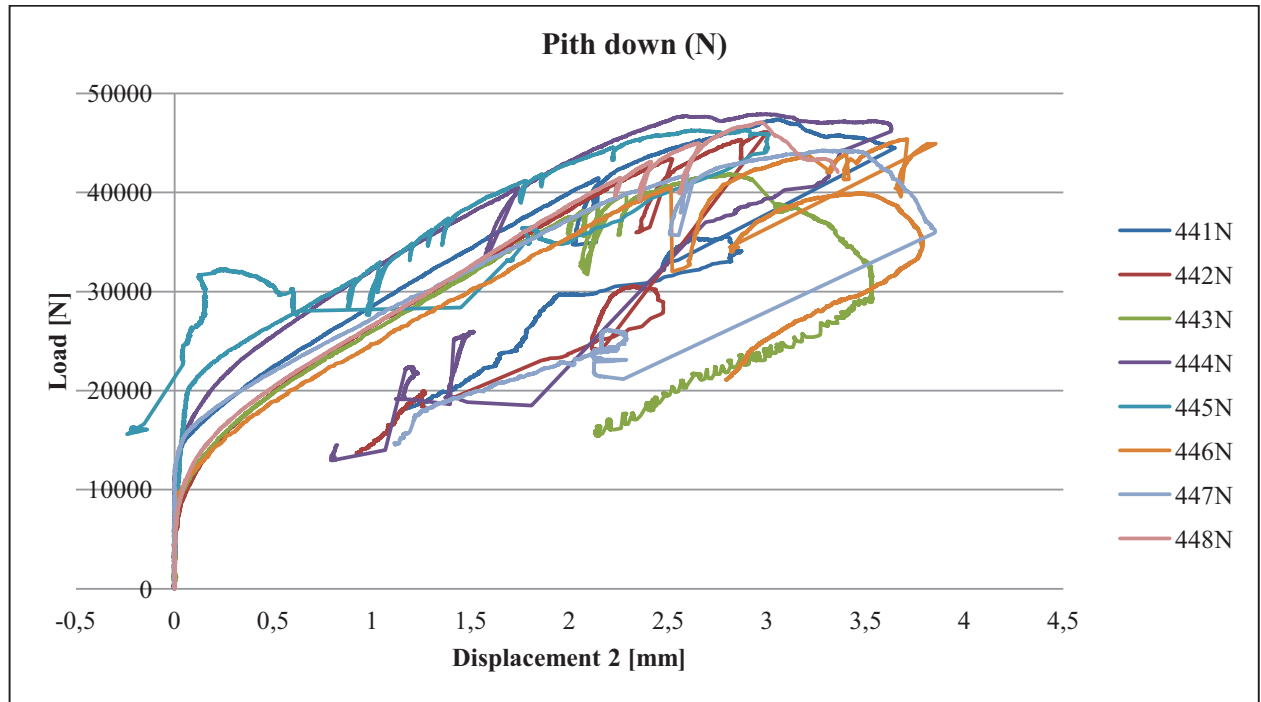


Figure 34: Load vs. displacement curves of bottom rail with pith down of Series 4 – Set 4. 1 failure mode of type 1, 4 failure mode of type 2 and 3 failure mode of type 3

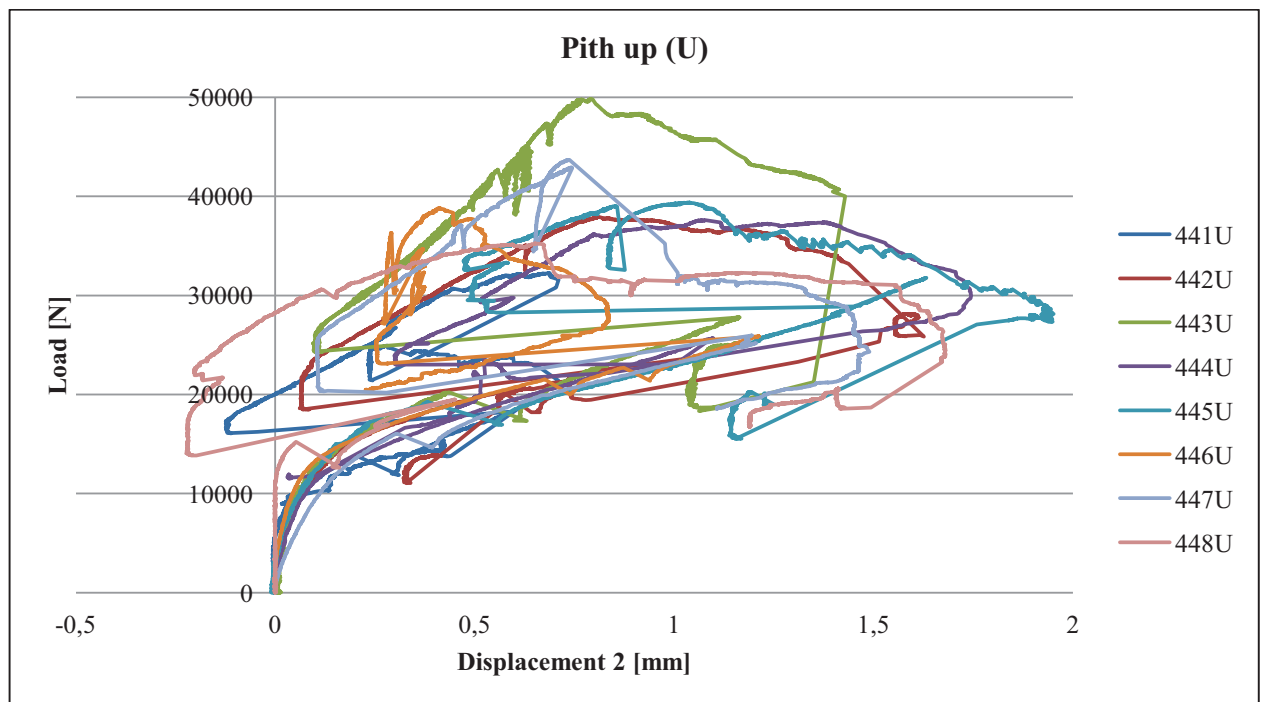


Figure 35: Load vs. displacement curves of bottom rail with pith up of Series 4 – Set 4. 8 failure mode of type 1 (see Appendix B notes ⁽¹⁾, ⁽²⁾ and ⁽³⁾ about the type of failure of this set)

Summary of test results

The tables below summarize the average results from the tests for each set. Failure load, displacements at failure, edge of the bottom rail to fracture line distance as well as the density and the moisture content of the bottom rail are shown in relation to the pith orientation.

Series 4 – Anchor bolt at centre, 60 mm from the sheathing

Set 1 – Washer size 40x40 mm, distance from sheathing to edge of washer 40 mm

Pith Up – 8 tests

Table 3: Summary of test results for series 4 – set 1 – pith up

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	16.8	10.9 ÷ 21.3	0.01	0.54	436.0	13.3
St. Dev.	3.65	-	-	-	41.9	0.83
Coeff. of Var. [%]	21.8	-	-	-	9.61	6.26
Char. Value_{0.05}	8.80	-	-	-	344.6	11.5

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	56.9	69.1	58.4	67.6
St. Dev.	7.26	9.73	4.37	9.78
Coeff. of Var. [%]	12.8	14.1	7.49	14.5
Char. Value_{0.05}	41.1	47.9	48.8	46.3

8 failure mode of type 1

Pith Down – 8 tests

Table 4: Summary of test results for series 4 – set 1 – pith down

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m³]	[%]
Average	22.4	21.0 ÷ 23.7	-0.03	1.90	414.4	13.0
St. Dev.	1.00	-	-	-	42.0	0.78
Coeff. of Var. [%]	4.46	-	-	-	10.1	6.05
Char. Value _{0.05}	20.2	-	-	-	322.8	11.3

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	67.3	57.6	64.3	61.9
St. Dev.	15.3	10.6	15.9	13.0
Coeff. of Var. [%]	22.7	18.4	24.8	21.0
Char. Value _{0.05}	33.9	34.5	29.5	33.6

8 failure mode of type 1

Set 1-BIS – Washer size 40x40 mm, distance from sheathing to edge of washer 40 mm

Pith Up – 8 tests

Table 5: Summary of test results for series 4 – set 1-BIS – pith up

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	17.5	15.6 ÷ 19.5	0.03	0.69	412.4	13.6
St. Dev.	1.58	-	-	-	42.2	0.39
Coeff. of Var. [%]	9.04	-	-	-	10.2	2.84
Char. Value _{0.05}	14.0	-	-	-	320.4	12.7

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	46.8	64.9	50.8	59.1
St. Dev.	8.15	4.67	8.83	3.36
Coeff. of Var. [%]	17.4	7.20	17.4	5.68
Char. Value _{0.05}	29.0	54.7	31.5	51.8

8 failure mode of type 1

Pith Down – 8 tests

Table 6: Summary of test results for series 4 – set 1-BIS – pith down

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	20.4	15.0 ÷ 24.0	0.01	1.56	404.1	13.4
St. Dev.	3.29	-	-	-	29.4	0.36
Coeff. of Var. [%]	16.1	-	-	-	7.27	2.70
Char. Value _{0.05}	13.3	-	-	-	340.0	12.6

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	68.0	45.0	65.4	47.5
St. Dev.	12.6	9.64	12.6	8.80
Coeff. of Var. [%]	18.5	21.4	19.2	18.5
Char. Value _{0.05}	40.6	24.0	38.0	28.3

8 failure mode of type 1

Set 2 – Washer size 60x60 mm, distance from sheathing to edge of washer 30 mm

Pith Up – 8 tests

Table 7: Summary of test results for series 4 – set 2 – pith up

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	19.3	15.2 ÷ 23.0	-0.01	0.74	424.4	12.7
St. Dev.	2.49	-	-	-	60.5	0.95
Coeff. of Var. [%]	12.9	-	-	-	14.3	7.52
Char. Value _{0.05}	13.9	-	-	-	292.4	10.6

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	60.0	68.4	61.6	67.6
St. Dev.	9.35	16.5	9.09	15.3
Coeff. of Var. [%]	15.6	24.1	14.7	22.6
Char. Value _{0.05}	39.6	32.5	41.8	34.4

8 failure mode of type 1

Pith Down – 8 tests

Table 8: Summary of test results for series 4 – set 2 – pith down

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	28.0	26.1 ÷ 31.3	0.01	1.86	403.6	13.1
St. Dev.	1.94	-	-	-	29.8	0.64
Coeff. of Var. [%]	6.94	-	-	-	7.38	4.89
Char. Value _{0.05}	23.8	-	-	-	338.7	11.7

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	70.9	50.1	67.6	53.9
St. Dev.	16.4	8.15	13.7	8.36
Coeff. of Var. [%]	23.1	16.3	20.3	15.5
Char. Value _{0.05}	35.1	32.4	37.7	35.7

8 failure mode of type 1

Set 3 – Washer size 80x70 mm, distance from sheathing to edge of washer 20 mm

Pith Up – 8 tests

Table 9: Summary of test results for series 4 – set 3 – pith up

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	23.7	17.2 ÷ 34.1	0.02	0.92	426.6*	13.1*
St. Dev.	5.27	-	-	-	40.2	1.11
Coeff. of Var. [%]	22.2	-	-	-	9.41	8.51
Char. Value _{0.05}	12.2	-	-	-	336.7	10.6

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	52.9	68.8	56.3	67.1
St. Dev.	9.86	11.9	10.7	8.98
Coeff. of Var. [%]	18.7	17.3	18.9	13.4
Char. Value _{0.05}	31.4	42.9	33.0	47.5

**data available for seven tests*

8 failure mode of type 1

Pith Down – 8 tests

Table 10: Summary of test results for series 4 – set 3 – pith down

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m³]	[%]
Average	38.4	28.4 ÷ 46.6	0.07	2.08	441.1	13.2
St. Dev.	6.46	-	-	-	45.2	1.23
Coeff. of Var. [%]	16.8	-	-	-	10.2	9.37
Char. Value _{0.05}	24.3	-	-	-	342.6	10.5

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	66.3*	46.7*	63.2*	54.2*
St. Dev.	27.2	19.7	25.9	22.0
Coeff. of Var. [%]	41.0	42.3	41.0	40.6
Char. Value _{0.05}	2.92	0.73	2.90	2.98

*data available for six tests

6 failure mode of type 1 and 2 of type 2

Set 4 – Washer size 100x70 mm, distance from sheathing to edge of washer 10 mm

Pith Up – 8 tests

Table 11: Summary of test results for series 4 – set 4 – pith up

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	20.0	13.8 ÷ 25.9	0.04	0.60	410.3	12.0
St. Dev.	4.80	-	-	-	34.1	1.41
Coeff. of Var. [%]	23.9	-	-	-	8.32	11.8
Char. Value _{0.05}	9.59	-	-	-	335.9	8.89

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	49.6	61.4	53.5	60.0
St. Dev.	14.0	4.14	11.7	1.41
Coeff. of Var. [%]	28.2	6.74	21.8	2.36
Char. Value _{0.05}	19.2	52.4	28.1	56.9

8 failure mode of type 1 (see Appendix B notes ⁽¹⁾, ⁽²⁾ and ⁽³⁾ about the type of failure of this set)

Pith Down – 8 tests

Table 12: Summary of test results for series 4 – set 4 – pith down

	Failure load	Min. and max. failure load	Movement of washer surface on the side 1 in line of the anchor bolt	Movement of rail surface in line of the anchor bolt at centre of the rail	Density	Moisture
	[kN]	[kN]	[mm]	[mm]	[kg/m ³]	[%]
Average	45.8	41.9 ÷ 48.0	0.15	3.10	398.8	12.2
St. Dev.	1.97	-	-	-	16.8	1.07
Coeff. of Var. [%]	4.31	-	-	-	4.22	8.70
Char. Value _{0.05}	41.5	-	-	-	362.1	9.92

	Distance from edge of bottom rail to crack at the end on side 1	Distance from edge of bottom rail to crack at the end on side 2	Distance from edge of bottom rail to crack at anchor bolt 1	Distance from edge of bottom rail to crack at anchor bolt 2
	[mm]	[mm]	[mm]	[mm]
Average	50.0*	24.0*	54.0*	17.0*
St. Dev.	-	-	-	-
Coeff. of Var. [%]	-	-	-	-
Char. Value _{0.05}	-	-	-	-

*data available only for the specimen 446N, the only one with failure mode of type 1

1 failure mode of type 1, 4 failure mode of type 2 and 3 failure mode of type 3

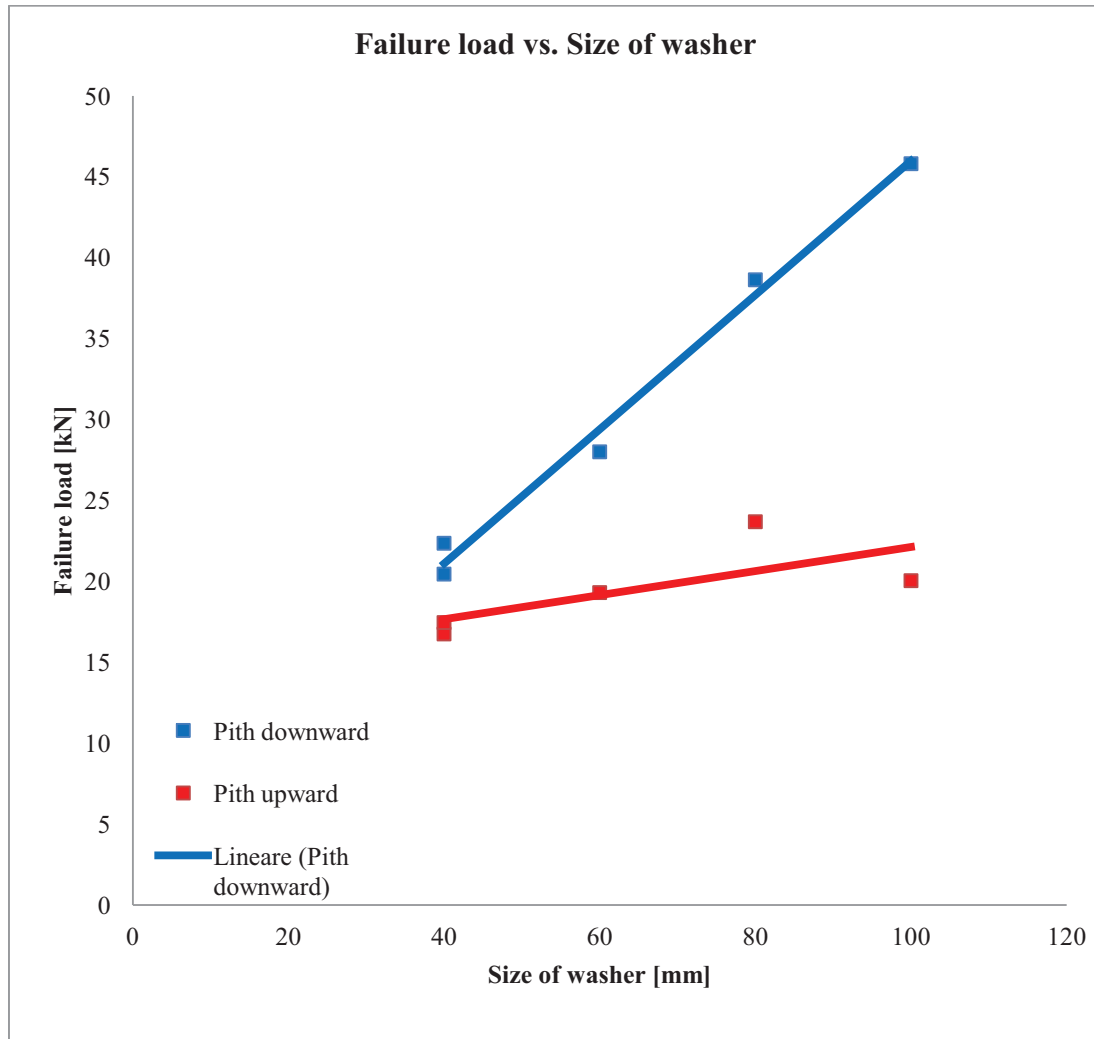


Figure 36: Failure load vs. size of washer of bottom rail with pith upward and pith downward

Summary of failure load

Table 13: Summary of failure load results for each set

Washer size [mm]	Average of failure load Pith up [kN]	Average of failure load Pith down [kN]	Figure of reference	Ratio between Pith up and Pith down failure load
40x40	16.8	22.4	Fig. 7 and 8	0.75
40x40 - Bis	17.5	20.4	Fig. 9 and 10	0.86
60x60	19.3	28.0	Fig. 7 and 8	0.69
80x70	23.7	38.4	Fig. 7 and 8	0.62
100x70	20.0	45.8	Fig. 7 and 8	0.44

Conclusions

The test results show that the size of the washer has a significant influence on the failure load and the failure modes. Moreover the results show that the orientation of the pith also has a significant influence on the failure load.

Three primary failure modes were found during the tests:

- failure mode 1: due to splitting of the underneath side of the bottom rail. This brittle type of failure occurs when medium sized washers are used with large distance to the loaded edge of the bottom rail;
- failure mode 2: due to splitting at the edge side of the bottom rail. This type of failure occurs when is decreased the distance between the edge of the washer and the edge of the bottom rail;
- failure mode 3: due to plastic bending and pull-out of nails (and therefore a detachment of the sheathing). This failure mode was not planned (the test series were planned so that splitting would occur), but happened when there was not splitting of the bottom rail due to large anchor bolts and small distance between the edge of the washer and the edge of the bottom rail.

It was found that decreasing the distance between the edge of the washer and the edge of the bottom rail increases the maximum load.

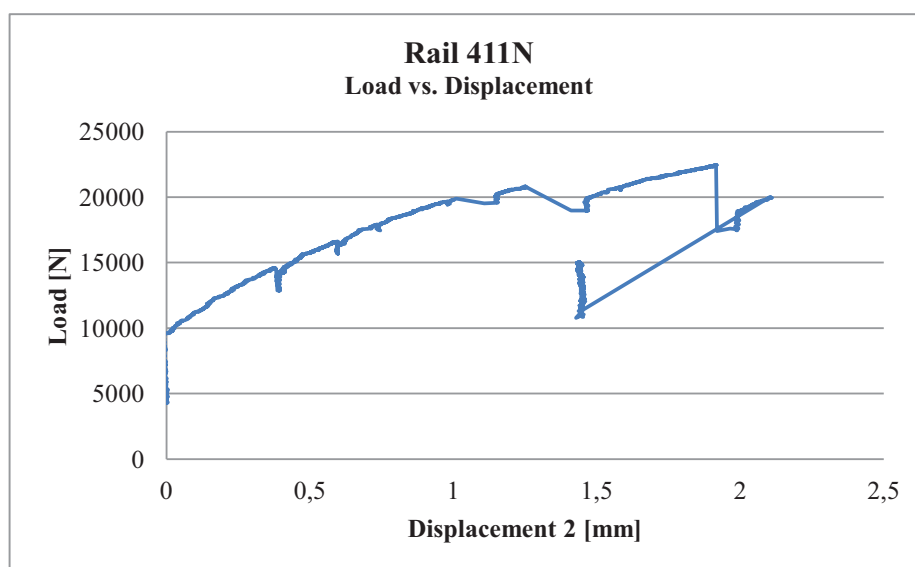
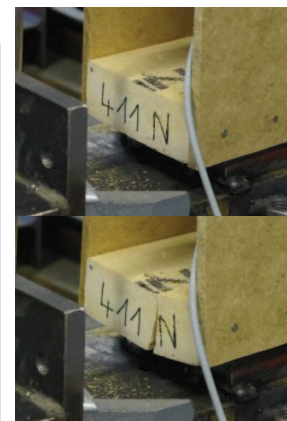
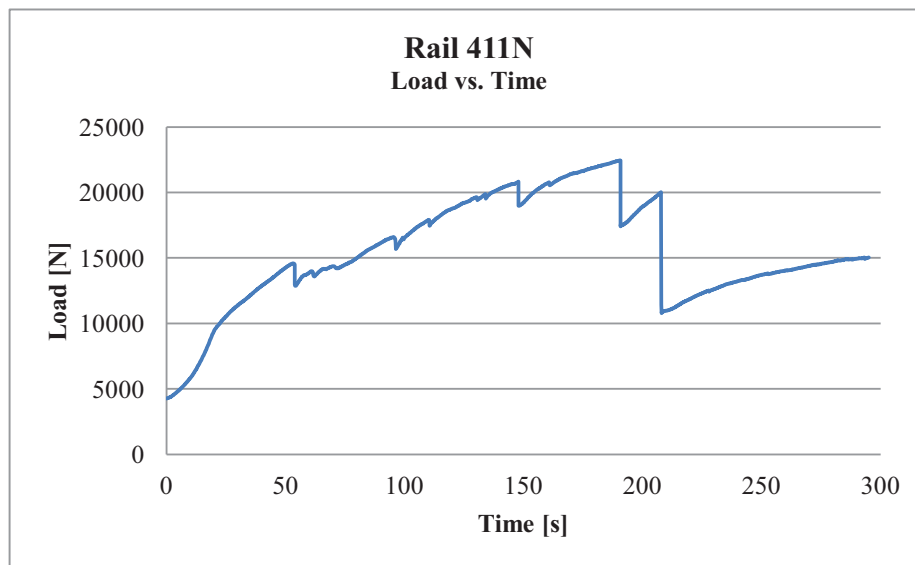
It was also observed that most the failure mode 1 (splitting of the underneath surface of the bottom rail) appears independently on either end of the bottom rail and sometime simultaneously on both length-wise ends of the bottom rail.

Appendix A

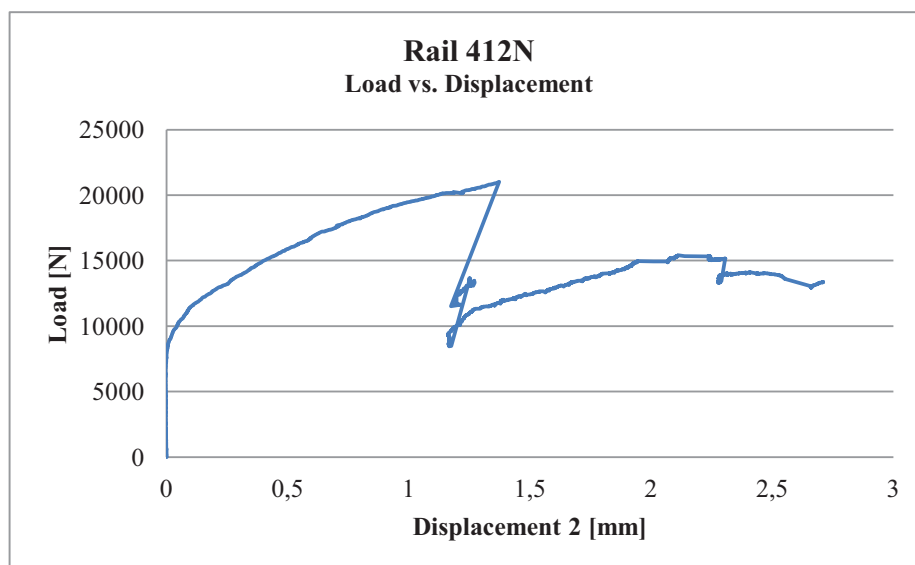
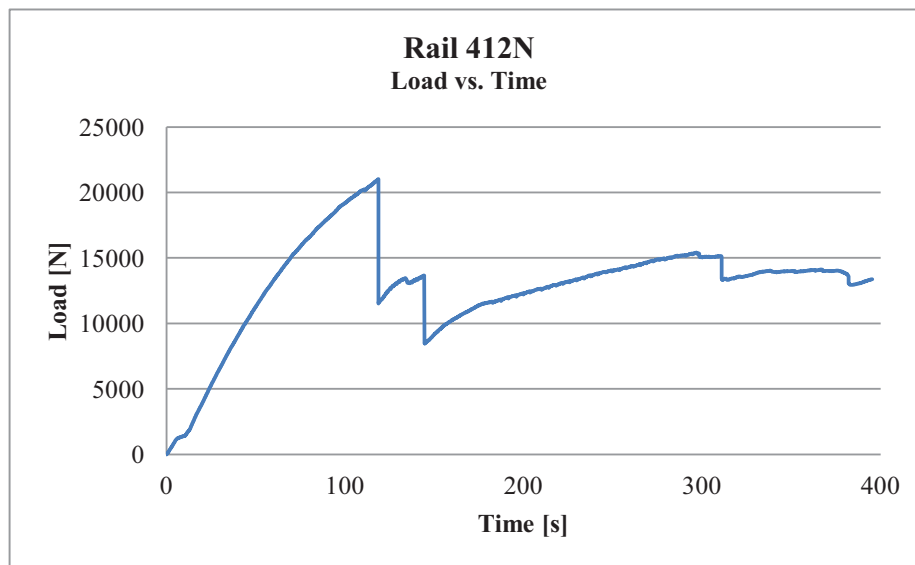
Series 4 – Anchor bolt at centre, 60 mm from the sheathing

Set 1 – Size of washer 40x40 mm

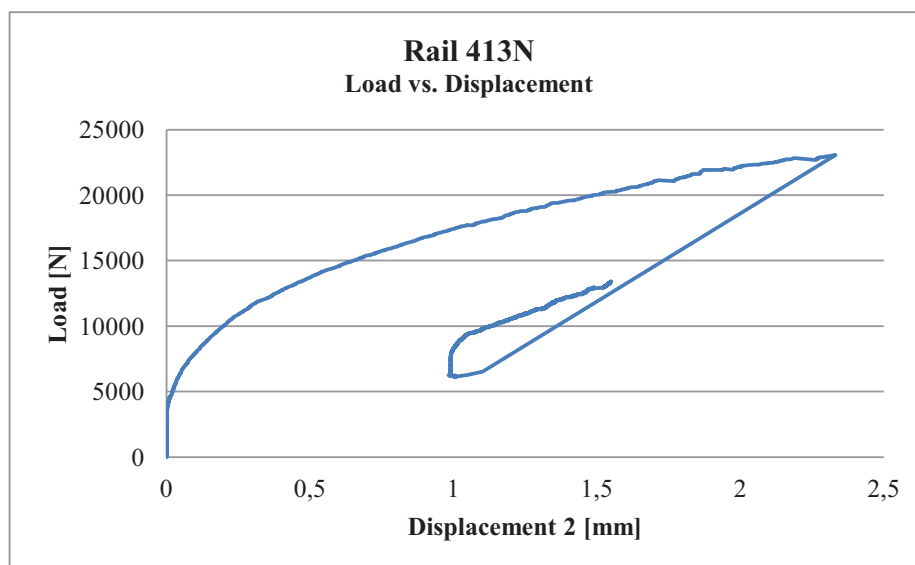
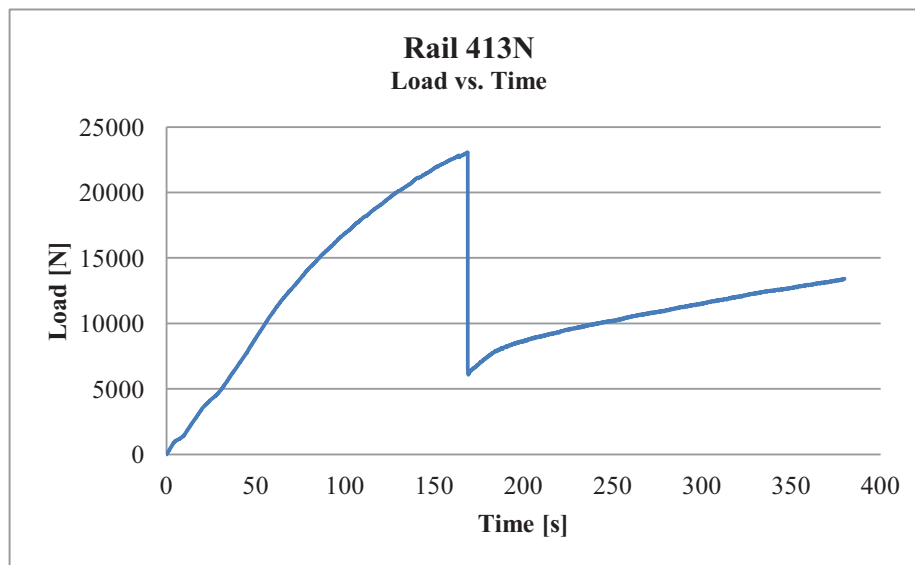
Pith Down



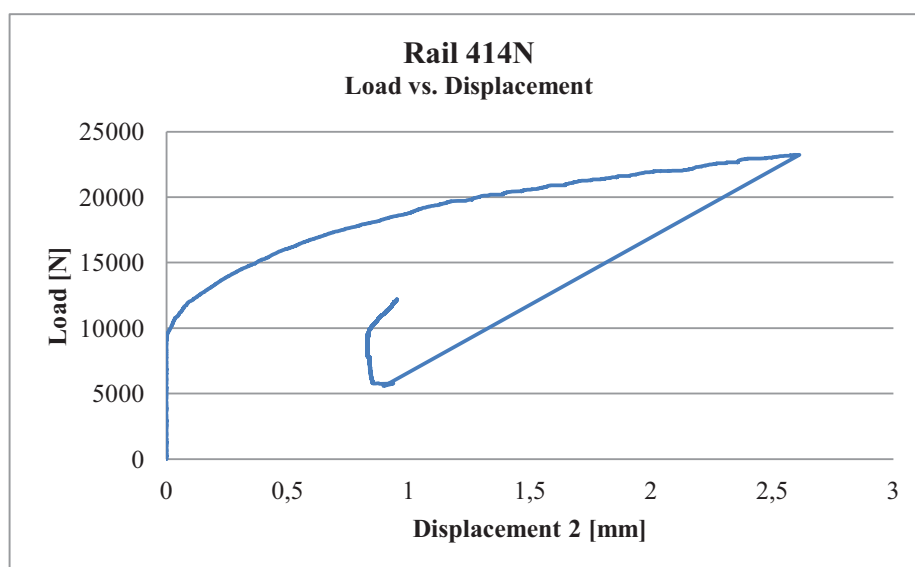
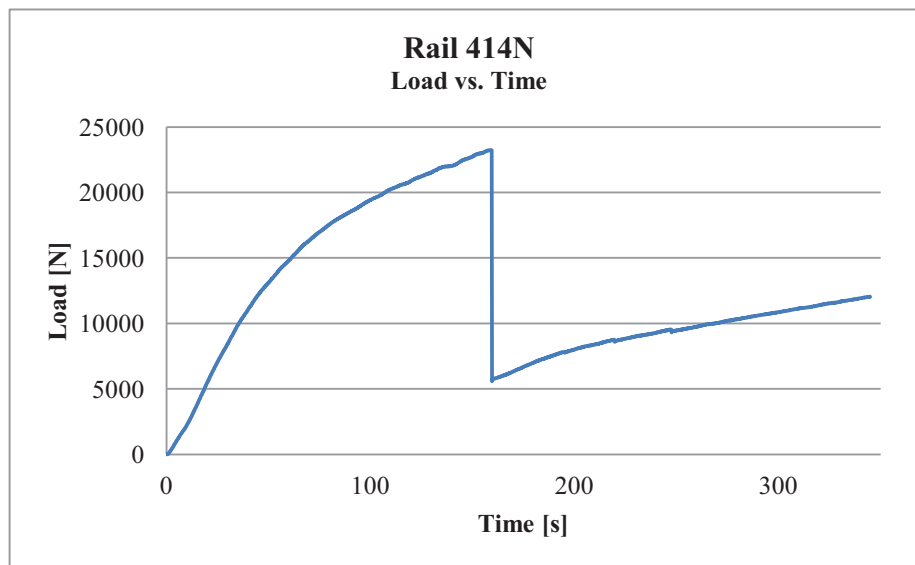
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	22451
Displacement 1 at failure [mm]	0,10
Displacement 2 at failure [mm]	1,91
Distance from crack to edge side 1 [mm]	50
Distance from crack to edge side 2 [mm]	72
Distance from crack to anchor bolt side 1 [mm]	45
Distance from crack to anchor bolt side 2 [mm]	83
Moisture [%]	11,8
Dry density [kg/m ³]	406



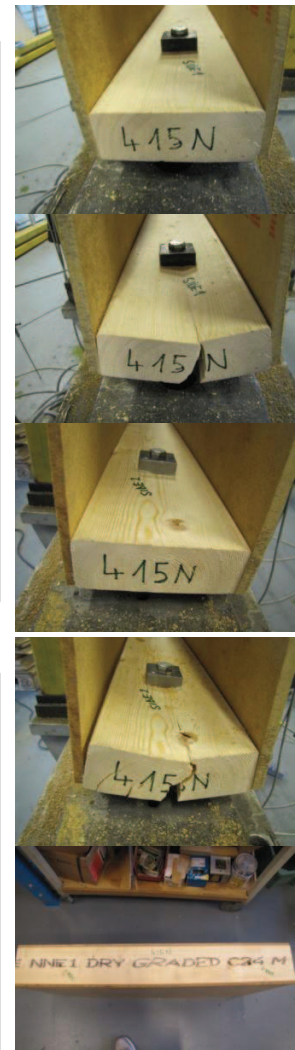
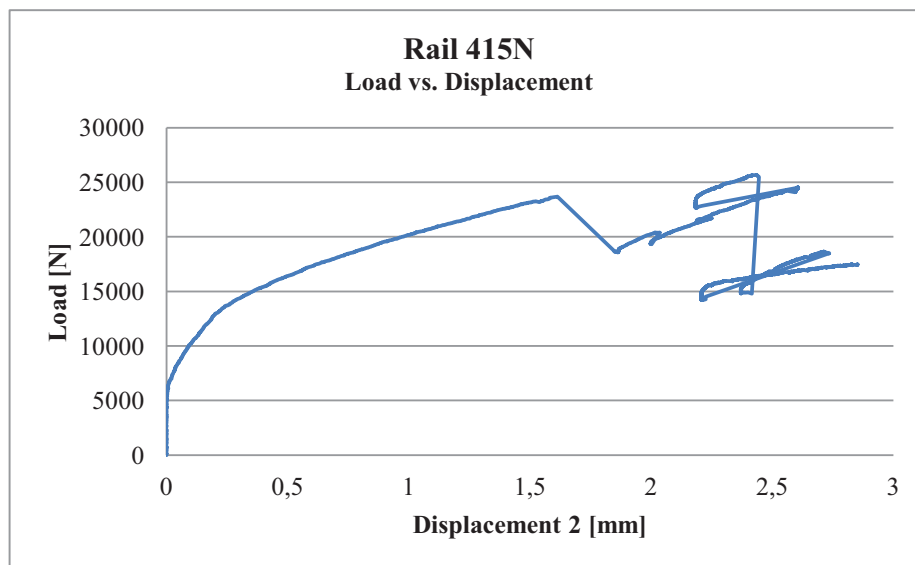
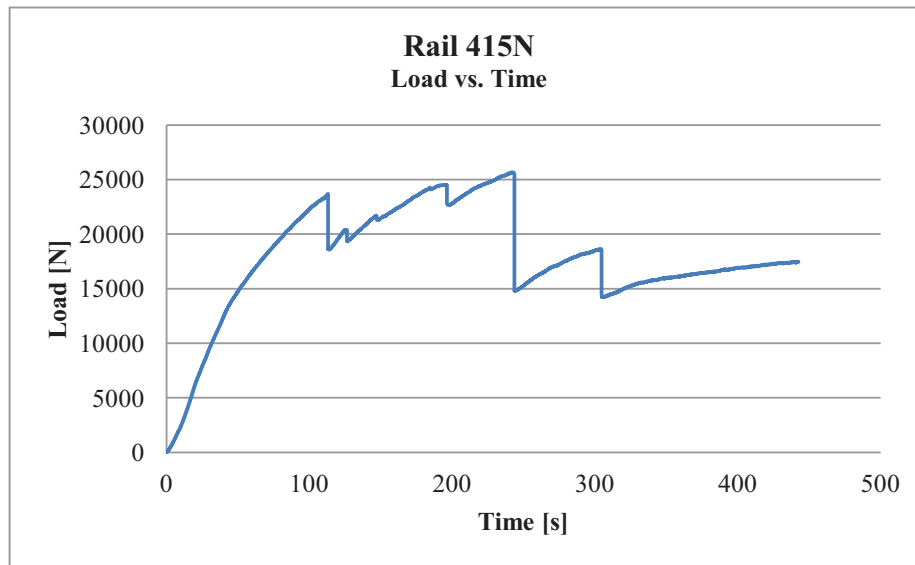
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	21010
Displacement 1 at failure [mm]	-0,02
Displacement 2 at failure [mm]	1,37
Distance from crack to edge side 1 [mm]	90
Distance from crack to edge side 2 [mm]	52
Distance from crack to anchor bolt side 1 [mm]	85
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	14,3
Dry density [kg/m ³]	462



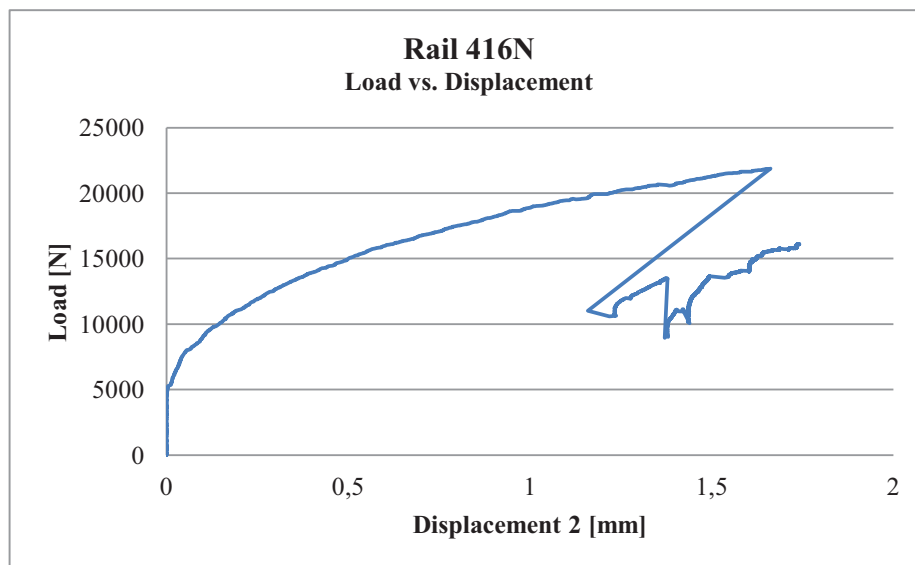
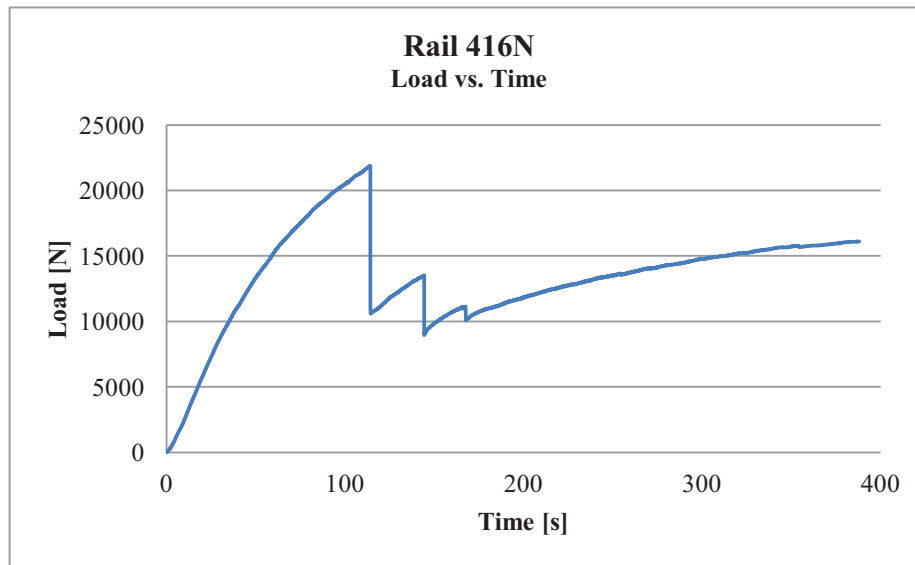
Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	23057
Displacement 1 at failure [mm]	-0,09
Displacement 2 at failure [mm]	2,33
Distance from crack to edge side 1 [mm]	60
Distance from crack to edge side 2 [mm]	54
Distance from crack to anchor bolt side 1 [mm]	55
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	12,4
Dry density [kg/m ³]	389



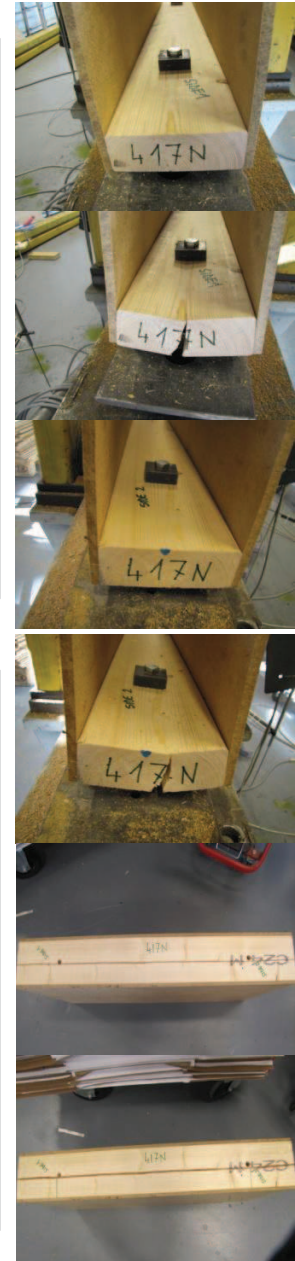
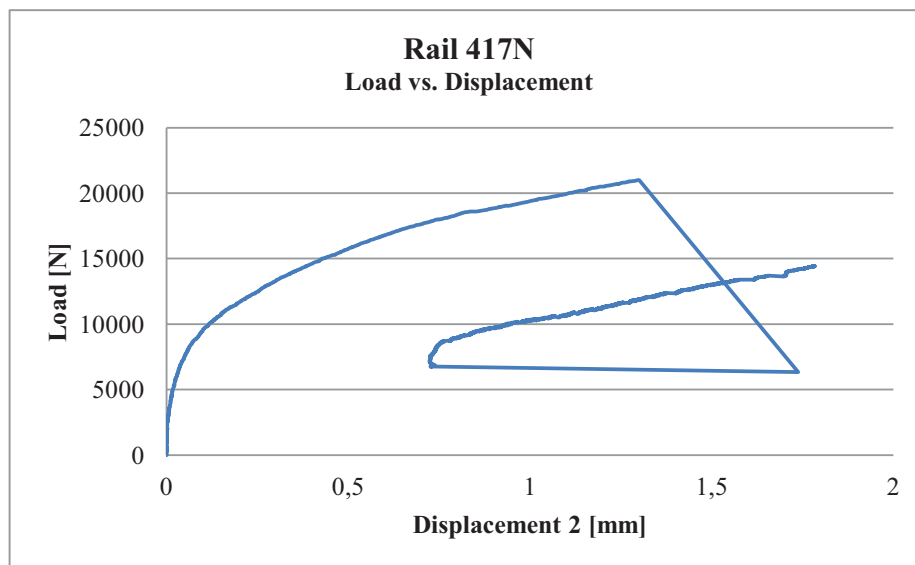
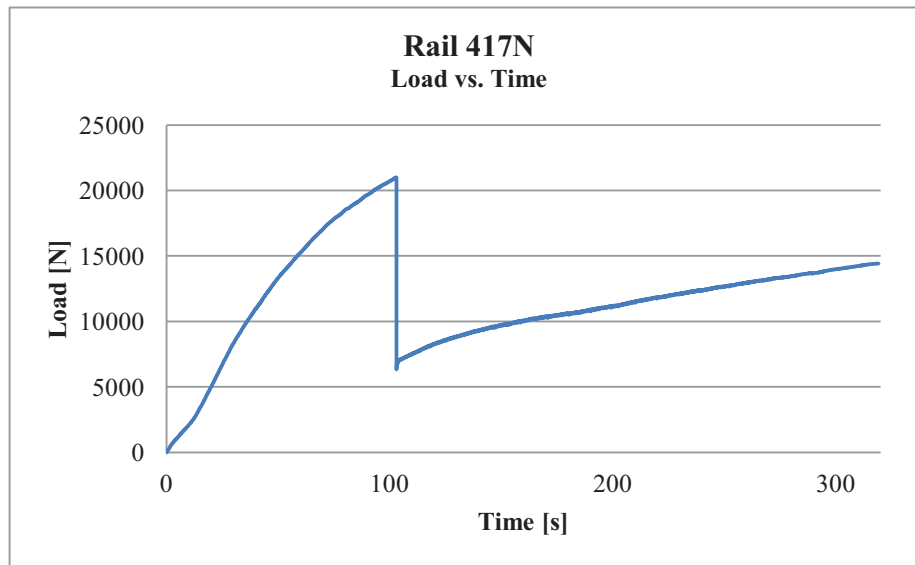
Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	23240
Displacement 1 at failure [mm]	-0,01
Displacement 2 at failure [mm]	2,61
Distance from crack to edge side 1 [mm]	65
Distance from crack to edge side 2 [mm]	57
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,0
Dry density [kg/m ³]	338



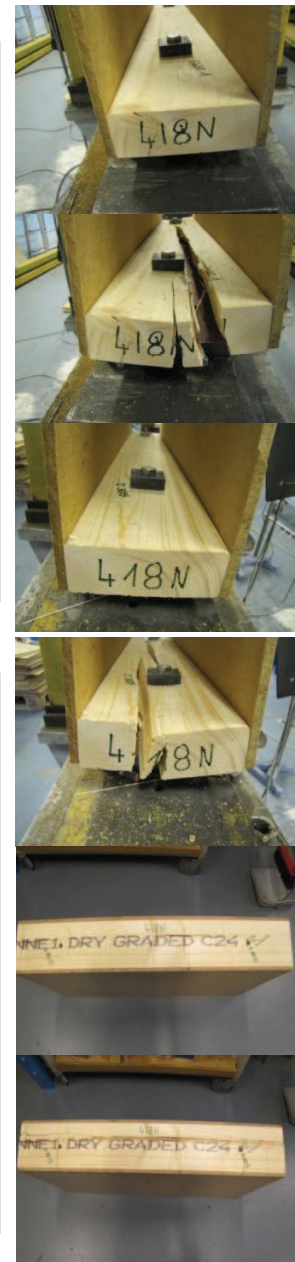
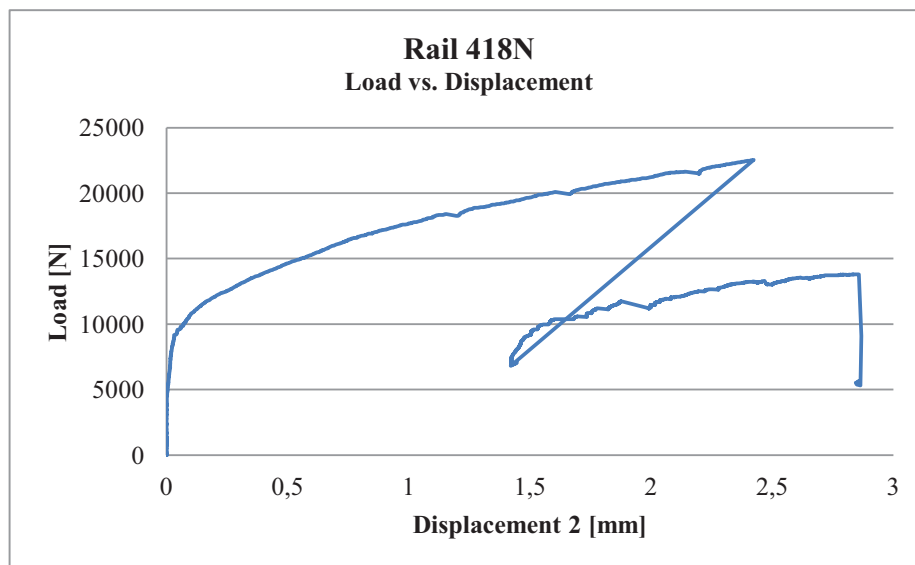
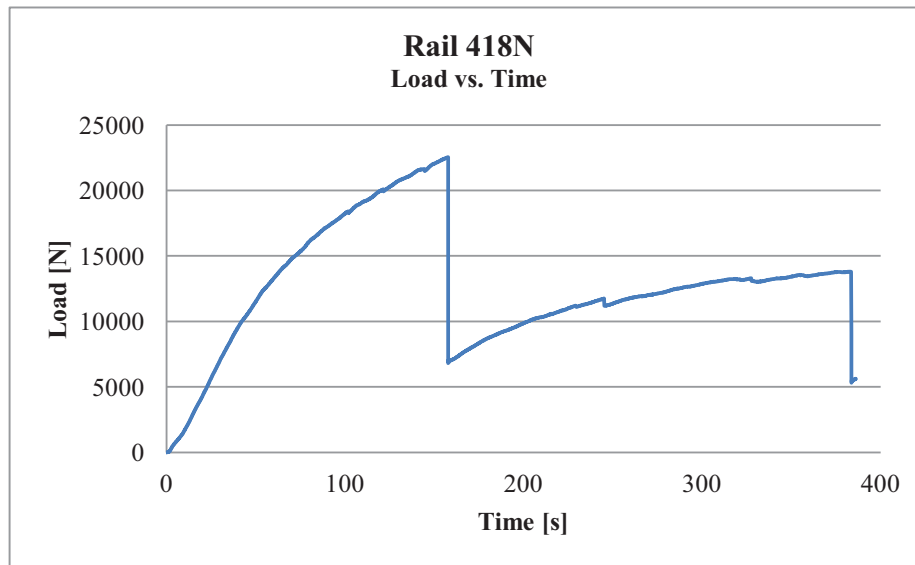
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	23676
Displacement 1 at failure [mm]	-0,04
Displacement 2 at failure [mm]	1,61
Distance from crack to edge side 1 [mm]	63
Distance from crack to edge side 2 [mm]	60
Distance from crack to anchor bolt side 1 [mm]	66
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	12,8
Dry density [kg/m ³]	449



Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	21866
Displacement 1 at failure [mm]	-0,02
Displacement 2 at failure [mm]	1,66
Distance from crack to edge side 1 [mm]	65
Distance from crack to edge side 2 [mm]	40
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	44
Moisture [%]	13,6
Dry density [kg/m ³]	443

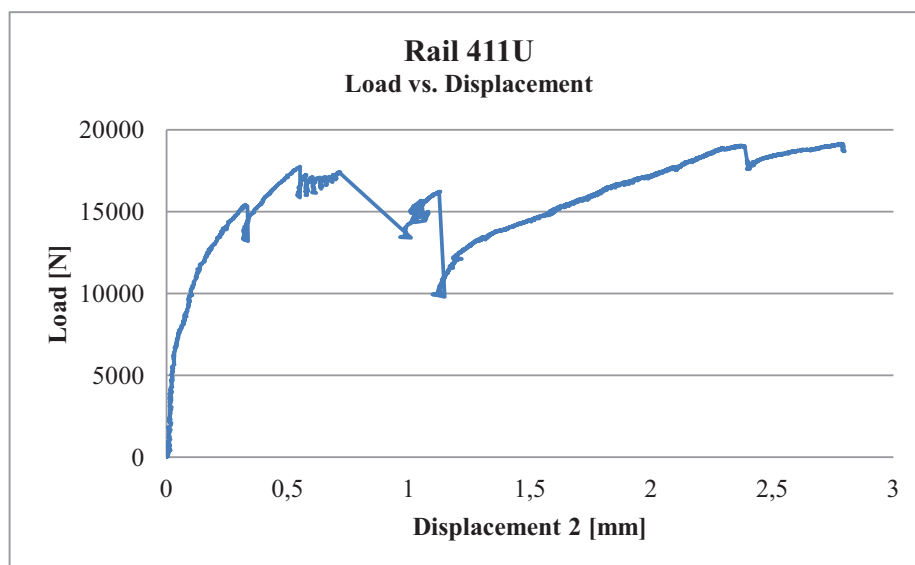
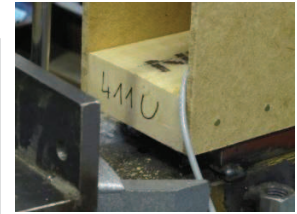
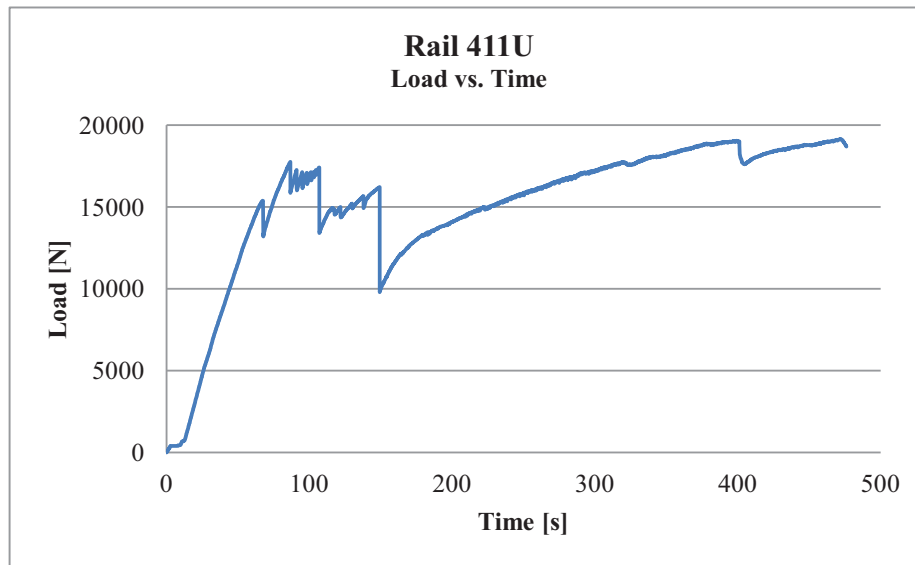


Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	20995
Displacement 1 at failure [mm]	-0,01
Displacement 2 at failure [mm]	1,30
Distance from crack to edge side 1 [mm]	54
Distance from crack to edge side 2 [mm]	54
Distance from crack to anchor bolt side 1 [mm]	53
Distance from crack to anchor bolt side 2 [mm]	50
Moisture [%]	12,3
Dry density [kg/m ³]	442

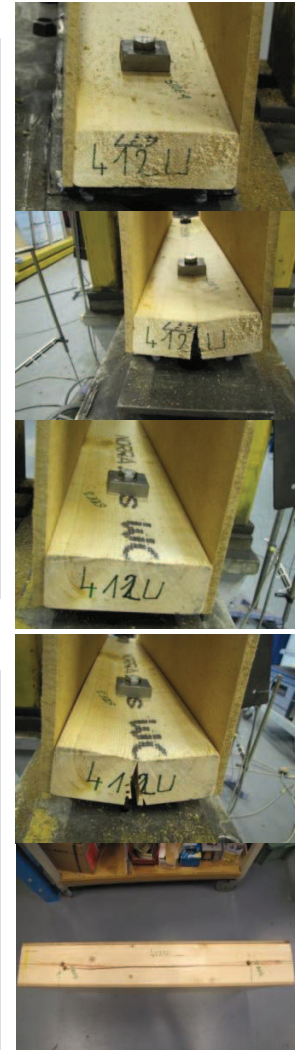
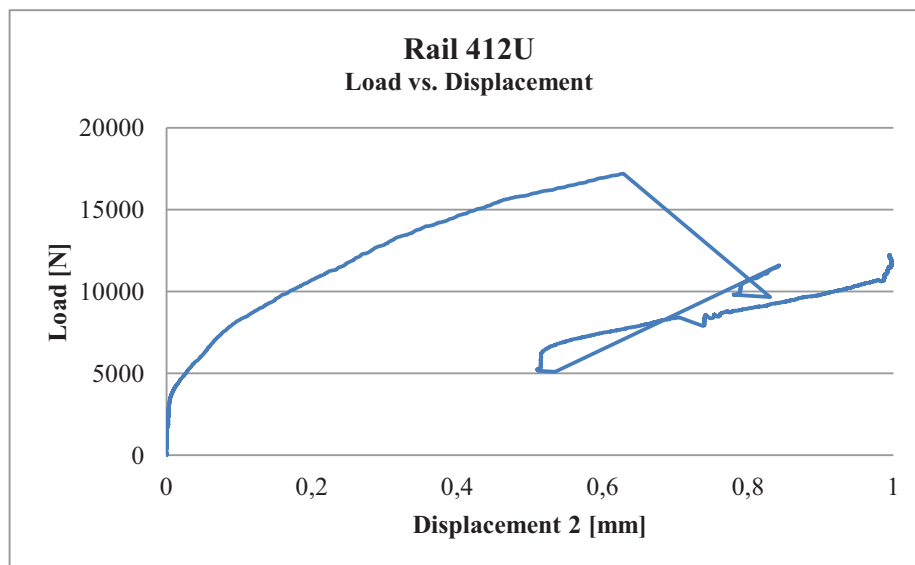
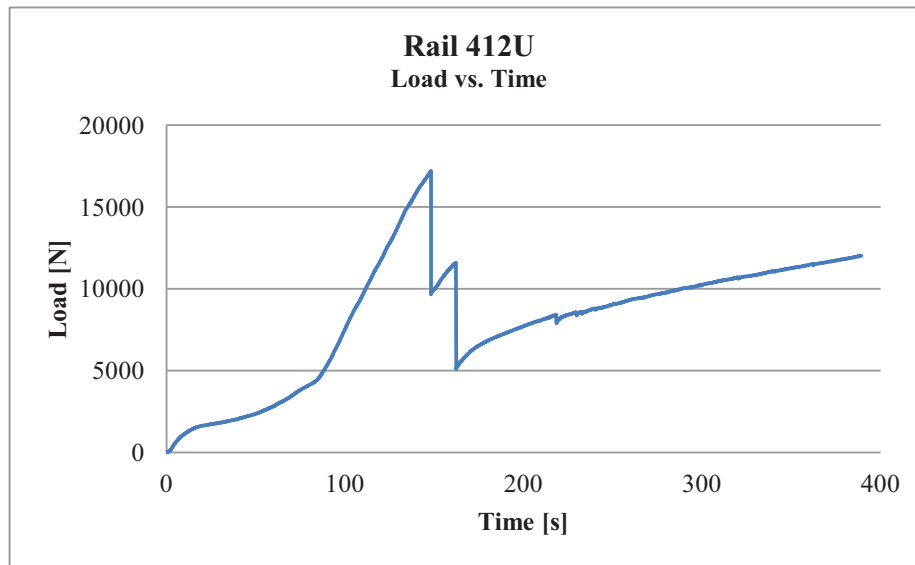


Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	22532
Displacement 1 at failure [mm]	-0,20
Displacement 2 at failure [mm]	2,42
Distance from crack to edge side 1 [mm]	91
Distance from crack to edge side 2 [mm]	72
Distance from crack to anchor bolt side 1 [mm]	91
Distance from crack to anchor bolt side 2 [mm]	78
Moisture [%]	13,2
Dry density [kg/m ³]	386

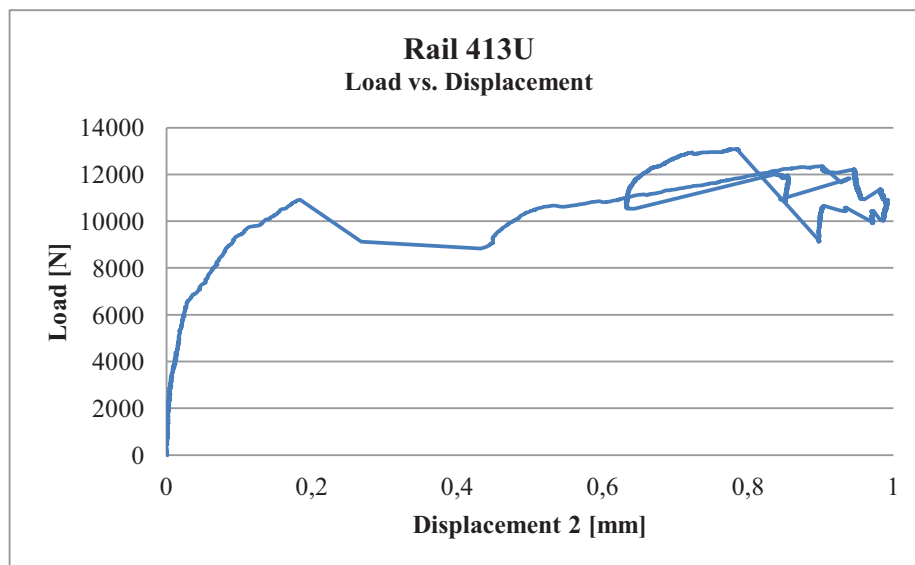
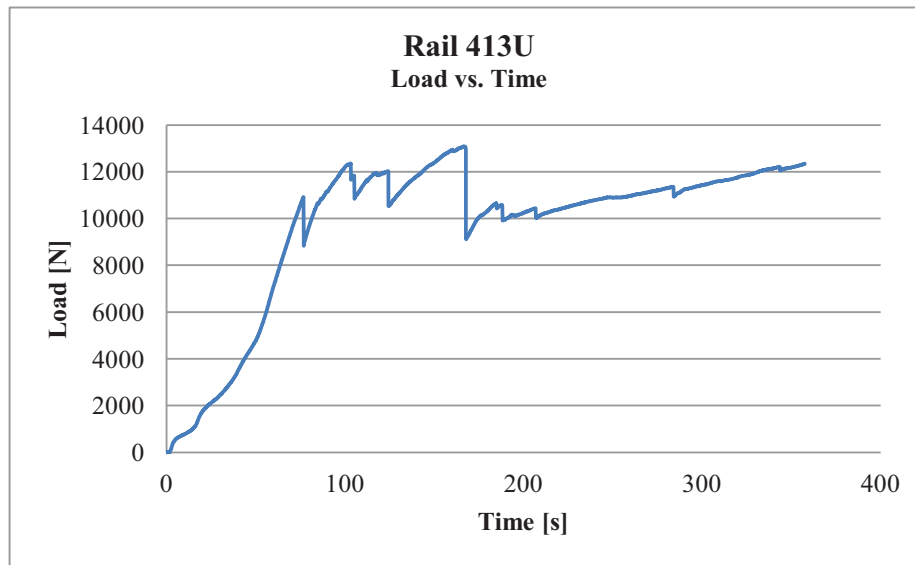
Pith Up



Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	17745
Displacement 1 at failure [mm]	0,01
Displacement 2 at failure [mm]	0,55
Distance from crack to edge side 1 [mm]	52
Distance from crack to edge side 2 [mm]	65
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	12,4
Dry density [kg/m ³]	443

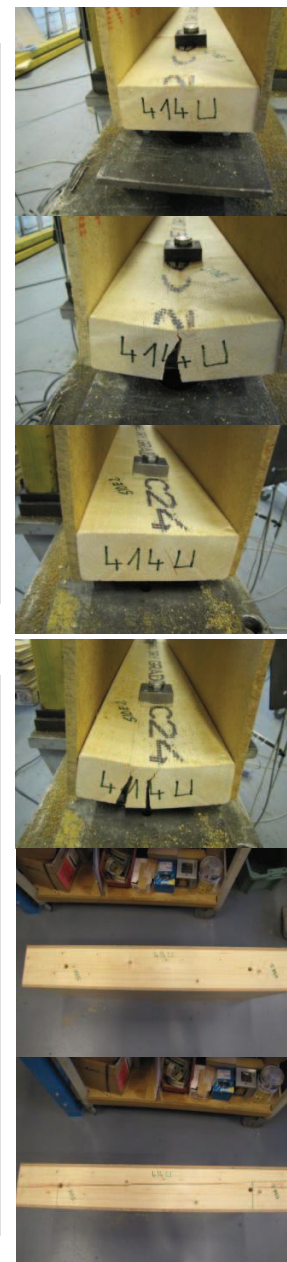
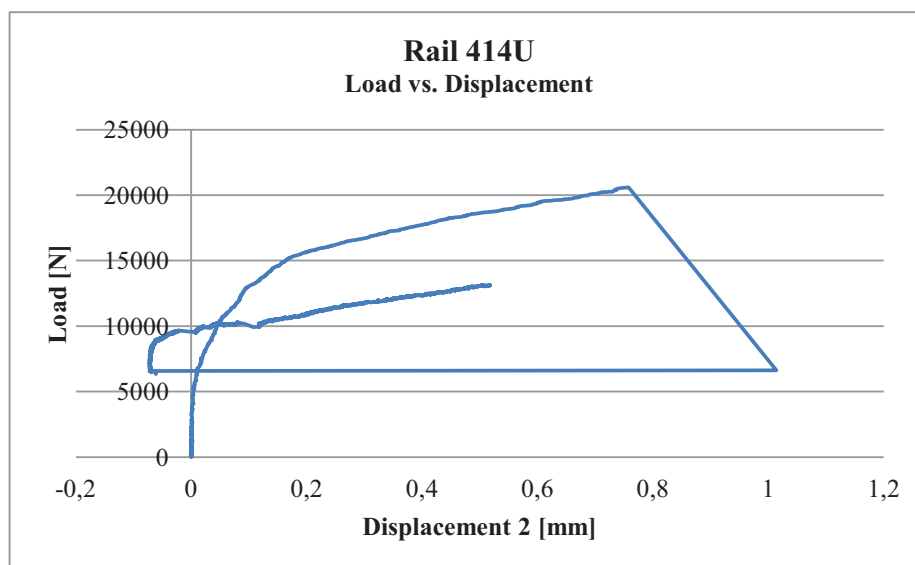
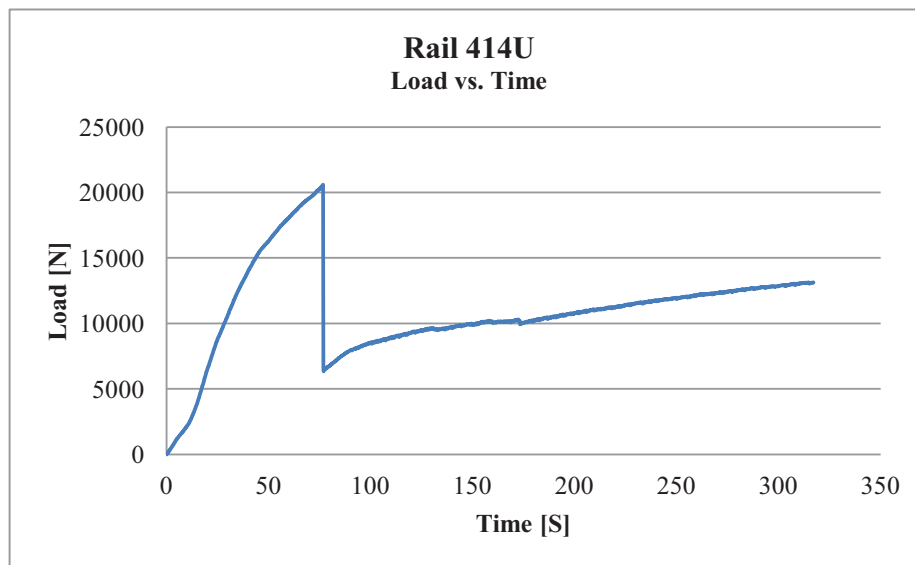


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	17193
Displacement 1 at failure [mm]	0,06
Displacement 2 at failure [mm]	0,63
Distance from crack to edge side 1 [mm]	59
Distance from crack to edge side 2 [mm]	63
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	64
Moisture [%]	13,8
Dry density [kg/m ³]	445

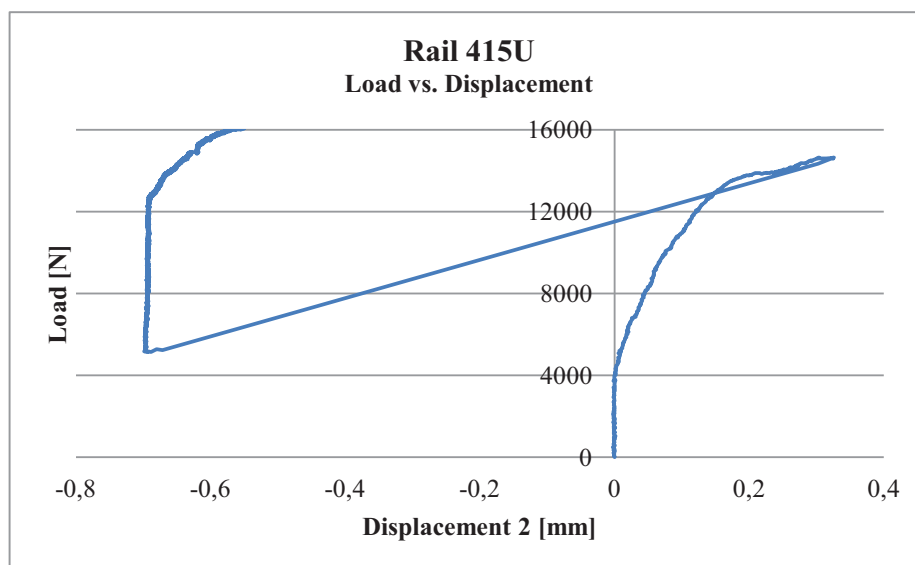
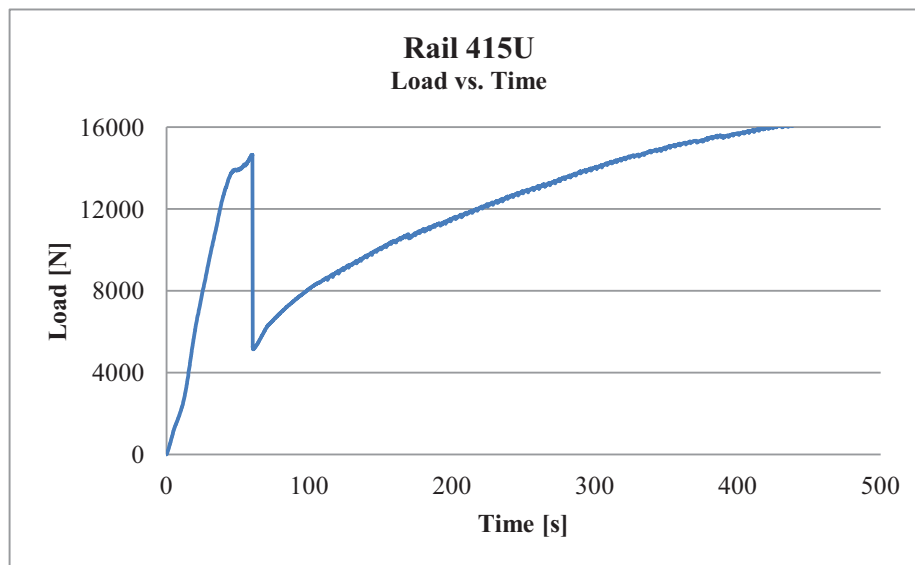


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	10922
Displacement 1 at failure [mm]	-0,03
Displacement 2 at failure [mm]	0,18
Distance from crack to edge side 1 [mm]	70
Distance from crack to edge side 2 [mm]	58
Distance from crack to anchor bolt side 1 [mm]	58
Distance from crack to anchor bolt side 2 [mm]	65
Moisture [%]	13,2
Dry density [kg/m ³]	422

Probable influence of the pre-crack in the side 1.

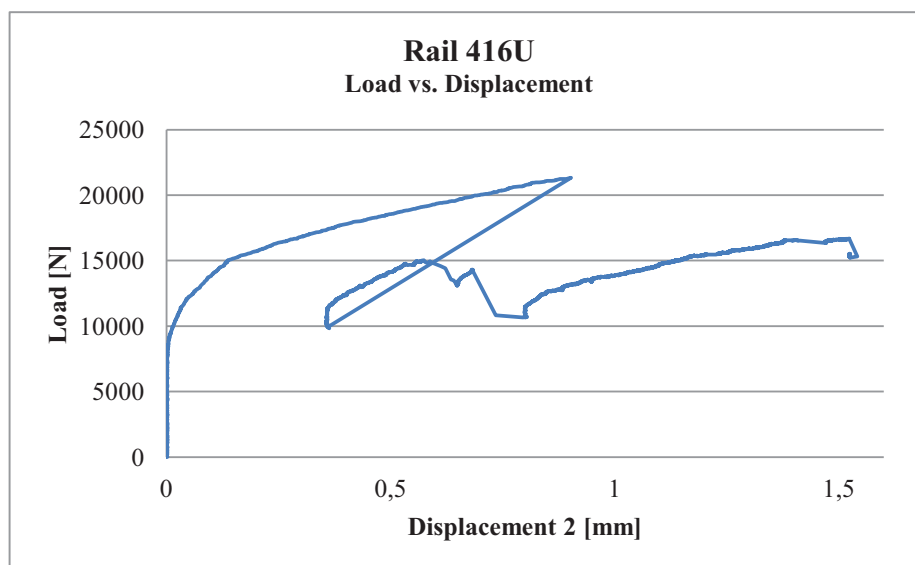
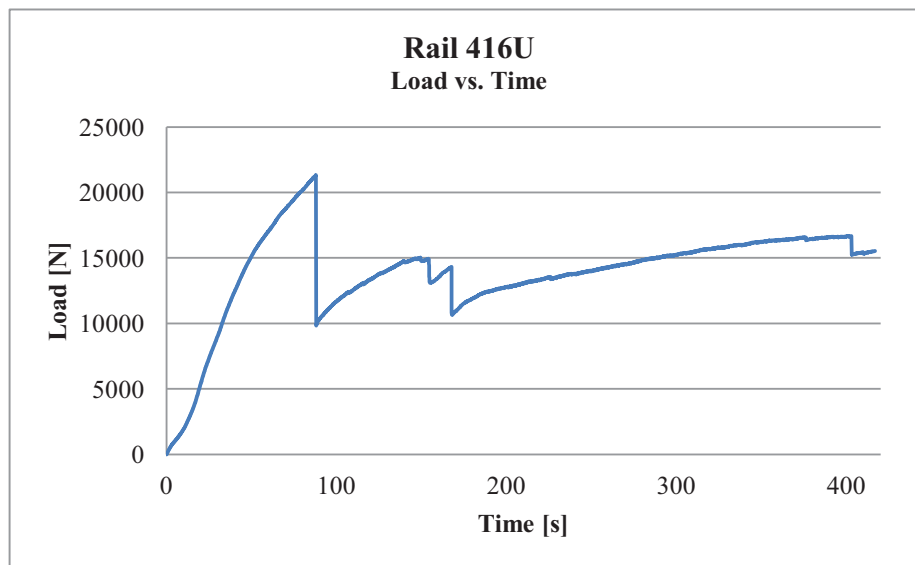


Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	20589
Displacement 1 at failure [mm]	0,03
Displacement 2 at failure [mm]	0,76
Distance from crack to edge side 1 [mm]	53
Distance from crack to edge side 2 [mm]	85
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	83
Moisture [%]	14,7
Dry density [kg/m ³]	434

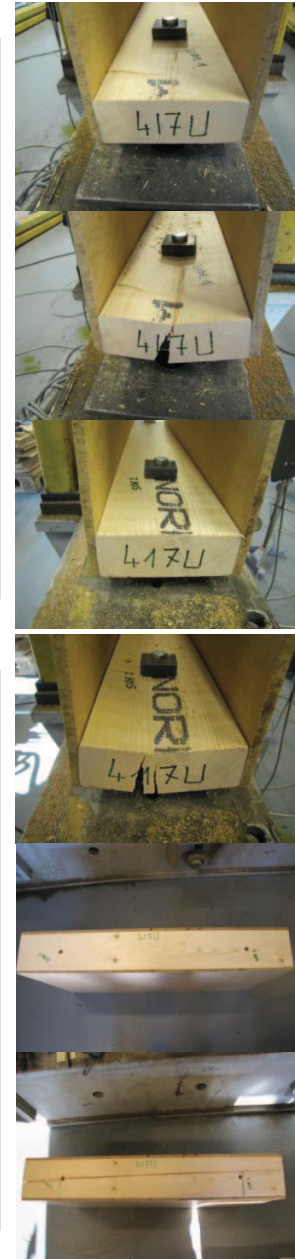
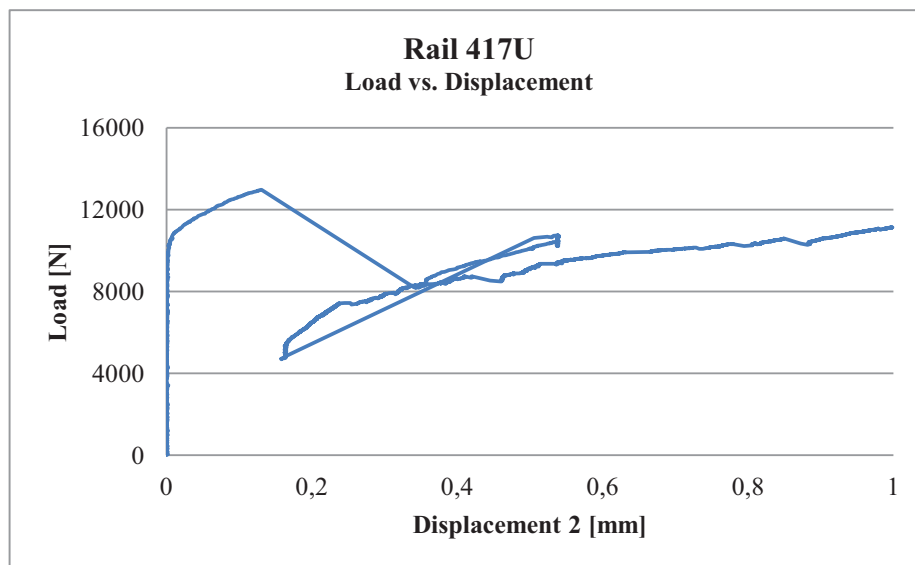
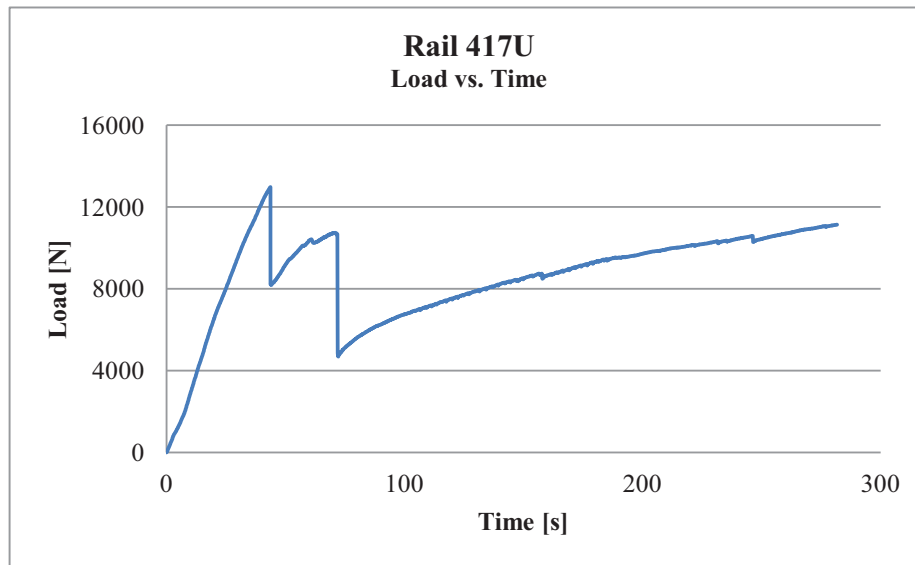


Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	14643
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	0,33
Distance from crack to edge side 1 [mm]	52
Distance from crack to edge side 2 [mm]	63
Distance from crack to anchor bolt side 1 [mm]	51
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,7
Dry density [kg/m ³]	523

Probable influence of the pre-crack in the side 2.

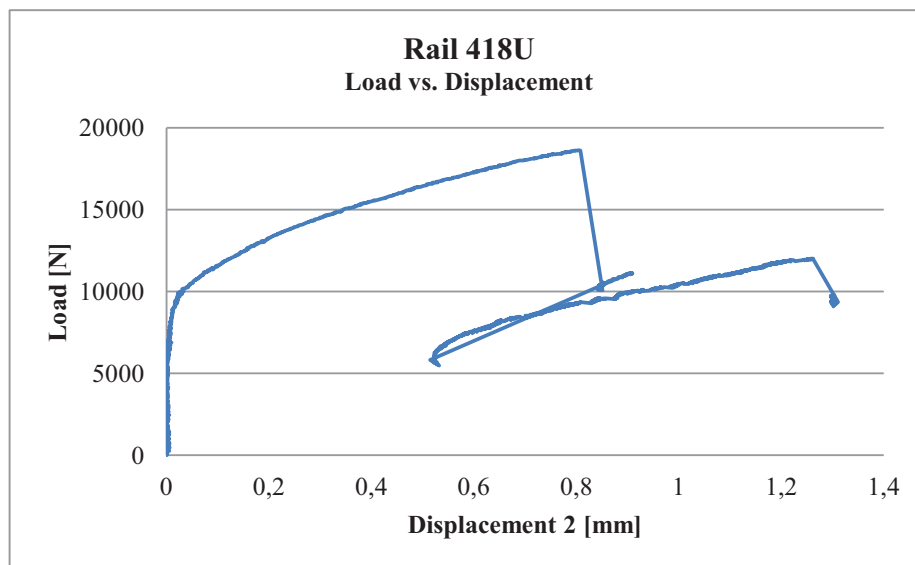
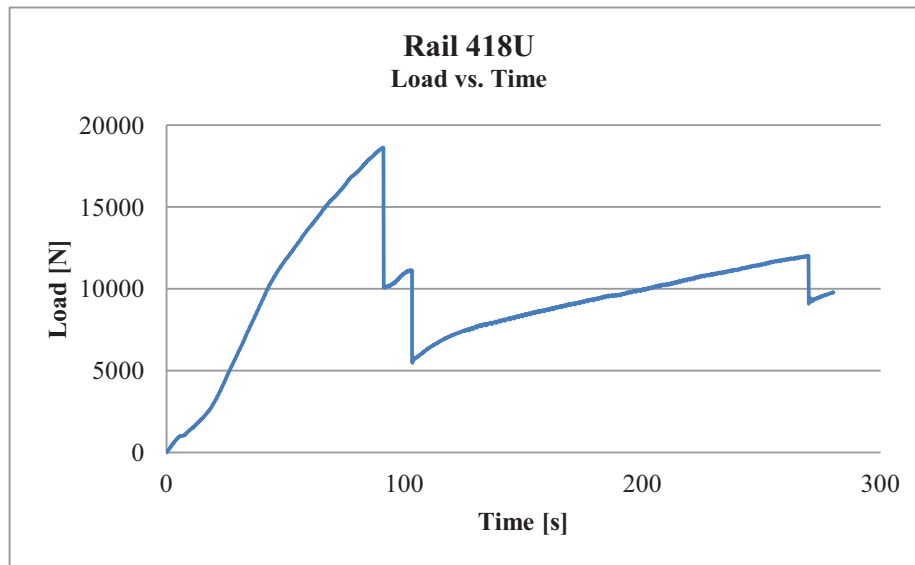


Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	21328
Displacement 1 at failure [mm]	0,03
Displacement 2 at failure [mm]	0,90
Distance from crack to edge side 1 [mm]	57
Distance from crack to edge side 2 [mm]	63
Distance from crack to anchor bolt side 1 [mm]	64
Distance from crack to anchor bolt side 2 [mm]	56
Moisture [%]	12,8
Dry density [kg/m ³]	435



Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	12972
Displacement 1 at failure [mm]	-0,01
Displacement 2 at failure [mm]	0,13
Distance from crack to edge side 1 [mm]	48
Distance from crack to edge side 2 [mm]	78
Distance from crack to anchor bolt side 1 [mm]	53
Distance from crack to anchor bolt side 2 [mm]	75
Moisture [%]	13,1
Dry density [kg/m ³]	374

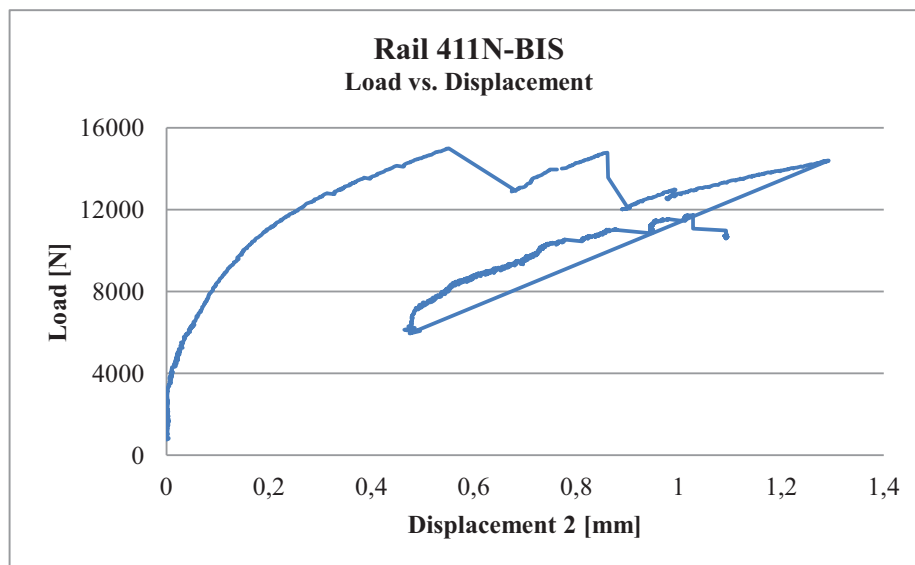
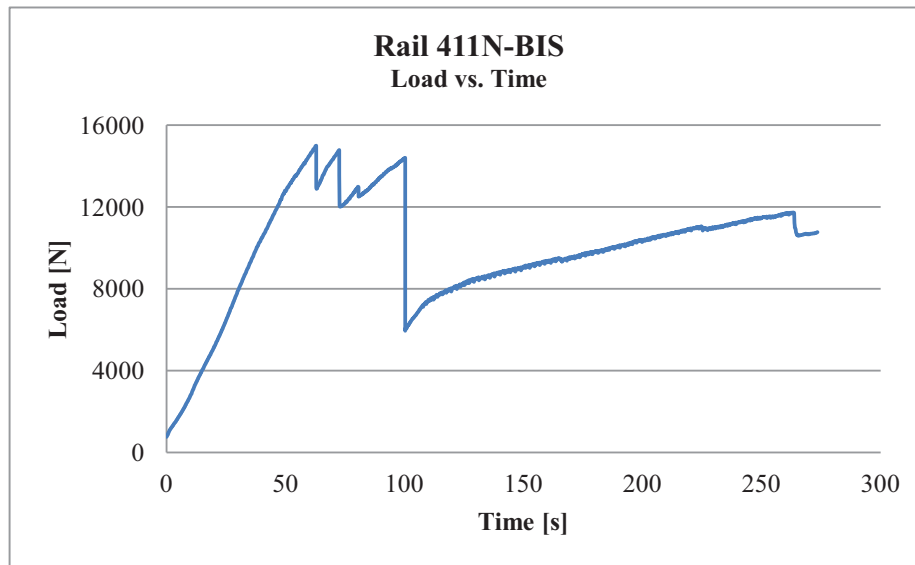
Possible pre-crack on the side 1.



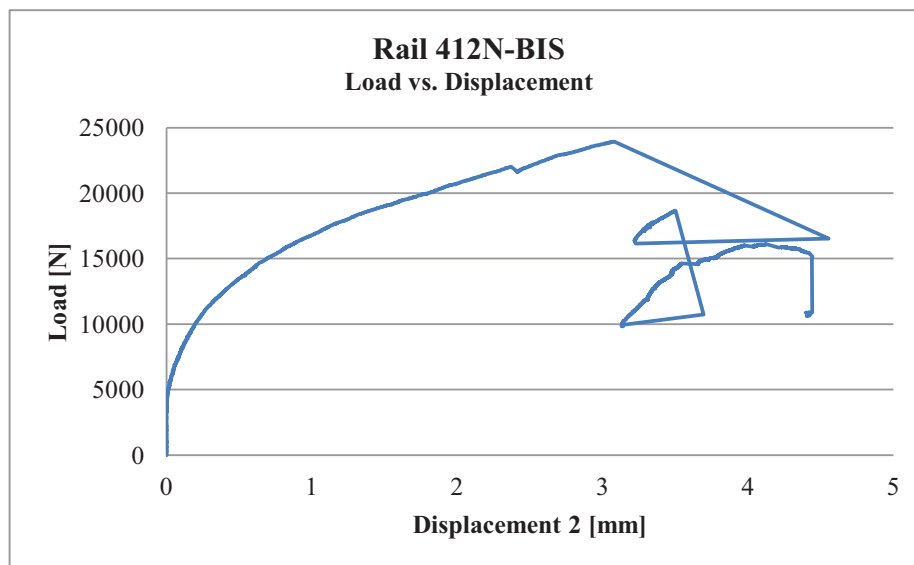
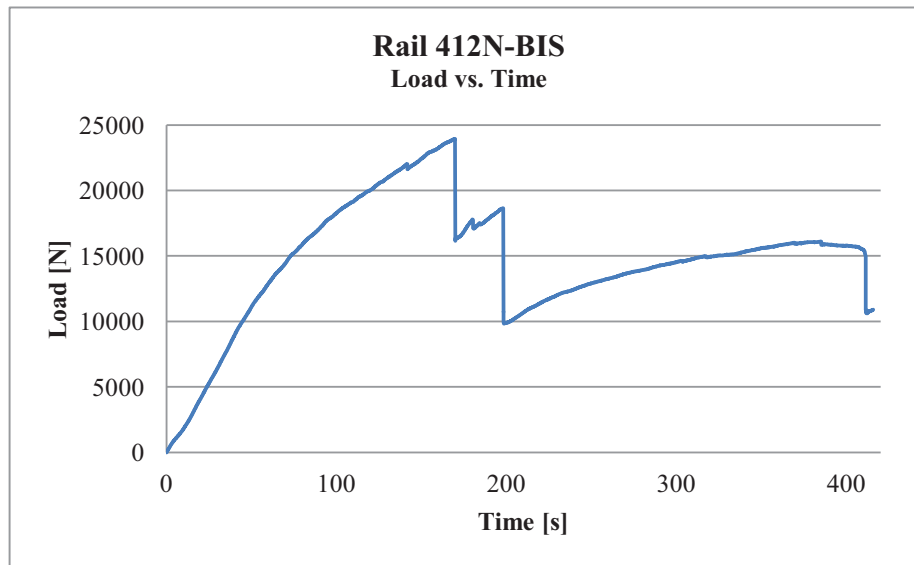
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	18612
Displacement 1 at failure [mm]	-0,02
Displacement 2 at failure [mm]	0,80
Distance from crack to edge side 1 [mm]	64
Distance from crack to edge side 2 [mm]	78
Distance from crack to anchor bolt side 1 [mm]	62
Distance from crack to anchor bolt side 2 [mm]	78
Moisture [%]	12,2
Dry density [kg/m ³]	411

Set 1-BIS – Size of washer 40x40 mm

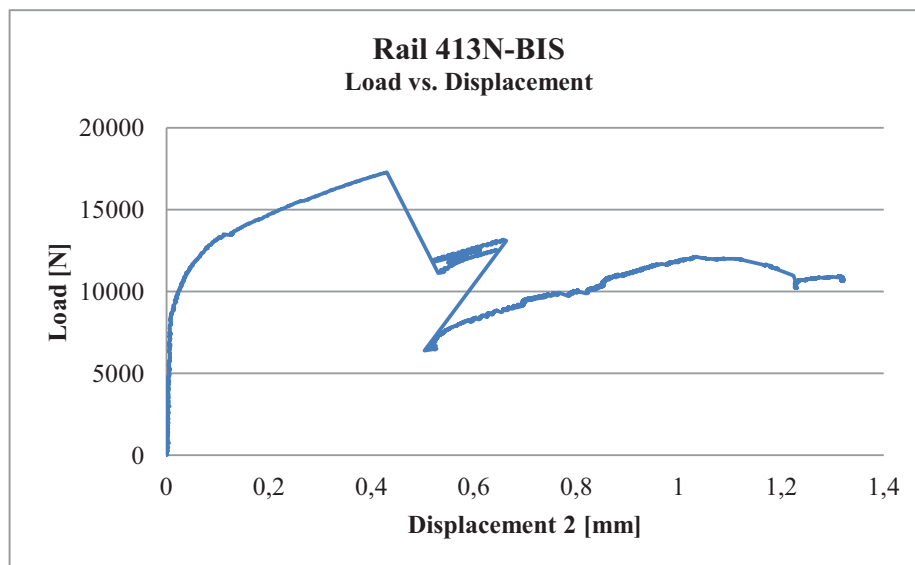
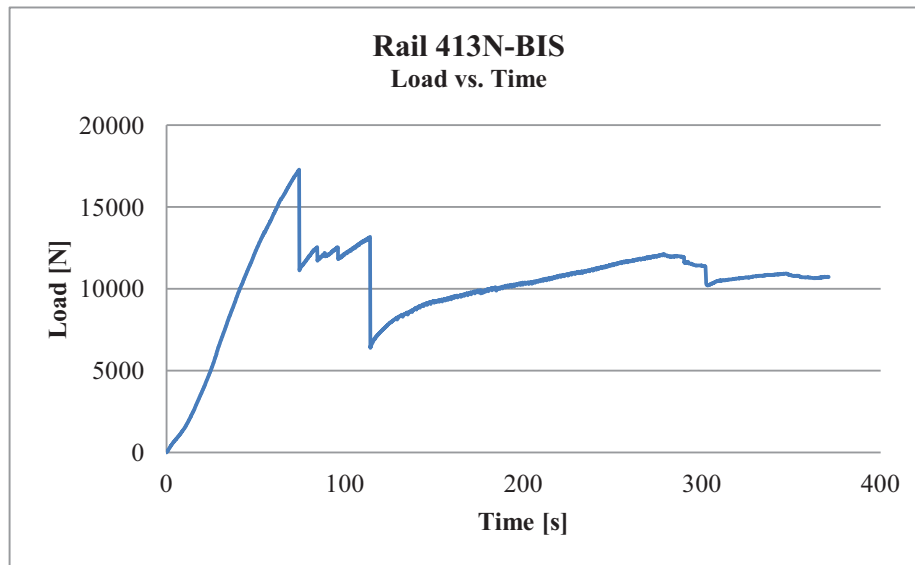
Pith down



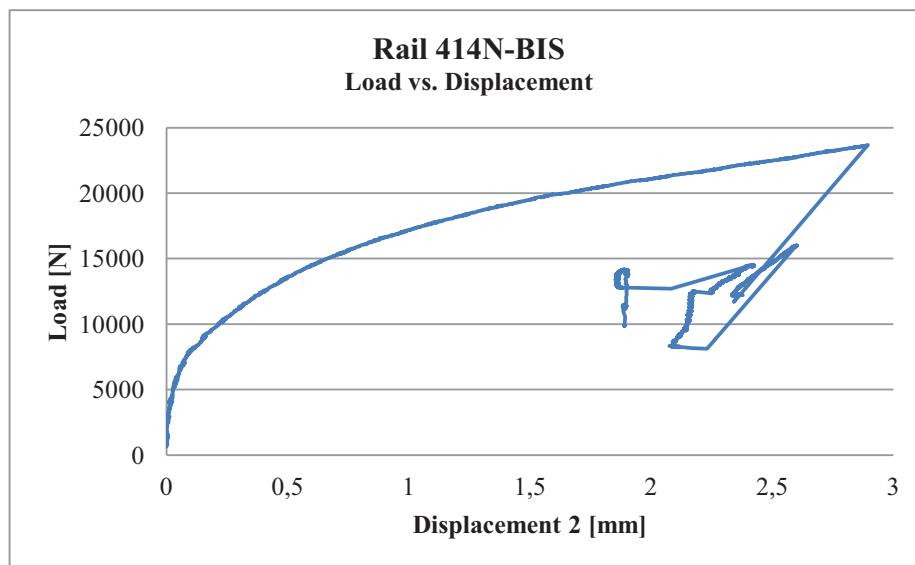
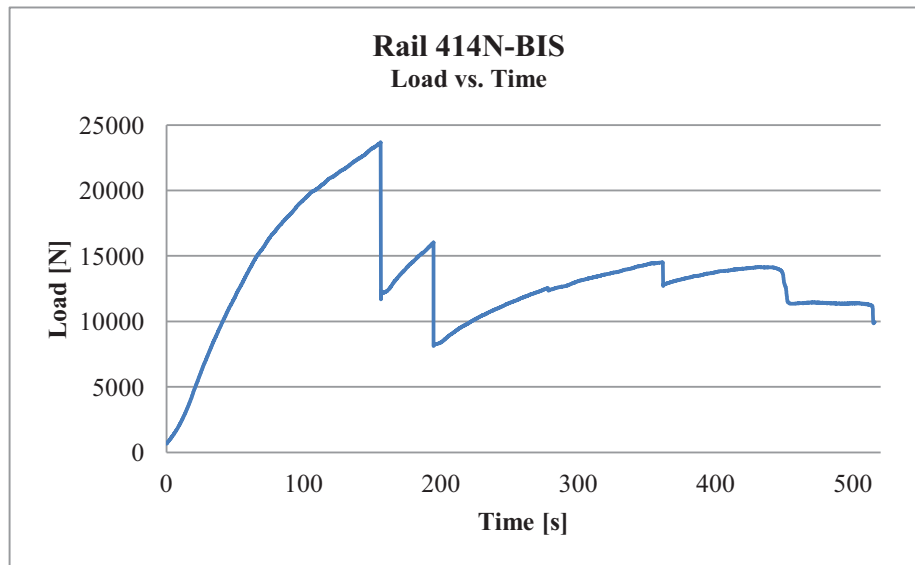
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	14987
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	0,55
Distance from crack to edge side 1 [mm]	53
Distance from crack to edge side 2 [mm]	40
Distance from crack to anchor bolt side 1 [mm]	54
Distance from crack to anchor bolt side 2 [mm]	39
Moisture [%]	13,8
Dry density [kg/m ³]	357



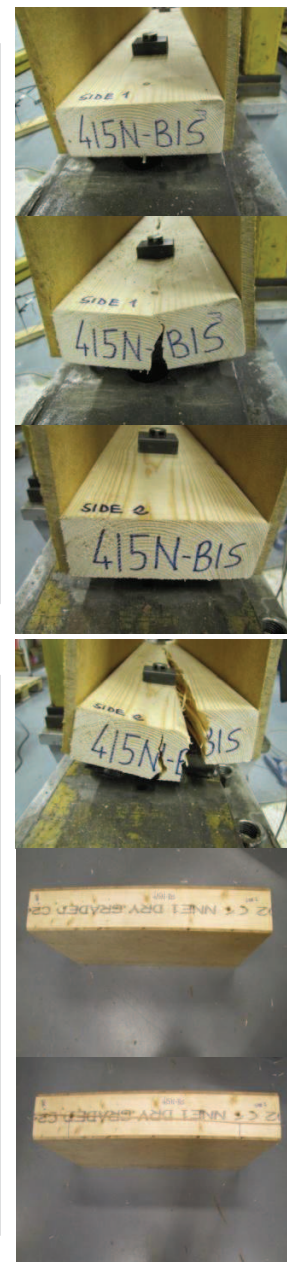
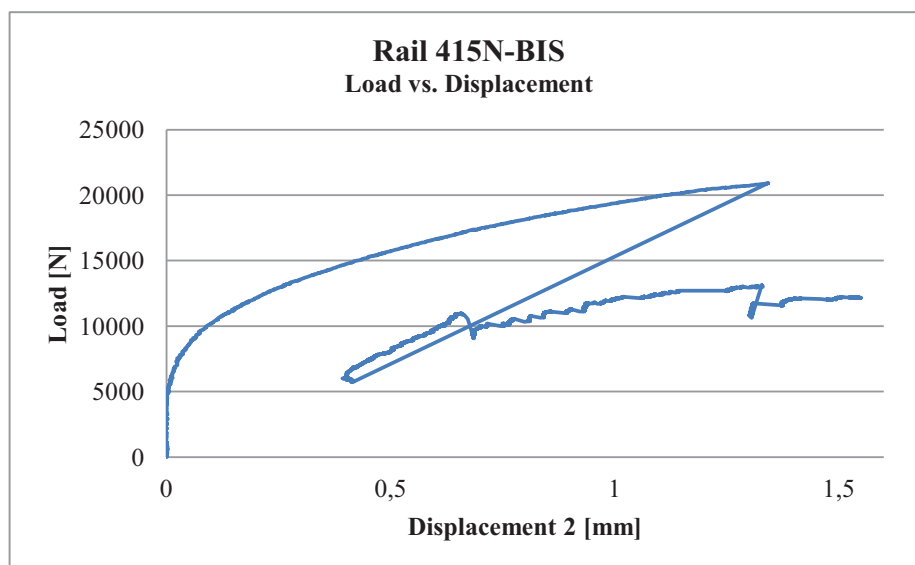
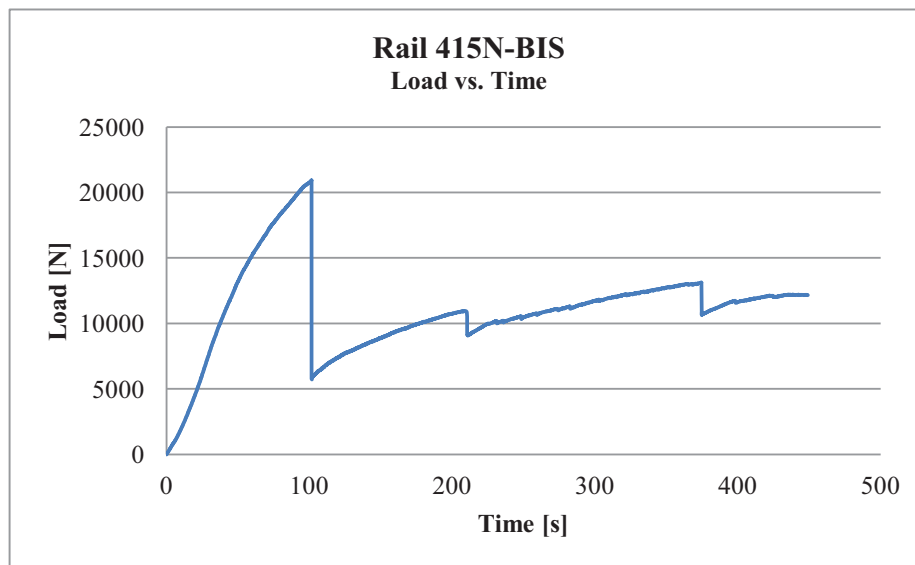
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	23952
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	3,08
Distance from crack to edge side 1 [mm]	84
Distance from crack to edge side 2 [mm]	40
Distance from crack to anchor bolt side 1 [mm]	85
Distance from crack to anchor bolt side 2 [mm]	55
Moisture [%]	13,8
Dry density [kg/m ³]	369



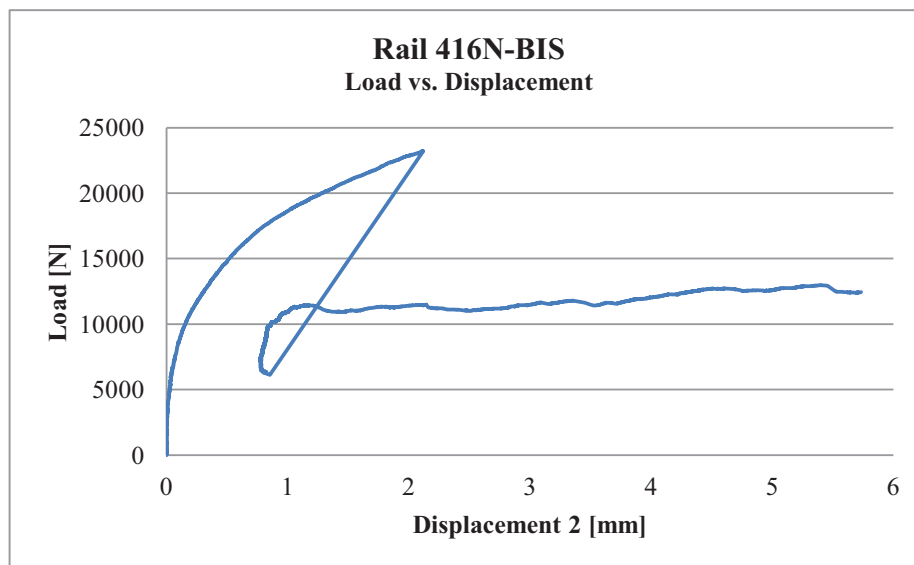
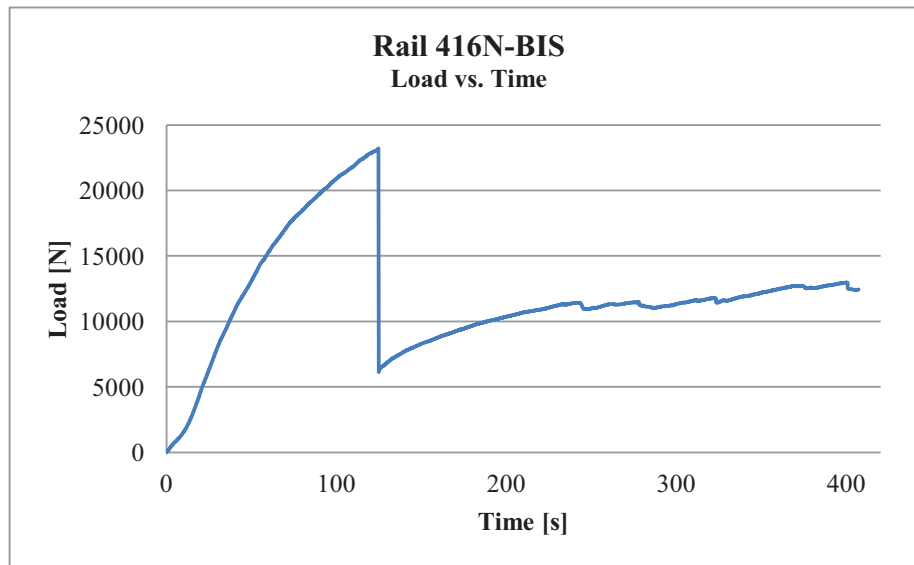
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	17263
Displacement 1 at failure [mm]	-0,03
Displacement 2 at failure [mm]	0,43
Distance from crack to edge side 1 [mm]	59
Distance from crack to edge side 2 [mm]	44
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	44
Moisture [%]	12,9
Dry density [kg/m ³]	410



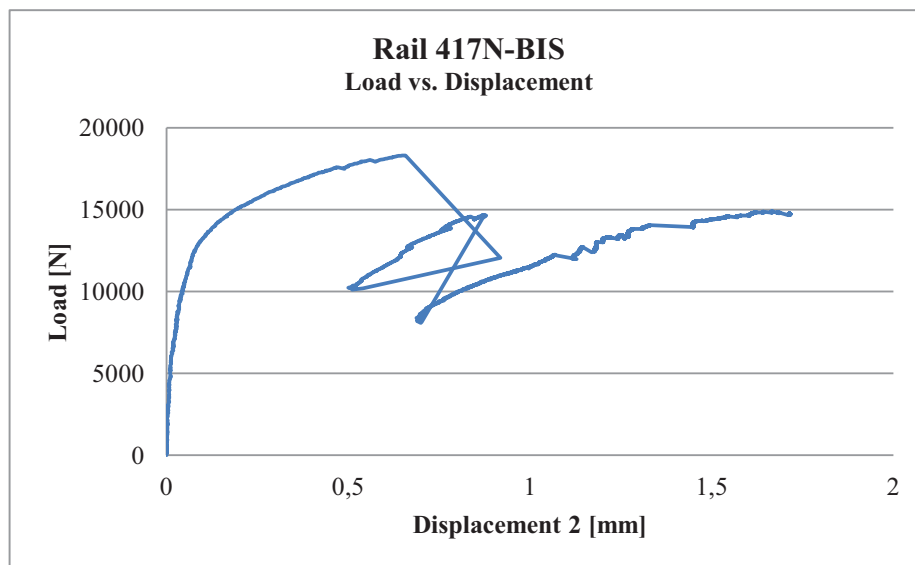
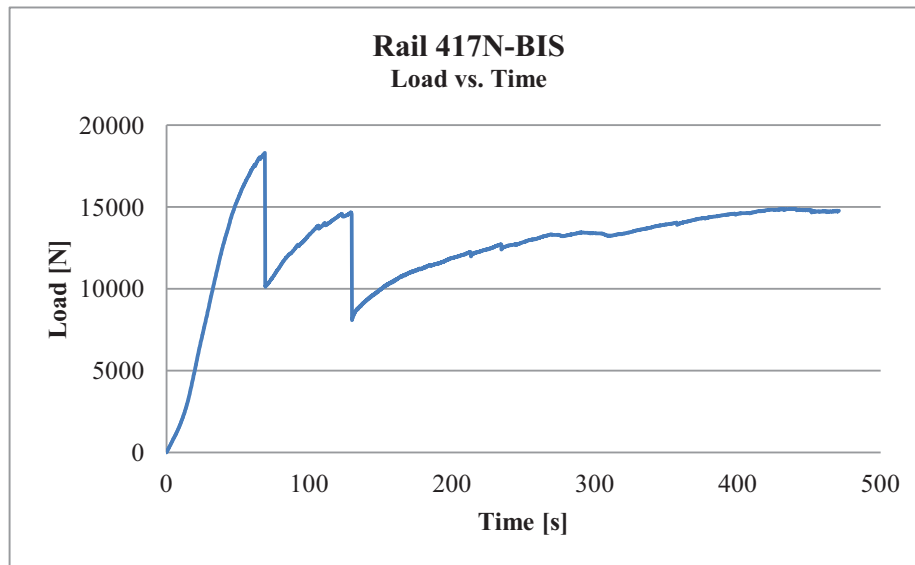
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	23682
Displacement 1 at failure [mm]	0,01
Displacement 2 at failure [mm]	2,89
Distance from crack to edge side 1 [mm]	65
Distance from crack to edge side 2 [mm]	48
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	52
Moisture [%]	13,5
Dry density [kg/m ³]	433



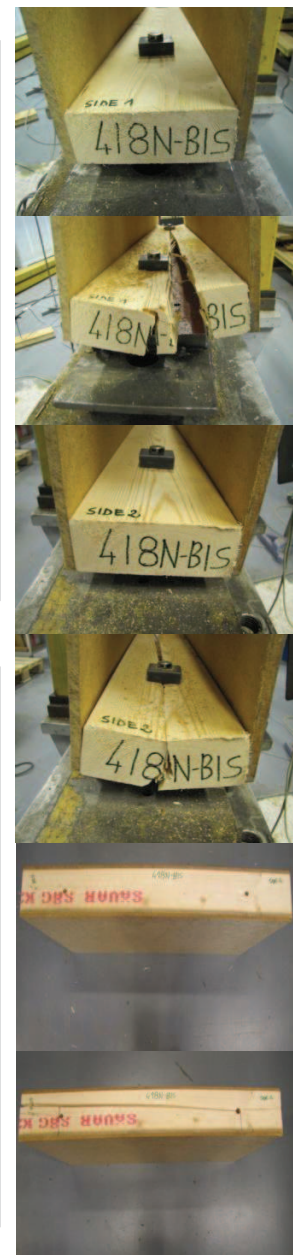
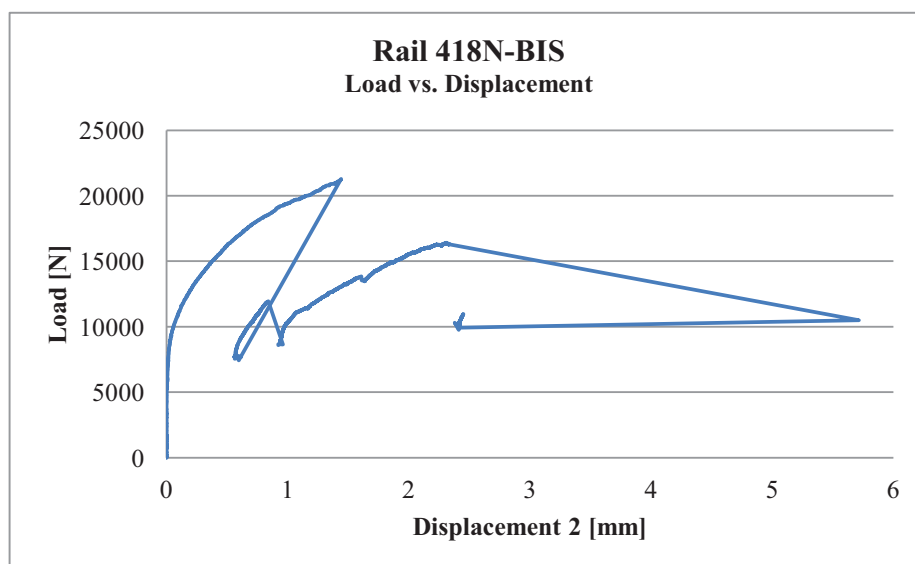
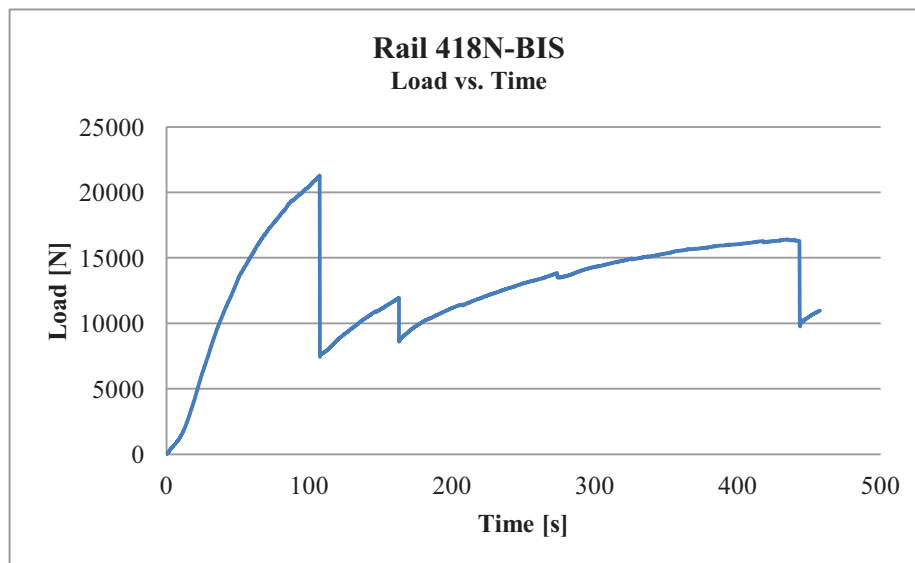
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	20917
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	1,34
Distance from crack to edge side 1 [mm]	65
Distance from crack to edge side 2 [mm]	36
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	36
Moisture [%]	13,6
Dry density [kg/m ³]	393



Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	23217
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	2,12
Distance from crack to edge side 1 [mm]	62
Distance from crack to edge side 2 [mm]	40
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	46
Moisture [%]	13,6
Dry density [kg/m ³]	433

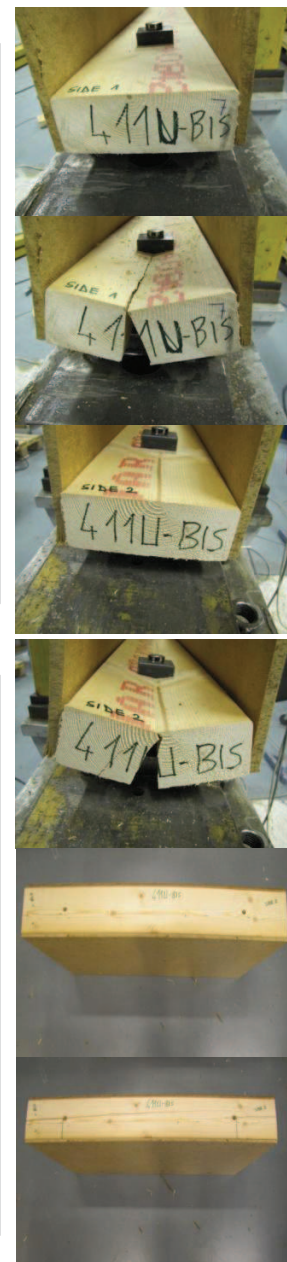
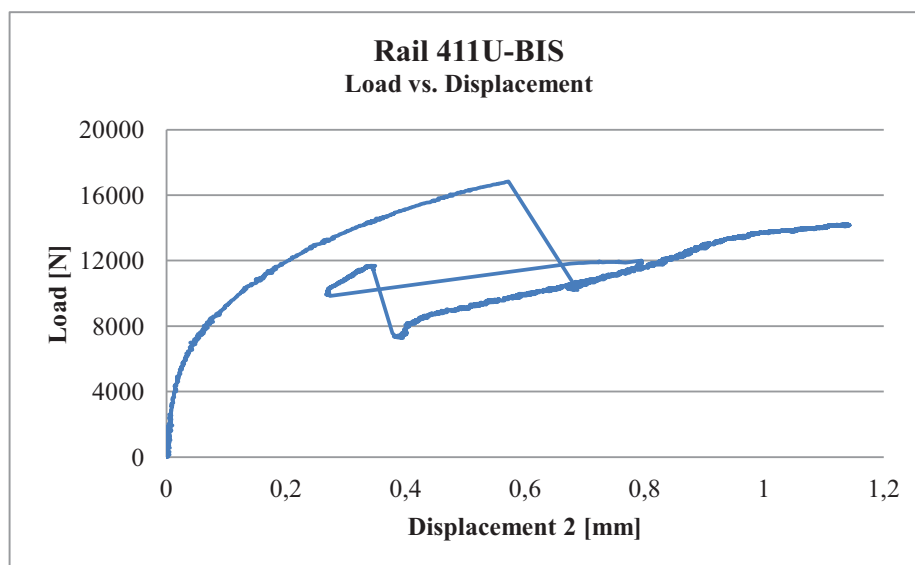
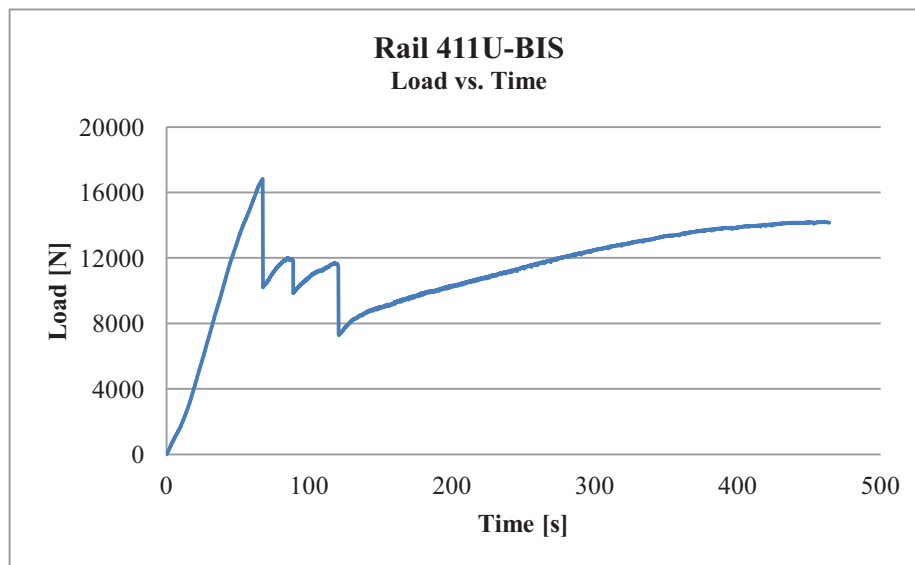


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	18293
Displacement 1 at failure [mm]	0,05
Displacement 2 at failure [mm]	0,65
Distance from crack to edge side 1 [mm]	66
Distance from crack to edge side 2 [mm]	45
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	45
Moisture [%]	13,2
Dry density [kg/m ³]	433

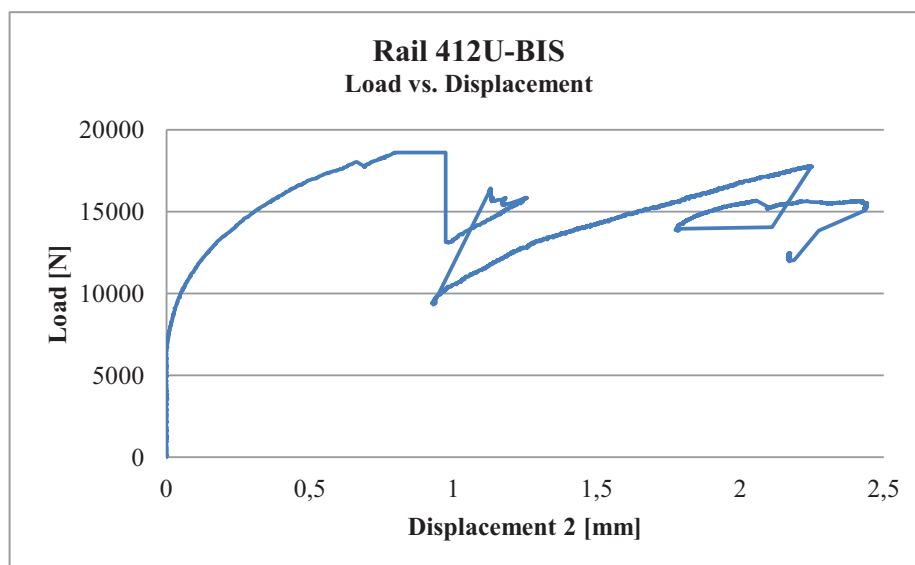
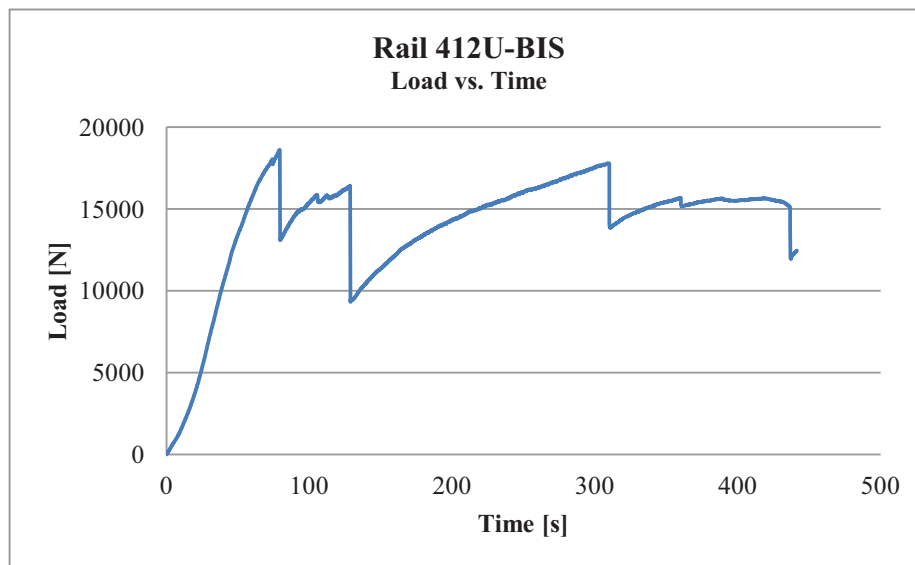


Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	21276
Displacement 1 at failure [mm]	0,03
Displacement 2 at failure [mm]	1,44
Distance from crack to edge side 1 [mm]	90
Distance from crack to edge side 2 [mm]	67
Distance from crack to anchor bolt side 1 [mm]	86
Distance from crack to anchor bolt side 2 [mm]	63
Moisture [%]	13,0
Dry density [kg/m ³]	404

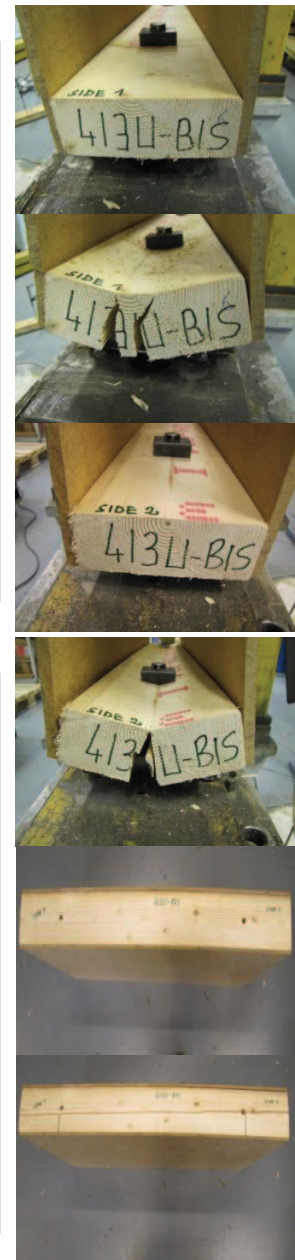
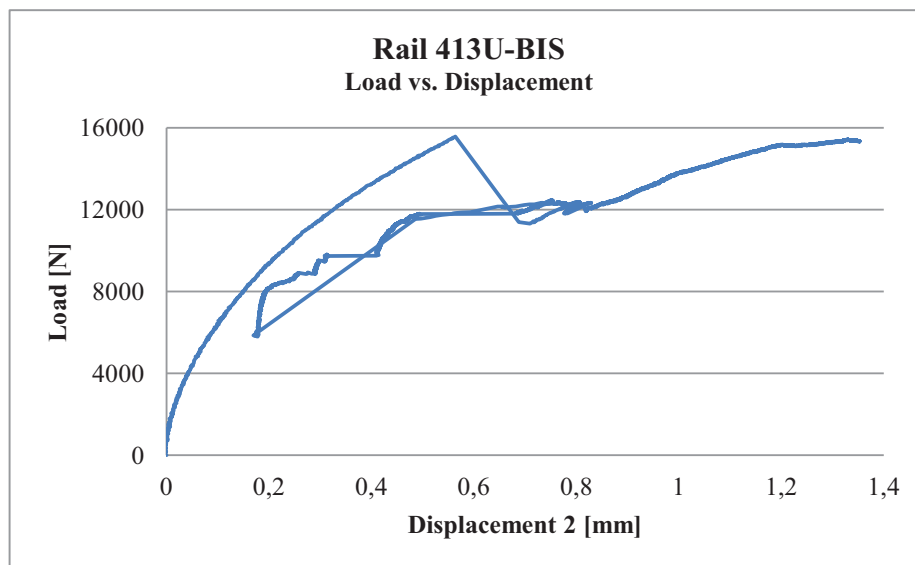
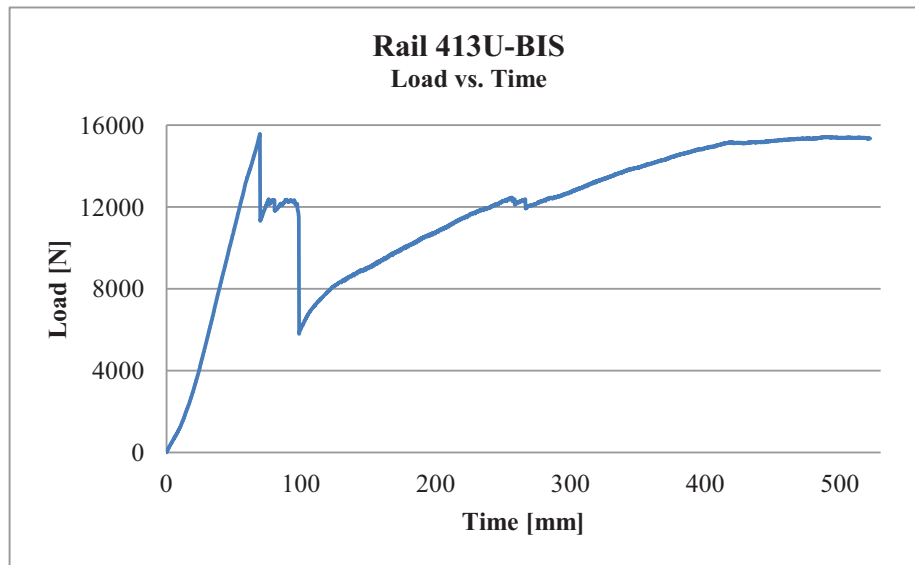
Pith Up



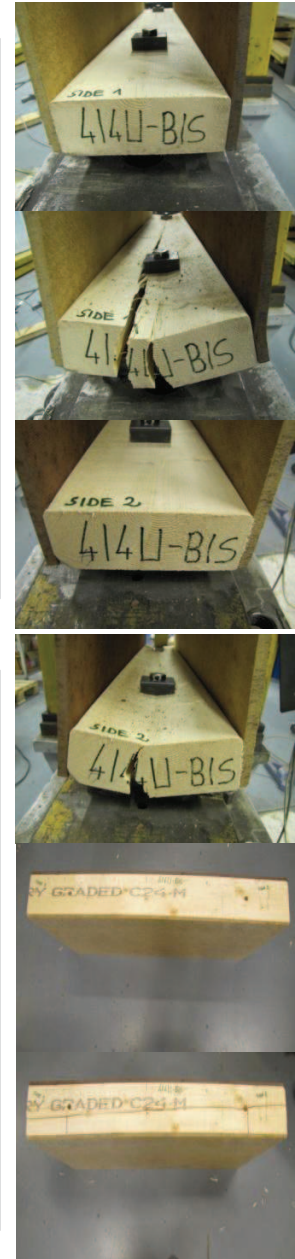
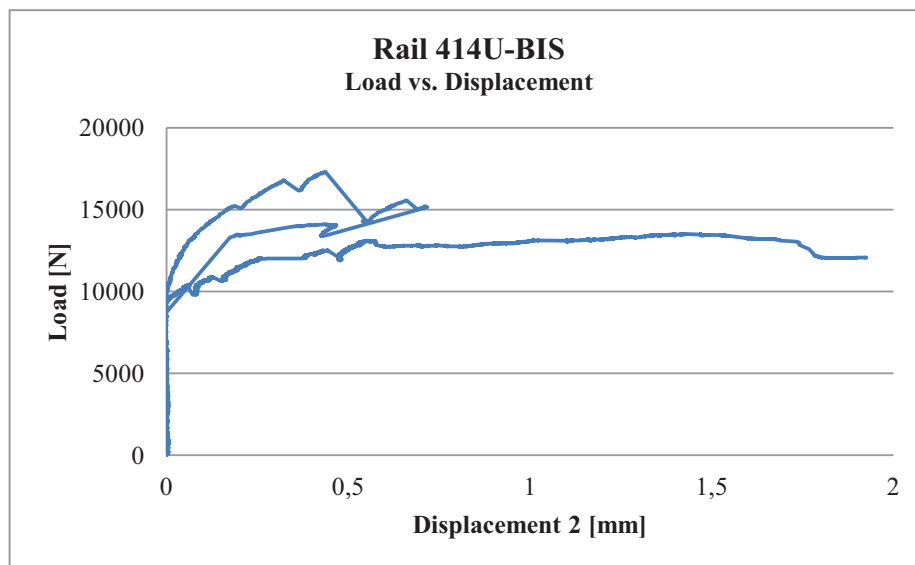
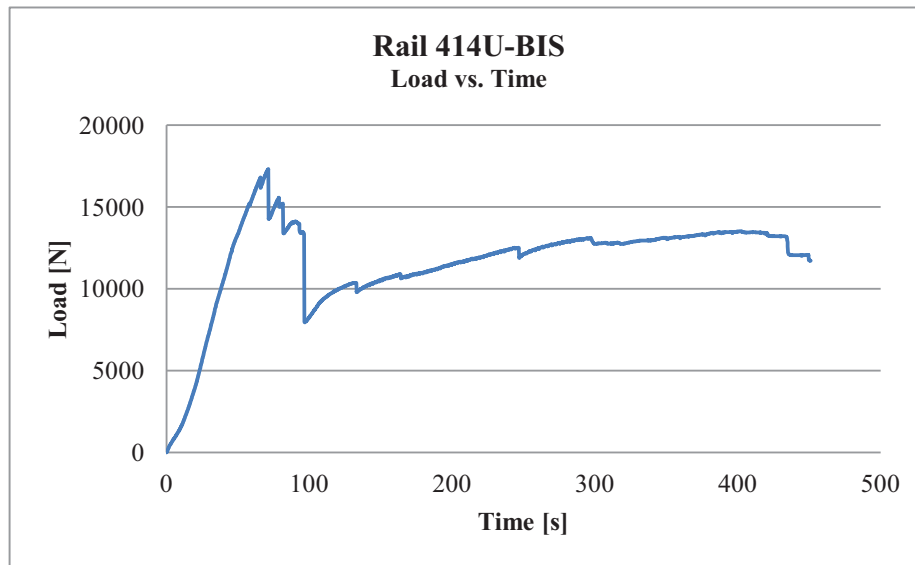
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	21276
Displacement 1 at failure [mm]	0,10
Displacement 2 at failure [mm]	0,57
Distance from crack to edge side 1 [mm]	58
Distance from crack to edge side 2 [mm]	67
Distance from crack to anchor bolt side 1 [mm]	61
Distance from crack to anchor bolt side 2 [mm]	62
Moisture [%]	14,0
Dry density [kg/m ³]	364



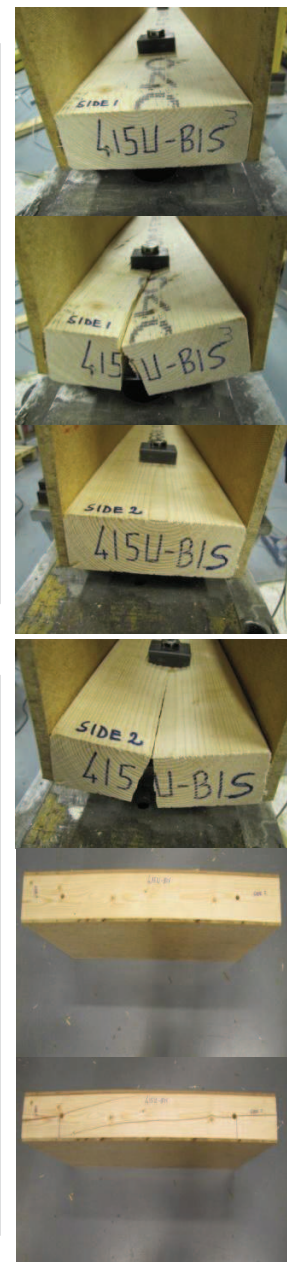
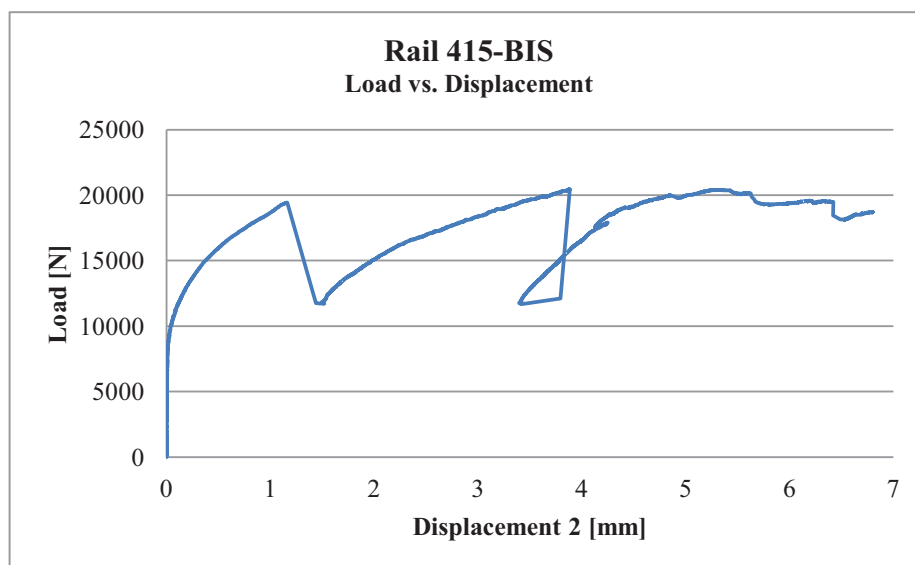
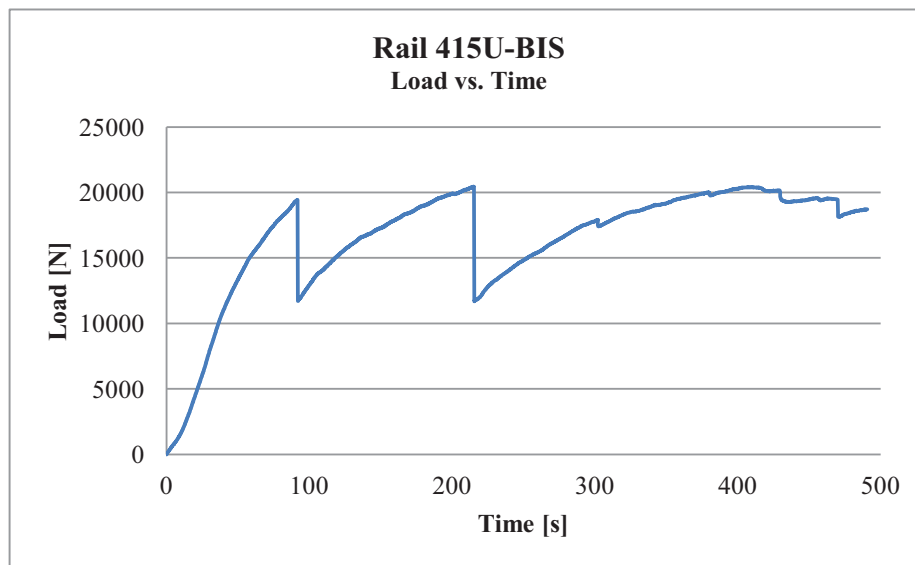
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	18601
Displacement 1 at failure [mm]	0,09
Displacement 2 at failure [mm]	0,97
Distance from crack to edge side 1 [mm]	57
Distance from crack to edge side 2 [mm]	70
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,8
Dry density [kg/m ³]	396



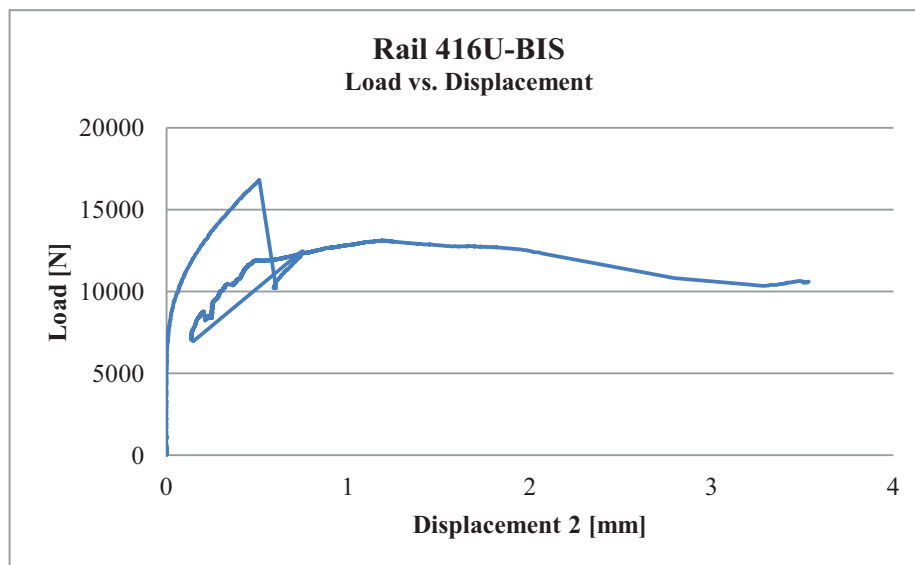
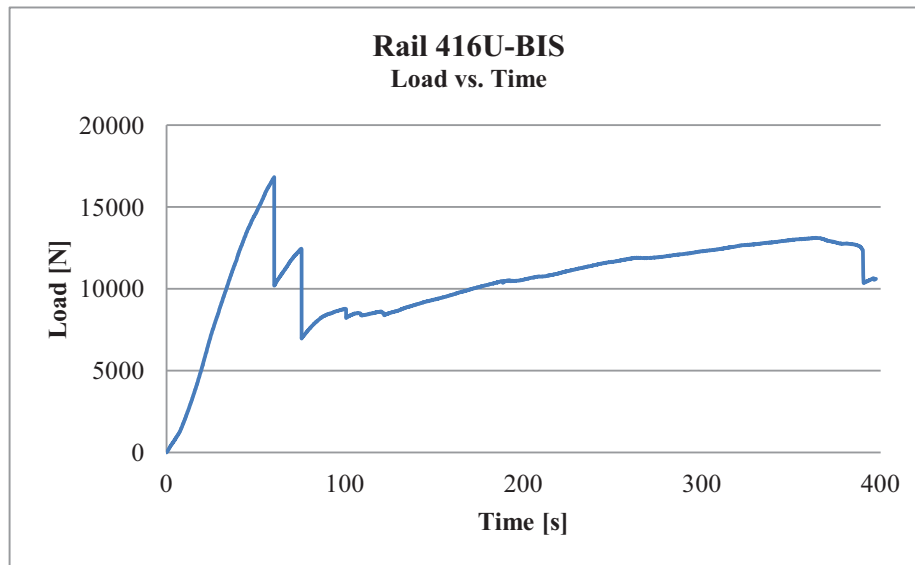
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	15560
Displacement 1 at failure [mm]	0,01
Displacement 2 at failure [mm]	0,56
Distance from crack to edge side 1 [mm]	44
Distance from crack to edge side 2 [mm]	64
Distance from crack to anchor bolt side 1 [mm]	46
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,7
Dry density [kg/m ³]	382



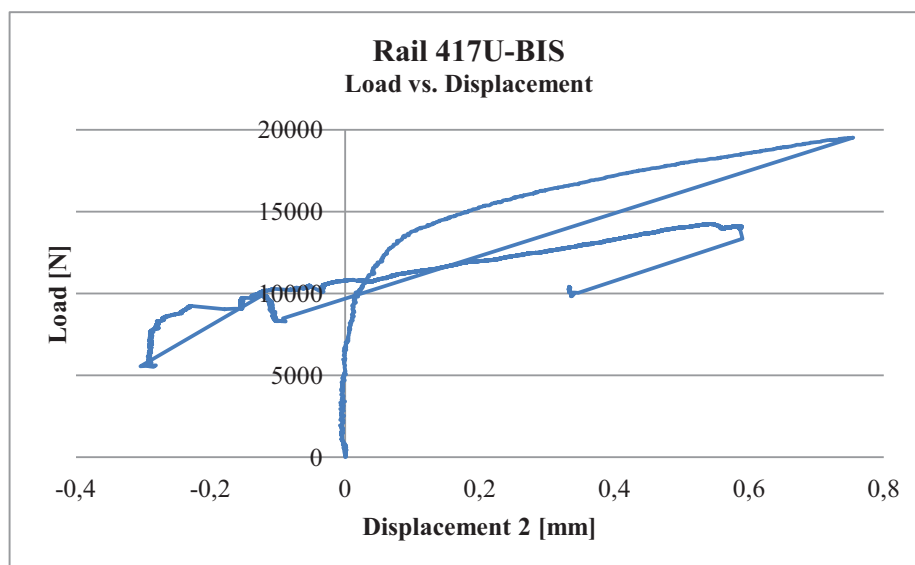
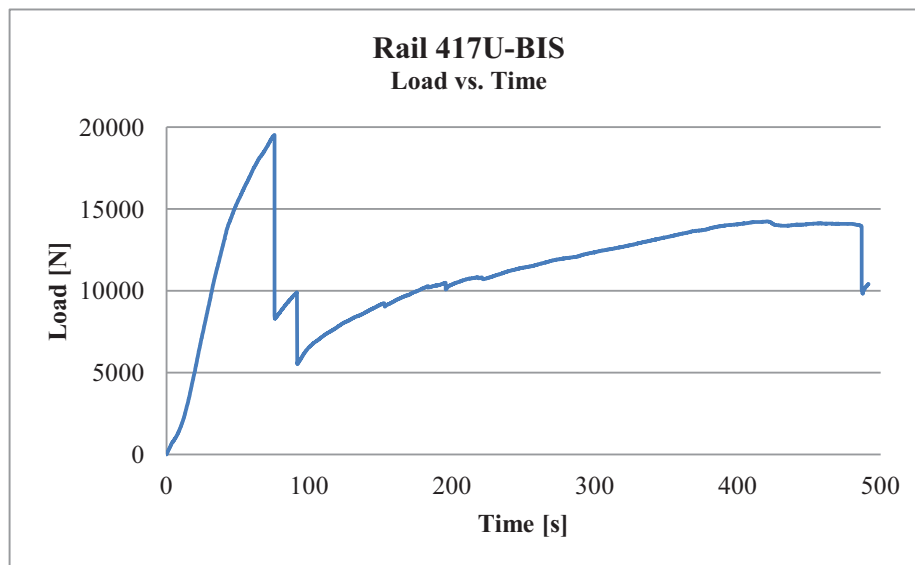
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	17313
Displacement 1 at failure [mm]	-0,01
Displacement 2 at failure [mm]	0,44
Distance from crack to edge side 1 [mm]	40
Distance from crack to edge side 2 [mm]	70
Distance from crack to anchor bolt side 1 [mm]	42
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,0
Dry density [kg/m ³]	503



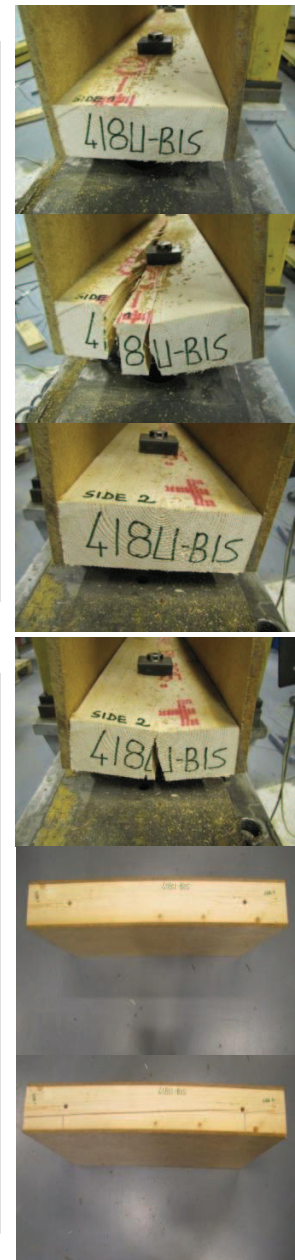
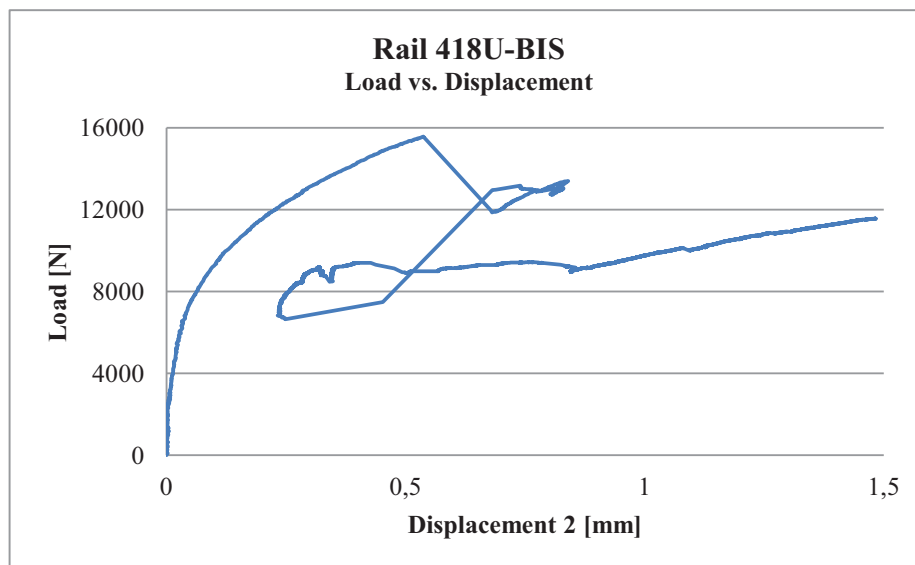
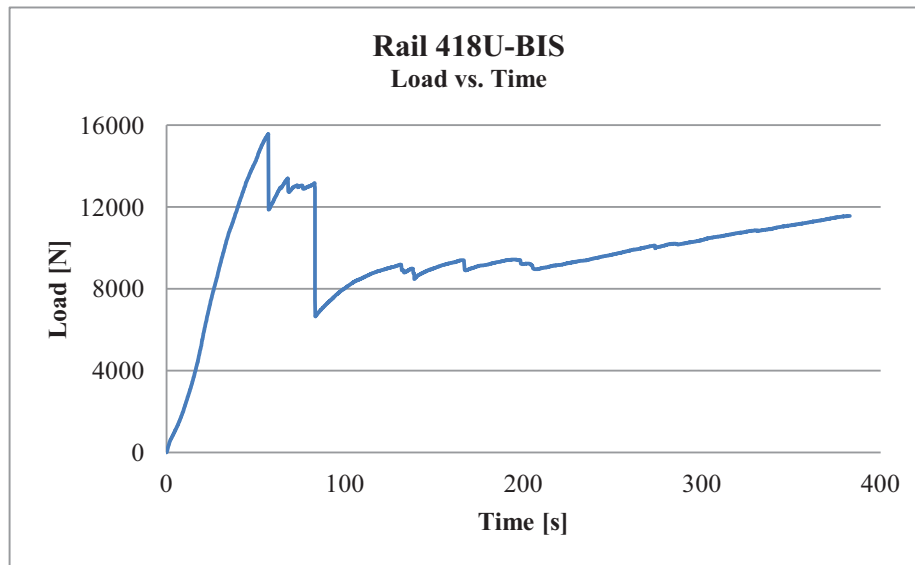
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	19426
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	1,16
Distance from crack to edge side 1 [mm]	50
Distance from crack to edge side 2 [mm]	67
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	14,0
Dry density [kg/m ³]	410



Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	16809
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	0,51
Distance from crack to edge side 1 [mm]	47
Distance from crack to edge side 2 [mm]	63
Distance from crack to anchor bolt side 1 [mm]	51
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,3
Dry density [kg/m ³]	428



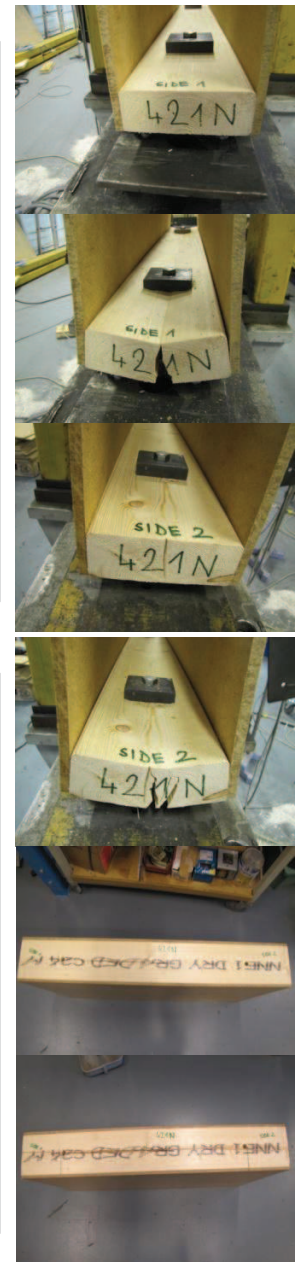
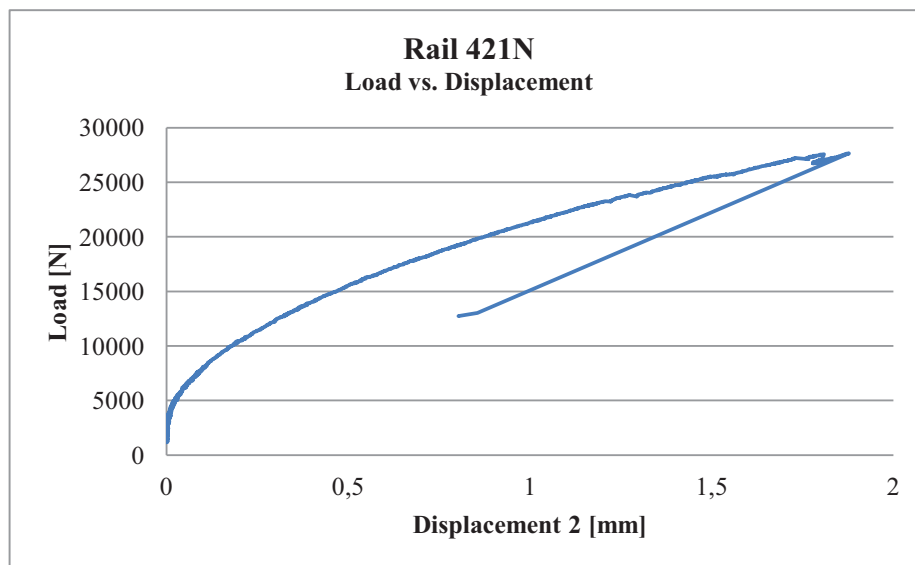
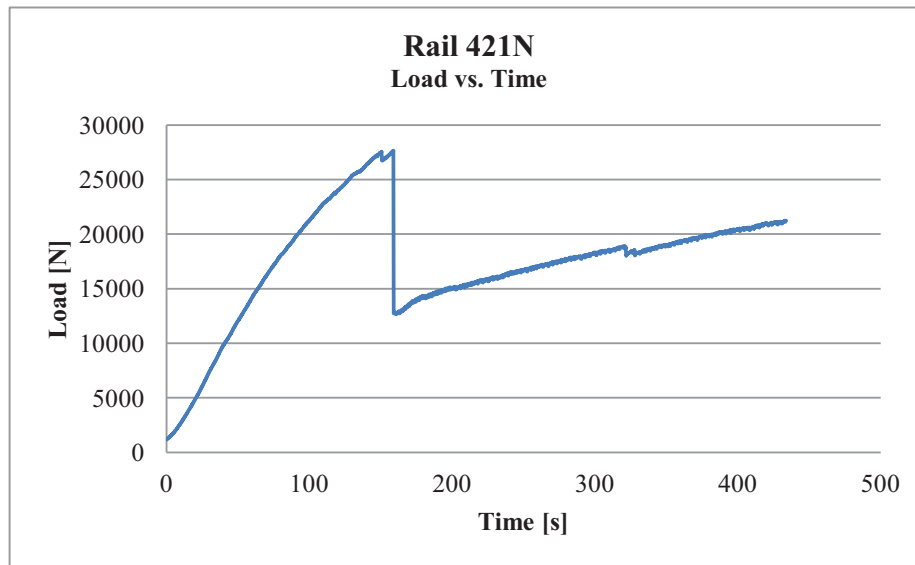
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	19519
Displacement 1 at failure [mm]	0,08
Displacement 2 at failure [mm]	0,75
Distance from crack to edge side 1 [mm]	44
Distance from crack to edge side 2 [mm]	62
Distance from crack to anchor bolt side 1 [mm]	48
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,2
Dry density [kg/m ³]	424



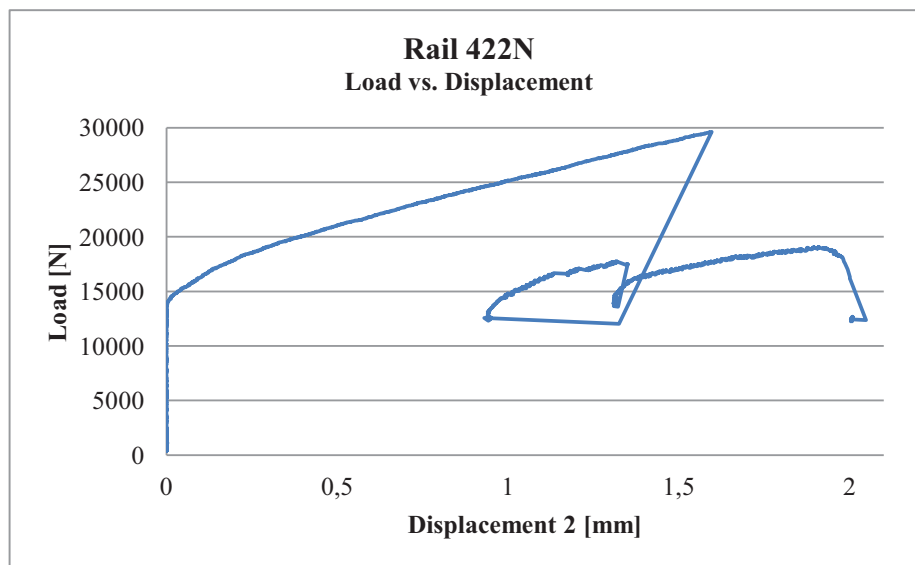
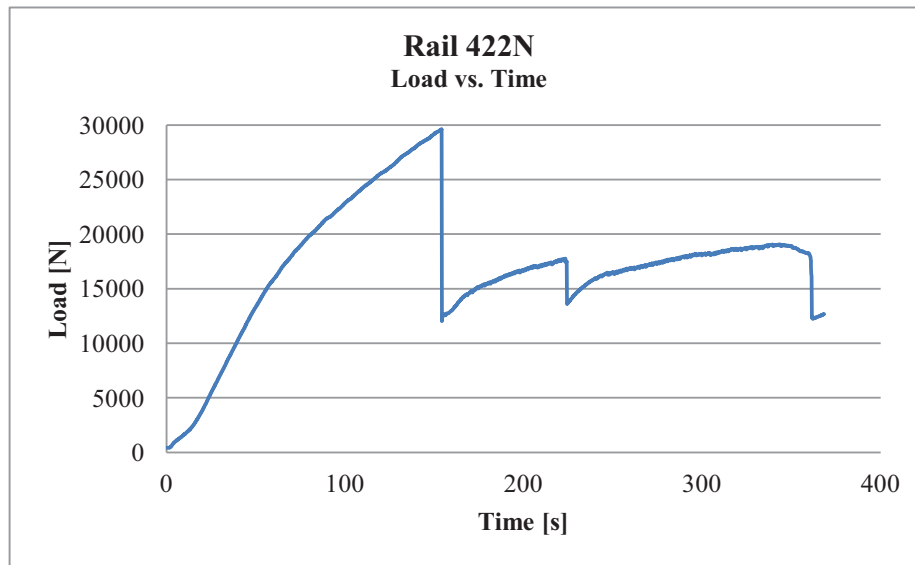
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	15569
Displacement 1 at failure [mm]	-0,02
Displacement 2 at failure [mm]	0,54
Distance from crack to edge side 1 [mm]	34
Distance from crack to edge side 2 [mm]	56
Distance from crack to anchor bolt side 1 [mm]	38
Distance from crack to anchor bolt side 2 [mm]	51
Moisture [%]	13,5
Dry density [kg/m ³]	392

Set 2 – Size of washer 60x60mm

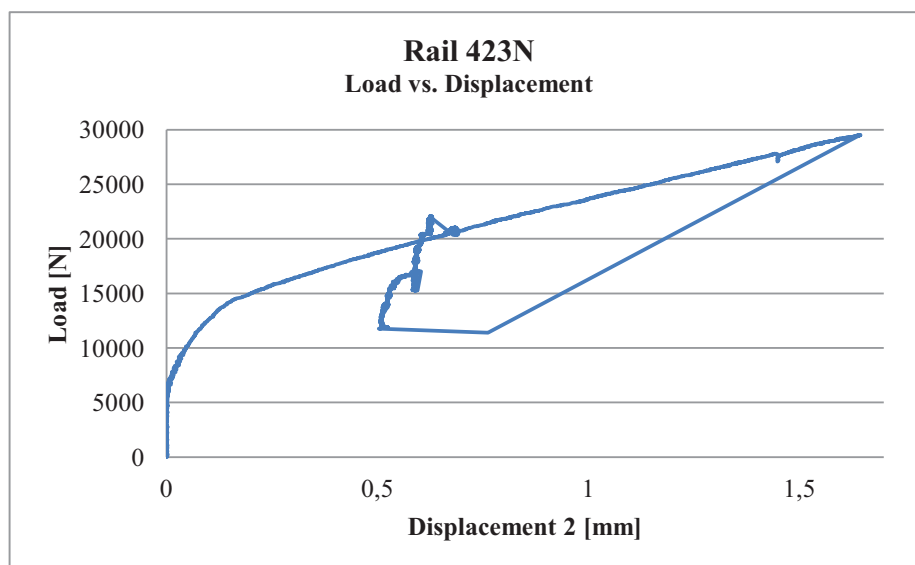
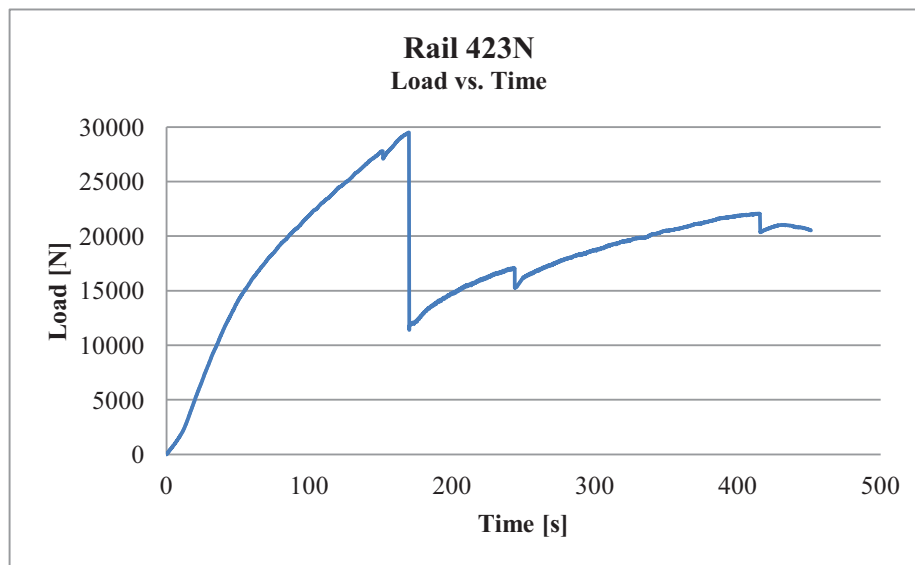
Pith Down



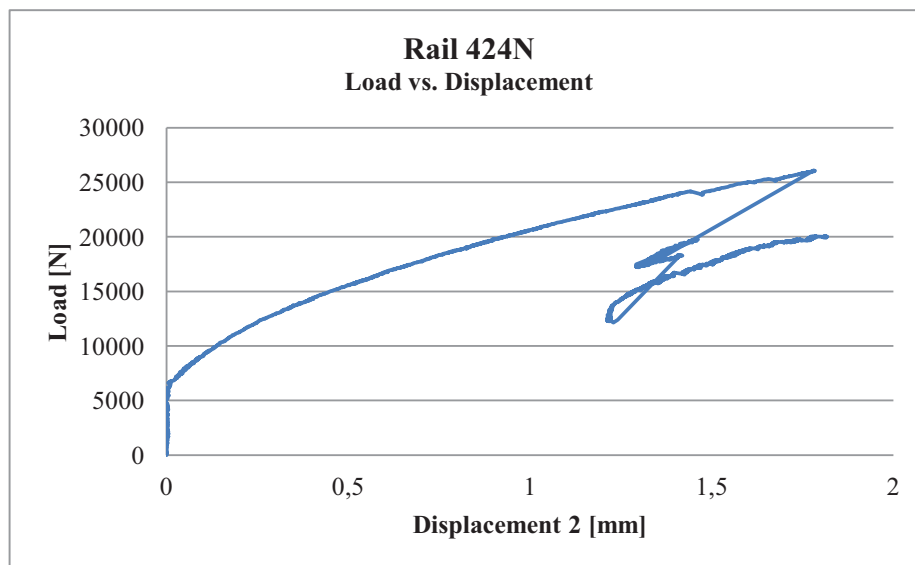
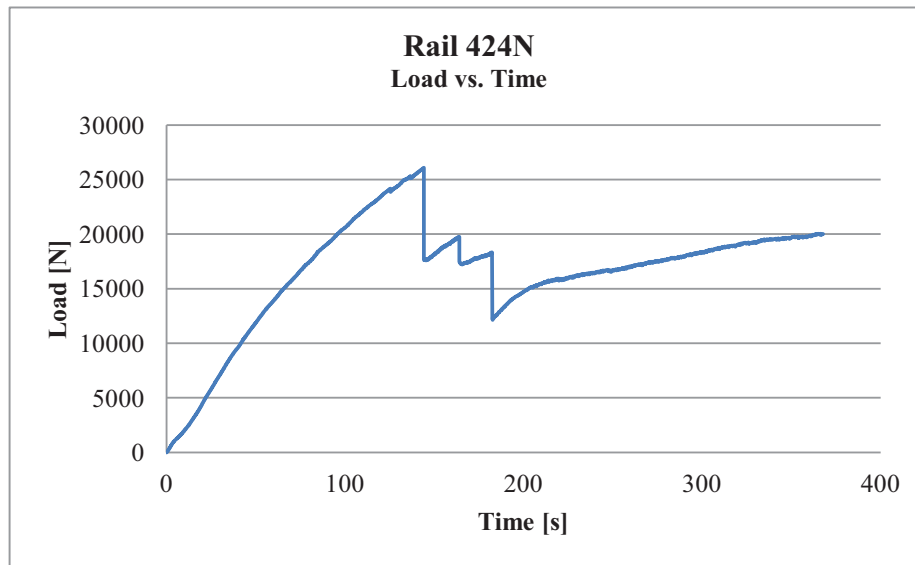
Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	27643
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	1,88
Distance from crack to edge side 1 [mm]	68
Distance from crack to edge side 2 [mm]	55
Distance from crack to anchor bolt side 1 [mm]	65
Distance from crack to anchor bolt side 2 [mm]	62
Moisture [%]	13,1
Dry density [kg/m ³]	393



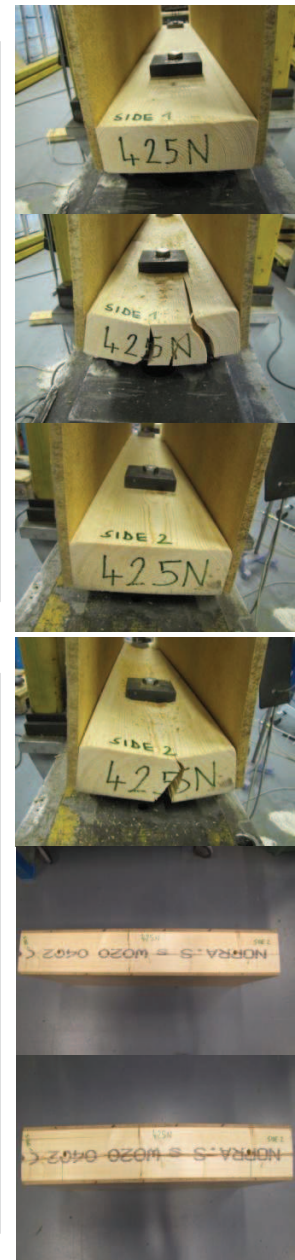
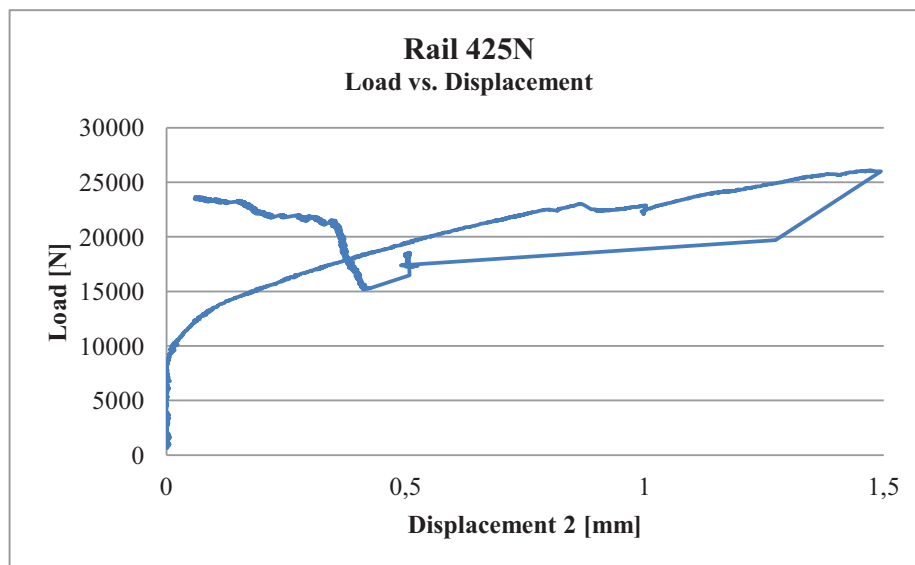
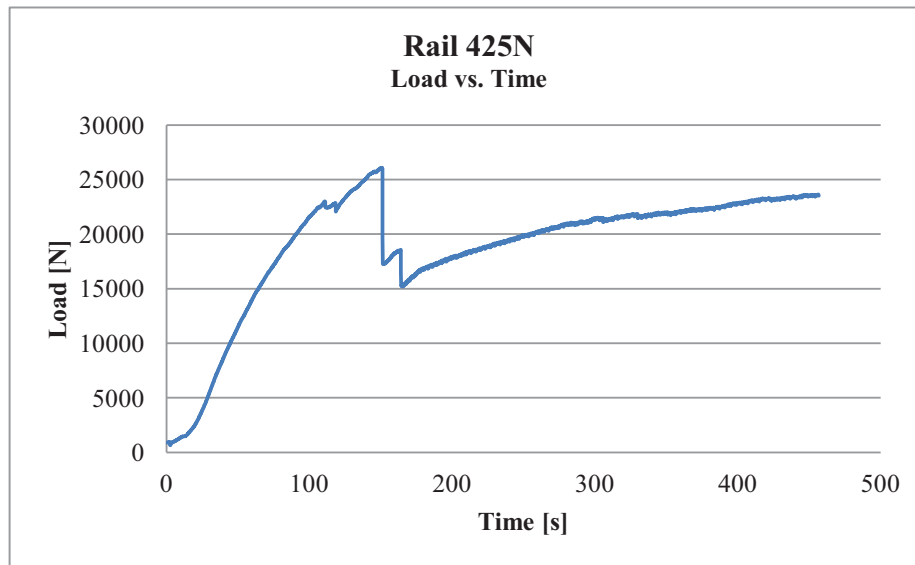
Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	29616
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	1,60
Distance from crack to edge side 1 [mm]	98
Distance from crack to edge side 2 [mm]	54
Distance from crack to anchor bolt side 1 [mm]	88
Distance from crack to anchor bolt side 2 [mm]	61
Moisture [%]	13,4
Dry density [kg/m ³]	419



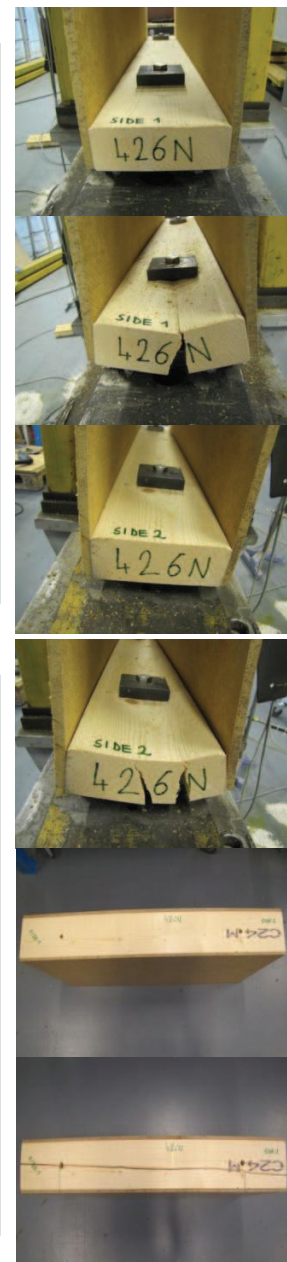
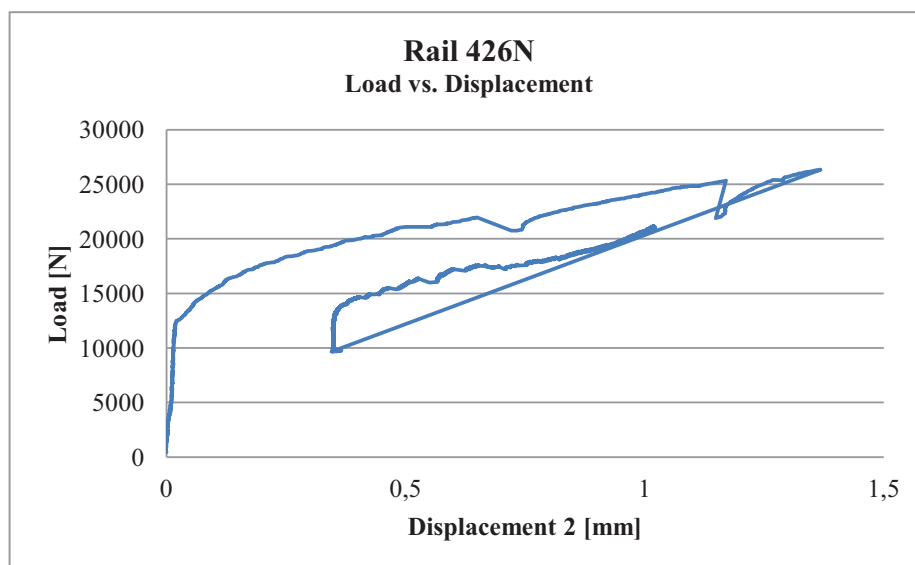
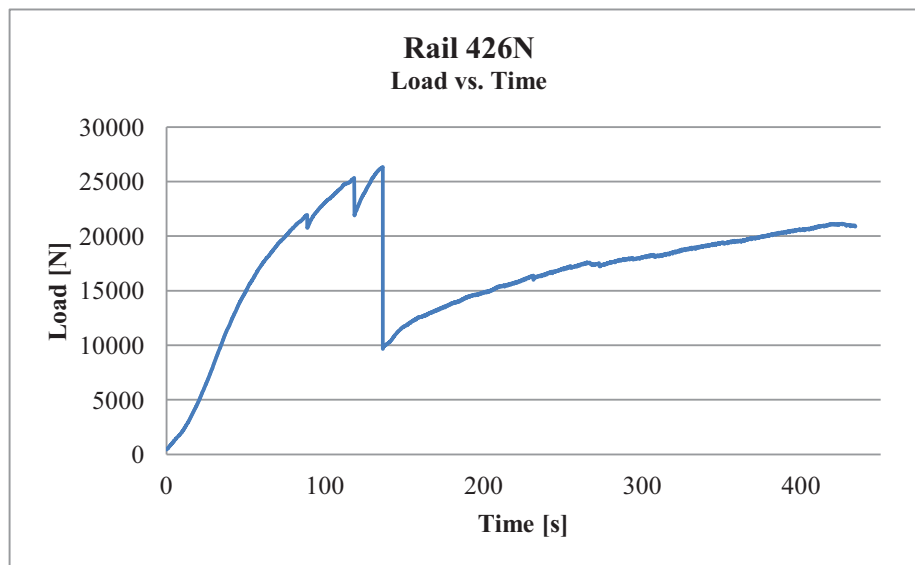
Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	29506
Displacement 1 at failure [mm]	-0,12
Displacement 2 at failure [mm]	1,64
Distance from crack to edge side 1 [mm]	62
Distance from crack to edge side 2 [mm]	45
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	50
Moisture [%]	13,4
Dry density [kg/m ³]	367



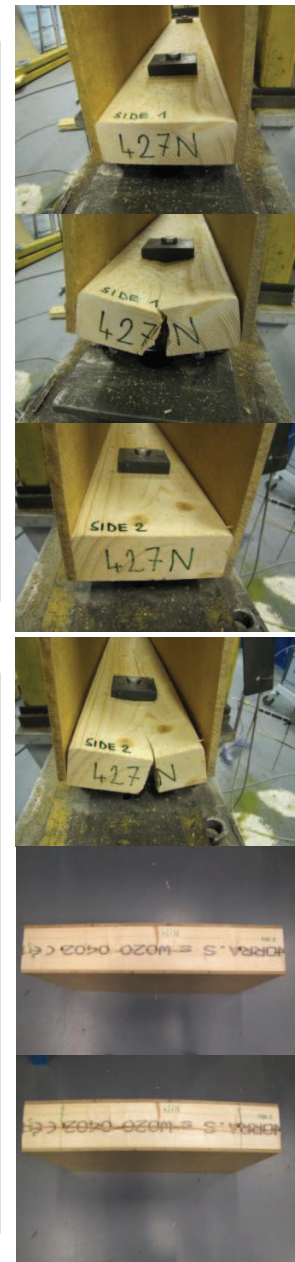
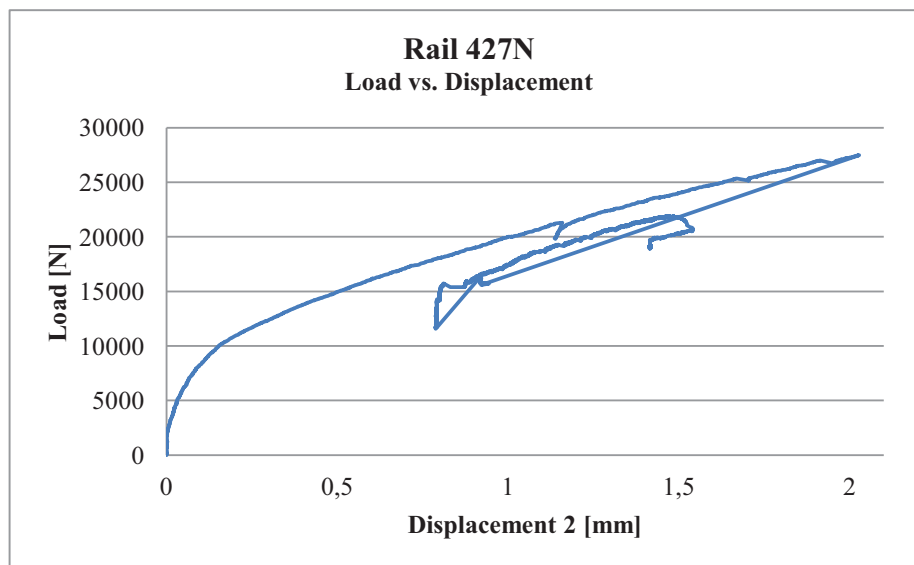
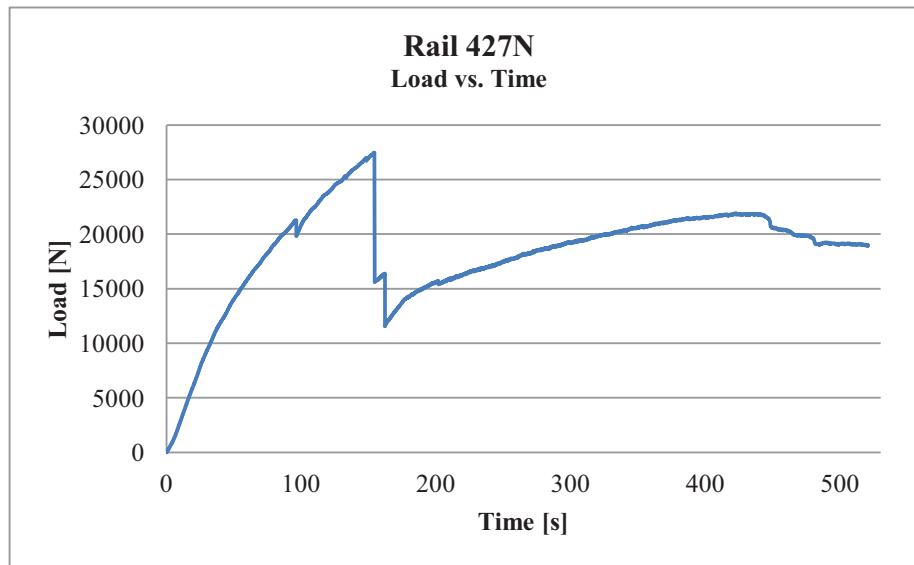
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	26065
Displacement 1 at failure [mm]	0,03
Displacement 2 at failure [mm]	1,78
Distance from crack to edge side 1 [mm]	82
Distance from crack to edge side 2 [mm]	55
Distance from crack to anchor bolt side 1 [mm]	80
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	12,3
Dry density [kg/m ³]	367



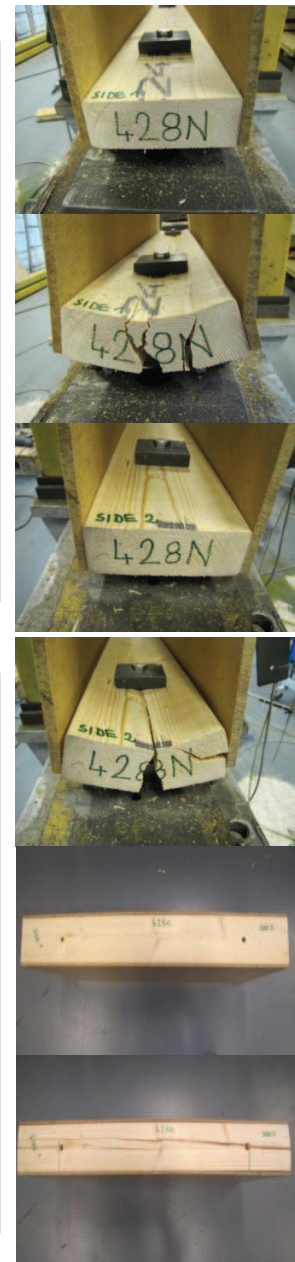
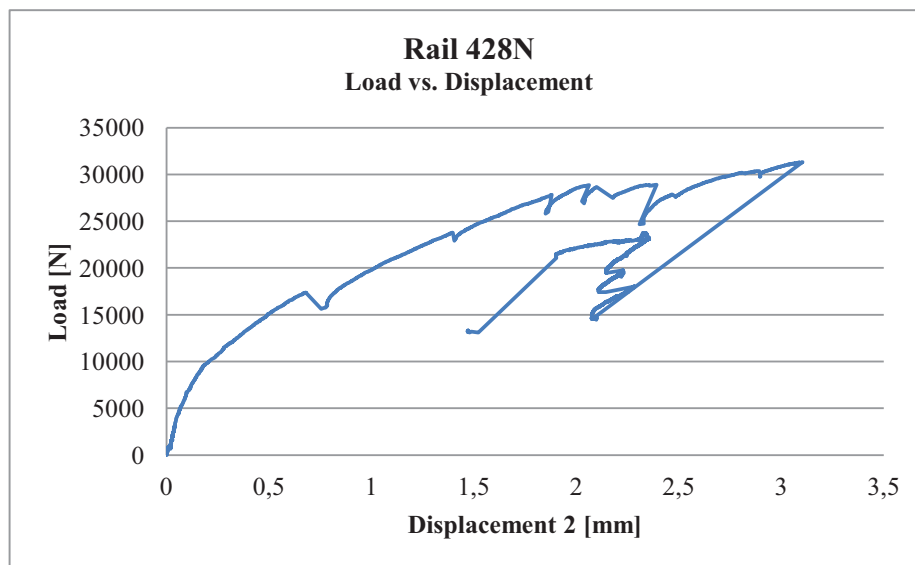
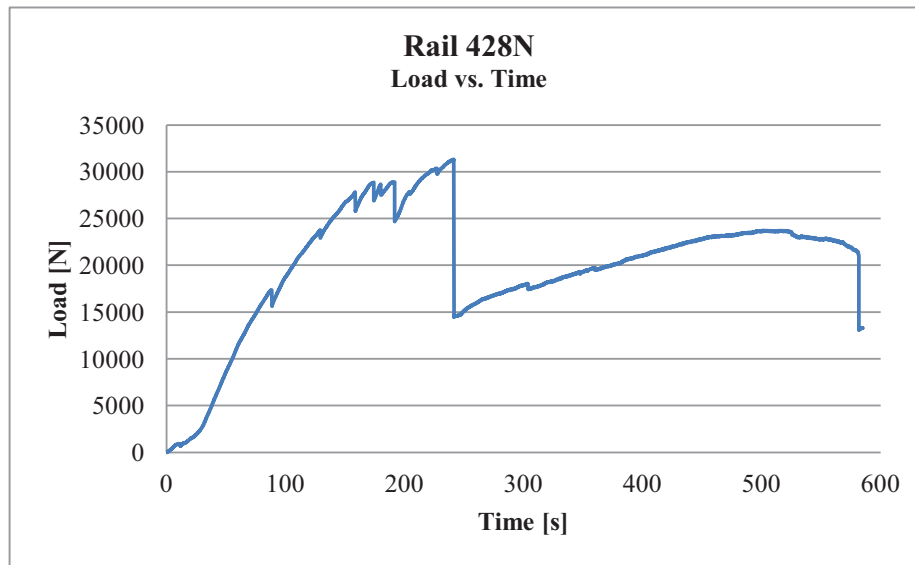
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	26069
Displacement 1 at failure [mm]	-0,02
Displacement 2 at failure [mm]	1,47
Distance from crack to edge side 1 [mm]	47
Distance from crack to edge side 2 [mm]	55
Distance from crack to anchor bolt side 1 [mm]	52
Distance from crack to anchor bolt side 2 [mm]	54
Moisture [%]	13,9
Dry density [kg/m ³]	432



Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	26334
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	1,37
Distance from crack to edge side 1 [mm]	66
Distance from crack to edge side 2 [mm]	32
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	42
Moisture [%]	12,9
Dry density [kg/m ³]	409

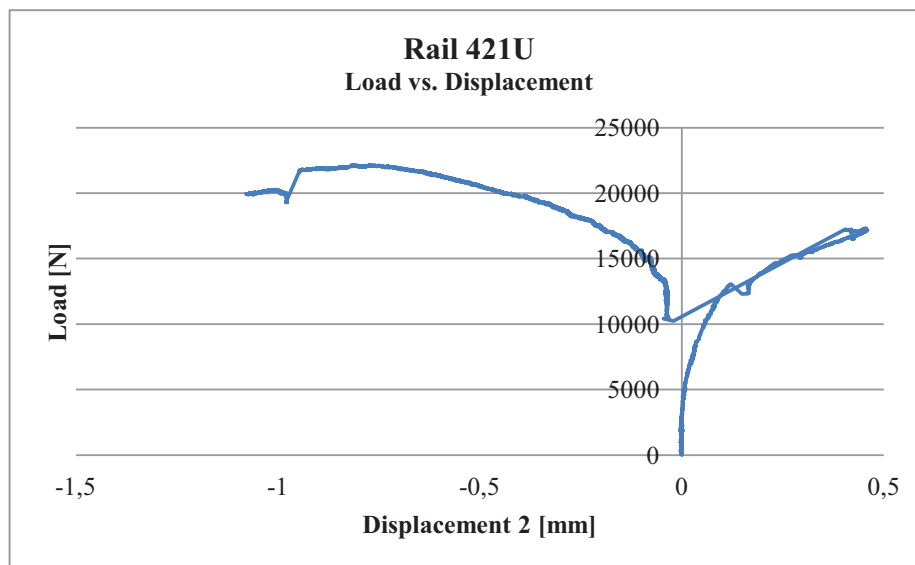
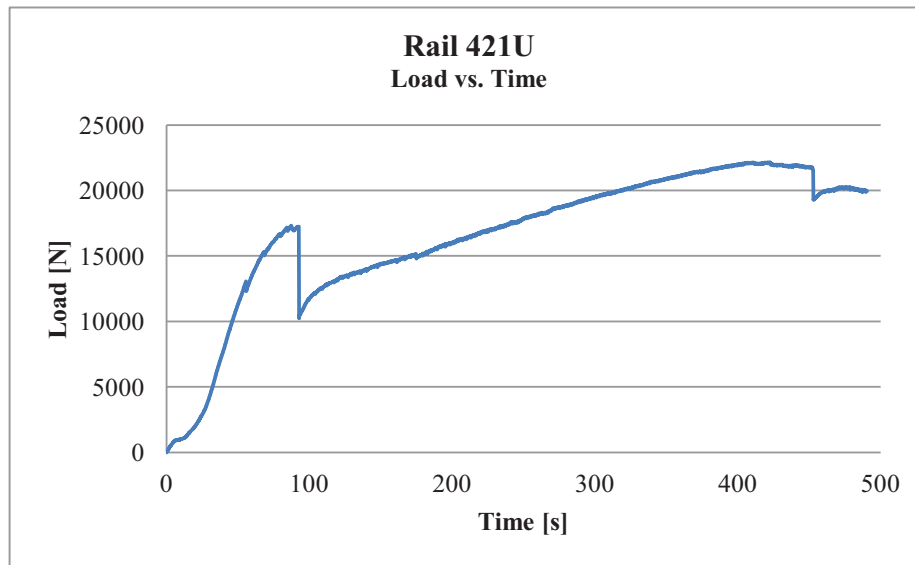


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	27485
Displacement 1 at failure [mm]	0,07
Displacement 2 at failure [mm]	2,03
Distance from crack to edge side 1 [mm]	59
Distance from crack to edge side 2 [mm]	50
Distance from crack to anchor bolt side 1 [mm]	55
Distance from crack to anchor bolt side 2 [mm]	42
Moisture [%]	12,0
Dry density [kg/m ³]	389



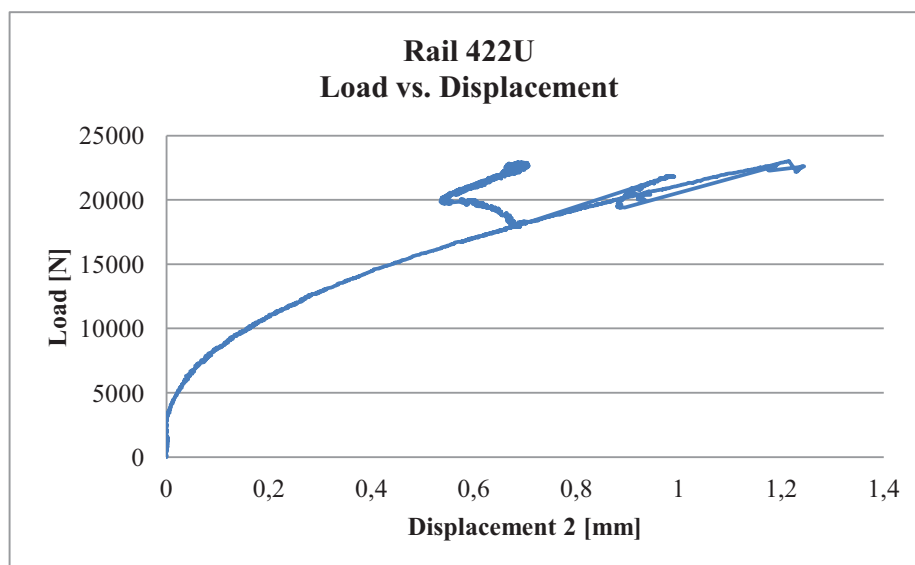
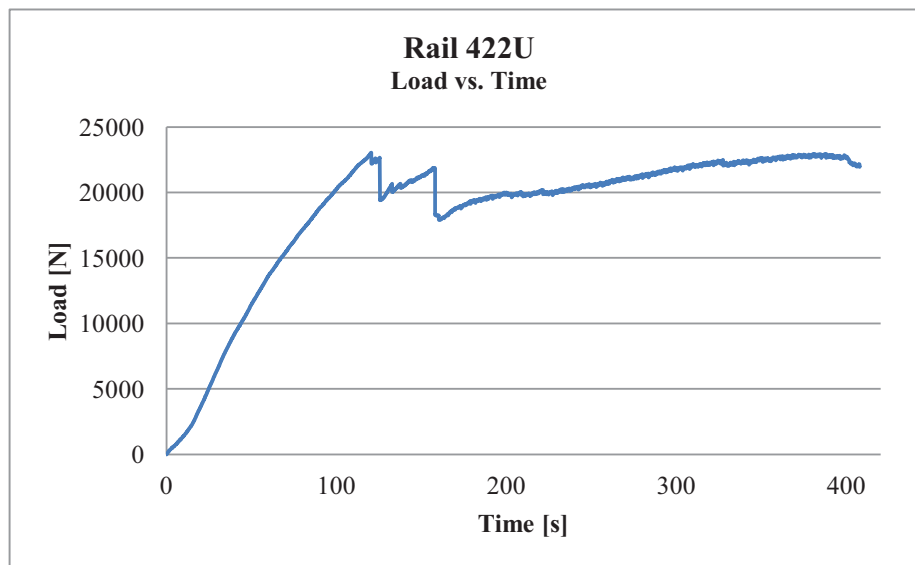
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	31310
Displacement 1 at failure [mm]	0,05
Displacement 2 at failure [mm]	3,10
Distance from crack to edge side 1 [mm]	85
Distance from crack to edge side 2 [mm]	55
Distance from crack to anchor bolt side 1 [mm]	82
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,5
Dry density [kg/m ³]	450

Pith Up

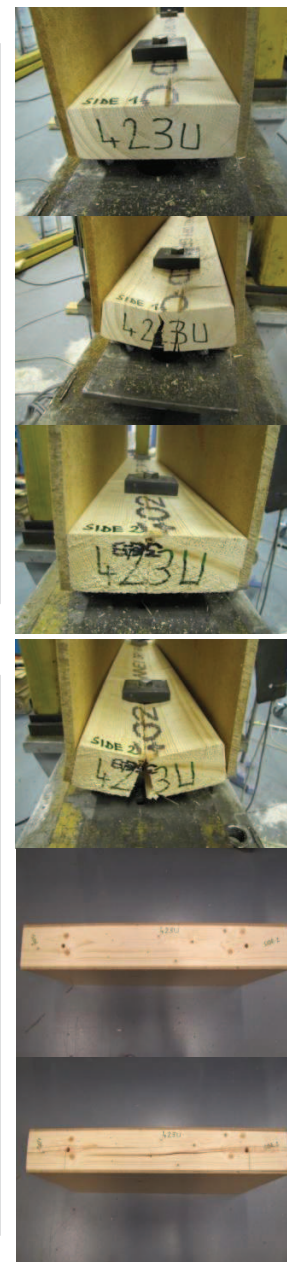
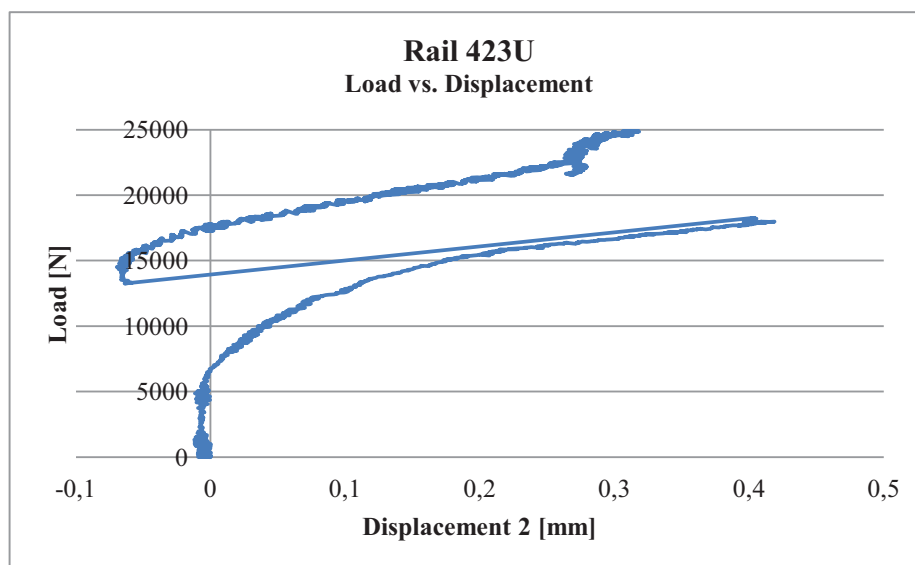
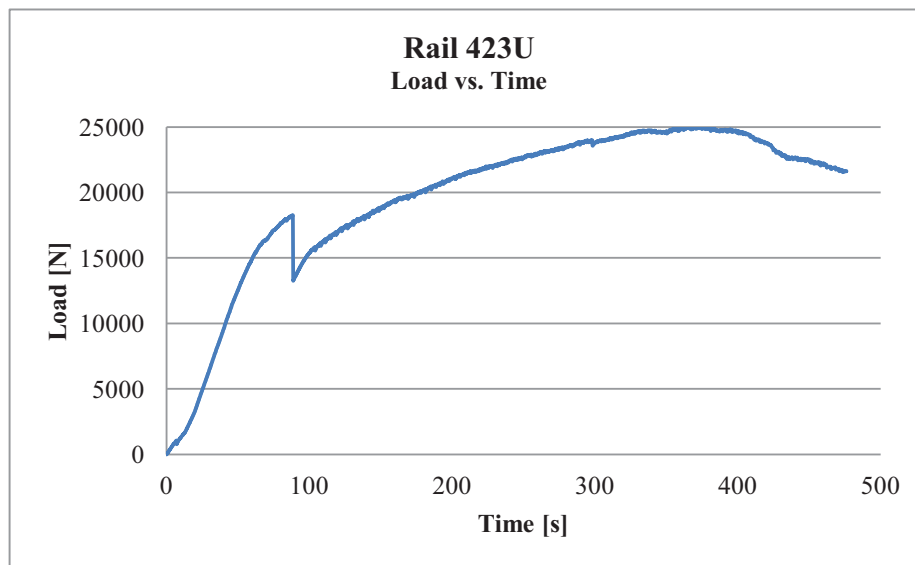


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	17315
Displacement 1 at failure [mm]	-0,02
Displacement 2 at failure [mm]	0,46
Distance from crack to edge side 1 [mm]	62
Distance from crack to edge side 2 [mm]	57
Distance from crack to anchor bolt side 1 [mm]	62
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,9
Dry density [kg/m ³]	390

Probable problem not visible in the rail, because the failure load is under the average.

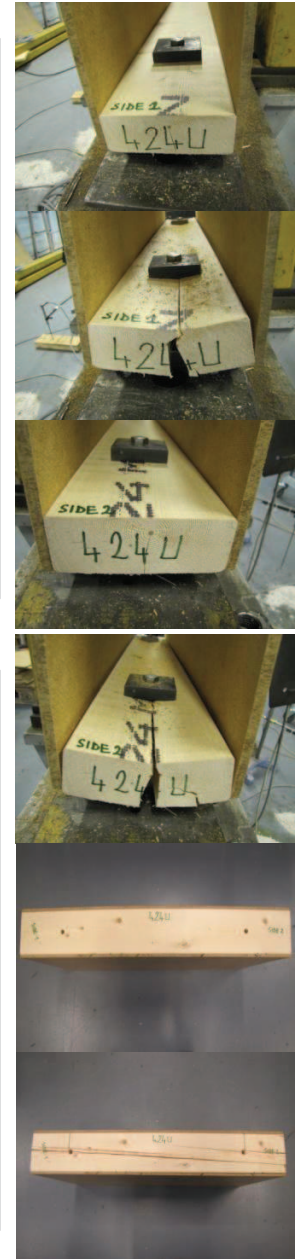
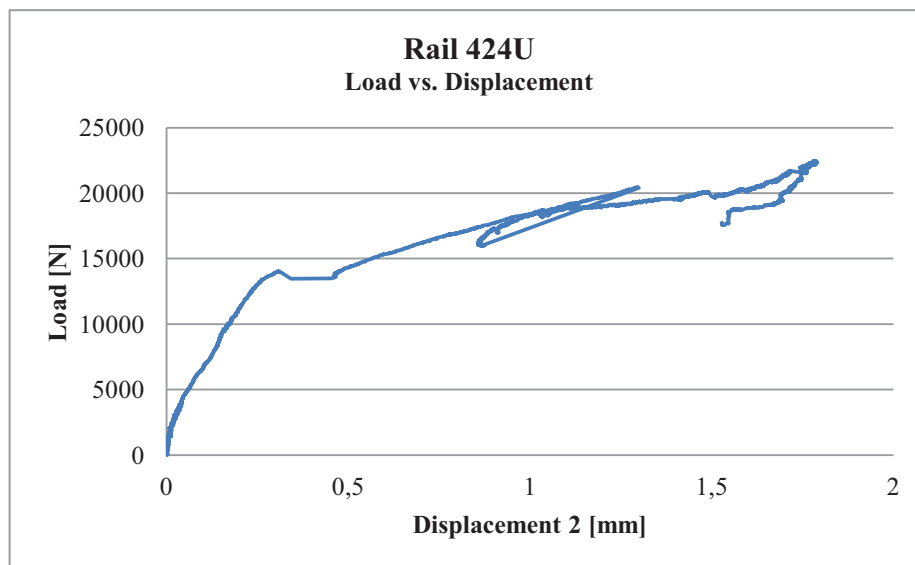
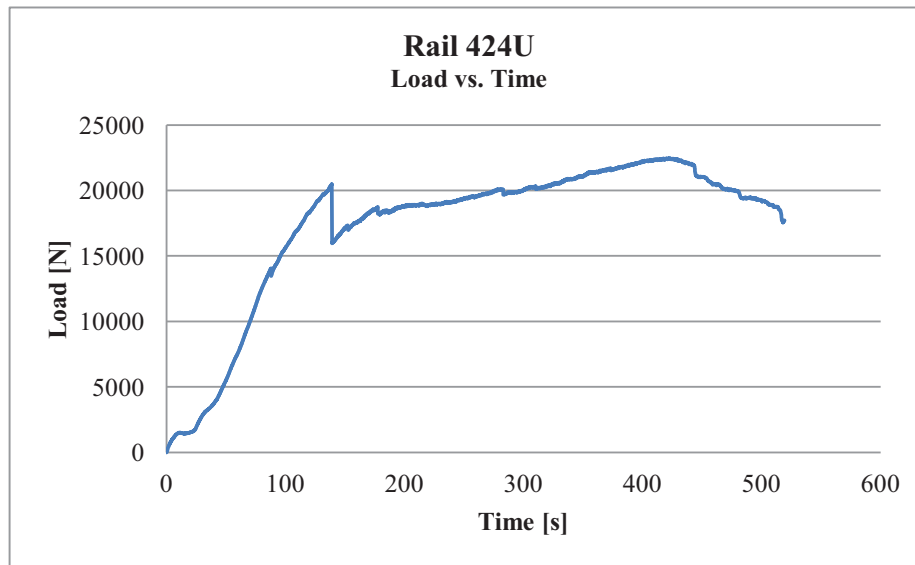


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	23037
Displacement 1 at failure [mm]	0,07
Displacement 2 at failure [mm]	1,21
Distance from crack to edge side 1 [mm]	64
Distance from crack to edge side 2 [mm]	55
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	11,0
Dry density [kg/m ³]	390



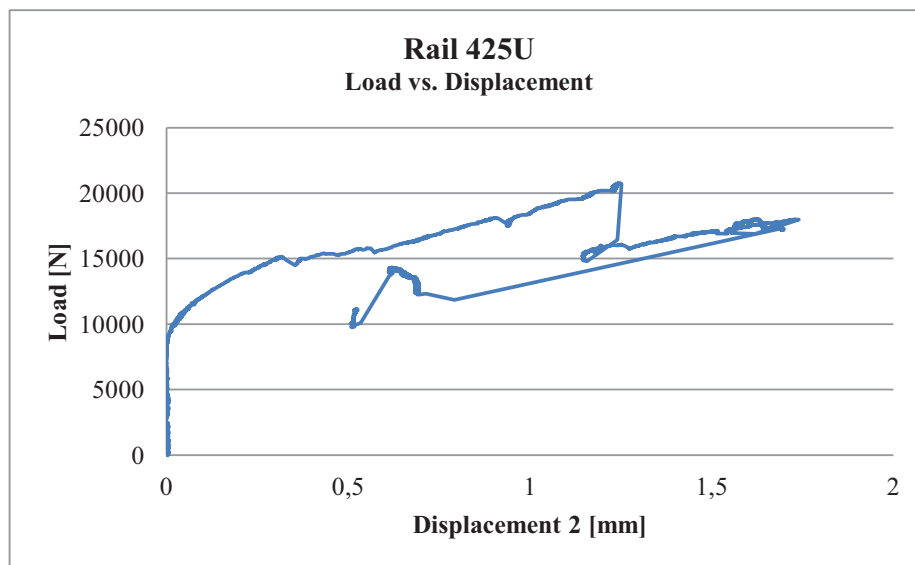
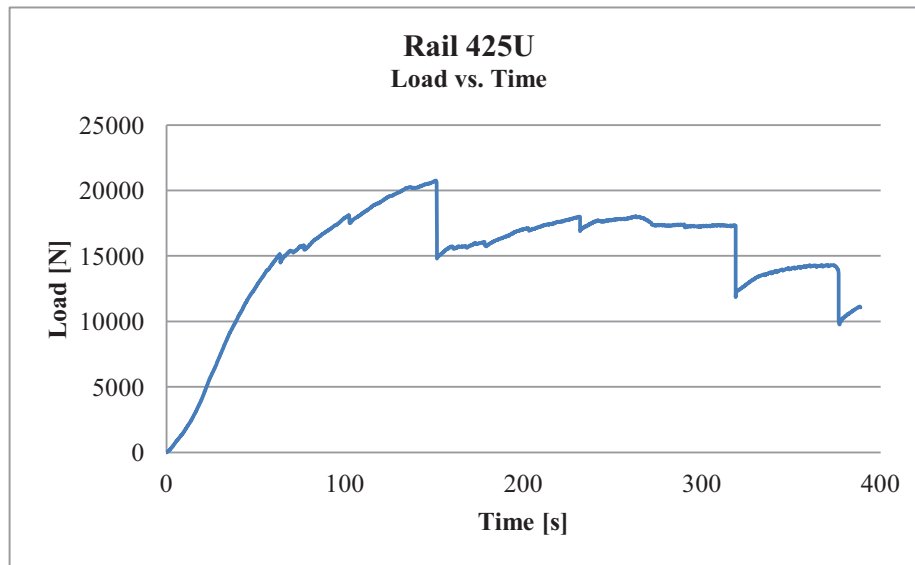
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	18253
Displacement 1 at failure [mm]	-0,02
Displacement 2 at failure [mm]	0,40
Distance from crack to edge side 1 [mm]	53
Distance from crack to edge side 2 [mm]	69
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	58
Moisture [%]	11,9
Dry density [kg/m ³]	377

Pre-crack on the side 2 by tightening the bolt. This had considerable influence in the test.



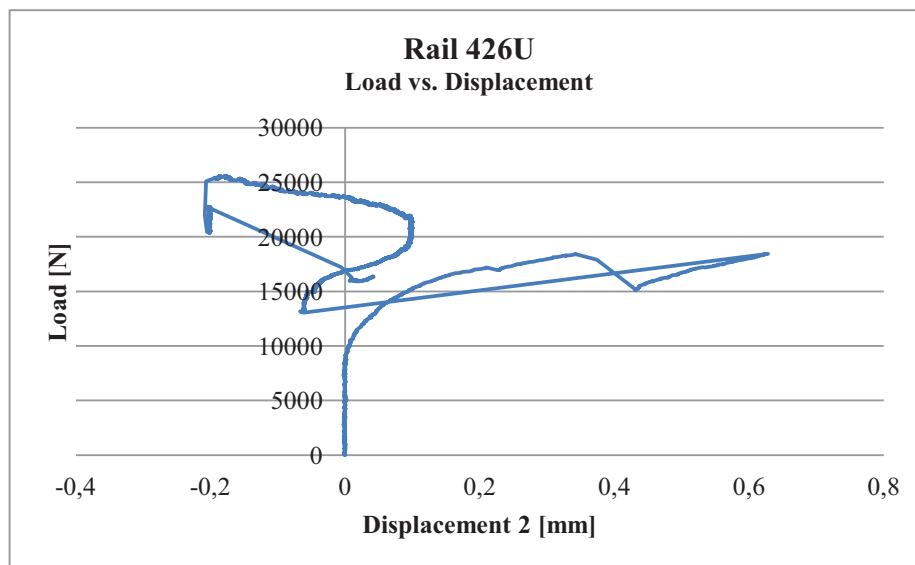
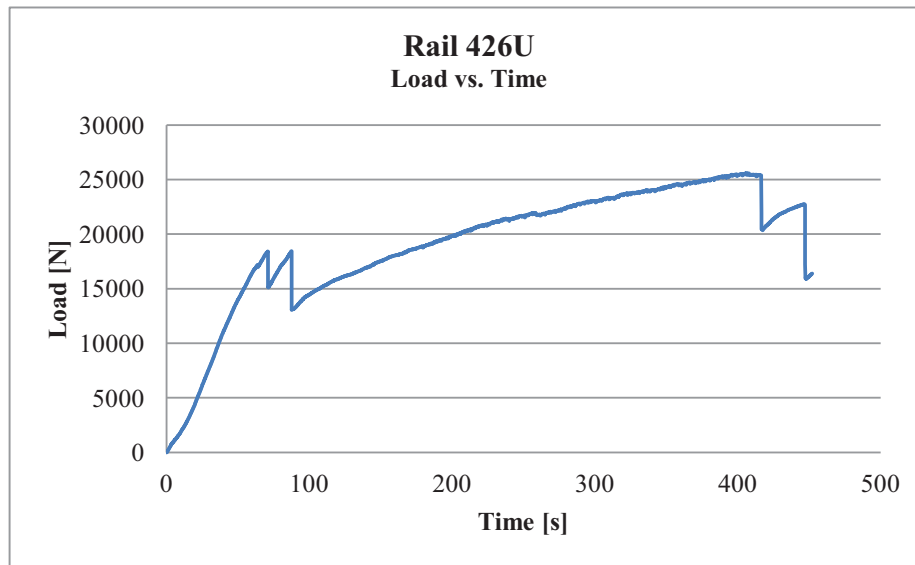
Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	20464
Displacement 1 at failure [mm]	-0,01
Displacement 2 at failure [mm]	1,30
Distance from crack to edge side 1 [mm]	67
Distance from crack to edge side 2 [mm]	60
Distance from crack to anchor bolt side 1 [mm]	63
Distance from crack to anchor bolt side 2 [mm]	68
Moisture [%]	12,2
Dry density [kg/m ³]	375

Pre-crack on both sides.



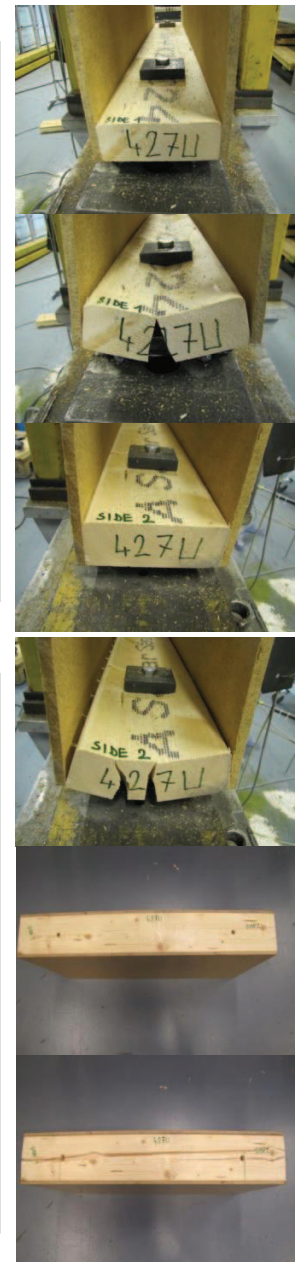
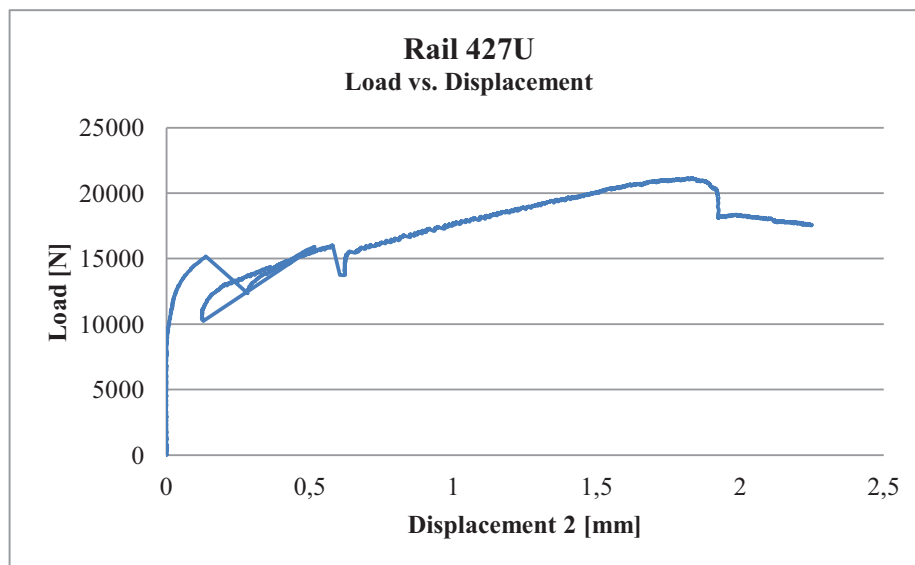
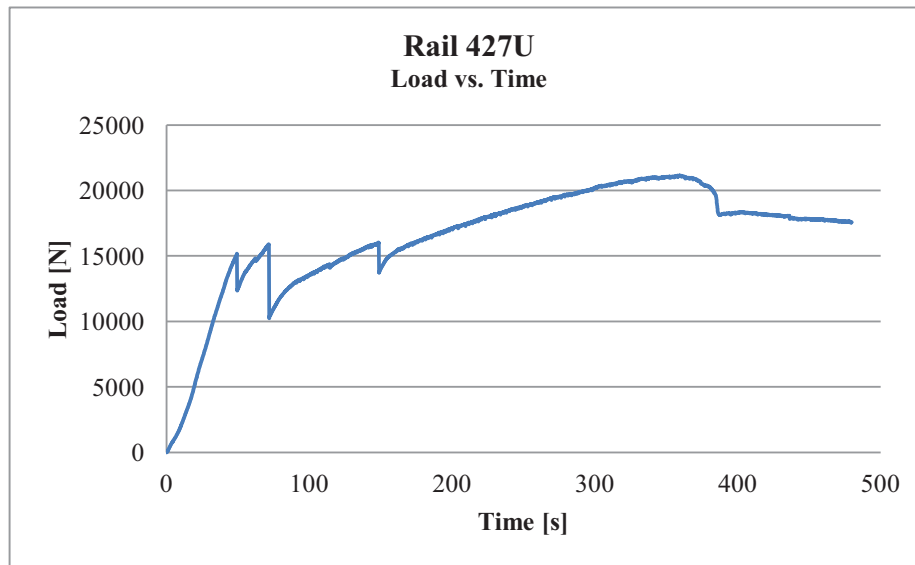
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	20768
Displacement 1 at failure [mm]	-0,11
Displacement 2 at failure [mm]	1,25
Distance from crack to edge side 1 [mm]	75
Distance from crack to edge side 2 [mm]	104
Distance from crack to anchor bolt side 1 [mm]	81
Distance from crack to anchor bolt side 2 [mm]	102
Moisture [%]	12,9
Dry density [kg/m ³]	404

Pre-crack on the side 1. The crack started immediately from the side 1 until the side 2.

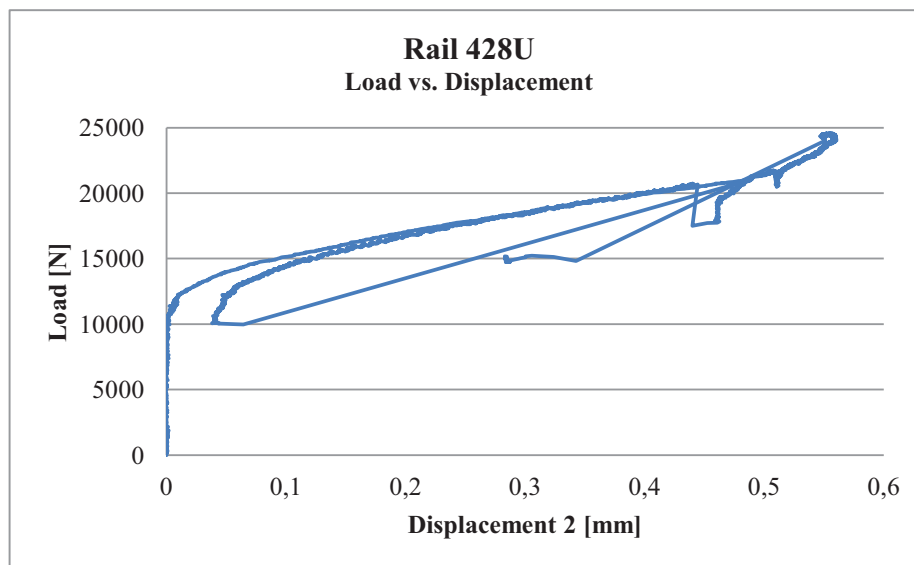
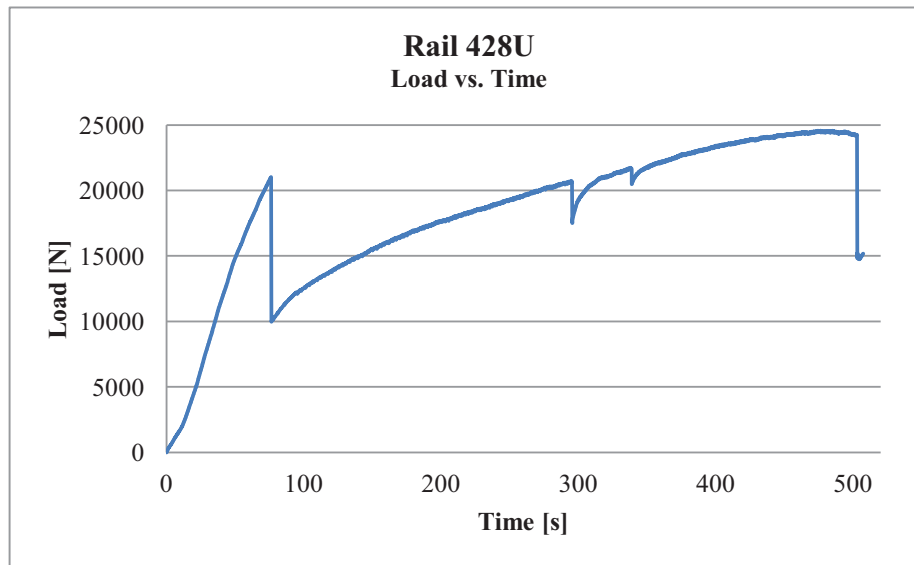


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	18409
Displacement 1 at failure [mm]	-0,01
Displacement 2 at failure [mm]	0,34
Distance from crack to edge side 1 [mm]	44 (<i>pre-crack</i>) – 56 (<i>failure crack</i>)
Distance from crack to edge side 2 [mm]	62
Distance from crack to anchor bolt side 1 [mm]	48 (<i>pre-crack</i>) – 61 (<i>failure crack</i>)
Distance from crack to anchor bolt side 2 [mm]	58
Moisture [%]	13,5
Dry density [kg/m ³]	437

First crack started from the pre-crack on the side 1 but after another crack line happened.



Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	15180
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	0,45
Distance from crack to edge side 1 [mm]	57
Distance from crack to edge side 2 [mm]	80
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	76
Moisture [%]	13,3
Dry density [kg/m ³]	550

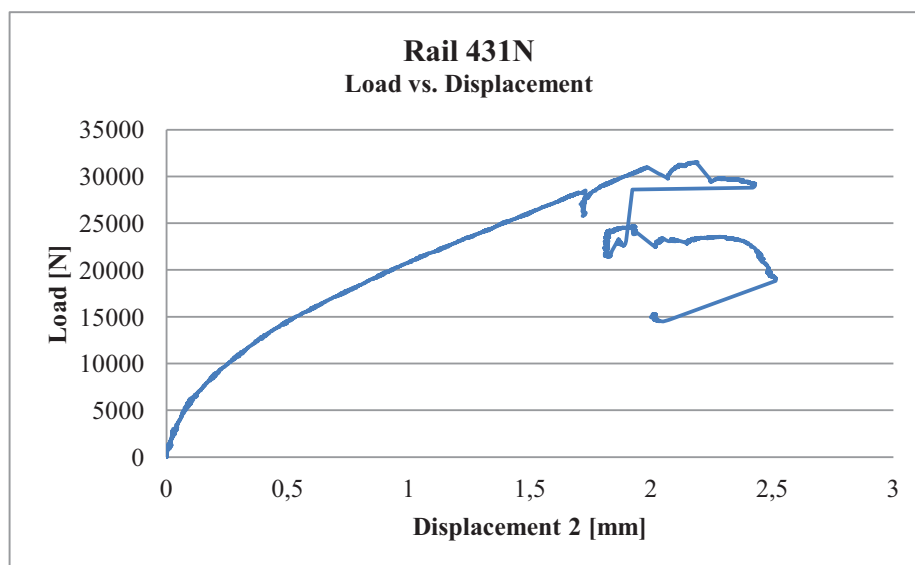
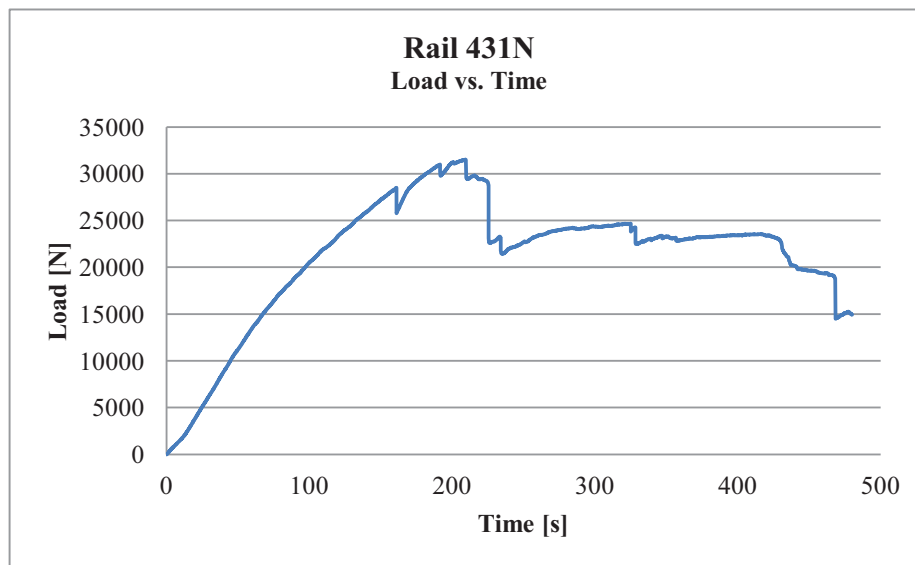


Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	21019
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	0,49
Distance from crack to edge side 1 [mm]	58
Distance from crack to edge side 2 [mm]	60
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	59
Moisture [%]	12,7
Dry density [kg/m ³]	471

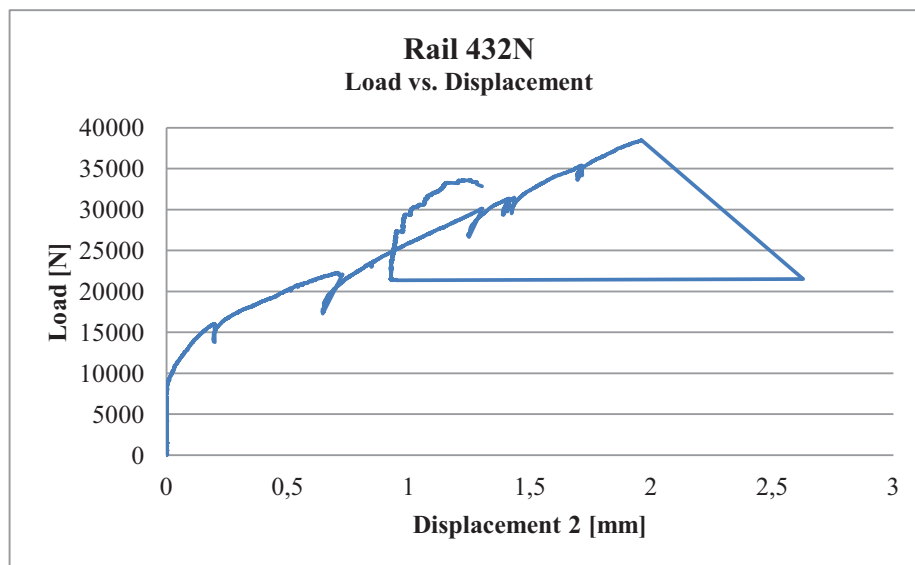
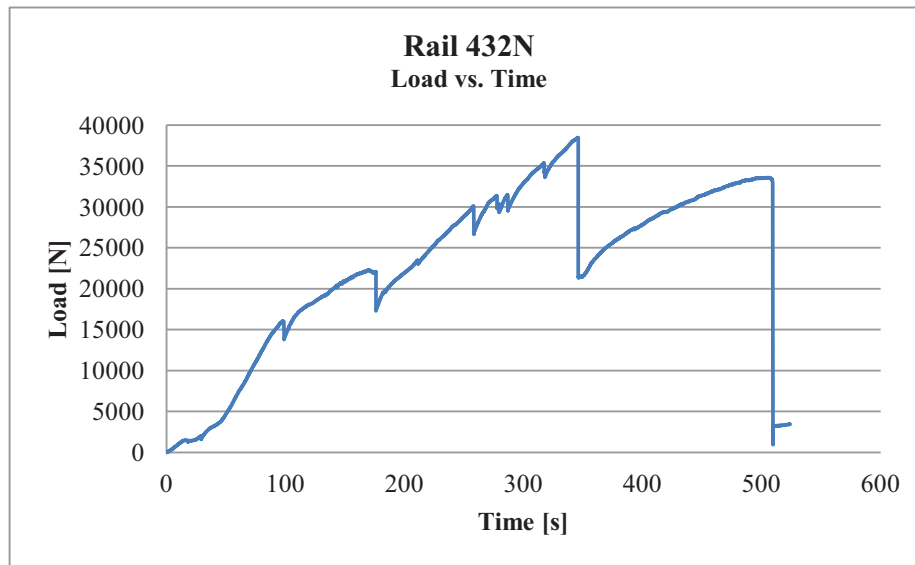
Possible pre-crack on both sides but they seem do not have any influence on the test.

Set 3 – Size of washer 80x70 mm

Pith Down

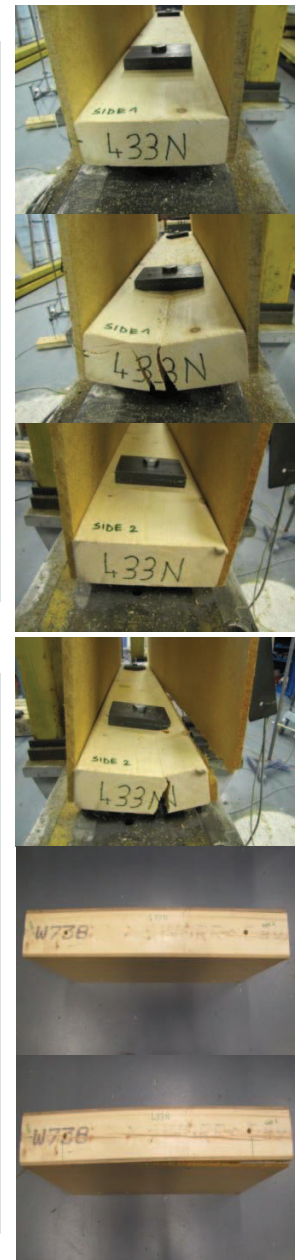
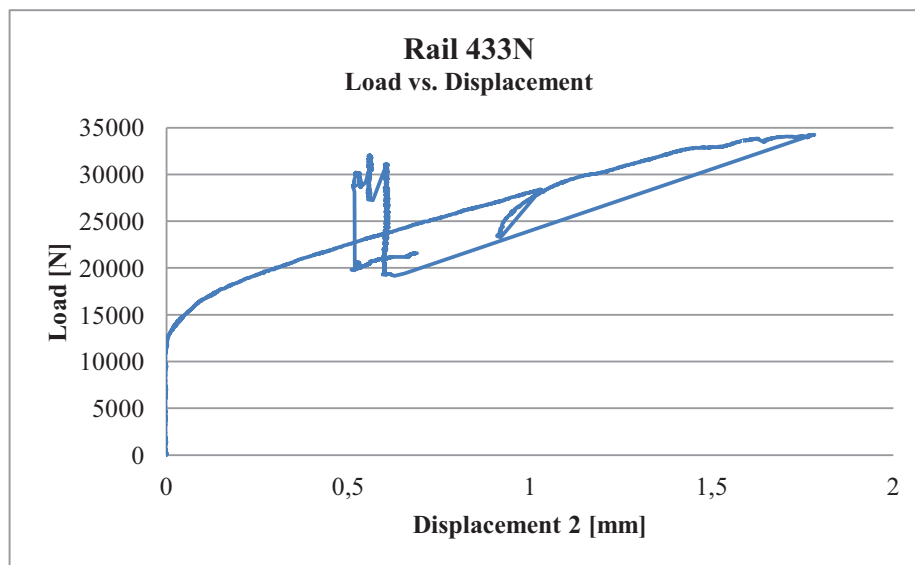
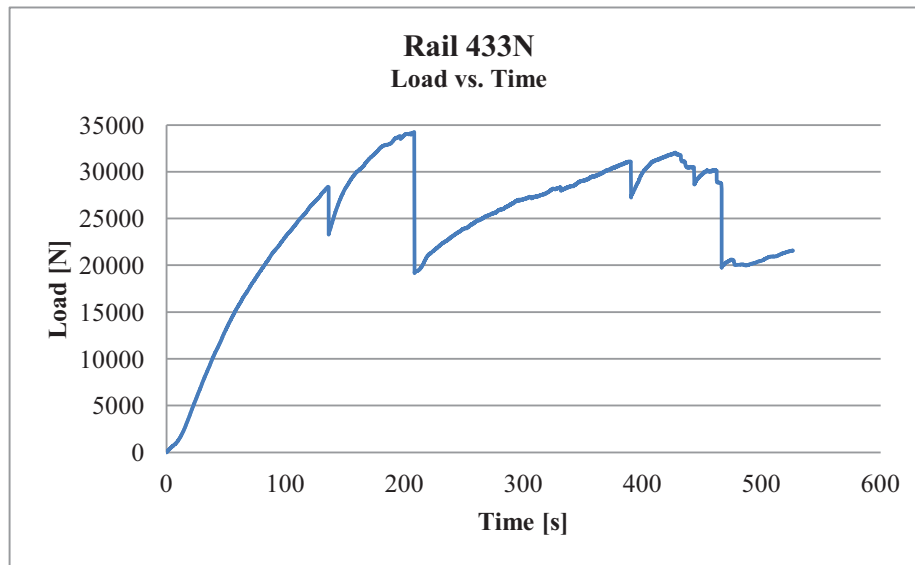


Type of failure	Failure 2 – 1 st crack at side 1
Failure load [N]	31530
Displacement 1 at failure [mm]	0,14
Displacement 2 at failure [mm]	2,19
Moisture [%]	14,5
Dry density [kg/m ³]	455

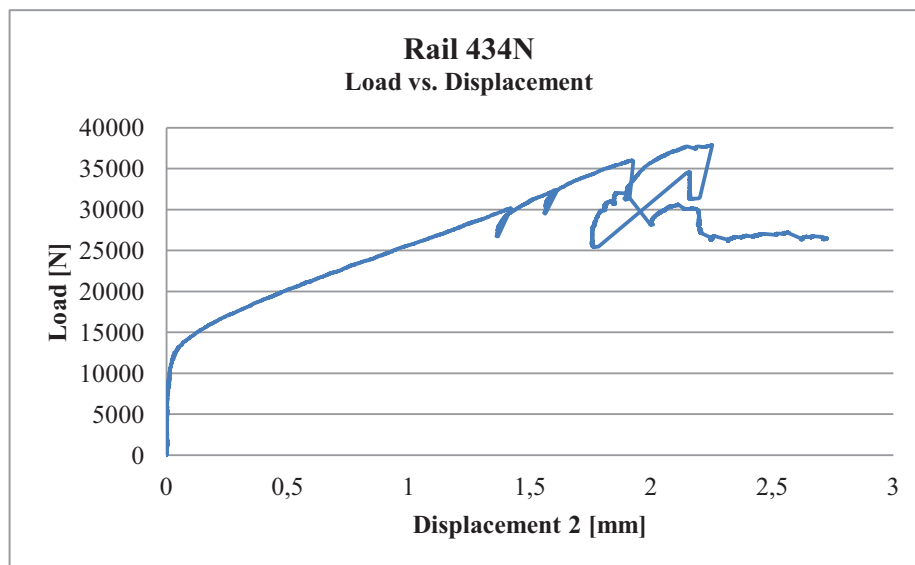
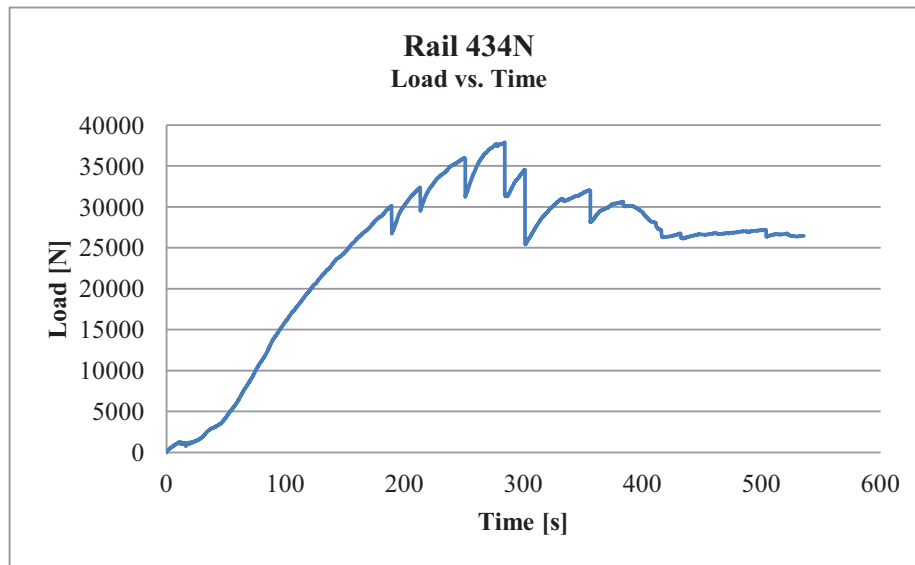


Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	38469
Displacement 1 at failure [mm]	-0,01
Displacement 2 at failure [mm]	1,96
Distance from crack to edge side 1 [mm]	89
Distance from crack to edge side 2 [mm]	50
Distance from crack to anchor bolt side 1 [mm]	85
Distance from crack to anchor bolt side 2 [mm]	62
Moisture [%]	14,4
Dry density [kg/m ³]	450

The cracks before the failure at 38 kN are movement of the rail. Anchor bolt failure at 33 kN.

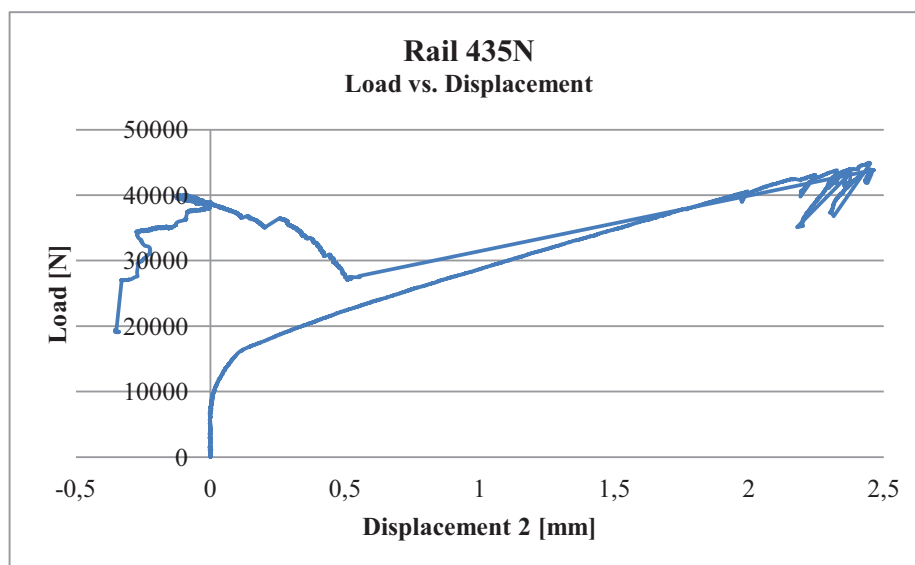
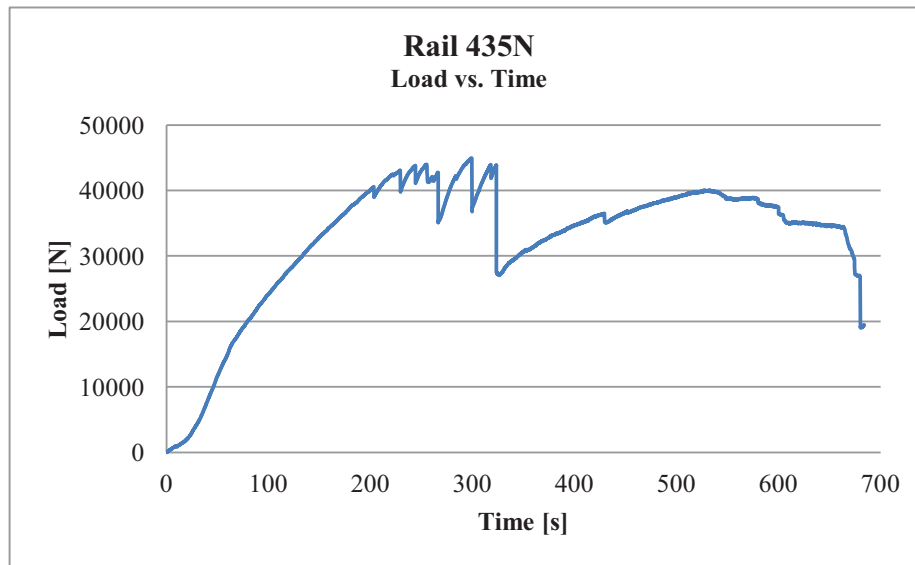


Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	28381
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	1,03
Distance from crack to edge side 1 [mm]	54
Distance from crack to edge side 2 [mm]	44
Distance from crack to anchor bolt side 1 [mm]	54
Distance from crack to anchor bolt side 2 [mm]	48
Moisture [%]	12,3
Dry density [kg/m ³]	394

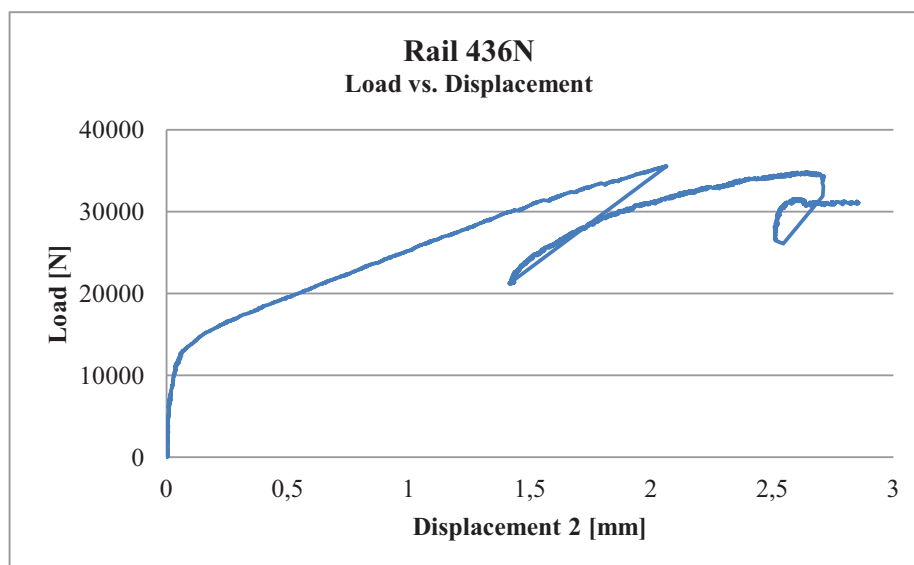
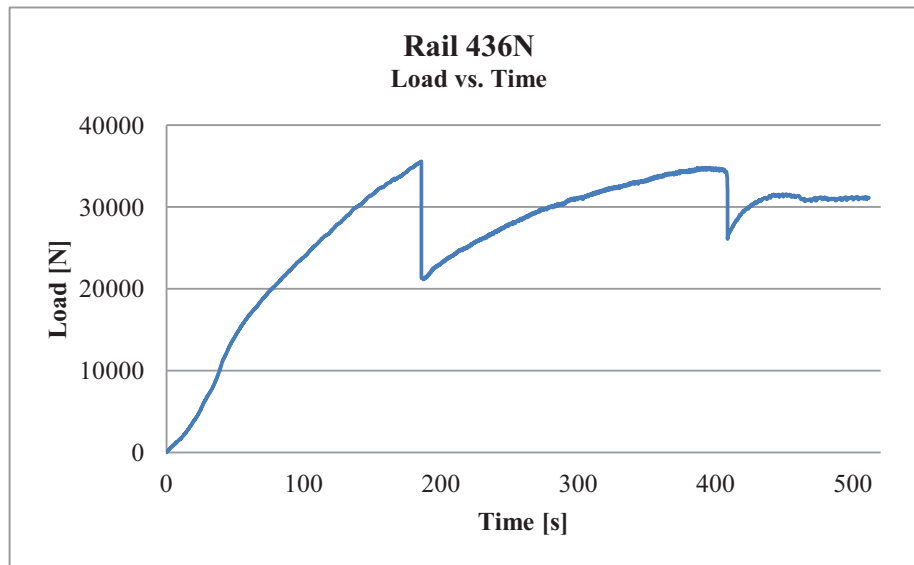


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	37884
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	2,25
Distance from crack to edge side 1 [mm]	19
Distance from crack to edge side 2 [mm]	14
Distance from crack to anchor bolt side 1 [mm]	18
Distance from crack to anchor bolt side 2 [mm]	16
Moisture [%]	12,9
Dry density [kg/m ³]	421

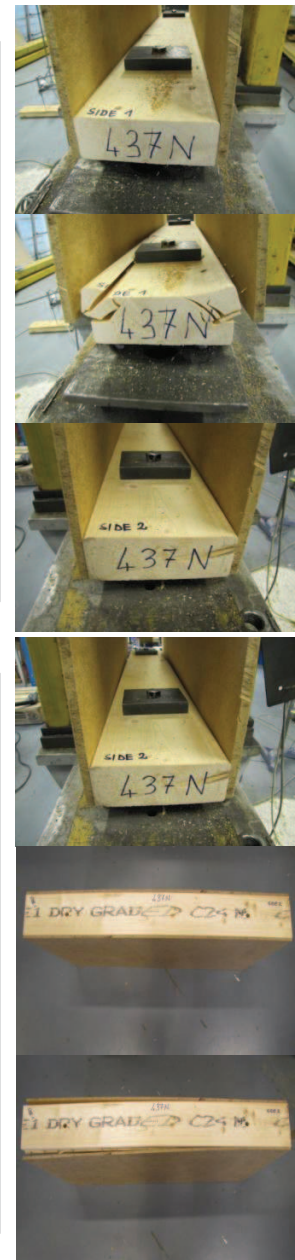
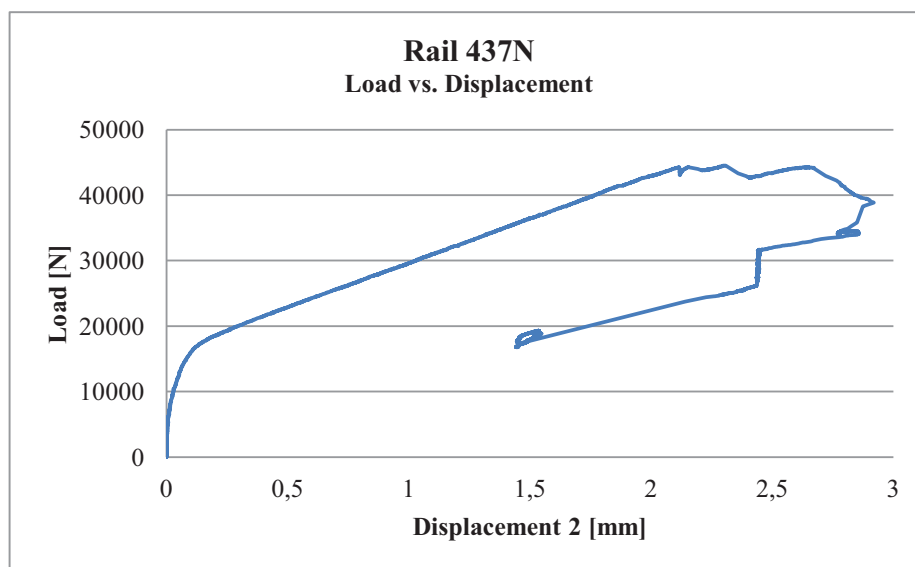
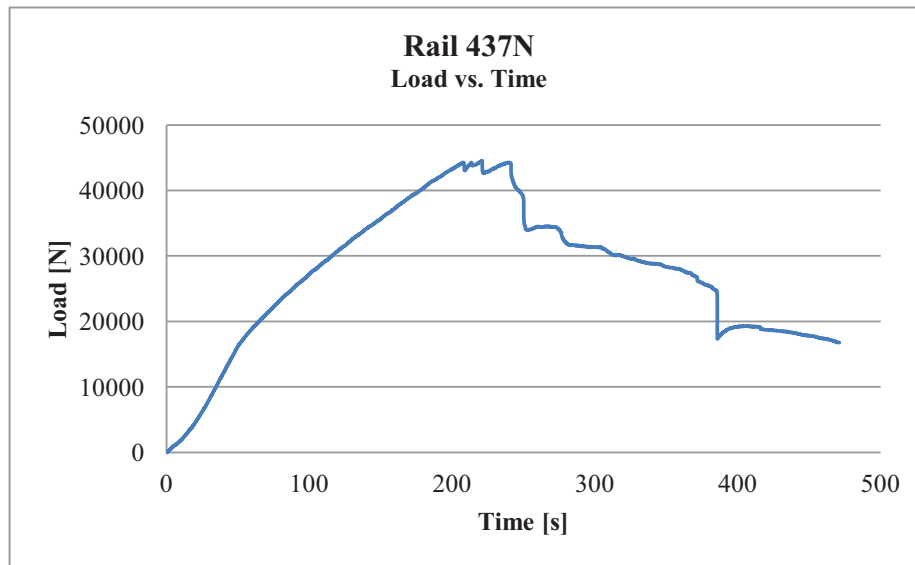
The cracks before the failure at 37 kN are movement of the rail.



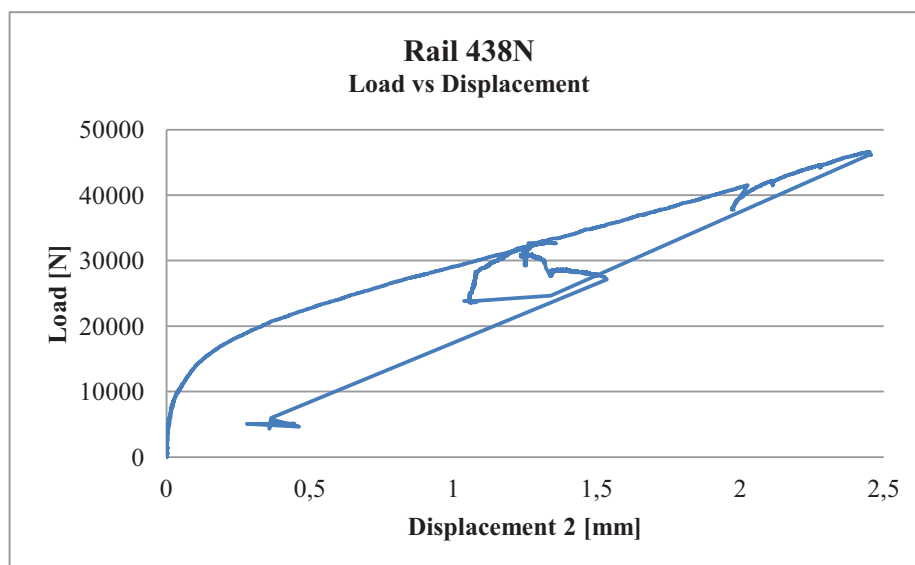
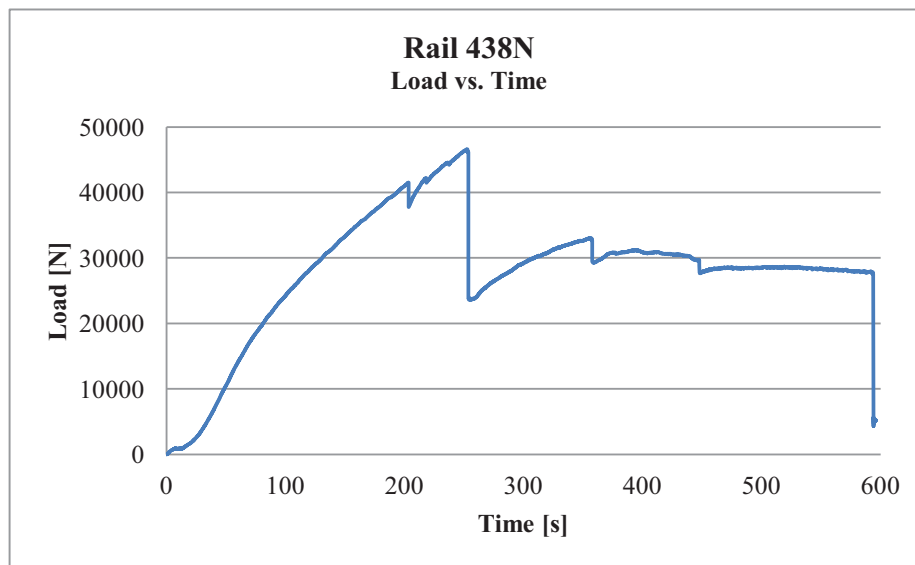
Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	43987
Displacement 1 at failure [mm]	0,06
Displacement 2 at failure [mm]	2,37
Distance from crack to edge side 1 [mm]	65
Distance from crack to edge side 2 [mm]	39
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	50
Moisture [%]	11,7
Dry density [kg/m ³]	449



Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	35521
Displacement 1 at failure [mm]	0,03
Displacement 2 at failure [mm]	2,06
Distance from crack to edge side 1 [mm]	80
Distance from crack to edge side 2 [mm]	64
Distance from crack to anchor bolt side 1 [mm]	74
Distance from crack to anchor bolt side 2 [mm]	72
Moisture [%]	13,6
Dry density [kg/m ³]	378

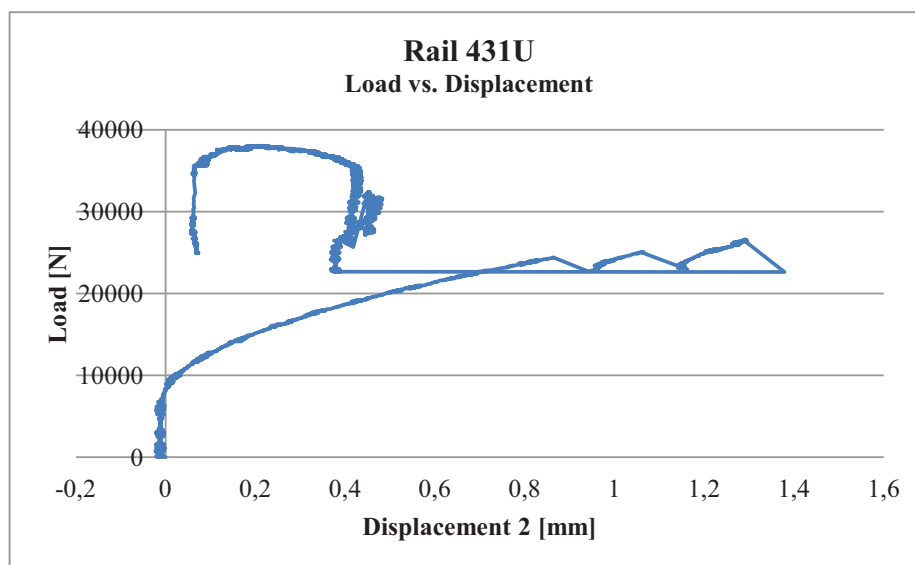
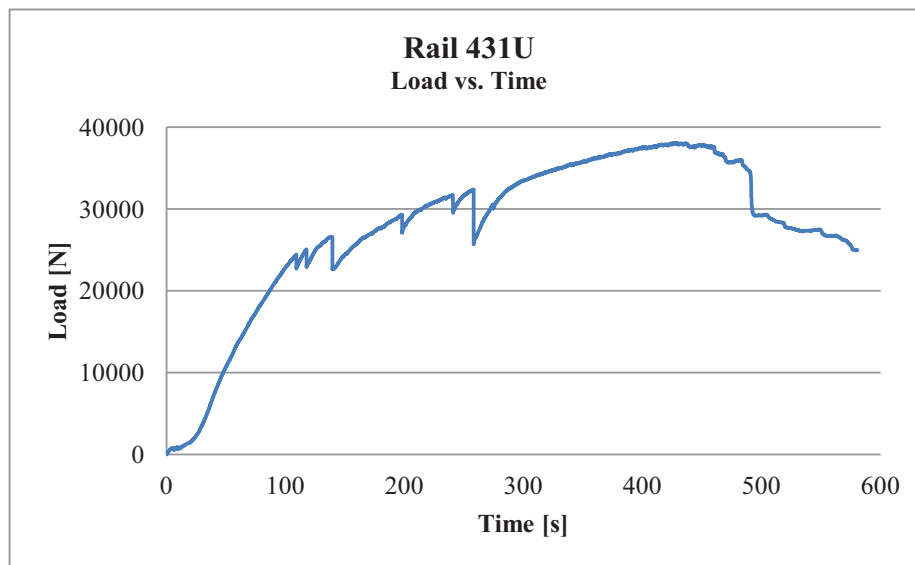


Type of failure	Failure 2 – 1 st crack at side 1
Failure load [N]	44512
Displacement 1 at failure [mm]	0,20
Displacement 2 at failure [mm]	2,31
Moisture [%]	14,3
Dry density [kg/m ³]	526

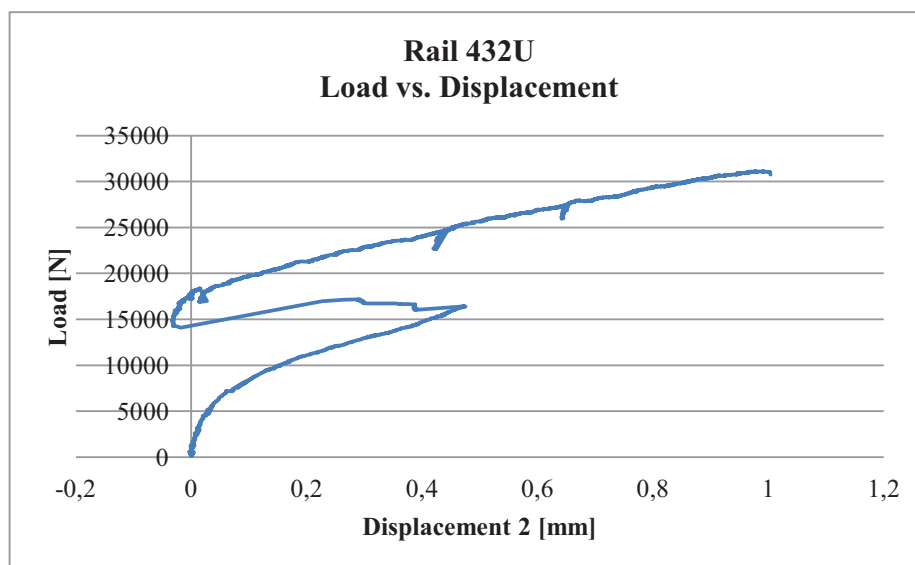
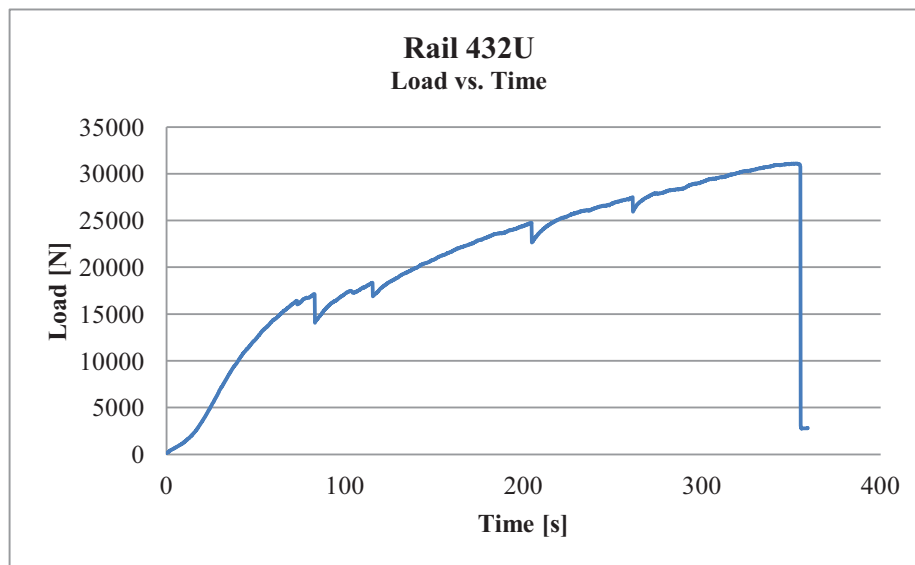


Type of failure	Failure 1 – Instantaneous crack on both sides
Failure load [N]	46611
Displacement 1 at failure [mm]	0,09
Displacement 2 at failure [mm]	2,45
Distance from crack to edge side 1 [mm]	91
Distance from crack to edge side 2 [mm]	69
Distance from crack to anchor bolt side 1 [mm]	88
Distance from crack to anchor bolt side 2 [mm]	77
Moisture [%]	11,4
Dry density [kg/m ³]	454

Pith Up

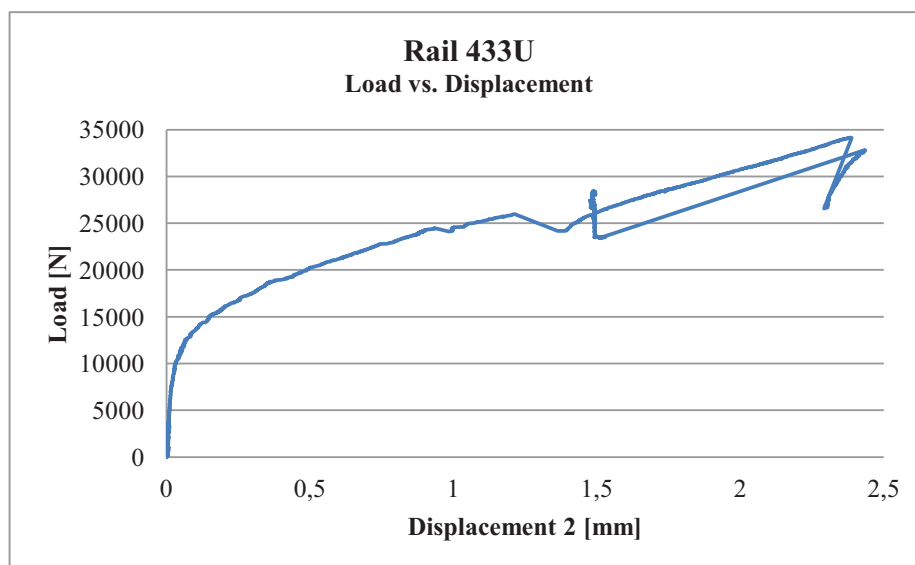
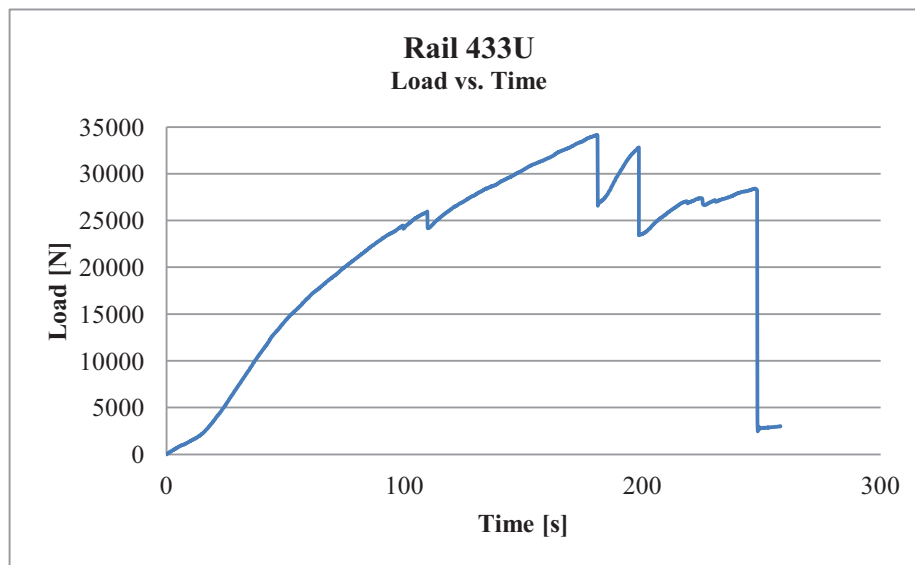


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	26576
Displacement 1 at failure [mm]	0,04
Displacement 2 at failure [mm]	1,29
Distance from crack to edge side 1 [mm]	56
Distance from crack to edge side 2 [mm]	63
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	14,6
Dry density [kg/m ³]	464



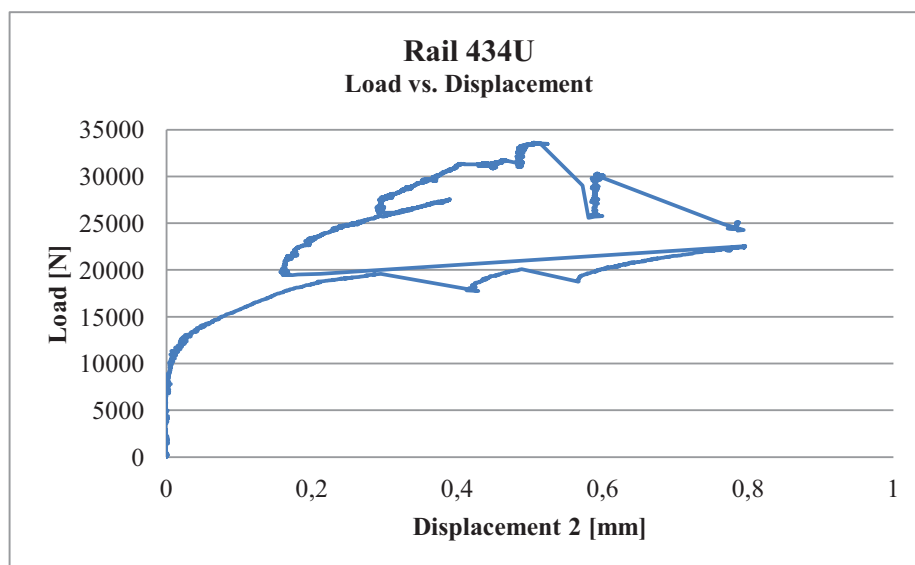
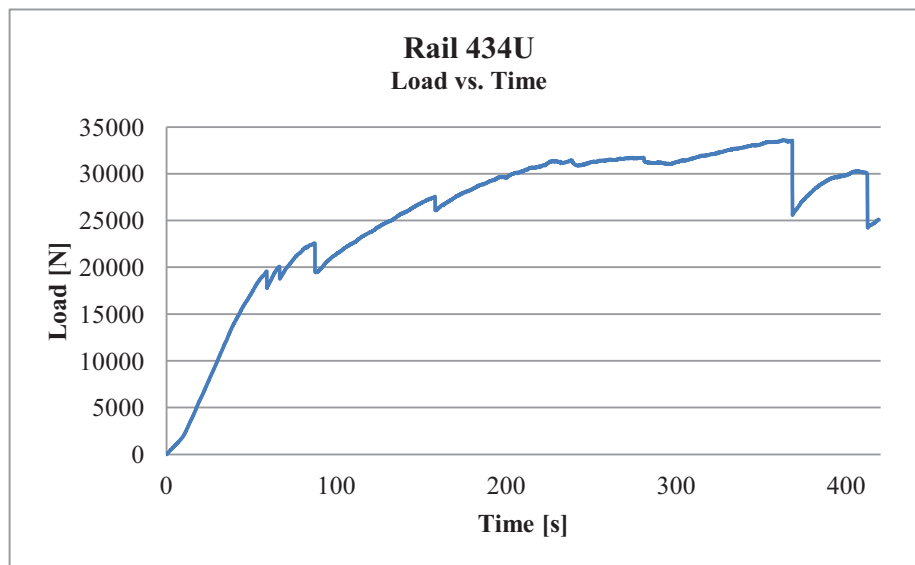
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	17161
Displacement 1 at failure [mm]	-0,04
Displacement 2 at failure [mm]	0,28
Distance from crack to edge side 1 [mm]	55
Distance from crack to edge side 2 [mm]	86
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	81
Moisture [%]	11,8
Dry density [kg/m ³]	394

Pre-crack on the side 1 by tightening the bolt. This had considerable influence in the test.

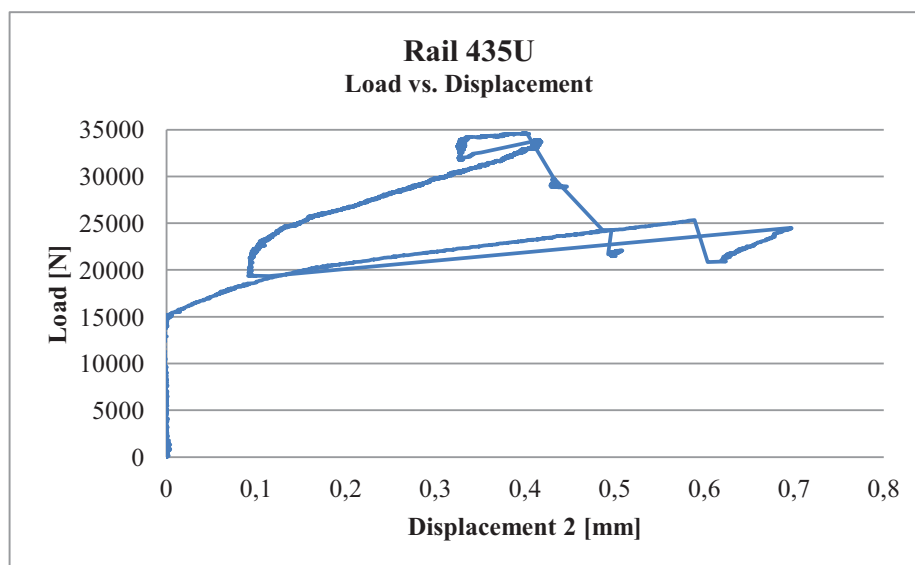
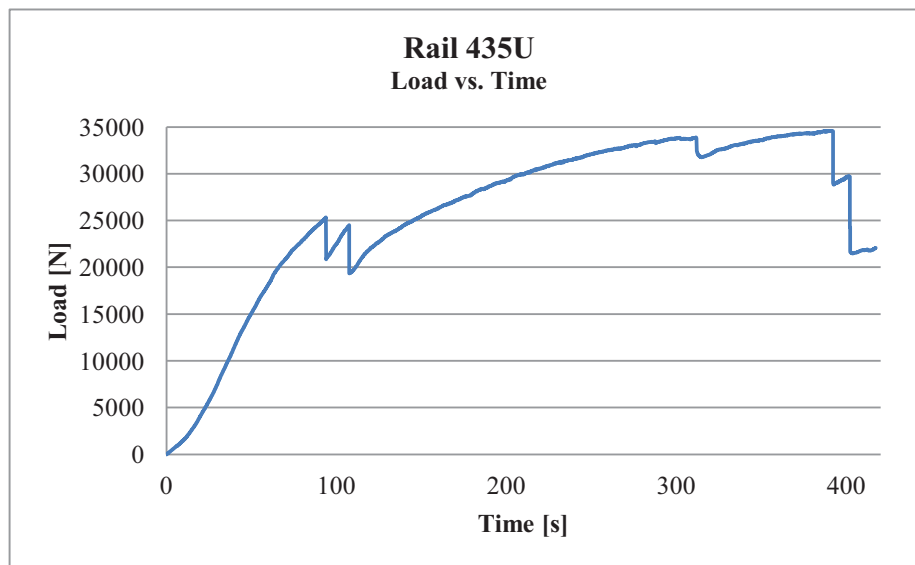


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	34145
Displacement 1 at failure [mm]	0,06
Displacement 2 at failure [mm]	2,38
Distance from crack to edge side 1 [mm]	29
Distance from crack to edge side 2 [mm]	59
Distance from crack to anchor bolt side 1 [mm]	30
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	14,0
Dry density [kg/m ³]	489

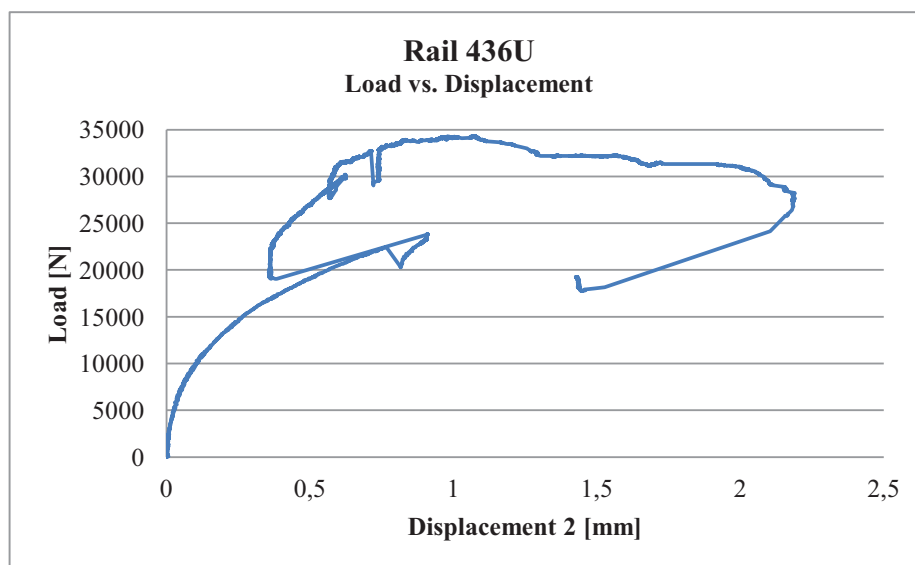
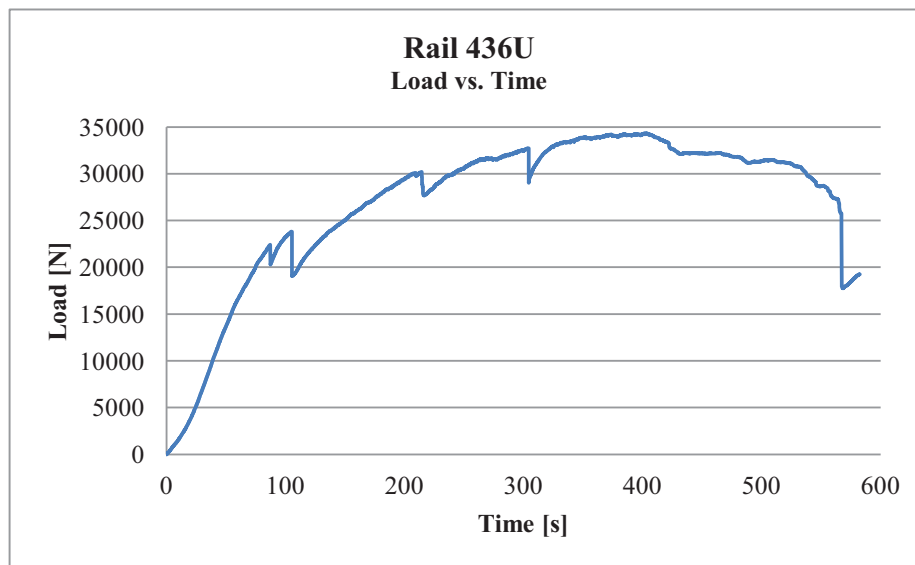
The last crack is caused by the anchor bolt failure on the side 2.



Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	22564
Displacement 1 at failure [mm]	0,01
Displacement 2 at failure [mm]	0,80
Distance from crack to edge side 1 [mm]	54
Distance from crack to edge side 2 [mm]	75
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	71
Moisture [%]	13,1
Dry density [kg/m ³]	425

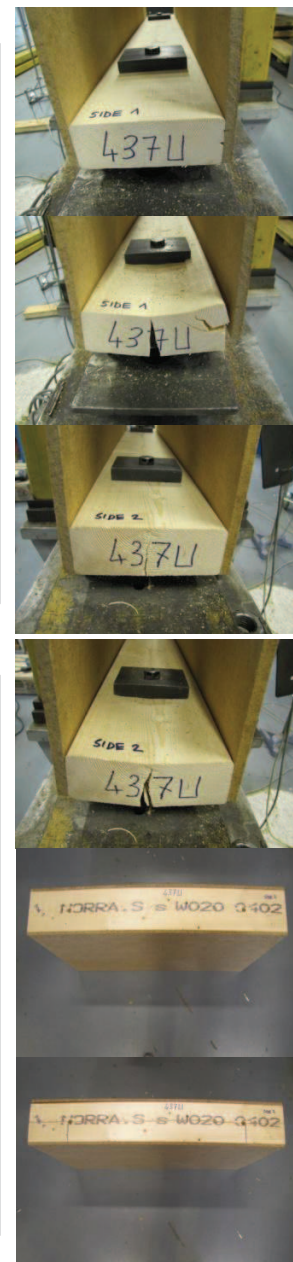
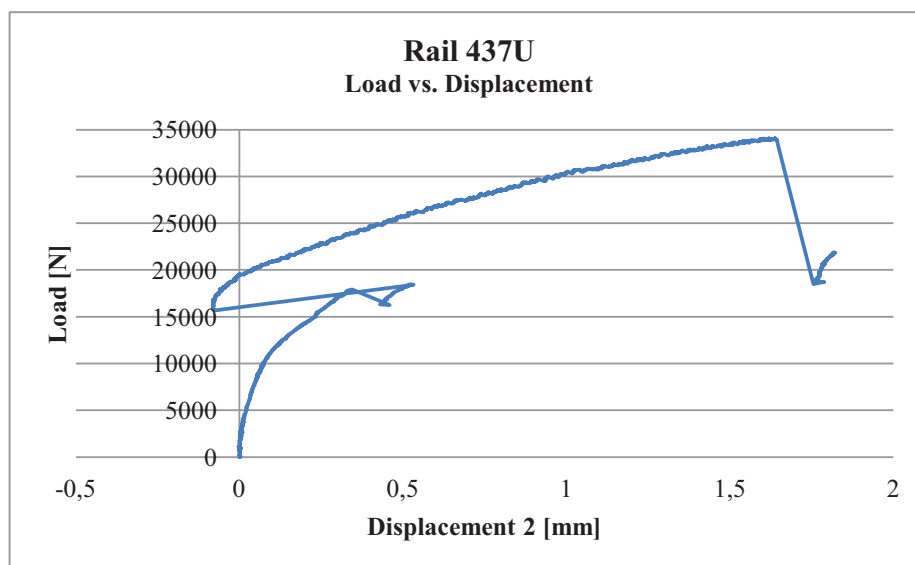
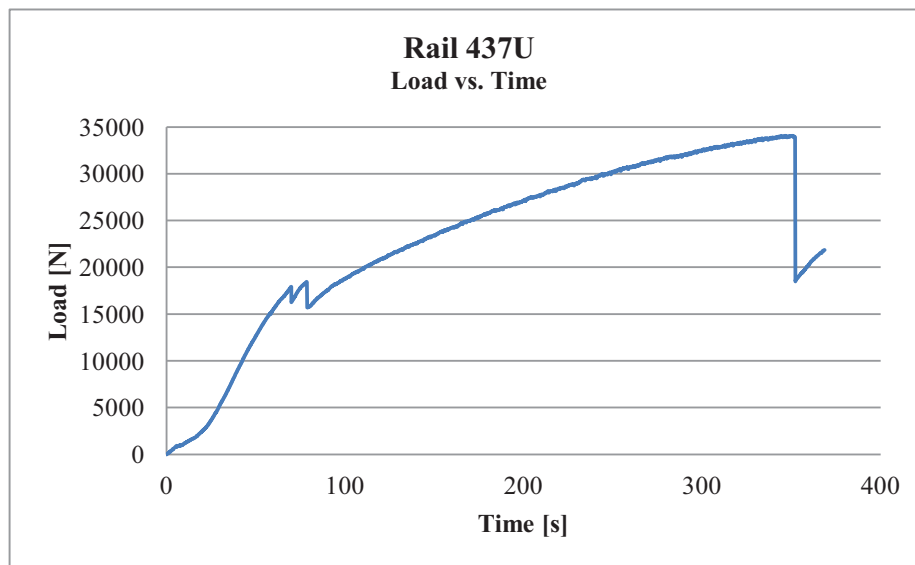


Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	24986
Displacement 1 at failure [mm]	0,03
Displacement 2 at failure [mm]	0,56
Distance from crack to edge side 1 [mm]	57
Distance from crack to edge side 2 [mm]	75
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	72
Moisture [%]	13,2
Dry density [kg/m ³]	411



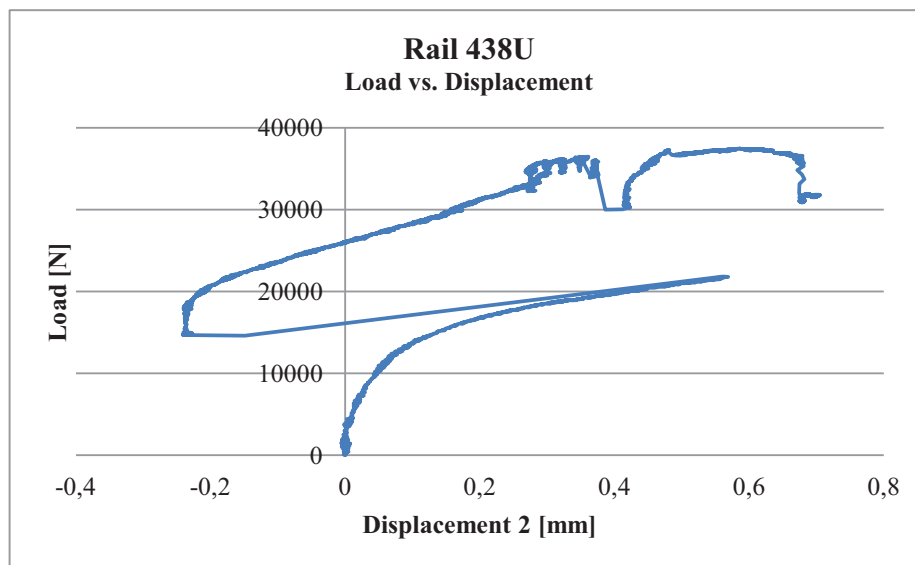
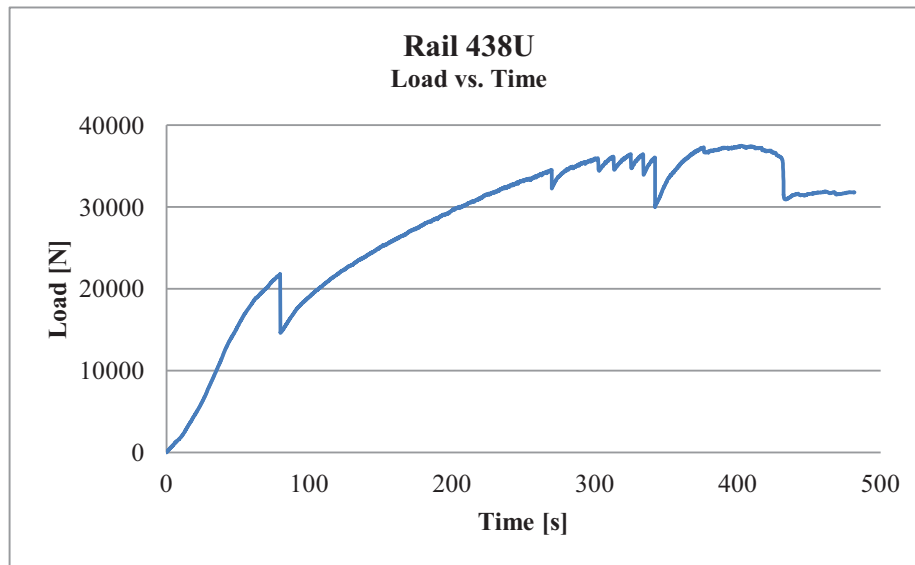
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	23822
Displacement 1 at failure [mm]	0,05
Displacement 2 at failure [mm]	0,91
Distance from crack to edge side 1 [mm]	58
Distance from crack to edge side 2 [mm]	80
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	76
Moisture [%]	-
Dry density [kg/m ³]	-

Due problems with the rail, moisture and density were not measured.



Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	18467
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	0,52
Distance from crack to edge side 1 [mm]	60
Distance from crack to edge side 2 [mm]	60
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,2
Dry density [kg/m ³]	371

Pre-crack on the side 2 by tightening the bolt. This had considerable influence in the test.

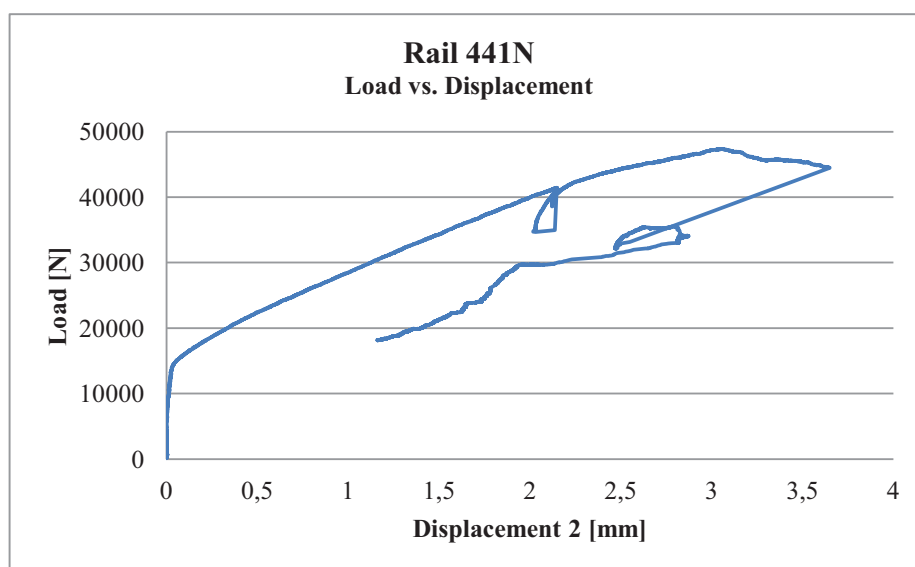
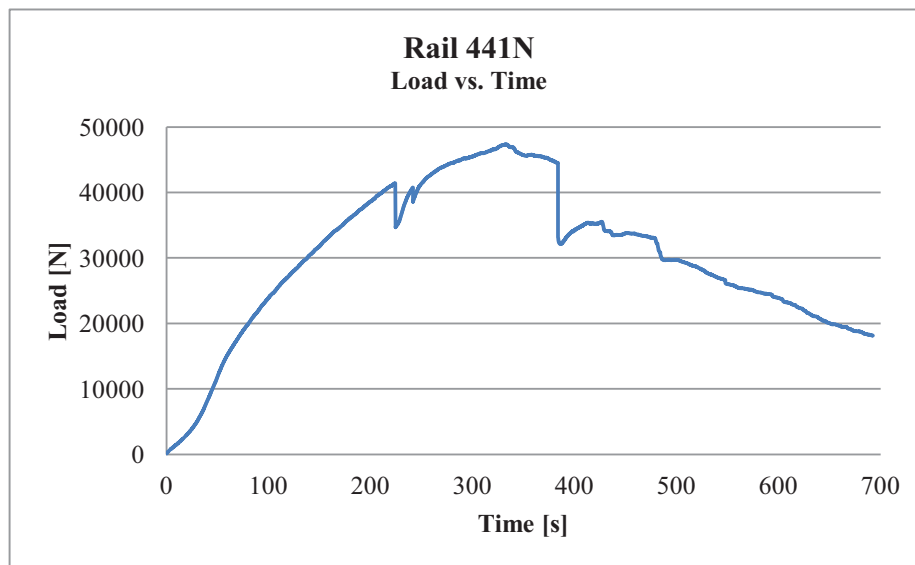


Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	21747
Displacement 1 at failure [mm]	0,03
Displacement 2 at failure [mm]	0,56
Distance from crack to edge side 1 [mm]	54
Distance from crack to edge side 2 [mm]	52
Distance from crack to anchor bolt side 1 [mm]	62
Distance from crack to anchor bolt side 2 [mm]	57
Moisture [%]	11,5
Dry density [kg/m ³]	433

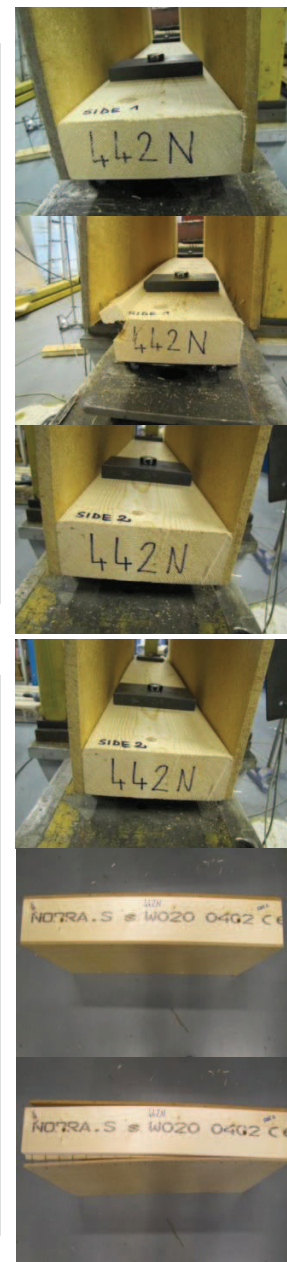
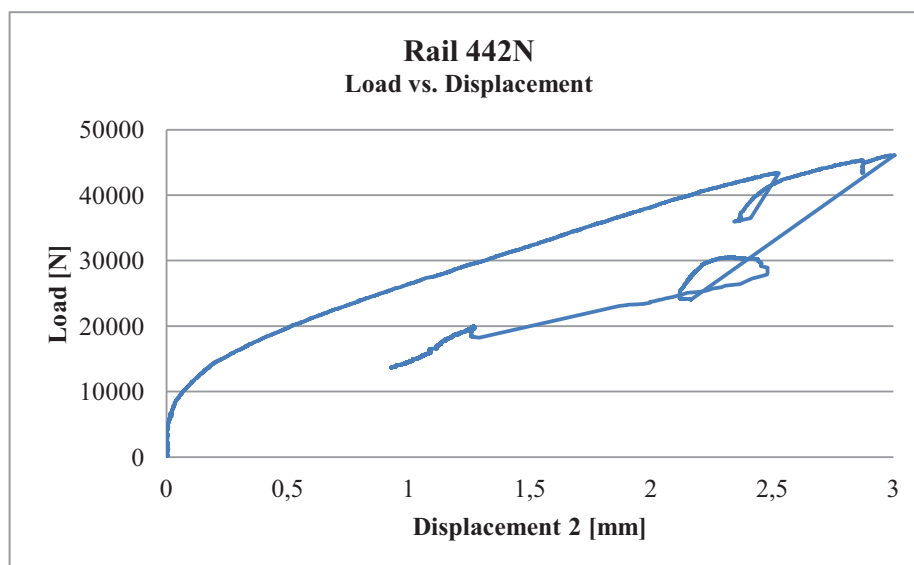
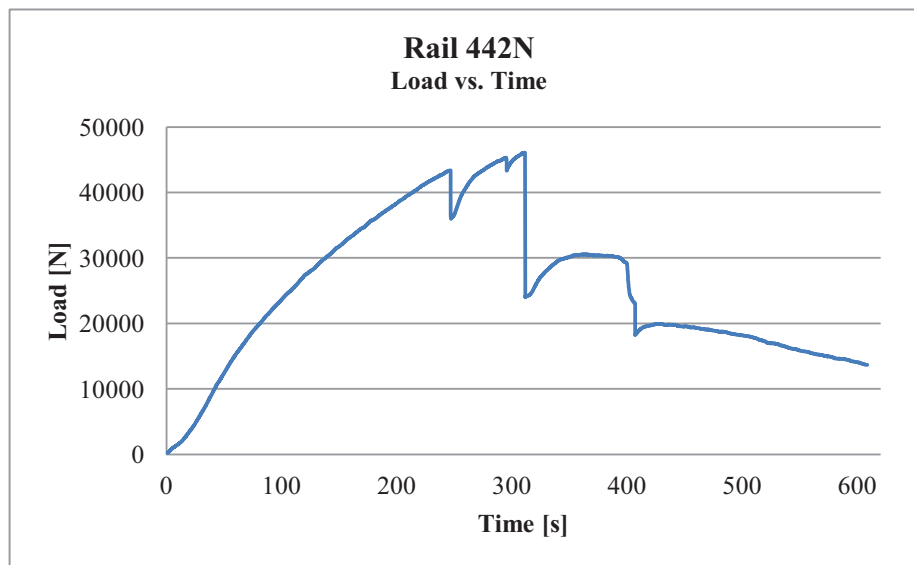
Pre-crack on the side 2 by tightening the bolt. This had considerable influence in the test.

Set 4 – Size of washer 100x70 mm

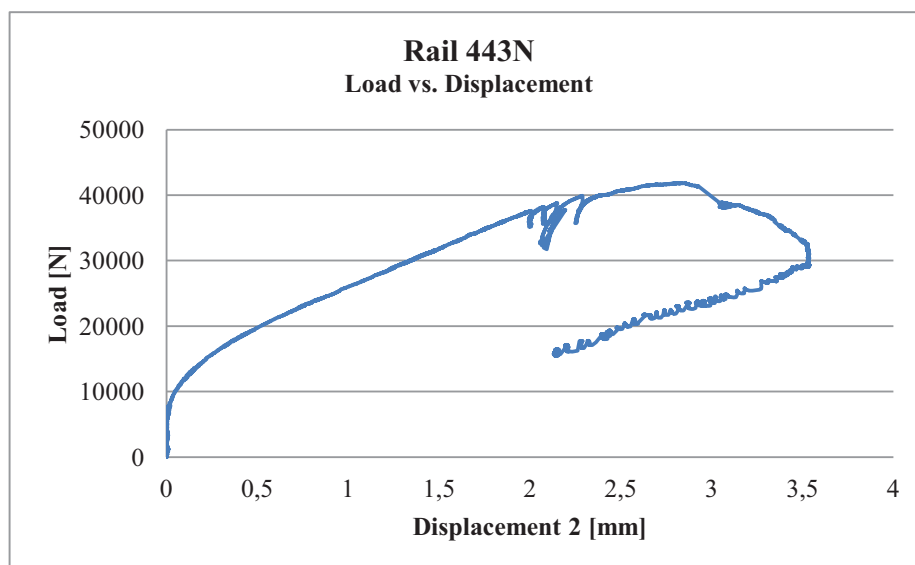
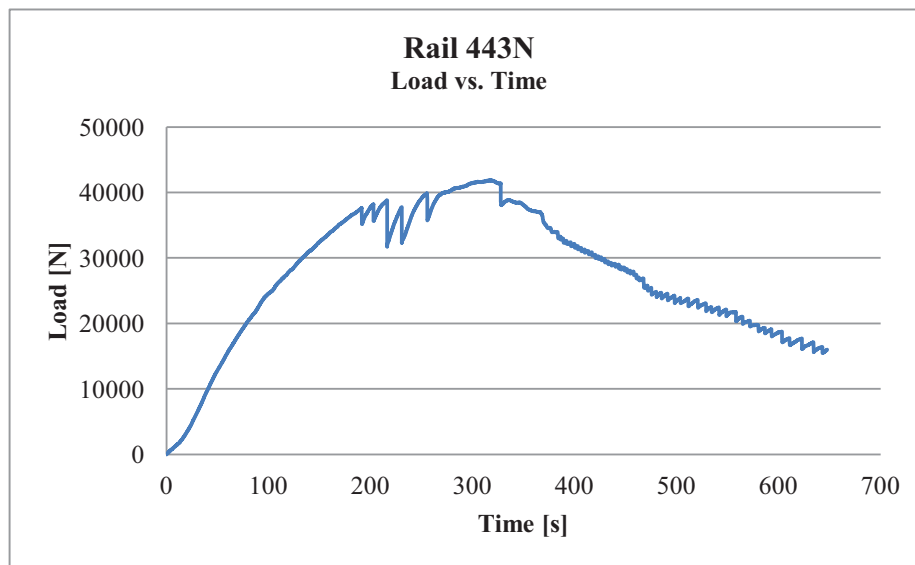
Pith down



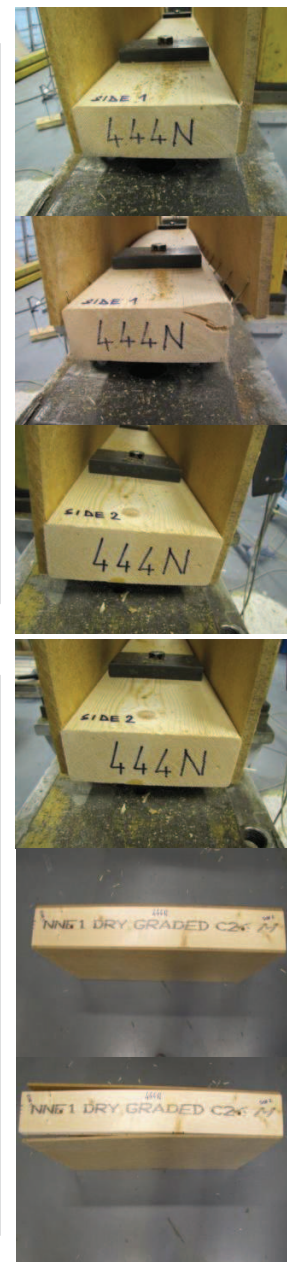
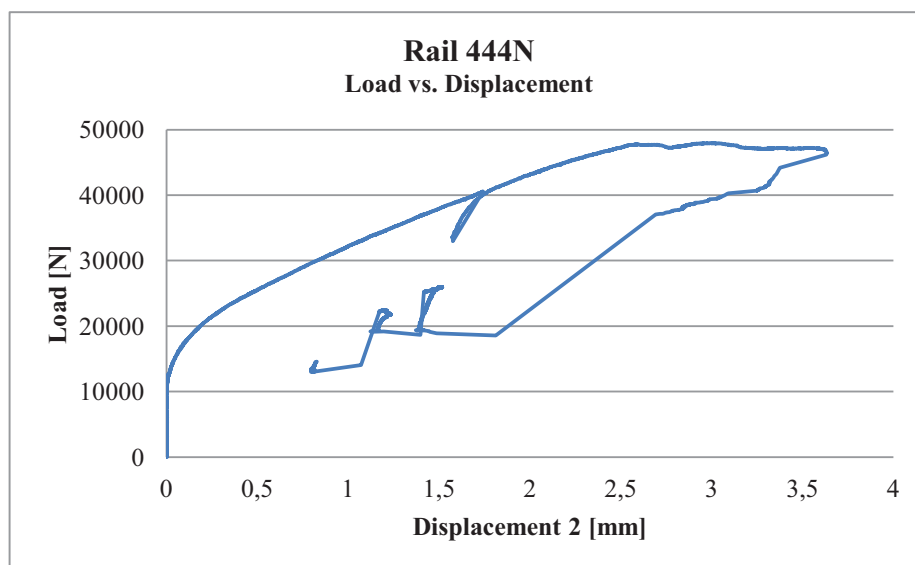
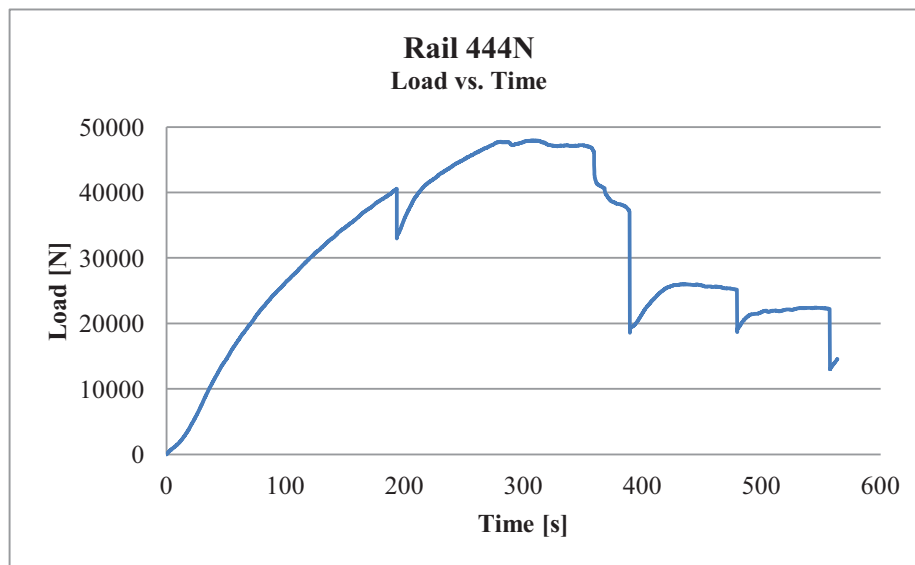
Type of failure	Failure 2 – 1 st crack at side 2
Failure load [N]	47372
Displacement 1 at failure [mm]	0,16
Displacement 2 at failure [mm]	3,06
Moisture [%]	12,9
Dry density [kg/m ³]	395



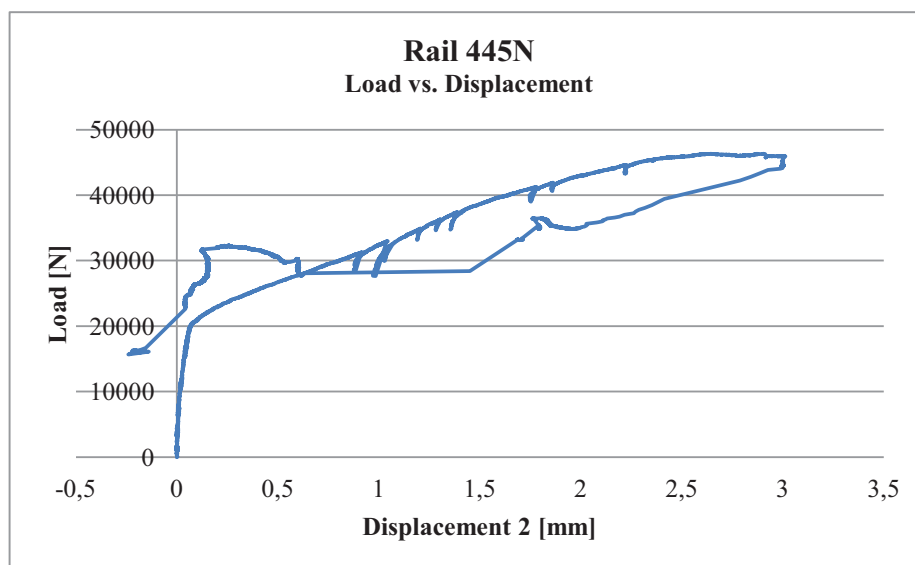
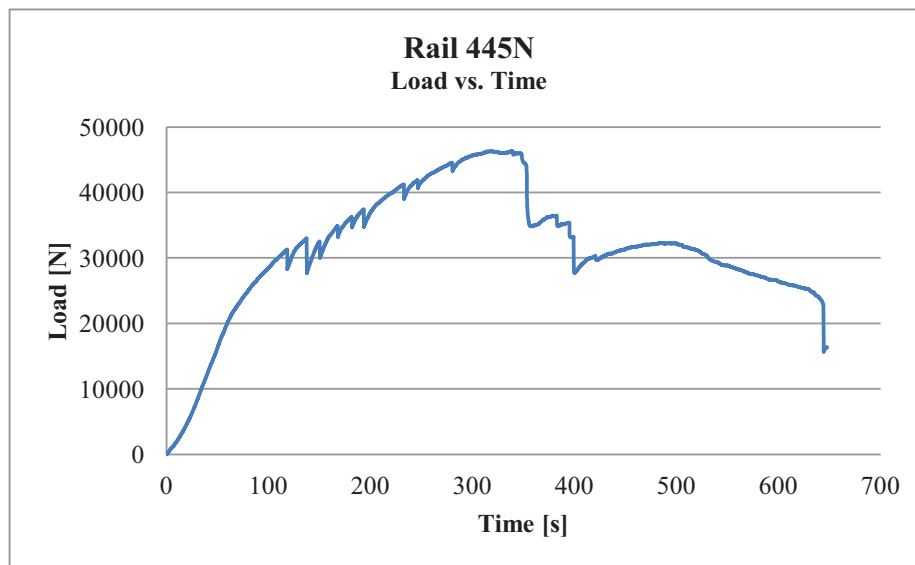
Type of failure	Failure 2 – 1 st crack at side 1
Failure load [N]	46087
Displacement 1 at failure [mm]	0,10
Displacement 2 at failure [mm]	2,99
Moisture [%]	12,0
Dry density [kg/m ³]	433



Type of failure	Failure 3
Failure load [N]	41868
Displacement 1 at failure [mm]	0,07
Displacement 2 at failure [mm]	2,80
Moisture [%]	11,6
Dry density [kg/m ³]	385

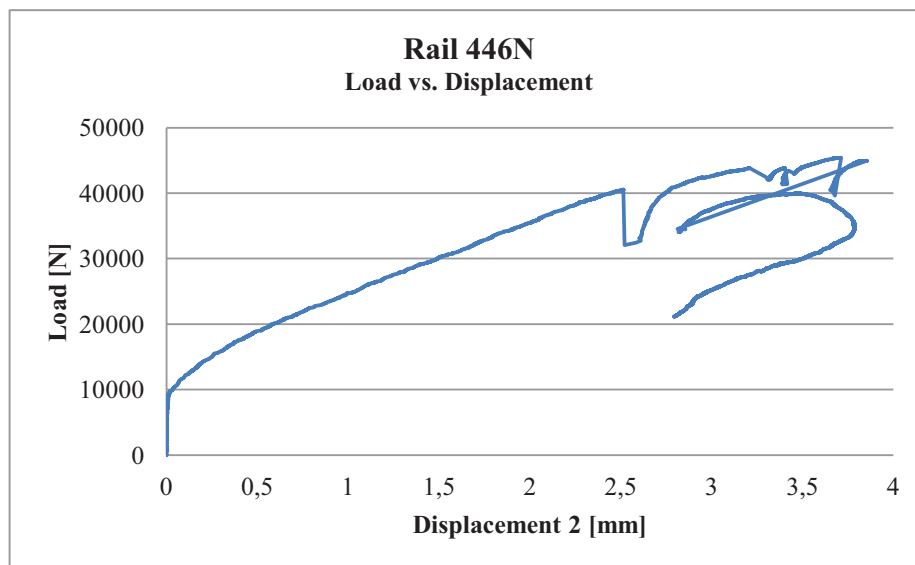
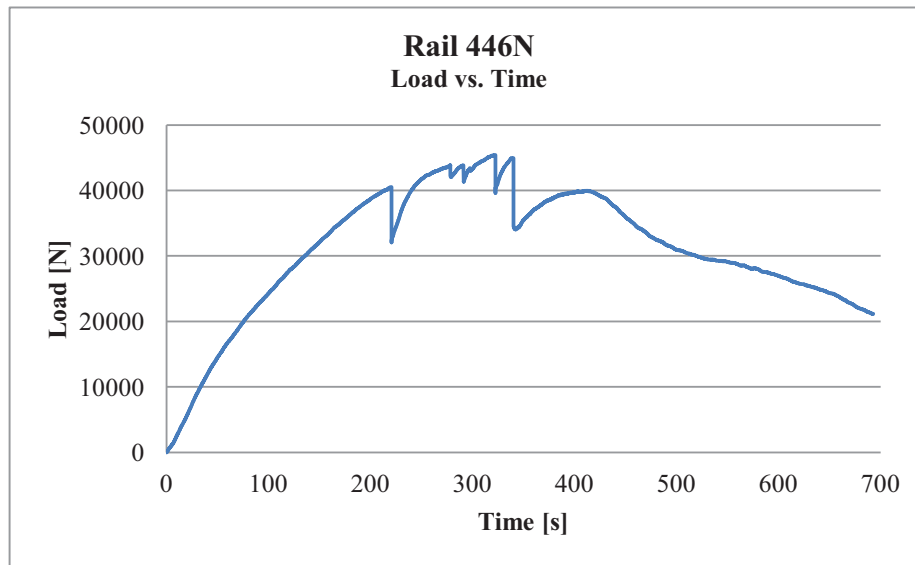


Type of failure	Failure 2 – 1 st crack at side 1
Failure load [N]	47952
Displacement 1 at failure [mm]	0,18
Displacement 2 at failure [mm]	2,99
Moisture [%]	13,5
Dry density [kg/m ³]	410

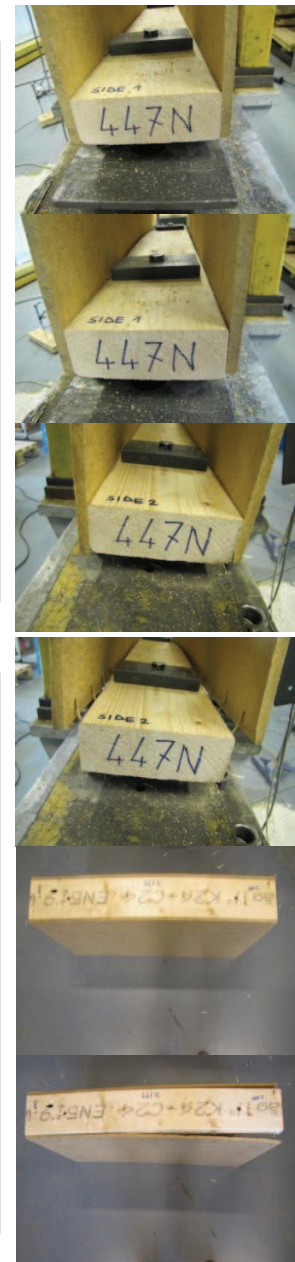
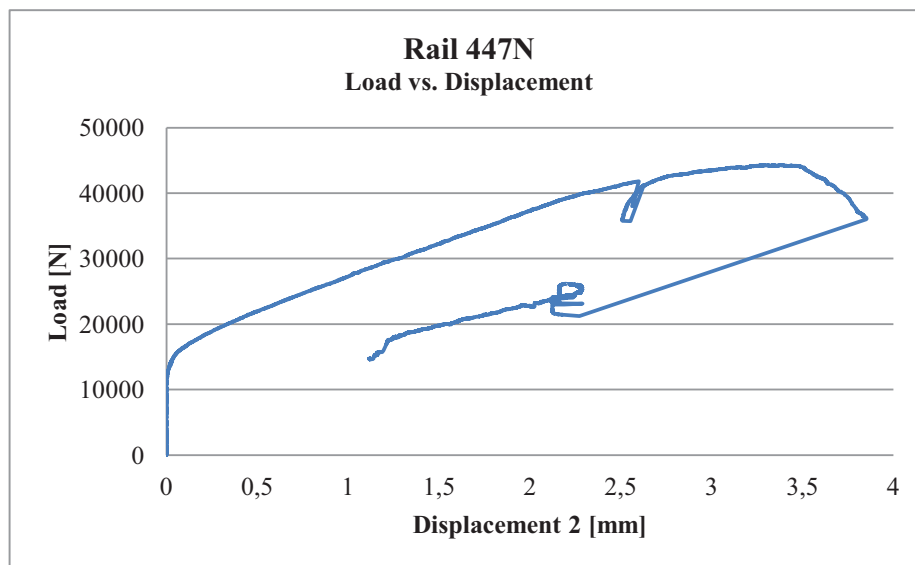
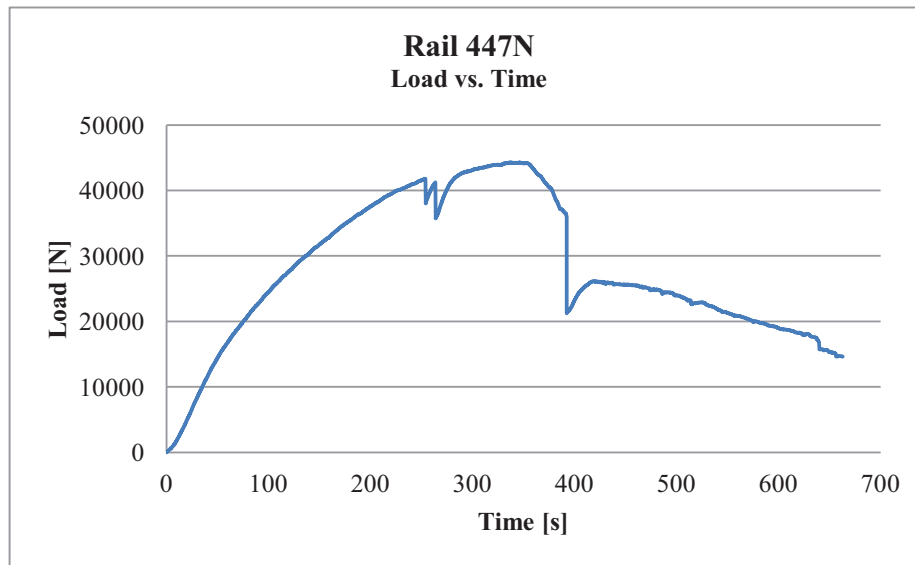


Type of failure	Failure 3
Failure load [N]	46306
Displacement 1 at failure [mm]	0,15
Displacement 2 at failure [mm]	2,90
Moisture [%]	12,8
Dry density [kg/m ³]	400

The bottom rail failure happens after the nails pull-out.

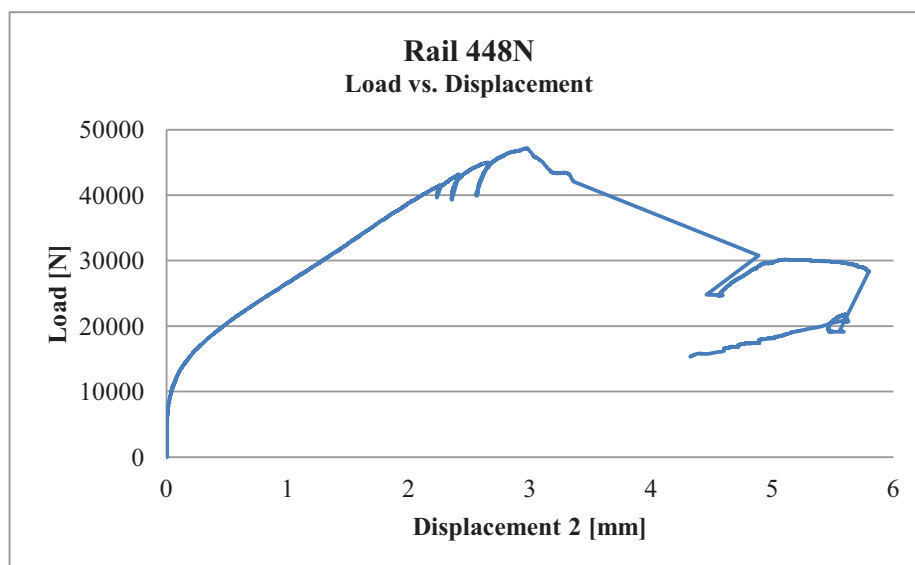
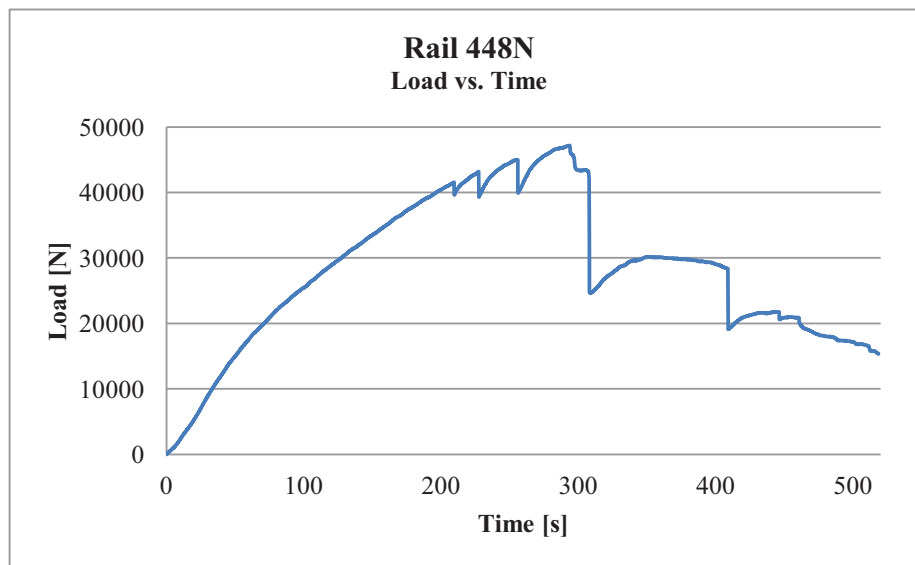


Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	45414
Displacement 1 at failure [mm]	0,26
Displacement 2 at failure [mm]	3,71
Distance from crack to edge side 1 [mm]	50
Distance from crack to edge side 2 [mm]	24
Distance from crack to anchor bolt side 1 [mm]	54
Distance from crack to anchor bolt side 2 [mm]	17
Moisture [%]	12,7
Dry density [kg/m ³]	396



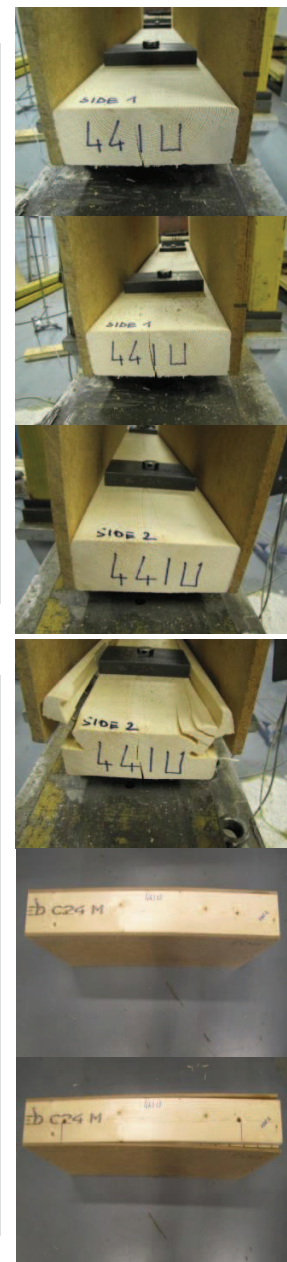
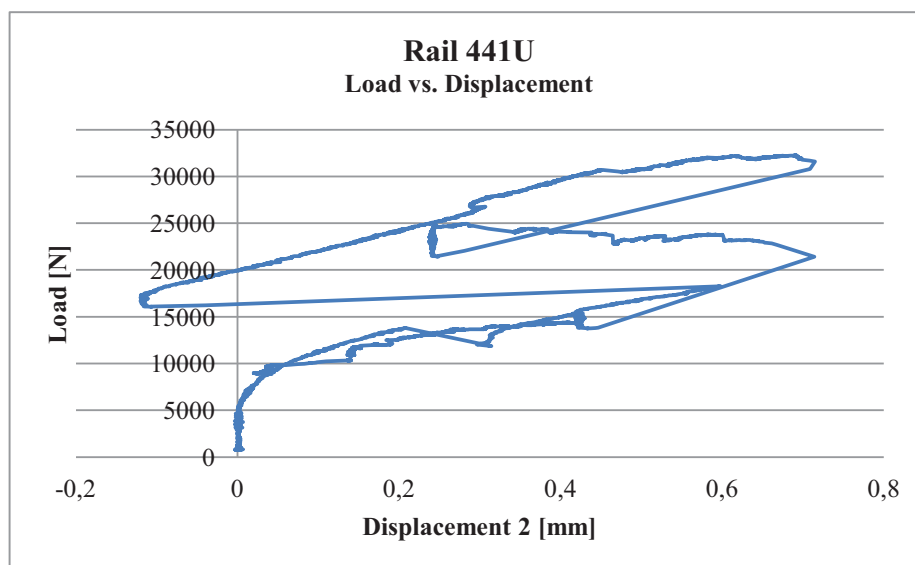
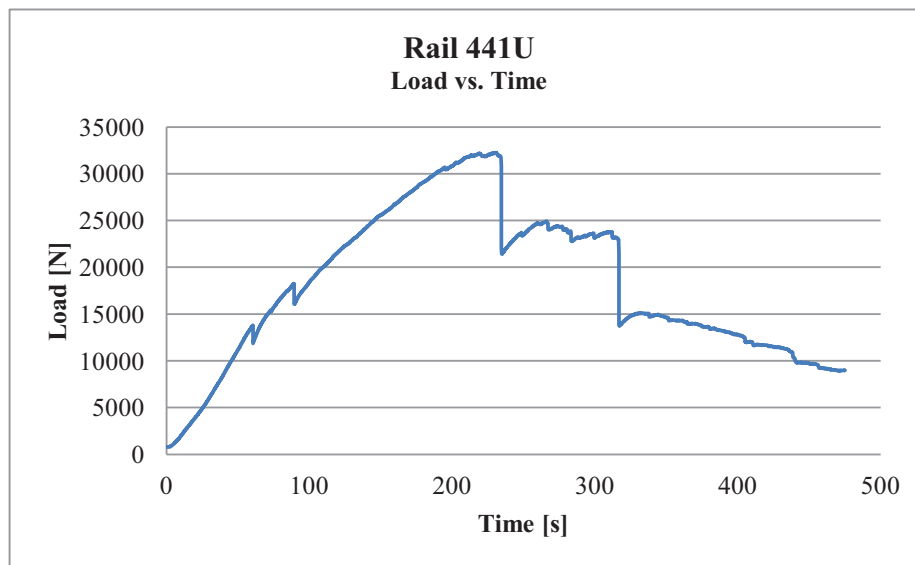
Type of failure	Failure 3
Failure load [N]	44278
Displacement 1 at failure [mm]	0,12
Displacement 2 at failure [mm]	3,38
Moisture [%]	10,0
Dry density [kg/m ³]	390

After test some crack was found on the rail in the nails line. However the first type of failure is nails pull-out.



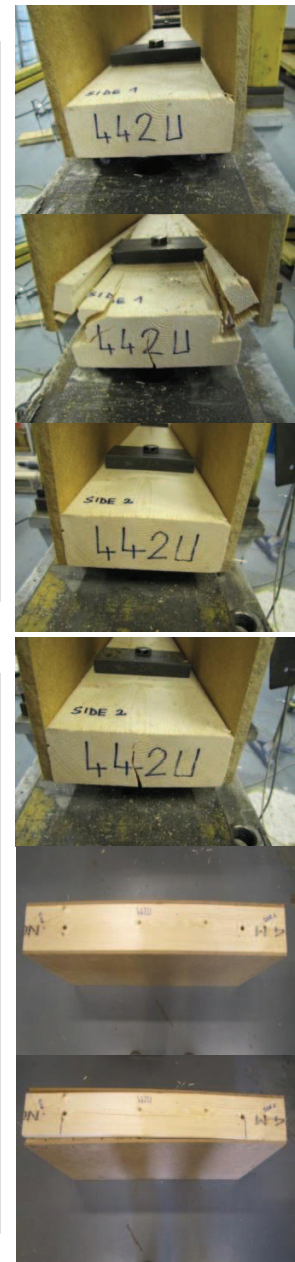
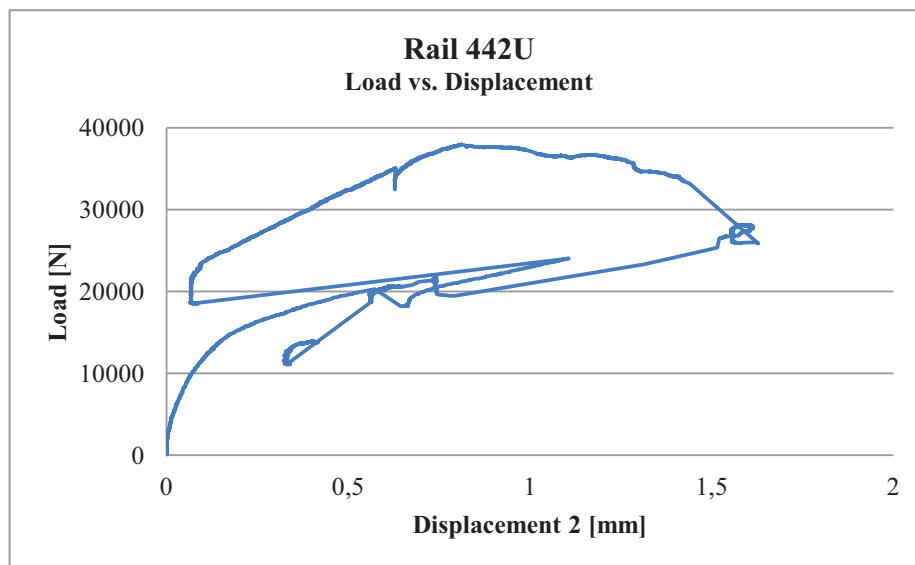
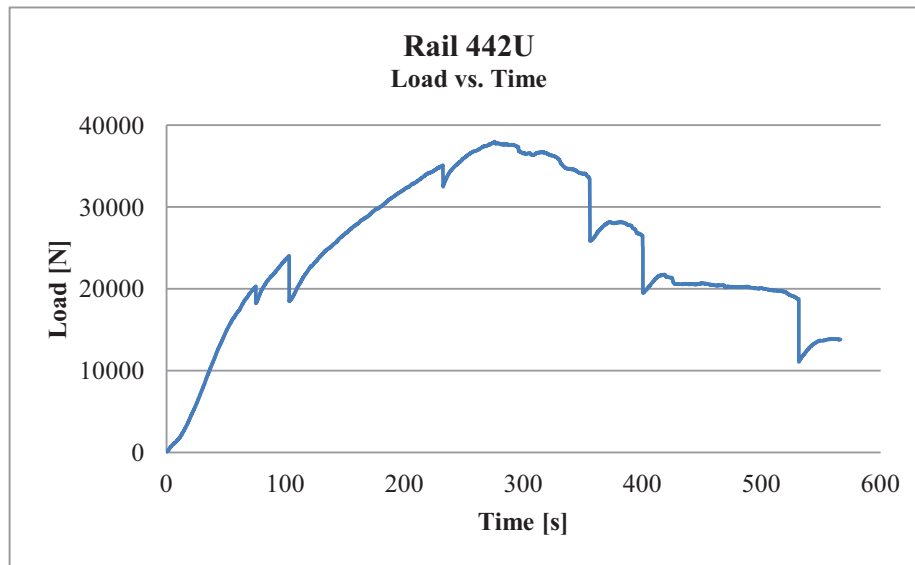
Type of failure	Failure 2 – 1 st crack at side 2
Failure load [N]	47164
Displacement 1 at failure [mm]	0,16
Displacement 2 at failure [mm]	2,97
Moisture [%]	12,3
Dry density [kg/m ³]	380

Pith Up



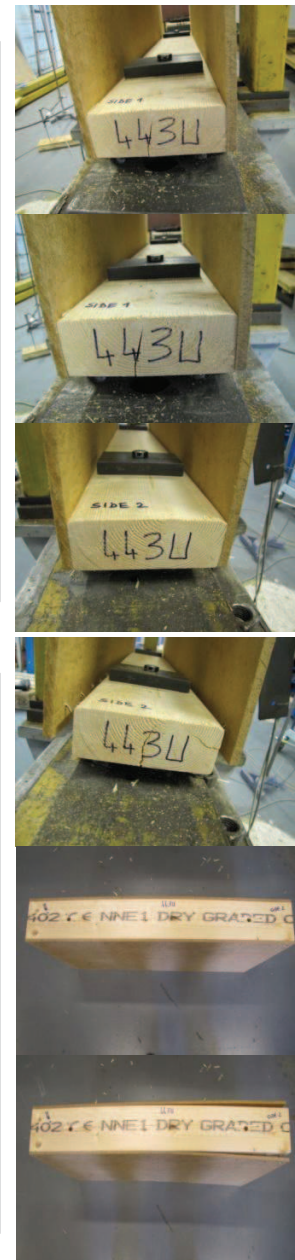
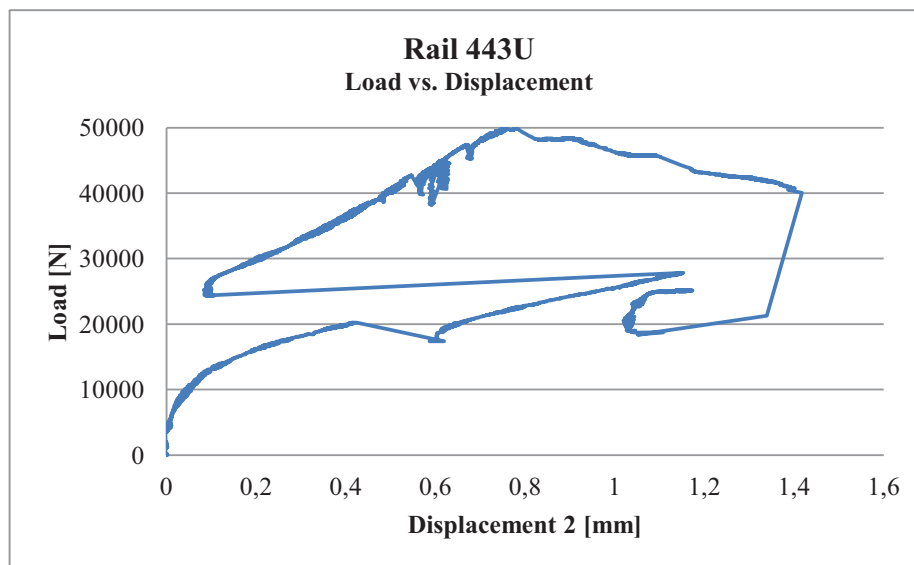
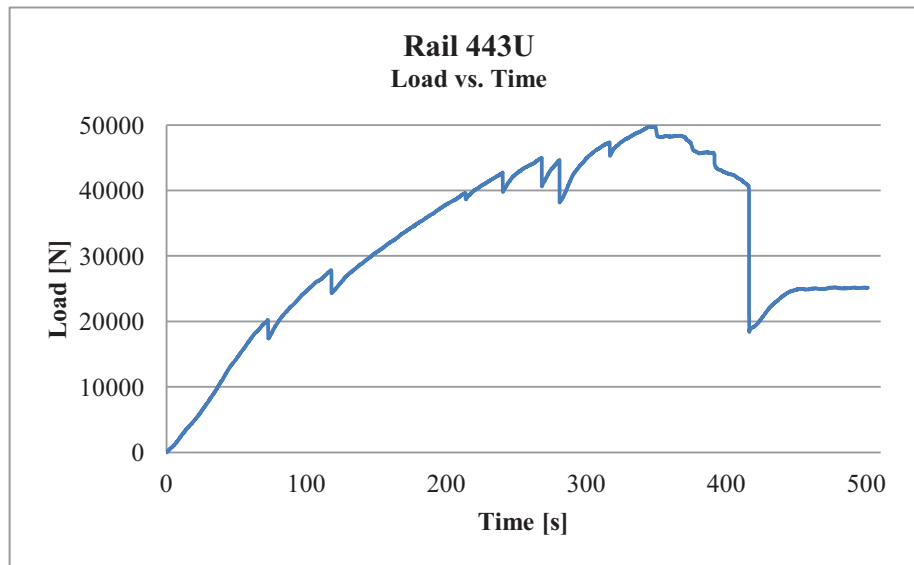
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	13807
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	0,21
Distance from crack to edge side 1 [mm]	57
Distance from crack to edge side 2 [mm]	60
Distance from crack to anchor bolt side 1 [mm]	57
Distance from crack to anchor bolt side 2 [mm]	59
Moisture [%]	10,8
Dry density [kg/m ³]	370

Pre-crack on the side 1, without it the failure would have been crack in the nails line.



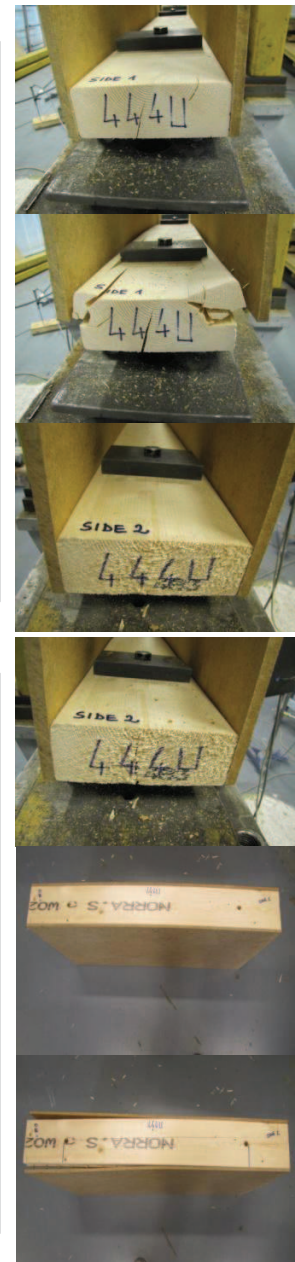
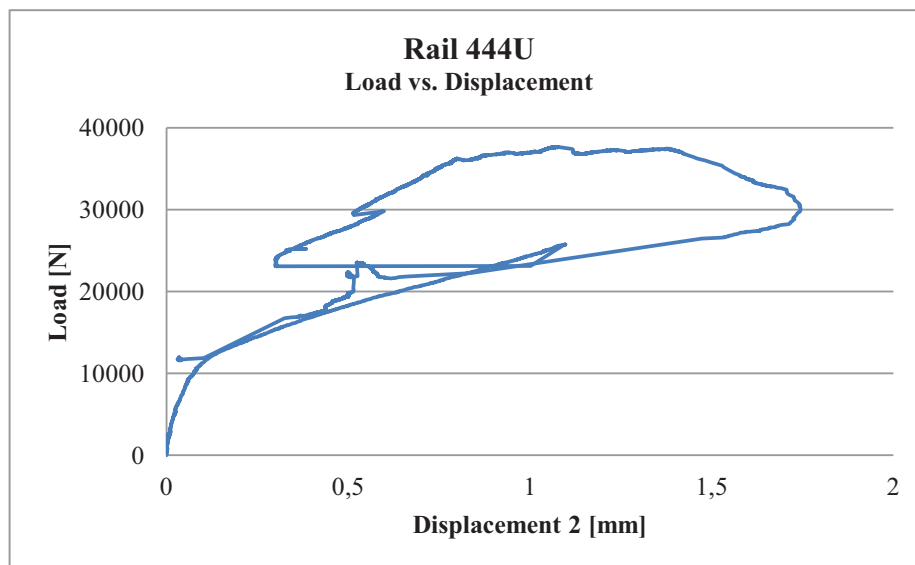
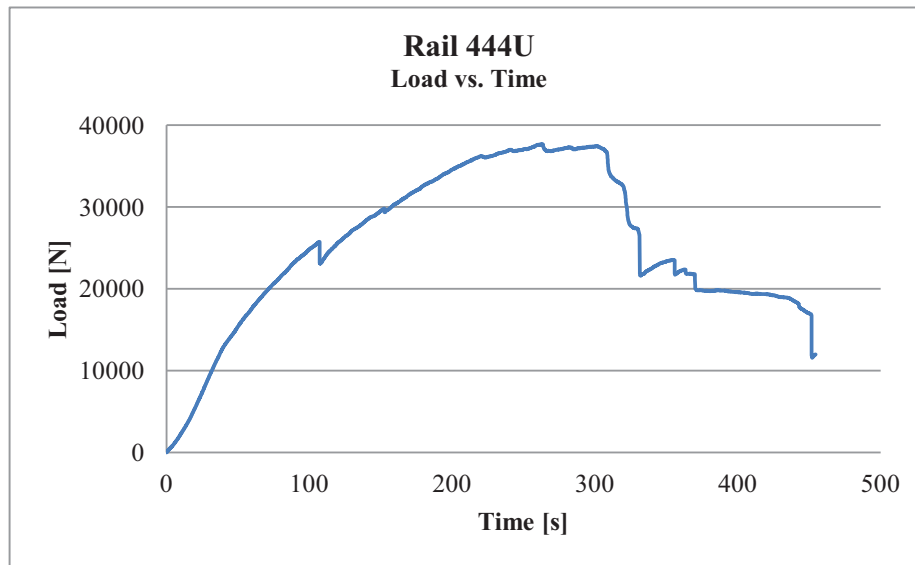
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	24015
Displacement 1 at failure [mm]	0,08
Displacement 2 at failure [mm]	1,11
Distance from crack to edge side 1 [mm]	57
Distance from crack to edge side 2 [mm]	59
Distance from crack to anchor bolt side 1 [mm]	57
Distance from crack to anchor bolt side 2 [mm]	59
Moisture [%]	14,2
Dry density [kg/m ³]	469

After the crack at 24 kN the load increase a lot until 38 kN. Probably the failure type is 2.



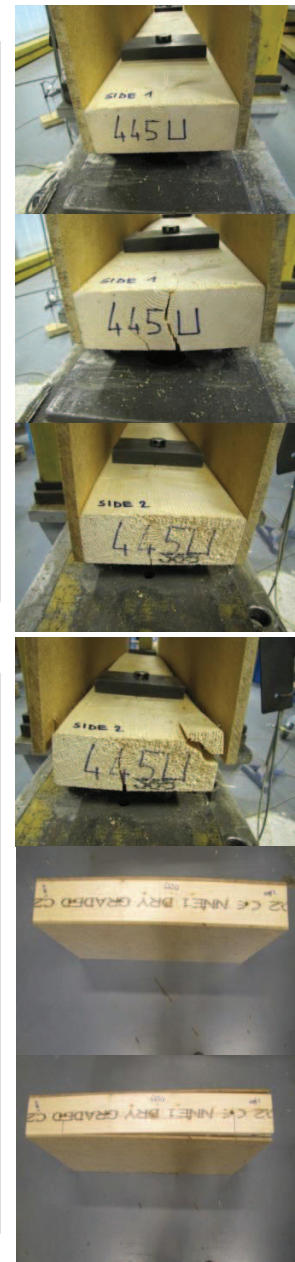
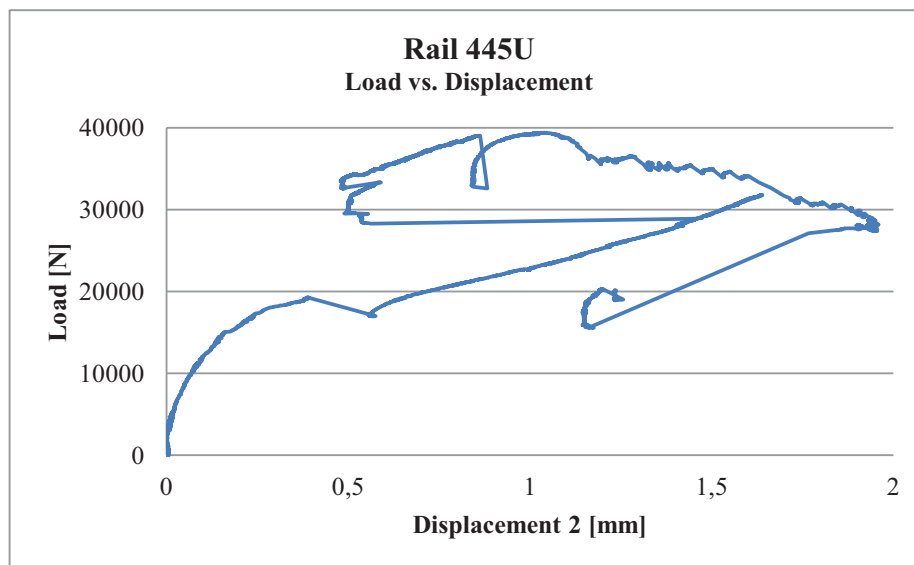
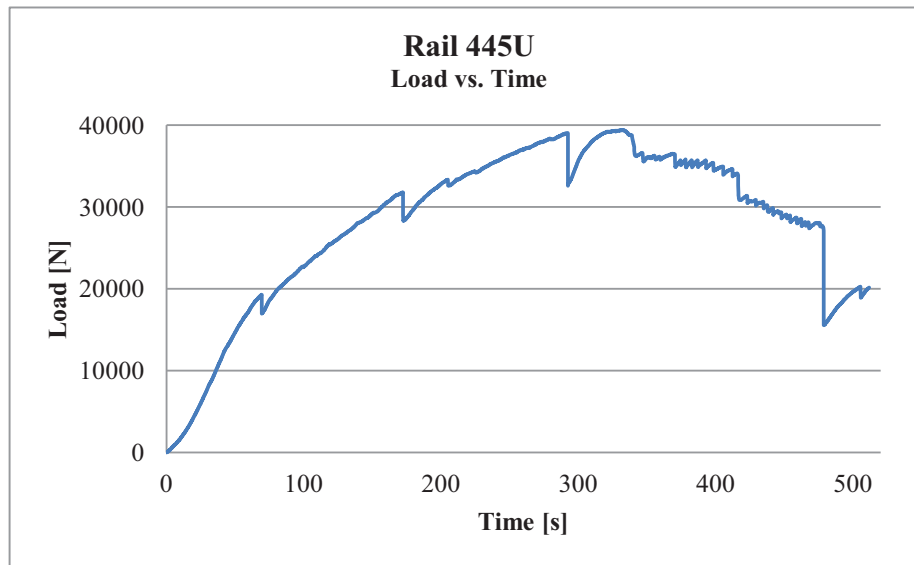
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	20250
Displacement 1 at failure [mm]	0,02
Displacement 2 at failure [mm]	0,42
Distance from crack to edge side 1 [mm]	52
Distance from crack to edge side 2 [mm]	63
Distance from crack to anchor bolt side 1 [mm]	62
Distance from crack to anchor bolt side 2 [mm]	63
Moisture [%]	12,0
Dry density [kg/m ³]	451

Failure 1 caused by pre-crack on side 1 but the failure type could be 2.



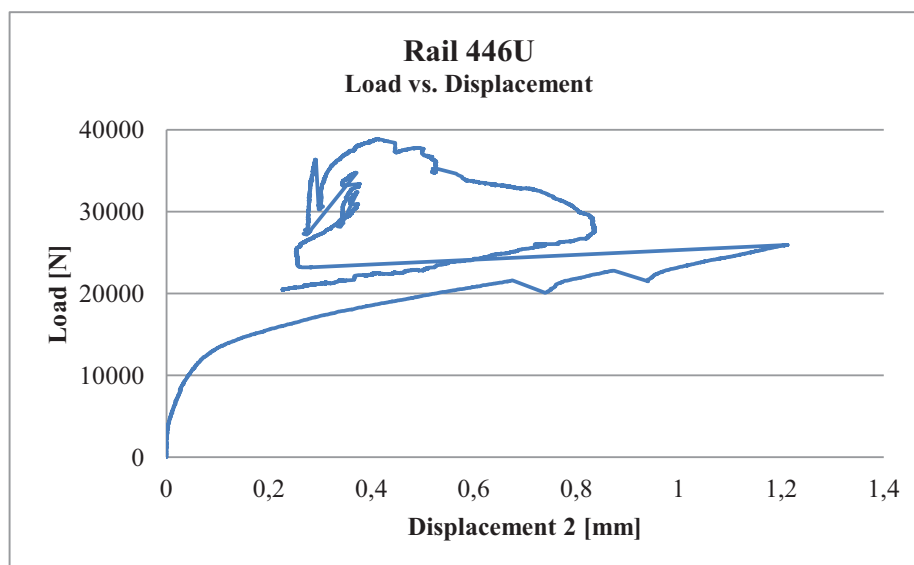
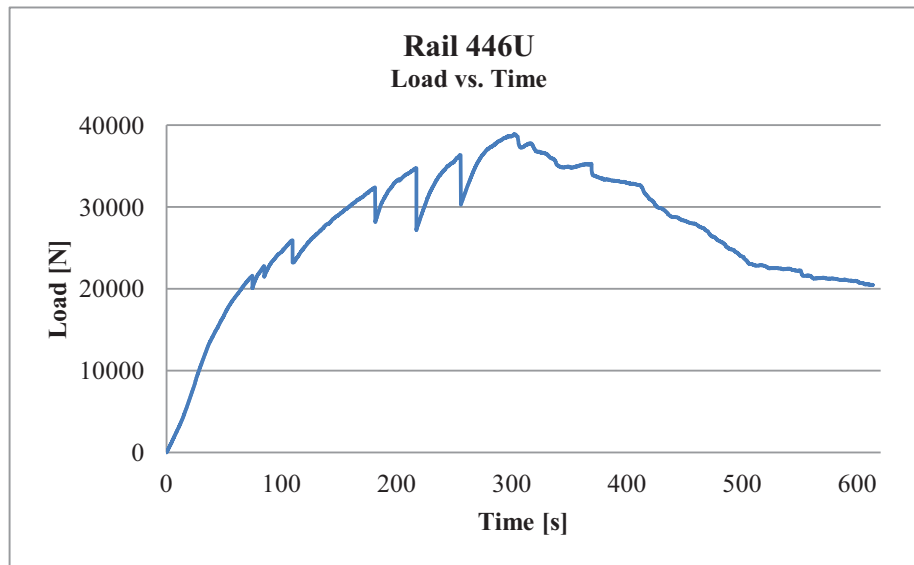
Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	25737
Displacement 1 at failure [mm]	0,13
Displacement 2 at failure [mm]	1,08
Distance from crack to edge side 1 [mm]	47
Distance from crack to edge side 2 [mm]	60
Distance from crack to anchor bolt side 1 [mm]	62
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	11,3
Dry density [kg/m ³]	398

Failure 1 caused by pre-crack on side 1 but the failure type could be 2.



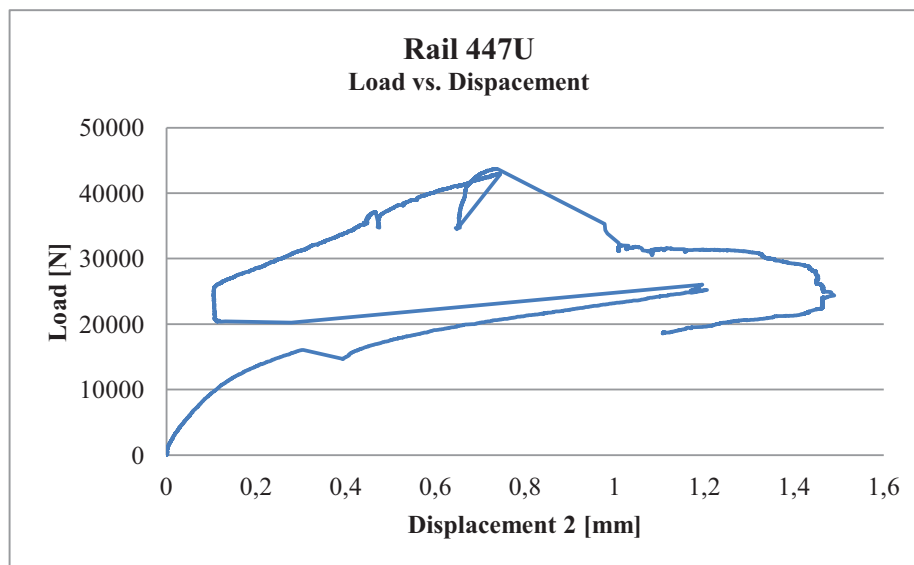
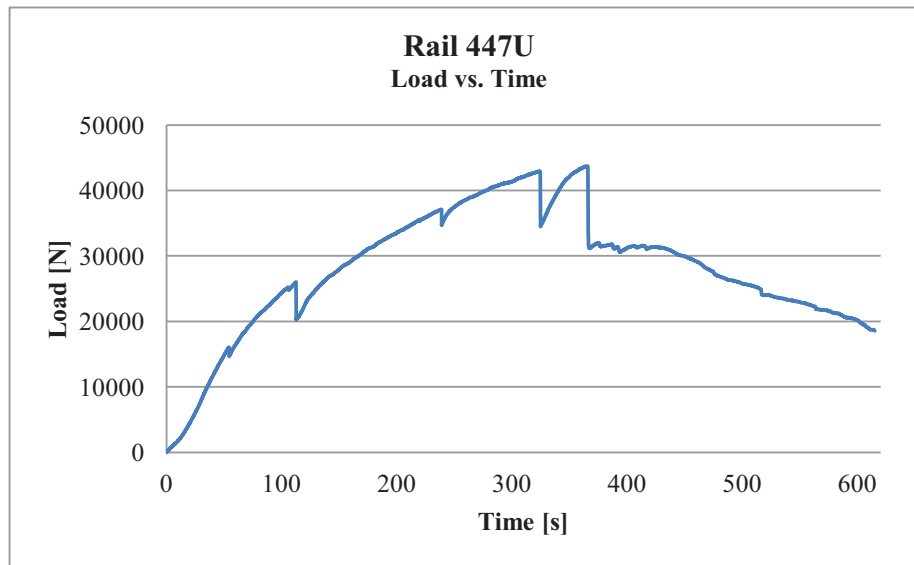
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	19253
Displacement 1 at failure [mm]	0,00
Displacement 2 at failure [mm]	0,39
Distance from crack to edge side 1 [mm]	65 (<i>pre-crack</i>) – 46 (<i>crack line</i>)
Distance from crack to edge side 2 [mm]	68
Distance from crack to anchor bolt side 1 [mm]	70 (<i>pre-crack</i>) – 41 (<i>crack line</i>)
Distance from crack to anchor bolt side 2 [mm]	60
Moisture [%]	13,1
Dry density [kg/m ³]	421

Pre-crack on side 2 tightening the anchor bolt, without it failure type would have been 2.



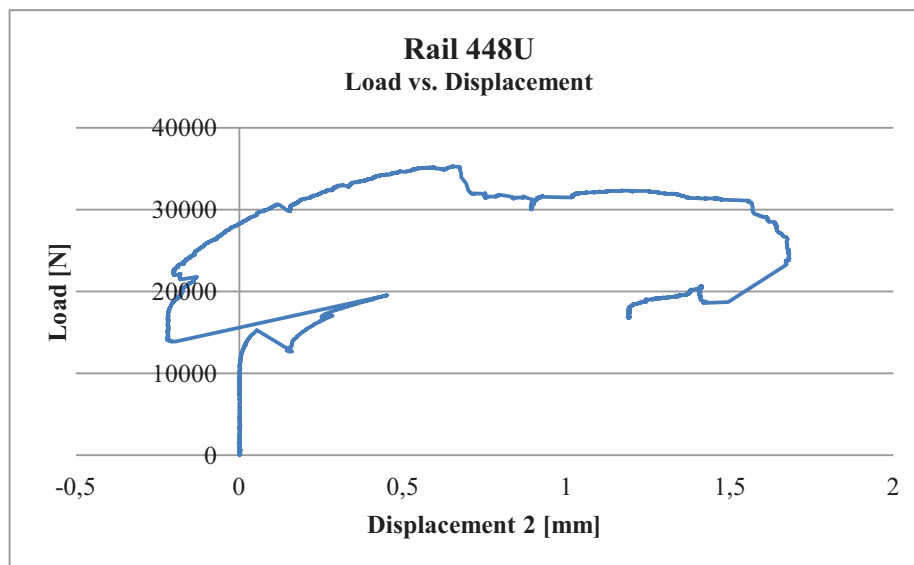
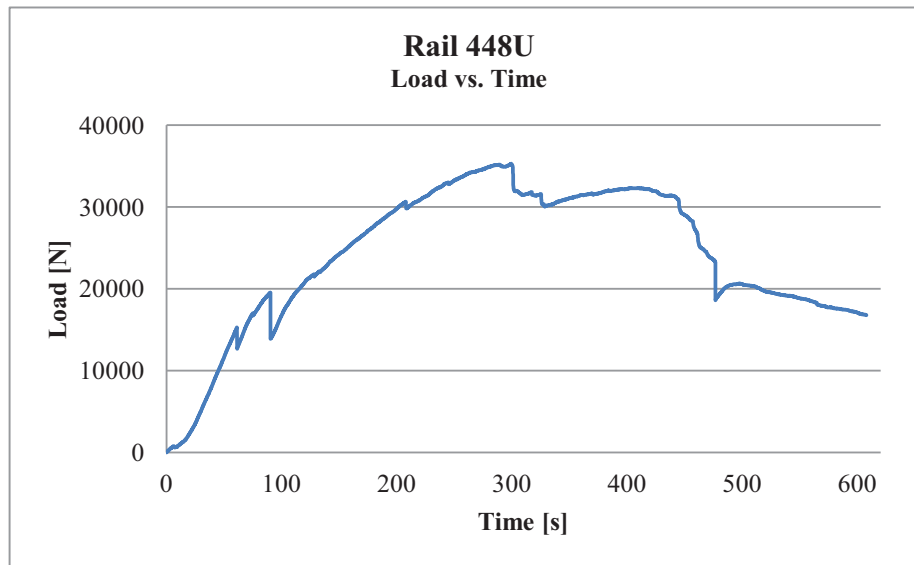
Type of failure	Failure 1 – 1 st crack at side 2
Failure load [N]	25930
Displacement 1 at failure [mm]	0,04
Displacement 2 at failure [mm]	1,21
Distance from crack to edge side 1 [mm]	57
Distance from crack to edge side 2 [mm]	60
Distance from crack to anchor bolt side 1 [mm]	59
Distance from crack to anchor bolt side 2 [mm]	59
Moisture [%]	13,1
Dry density [kg/m ³]	490

After the crack at 26 kN the load increase a lot until 39 kN causing the failure type 2 and 3.



Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	16068
Displacement 1 at failure [mm]	0,04
Displacement 2 at failure [mm]	0,30
Distance from crack to edge side 1 [mm]	63
Distance from crack to edge side 2 [mm]	55
Distance from crack to anchor bolt side 1 [mm]	60
Distance from crack to anchor bolt side 2 [mm]	59
Moisture [%]	11,2
Dry density [kg/m ³]	385

After the crack at 16 kN the load increase a lot until 44 kN causing the failure type 2.



Type of failure	Failure 1 – 1 st crack at side 1
Failure load [N]	15266
Displacement 1 at failure [mm]	-0,03
Displacement 2 at failure [mm]	0,05
Distance from crack to edge side 1 [mm]	18
Distance from crack to edge side 2 [mm]	66
Distance from crack to anchor bolt side 1 [mm]	30
Distance from crack to anchor bolt side 2 [mm]	61
Moisture [%]	9,97
Dry density [kg/m ³]	398

After the crack at 15 kN the load increase a lot until 35 kN causing the failure type 2.

Appendix B – Chronological summary of the conduction of the tests.

<i>Specimen</i>	<i>Construction date</i>	<i>Testing date</i>	<i>Dens. & Moist. C. Date</i>	<i>Comments</i>	<i>Failure mode</i>
411U	07/06/2011	08/06/2011	10/06/2011	-	1
411N	07/06/2011	08/06/2011	10/06/2011	-	1
412U	07/06/2011	09/06/2011	10/06/2011	Close to the hole for the anchor bolt in the rail on side 1 by mistake there was another hole. However this had no influence on the test.	1
412N	07/06/2011	09/06/2011	10/06/2011	-	1
413U	07/06/2011	09/06/2011	10/06/2011	Probably there was some problem not visible in the rail because the failure load is well below the average.	1
413N	07/06/2011	09/06/2011	10/06/2011	-	1
414U	07/06/2011	09/06/2011	10/06/2011	-	1
414N	07/06/2011	09/06/2011	10/06/2011	-	1
415U	07/06/2011	09/06/2011	10/06/2011	Influence of the pre-crack present on the side 2.	1
415N	07/06/2011	09/06/2011	10/06/2011	-	1
416U	07/06/2011	09/06/2011	10/06/2011	-	1
416N	07/06/2011	09/06/2011	10/06/2011	-	1
417U	07/06/2011	09/06/2011	10/06/2011	-	1
417N	07/06/2011	09/06/2011	10/06/2011	Close to the hole for the anchor bolt in the rail on side 2 by mistake there was another hole. However this had no influence on the test.	1
418U	07/06/2011	10/06/2011	10/06/2011	-	1
418N	07/06/2011	10/06/2011	10/06/2011	-	1
411U-BIS	23/06/2011	23/06/2011	23/06/2011	-	1
411N-BIS	23/06/2011	23/06/2011	23/06/2011	-	1
412U-BIS	23/06/2011	23/06/2011	23/06/2011	-	1
412N-BIS	23/06/2011	23/06/2011	23/06/2011	-	1
413U-BIS	23/06/2011	23/06/2011	23/06/2011	-	1
413N-BIS	23/06/2011	23/06/2011	23/06/2011	-	1
414U-BIS	23/06/2011	24/06/2011	24/06/2011	-	1
414N-BIS	23/06/2011	24/06/2011	24/06/2011	-	1
415U-BIS	23/06/2011	24/06/2011	24/06/2011	-	1
415N-BIS	23/06/2011	24/06/2011	24/06/2011	-	1
416U-BIS	24/06/2011	24/06/2011	24/06/2011	-	1

416N-BIS	24/06/2011	24/06/2011	24/06/2011	-	1
417U-BIS	24/06/2011	24/06/2011	24/06/2011	-	1
417N-BIS	24/06/2011	24/06/2011	24/06/2011	Close to the hole for the anchor bolt in the rail on side 2 by mistake there was another hole. However this had no influence on the test.	1
418U-BIS	24/06/2011	24/06/2011	24/06/2011	-	1
418N-BIS	24/06/2011	24/06/2011	24/06/2011	-	1
421U	10/06/2011	13/06/2011	13/06/2011	Probably there was some problem not visible in the rail because the failure load is well below the average.	1
421N	10/06/2011	13/06/2011	13/06/2011	-	1
422U	10/06/2011	13/06/2011	13/06/2011	-	1
422N	10/06/2011	13/06/2011	13/06/2011	-	1
423U	10/06/2011	13/06/2011	13/06/2011	Pre-crack on the side 2 by tightening the bolt.	1
423N	10/06/2011	13/06/2011	13/06/2011	-	1
424U	10/06/2011	13/06/2011	13/06/2011	Pre-crack on both sides of the rail.	1
424N	10/06/2011	13/06/2011	13/06/2011	-	1
425U	13/06/2011	14/06/2011	14/06/2011	Pre-crack on the side 1 of the rail.	1
425N	13/06/2011	14/06/2011	14/06/2011	-	1
426U	13/06/2011	14/06/2011	14/06/2011	Pre-crack on the side 1 of the rail. First crack started from the pre-crack but after another crack line happened.	1
426N	13/06/2011	14/06/2011	14/06/2011	-	1
427U	13/06/2011	14/06/2011	14/06/2011	-	1
427N	13/06/2011	14/06/2011	14/06/2011	-	1
428U	13/06/2011	14/06/2011	14/06/2011	Possible pre-crack on both sides but they seem do not have any influence on the test.	1
428N	13/06/2011	14/06/2011	14/06/2011	-	1
431U	14/06/2011	15/06/2011	15/06/2011	-	1
431N	14/06/2011	15/06/2011	15/06/2011	-	2
432U	14/06/2011	15/06/2011	15/06/2011	Pre-crack on the side 1 by tightening the bolt.	1
432N	14/06/2011	15/06/2011	15/06/2011	-	1
433U	14/06/2011	15/06/2011	15/06/2011	Anchor bolt failure during the test on the side 2.	1
433N	14/06/2011	15/06/2011	15/06/2011	-	1

434U	14/06/2011	15/06/2011	15/06/2011	-	1
434N	14/06/2011	15/06/2011	15/06/2011	-	1
435U	15/06/2011	16/06/2011	16/06/2011	-	1
435N	15/06/2011	16/06/2011	16/06/2011	-	1
436U	15/06/2011	16/06/2011	16/06/2011	Moisture and density are not measured.	1
436N	15/06/2011	16/06/2011	16/06/2011	-	1
437U	15/06/2011	16/06/2011	16/06/2011	Pre-crack on the side 2 by tightening the bolt.	1
437N	15/06/2011	16/06/2011	16/06/2011	-	2
438U	15/06/2011	16/06/2011	16/06/2011	Pre-crack on the side 2 by tightening the bolt.	1
438N	15/06/2011	16/06/2011	16/06/2011	-	1
441U	20/06/2011	21/06/2011	21/06/2011	Pre-crack on the side 1 by tightening the bolt.	1 ⁽¹⁾
441N	20/06/2011	21/06/2011	21/06/2011	-	2
442U	20/06/2011	21/06/2011	21/06/2011	-	1 ⁽²⁾
442N	20/06/2011	21/06/2011	21/06/2011	-	2
443U	20/06/2011	21/06/2011	21/06/2011	Pre-crack on the side 1 by tightening the bolt.	1 ⁽¹⁾
443N	20/06/2011	21/06/2011	21/06/2011	-	3
444U	20/06/2011	21/06/2011	21/06/2011	Pre-crack on the side 1 by tightening the bolt.	1 ⁽¹⁾
444N	20/06/2011	21/06/2011	21/06/2011	-	2
445U	21/06/2011	22/06/2011	22/06/2011	Pre-crack on the side 2 by tightening the bolt.	1 ⁽¹⁾
445N	21/06/2011	22/06/2011	22/06/2011	-	3
446U	21/06/2011	22/06/2011	22/06/2011	-	1 ⁽³⁾
446N	21/06/2011	22/06/2011	22/06/2011	-	1
447U	21/06/2011	22/06/2011	22/06/2011	-	1 ⁽²⁾
447N	21/06/2011	22/06/2011	22/06/2011	-	3
448U	21/06/2011	22/06/2011	22/06/2011	-	1 ⁽²⁾
448N	21/06/2011	22/06/2011	22/06/2011	-	2

⁽¹⁾ The type of failure of these tests was failure of the bottom rail. However this type of failure was caused by the presence of the pre-crack, in fact after the bottom rail failure the load increase a lot, sometime more than twice of the failure load, until the type of failure 2, which is the most probable with this test setup. Therefore it can be said that without pre-crack the type of failure would have been the type 2.

⁽²⁾ The type of failure of these tests was failure of the bottom rail. However after the bottom rail failure the load increase a lot, sometime more than twice of the failure load, until the type of failure 2, which is the most probable with this test setup. Probably this was caused by some problem in the rail does not visible. Therefore it can be said that without pre-crack the type of failure would have been the type 2.

⁽³⁾ The test results of this specimen are similar at (2), the only difference is that the second type of failure found were both 2 and 3 together.

Appendix C – Statistical data of test results

LOAD					
Serie 4 - Set 1 Pith UP	Serie 4 - Set 1 Pith DOWN	Serie 4 - Set 1 BIS Pith UP	Serie 4 - Set 1 BIS Pith DOWN	Serie 4 - Set 2 Pith UP	
17745,16	22451,50	16839,05	14986,65	17315,35	
17192,64	21010,33	18601,15	23952,51	23036,84	
10921,86	23056,98	15560,16	17262,99	18253,07	
20589,28	23240,51	17313,76	23682,27	20464,28	
14643,46	23675,91	19426,37	20916,63	20767,50	
21328,24	21866,02	16808,91	23217,45	18409,32	
12971,60	20995,53	19518,96	18293,45	15180,25	
18612,49	22531,89	15568,87	21276,05	21018,80	
16750,59	22353,58	17454,65	20448,50	19305,68	Average [N]
3645,67	996,97	1577,73	3293,50	2485,03	St. Dev.
21,76%	4,46%	9,04%	16,11%	12,87%	Coeff. Of Var. [%]
8803,03	20180,18	14015,21	13268,68	13888,31	Char. Value 0,05 [N]
DISPLACEMENT 1 AT FAILURE					
Serie 4 - Set 1 Pith UP	Serie 4 - Set 1 Pith DOWN	Serie 4 - Set 1 BIS Pith UP	Serie 4 - Set 1 BIS Pith DOWN	Serie 4 - Set 2 Pith UP	
0,012578125	0,095585938	0,098984375	-0,007421875	-0,017265625	
0,062539063	-0,01859375	0,093320312	0,024335938	0,07359375	
-0,031992188	-0,087734375	0,010390625	-0,029570312	-0,024375	
0,027734375	-0,0140625	-0,010273437	0,008046875	-0,012460937	
0,021054687	-0,039414062	-0,000976563	0,001125	-0,108828125	
0,034023437	0,01875	0,024101563	0,003789063	-0,014609375	
-0,013828125	-0,012109375	0,076679687	0,047304688	-0,0003125	
-0,0215625	-0,198164063	-0,015273437	0,026914062	0,019570313	
0,01	-0,03	0,03	0,01	-0,01	Average [mm]
0,03	0,08	0,05	0,02	0,05	St. Dev.
281,27%	-265,76%	137,35%	251,92%	-479,12%	Coeff. Of Var. [%]
-0,06	-0,22	-0,07	-0,04	-0,12	Char. Value 0,05 [mm]
DISPLACEMENT 2 AT FAILURE					
Serie 4 - Set 1 Pith UP	Serie 4 - Set 1 Pith DOWN	Serie 4 - Set 1 BIS Pith UP	Serie 4 - Set 1 BIS Pith DOWN	Serie 4 - Set 2 Pith UP	
0,551132812	1,91203125	0,571933594	0,5509375	0,456894531	
0,628111979	1,372929688	0,972415365	3,077369792	1,215019531	
0,183496094	2,331927083	0,5634375	0,429707031	0,403828125	
0,757897135	2,609589844	0,436210938	2,893997396	1,296386719	
0,326171875	1,6121875	1,161341146	1,342623698	1,246236979	
0,902050781	1,661901042	0,51061849	2,11906901	0,342597656	
0,130410156	1,300572917	0,754915365	0,647871094	0,453938802	
0,804355469	2,422447917	0,536770833	1,441588542	0,488606771	
0,54	1,90	0,69	1,56	0,74	Average [mm]
0,29	0,50	0,26	1,04	0,43	St. Dev.
54,53%	26,20%	37,08%	66,60%	58,12%	Coeff. Of Var. [%]
-0,09	0,82	0,13	-0,71	-0,20	Char. Value 0,05 [mm]

DISTANCE TO CRACK FROM EDGE SIDE 1					
Series 4 - Set 1 Pith UP	Series 4 - Set 1 Pith DOWN	Series 4 - Set 1 BIS Pith UP	Series 4 - Set 1 BIS Pith DOWN	Series 4 - Set 2 Pith UP	
52	50	58	53	62	
59	90	57	84	64	
70	60	44	59	53	
53	65	40	65	67	
52	63	50	65	75	
57	65	47	62	44	
48	54	44	66	57	
64	91	34	90	58	
56,88	67,25	46,75	68,00	60,00	Average [mm]
7,26	15,29	8,15	12,56	9,35	St. Dev.
12,76%	22,73%	17,44%	18,47%	15,58%	Coeff. Of Var. [%]
41,05	33,93	28,97	40,62	39,62	Char. Value 0,05 [mm]
DISTANCE TO CRACK FROM EDGE SIDE 2					
Series 4 - Set 1 Pith UP	Series 4 - Set 1 Pith DOWN	Series 4 - Set 1 BIS Pith UP	Series 4 - Set 1 BIS Pith DOWN	Series 4 - Set 2 Pith UP	
65	72	67	40	57	
63	52	70	40	55	
58	54	64	44	69	
85	57	70	48	60	
63	60	67	36	104	
63	40	63	40	62	
78	54	62	45	80	
78	72	56	67	60	
69,13	57,63	64,88	45,00	68,38	Average [mm]
9,73	10,61	4,67	9,64	16,45	St. Dev.
14,08%	18,41%	7,20%	21,41%	24,06%	Coeff. Of Var. [%]
47,91	34,50	54,69	23,99	32,52	Char. Value 0,05 [mm]
DISTANCE TO CRACK FROM ANCHORBOLT 1					
Series 4 - Set 1 Pith UP	Series 4 - Set 1 Pith DOWN	Series 4 - Set 1 BIS Pith UP	Series 4 - Set 1 BIS Pith DOWN	Series 4 - Set 2 Pith UP	
60	45	61	54	62	
59	85	60	85	60	
58	55	46	59	60	
60	60	42	59	63	
51	66	60	60	81	
64	59	51	60	48	
53	53	48	60	59	
62	91	38	86	60	
58,38	64,25	50,75	65,38	61,63	Average [mm]
4,37	15,94	8,83	12,58	9,09	St. Dev.
7,49%	24,80%	17,39%	19,24%	14,74%	Coeff. Of Var. [%]
48,84	29,51	31,51	37,95	41,82	Char. Value 0,05 [mm]

DISTANCE TO CRACK FROM ANCHORBOLT 2					
Serie 4 - Set 1 Pith UP	Serie 4 - Set 1 Pith DOWN	Serie 4 - Set 1 BIS Pith UP	Serie 4 - Set 1 BIS Pith DOWN	Serie 4 - Set 2 Pith UP	
60	83	62	39	60	
64	60	60	55	60	
65	60	60	44	58	
83	60	60	52	68	
60	60	60	36	102	
56	44	60	46	58	
75	50	60	45	76	
78	78	51	63	59	
67,63	61,88	59,13	47,50	67,63	Average [mm]
9,78	12,99	3,36	8,80	15,25	St. Dev.
14,47%	20,99%	5,68%	18,52%	22,55%	Coeff. Of Var. [%]
46,30	33,56	51,81	28,32	34,38	Char. Value 0,05 [mm]
DENSITY					
Serie 4 - Set 1 Pith UP	Serie 4 - Set 1 Pith DOWN	Serie 4 - Set 1 BIS Pith UP	Serie 4 - Set 1 BIS Pith DOWN	Serie 4 - Set 2 Pith UP	
442,8614981	406,017099	364,1825192	357,326247	390,3217528	
445,3850348	462,3345399	396,5118458	369,3448624	390,4805994	
421,7424758	388,575155	382,1961458	410,5554113	376,8889877	
434,5583404	338,2166578	502,8099158	432,9280741	375,1963088	
522,790461	448,9922807	409,7052405	393,3269024	403,7810073	
435,0774452	442,7566007	428,1903654	433,0097114	436,6177452	
374,4072421	441,7705422	424,0516218	432,7115989	550,4348886	
411,043541	386,5823563	391,7814698	403,656933	471,228207	
435,98	414,41	412,43	404,11	424,37	Average [kg/m ³]
41,90	42,02	42,23	29,37	60,52	St. Dev.
9,61%	10,14%	10,24%	7,27%	14,26%	Coeff. Of Var. [%]
344,64	322,79	320,38	340,08	292,43	Char. Value 0,05 [kg/m ³]
MOISTURE					
Serie 4 - Set 1 Pith UP	Serie 4 - Set 1 Pith DOWN	Serie 4 - Set 1 BIS Pith UP	Serie 4 - Set 1 BIS Pith DOWN	Serie 4 - Set 2 Pith UP	
12,36525048	11,83774834	14,05128205	13,79613357	13,9148073	
13,8184491	14,31860037	13,83694839	13,83347788	10,99691675	
13,22725012	12,44532803	13,69574378	12,86110012	11,88059701	
14,74916388	13,05623472	13,02465023	13,50519431	12,16367713	
13,75905201	12,84982263	14,03899721	13,585209	12,92257361	
12,79069767	13,59969266	13,2798574	13,62922231	13,49960412	
13,15673289	12,3100896	13,22525597	13,24392288	13,28016644	
12,25266362	13,22712116	13,51782863	12,98701299	12,75415896	
13,26	12,96	13,58	13,43	12,68	Average [%]
0,83	0,78	0,39	0,36	0,95	St. Dev.
6,26%	6,05%	2,84%	2,70%	7,52%	Coeff. Of Var. [%]
11,45	11,25	12,74	12,64	10,60	Char. Value 0,05 [%]

LOAD					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
27643,42	26375,64	31529,84	13807,47	47372,20	
29615,78	17161,24	38469,18	24014,67	46087,41	
29506,13	34145,47	28381,07	20249,77	41868,31	
26065,43	22564,35	37884,18	25737,08	47952,49	
26069,02	24986,38	43987,20	19253,06	46305,73	
26333,78	23822,10	35520,91	25930,73	45414,18	
27484,77	18467,28	44511,85	16068,53	44277,93	
31309,78	21746,91	46611,21	15266,15	47163,62	
28003,51	23683,67	38361,93	20040,93	45805,23	Average [N]
1944,73	5268,31	6460,01	4796,21	1972,18	St. Dev.
6,94%	22,24%	16,84%	23,93%	4,31%	Coeff. Of Var. [%]
23764,00	12198,75	24279,11	9585,20	41505,89	Char. Value 0,05 [N]
DISPLACEMENT 1 AT FAILURE					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
-0,004140625	0,03859375	0,139101563	0,025742187	0,16265625	
0,0228125	-0,041875	-0,013320312	0,076875	0,101484375	
-0,117382812	0,062578125	0,019257813	0,023320313	0,071210938	
0,0265625	0,011015625	0,01609375	0,135898438	0,177304687	
-0,018476563	0,02859375	0,063554687	0,007539062	0,153554688	
0,025898437	0,049804688	0,0353125	0,04375	0,2609375	
0,069453125	-0,00015625	0,19734375	0,04515625	0,118554687	
0,055078125	0,033671875	0,095234375	-0,02953125	0,16453125	
0,01	0,02	0,07	0,04	0,15	Average [mm]
0,06	0,03	0,07	0,05	0,06	St. Dev.
774,15%	144,29%	102,79%	119,77%	37,87%	Coeff. Of Var. [%]
-0,12	-0,05	-0,09	-0,07	0,03	Char. Value 0,05 [mm]
DISPLACEMENT 2 AT FAILURE					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
1,877076823	1,293398438	2,189915365	0,207988281	3,060423177	
1,596184896	0,285924479	1,960514323	1,106640625	2,991731771	
1,644980469	2,382441406	1,027838542	0,424095052	2,800891927	
1,780390625	0,796009115	2,248183594	1,078170573	2,994192708	
1,471601563	0,563496094	2,374824219	0,387766927	2,903463542	
1,367871094	0,910625	2,061041667	1,211783854	3,708177083	
2,027903646	0,523463542	2,307057292	0,305527344	3,379270833	
3,103229167	0,565052083	2,451510417	0,053235677	2,973561198	
1,86	0,92	2,08	0,60	3,10	Average [mm]
0,55	0,67	0,45	0,46	0,30	St. Dev.
29,39%	72,79%	21,82%	76,90%	9,57%	Coeff. Of Var. [%]
0,67	-0,54	1,09	-0,40	2,45	Char. Value 0,05 [mm]

DISTANCE TO CRACK FROM EDGE SIDE 1					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
68	56		57		
98	55	89	57		
62	29	54	52		
82	54	19	47		
47	57	65	46	75	
66	58	80	57	50	
59	60		63		
85	54	91	18		
70,88	52,88	66,33	49,63	62,50	Average [mm]
16,39	9,86	27,22	13,98	17,68	St. Dev.
23,13%	18,65%	41,03%	28,17%	28,28%	Coeff. Of Var. [%]
35,14	31,37	2,92	19,15		Char. Value 0,05 [mm]
DISTANCE TO CRACK FROM EDGE SIDE 2					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
55	63		60		
54	86	50	59		
45	59	44	63		
55	75	14	60		
55	75	39	68	64	
32	80	64	60	24	
50	60		55		
55	52	69	66		
50,13	68,75	46,67	61,38	44,00	Average [mm]
8,15	11,88	19,71	4,14	28,28	St. Dev.
16,26%	17,28%	42,25%	6,74%	64,28%	Coeff. Of Var. [%]
32,36	42,86	0,73	52,35		Char. Value 0,05 [mm]
DISTANCE TO CRACK FROM ANCHORBOLT 1					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
65	60		57		
88	60	85	57		
60	30	54	62		
80	59	18	62		
52	60	60	41	66	
59	59	74	59	54	
55	60		60		
82	62	88	30		
67,63	56,25	63,17	53,50	60,00	Average [mm]
13,72	10,65	25,86	11,65	8,49	St. Dev.
20,29%	18,93%	40,95%	21,78%	14,14%	Coeff. Of Var. [%]
37,71	33,04	2,90	28,10		Char. Value 0,05 [mm]

DISTANCE TO CRACK FROM ANCHORBOLT 2					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
62	60		59		
61	81	62	59		
50	60	48	63		
60	71	16	60		
54	72	50	60	60	
42	76	72	59	17	
42	60		59		
60	57	77	61		
53,88	67,13	54,17	60,00	38,50	Average [mm]
8,36	8,98	21,97	1,41	30,41	St. Dev.
15,51%	13,38%	40,56%	2,36%	78,98%	Coeff. Of Var. [%]
35,66	47,54	2,98	56,92		Char. Value 0,05 [mm]
DENSITY					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
393,4410169	463,6006074	454,9853986	370,1469925	394,7393494	
419,4784	393,8937568	450,3882516	468,7823074	433,3451878	
367,5401289	488,9644831	394,1796118	450,7832464	384,7178029	
367,2692428	424,71012	420,8982532	397,9739448	410,5799862	
432,6000389	410,8828148	449,0444505	421,4911751	400,4296264	
409,4173953		378,3341754	390,0647246	396,3939074	
389,0288069	371,3011501	526,0552726	384,6931165	390,4005585	
449,8896104	432,9828113	454,4972488	398,5233621	379,8159508	
403,58	426,62	441,05	410,31	398,81	Average [kg/m ³]
29,77	40,16	45,18	34,13	16,84	St. Dev.
7,38%	9,41%	10,24%	8,32%	4,22%	Coeff. Of Var. [%]
338,68	336,66	342,56	335,91	362,08	Char. Value 0,05 [kg/m ³]
MOISTURE					
Serie 4 - Set 2 Pith DOWN	Serie 4 - Set 3 Pith UP	Serie 4 - Set 3 Pith DOWN	Serie 4 - Set 4 Pith UP	Serie 4 - Set 4 Pith DOWN	
13,10427487	14,61024499	14,4622093	10,80139373	12,92360712	
13,45467523	11,7671346	14,42166911	14,20765027	12,02961135	
13,41870824	14,02877698	12,32876712	11,97525409	11,65620094	
12,31988473	13,1345689	12,89669142	11,3317757	13,48314607	
13,9212828	13,19444444	11,69950739	13,13364055	12,82240236	
12,87027579		13,56740355	13,1	12,69058296	
12,02072539	13,20868516	14,33666191	11,20802442	10,00446628	
13,46525097	11,52219873	11,4589156	9,974587039	12,30620155	
13,07	13,07	13,15	11,97	12,24	Average [%]
0,64	1,11	1,23	1,41	1,07	St. Dev.
4,89%	8,51%	9,37%	11,81%	8,70%	Coeff. Of Var. [%]
11,68	10,57	10,46	8,89	9,92	Char. Value 0,05 [%]

References

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