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Steel-Encased Pull-Through Tests of Seven-Wire Strands

KARIN LUNDGREN

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Department of Structural Engineering
Concrete Structures
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

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ABSTRACT

Pull-through tests of seven-wire strands were conducted to investigate the bond properties of strands with different surfaces. Three types of strands were tested, denoted “old smooth”, “new smooth”, and “indented”. Steel-encased specimens were used, and not only the bond and slip were measured, but also the tangential strain in the steel tube to investigate the normal stresses generated by the bond mechanism.

The tests show that the smooth strands behave stiffer initially than the indented strand. The “new smooth” has a higher bond capacity than the “old smooth”; for large slip values the “new smooth” even has a higher capacity than the indented strand. For slip values between 0.3 to 4 mm, the indented strand has the highest capacity. However, the indented strands also causes the largest tangential strains in the steel tube; i.e. the indented strands causes larger normal stresses than the smooth strands, which increases the risk for splitting failure. The two different types of smooth strands appear to cause approximately the same normal stresses.

Key words: Bond, seven-wire strands, steel-encased, pull-through tests

Stålmantlade utdragsförsök med sjutrådig lina
KARIN LUNDGREN
Institutionen för konstruktionsteknik
Betongbyggnad
Chalmers tekniska högskola

SAMMANFATTNING

Utdragsförsök med sjutrådiga linor utfördes för att undersöka vidhäftningsegenskaperna för linor med olika ytor. Tre sorters linor testades, betecknade "gamla släta", "nya släta" och indenterade. Stålmantlade provkroppar användes, och utöver vidhäftning och glidning mättes även den tangentiella töjningen i stålmanteln för att kunna undersöka normalspänningarna som resulterar av vidhäftningsmekanismen.

Försöken visar att de släta linorna har ett styvare beteende än den indenterade linan vid små glidningar. Den "nya släta" linan har högre vidhäftningskapacitet än den "gamla släta" - för stora glidningar har den "nya släta" till och med högre kapacitet än den indenterade linan. Vid glidningar mellan 0.3 och 4 mm har dock den indenterade linan högst kapacitet. Den indenterade linan ger dock också de högsta tangentiella töjningarna i stålmanteln, det vill säga den indenterade linan orsakar större normalspänningar än de släta linorna, vilket ökar risken för spjälkbrott. De två olika släta linorna orsakar ungefär lika stora normalspänningar.

Nyckelord: Vidhäftning, sjutrådig lina, stålmantlad, utdragsförsök

Contents

Preface

In this study, pull-through tests with seven-wire strands were done. The tests were carried out in June 2002. The project was initiated and financed by Fundia Hjulsbro AB.

It should be noted that the tests could never have been conducted without the sense of high quality and professionalism of the laboratory staff, Lars Wahlström and Nils Nilsson. Thanks also to my colleagues, Rikard Gustavson and Mario Plos, for their comments and discussions.

Göteborg July 2002

Karin Lundgren

1 Test Program

To investigate the bond properties of seven-wire strands with different surface treatments, pull-through tests were conducted. A bond situation where the strand and the concrete was enable to rotate relatively to each other was simulated in the tests. Specimens, five of each kind of strand, were examined in the test program. Three kinds of strands were tested, denoted “old smooth”, “new smooth”, and “indented”. The indented strands had indents according to prEN 10138, see Appendix D. The “old smoth“ strands were manufactured according to the present standards. They were all seven-wire strands, with a diameter of 12.9 mm and a cross-sectional area of 100 mm^2. All test specimens had equal geometry properties, as shown in Figure 1.

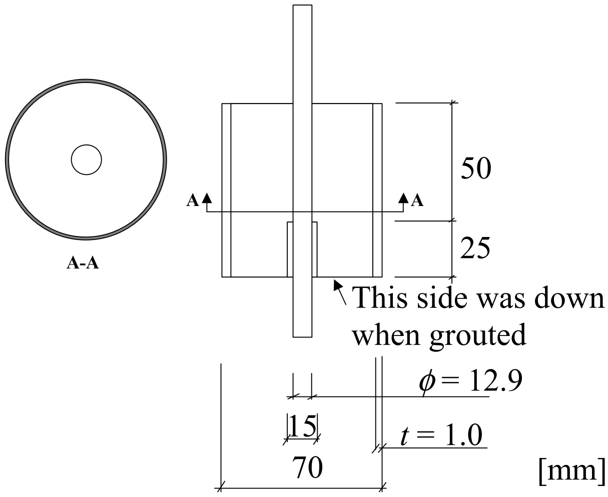


Figure 1 The geometry of the test specimens. (Försökskropparnas geometri.)

2 Test Arrangements

All test specimens were cast at the laboratory of the Department of Structural Engineering on the 23rd May 2002. Steel-tubes, diameter 70 mm, were used as forms, with plastic tops and bottoms, which also fixated the reinforcement bars. When casting the specimens, the concrete was vibrated and adjusted to fill the plastic tube to the upper edge. The upper edge of the plastic tube was dried off before putting on the plastic top. The test specimens were stored wet until testing. The top and bottom of the forms were removed just before the testing. Near the edge that was placed down during casting, an aluminium tube that was thread over the strand prevented the bond between the reinforcement bar and concrete. The strand was coated with a teflon tape before the aluminium tube, with a length of 25 mm and the outer diameter of 15 mm, was mounted. Three strain gauges were glued to the steel in the middle of the zone with bond, as shown in Figure 2.

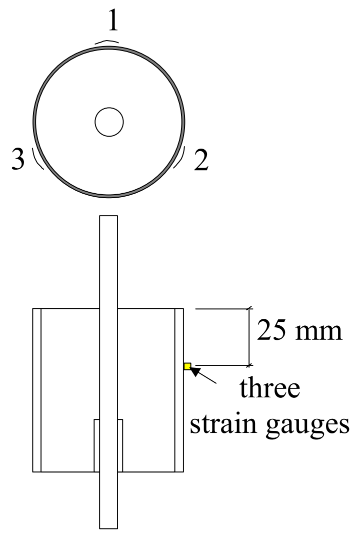


Figure 2 Placement of the strain gauges on the steel tubes, measuring the tangential strains. (Placering av trådtöjningsgivare som mäter de tangentiella töjningarna på stålrören.)

All test specimens were tested at the laboratory of the Department of Structural Engineering on the 25rd to 28th June 2002. The test set-up is shown in Figure 3. The grey parts in the figure were kept still during the loading in the tests. The black arrow indicates the positive loading direction. The load gauges and the displacement transducers are shown, together with their reference points. All test data was saved with an interval of 2 seconds on a computer. The strand in the tests was enable to rotate within the concrete as it was pulled through the specimen. The concrete had an age of 33-35 days and the strand was not prestressed. The end of the specimen where the bond between the strand and the reinforcement was prevented was placed downwards during the loading. The rotation was enabled by means of a thrust ball bearing that was placed between the specimen and the rigid support. A steel plate with a centric hole of 16 mm and with a circular cavity, depth 3.75 mm and diameter

70 mm, was placed between the specimen and the thrust ball bearing to insure that the specimen was loaded centric. The strand was pulled downwards by use of a wedge lock connected to a steel rod. The deformation rate was 1.5 mm/min during the whole test. The displacement of the strand was measured with two displacement transducers mounted at the top of the passive end.

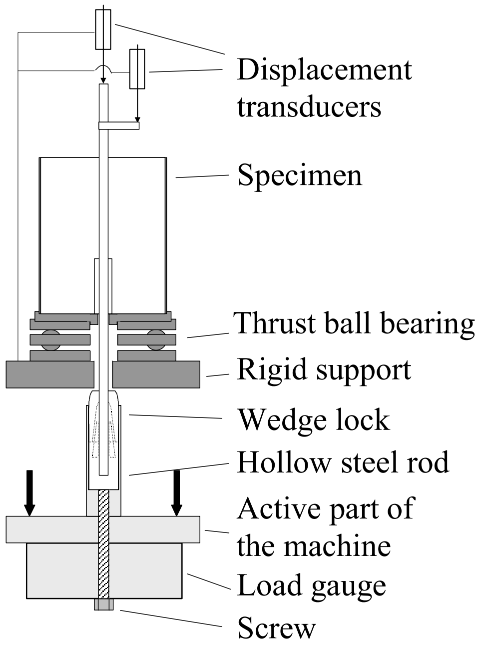


Figure 3 The set-up used in the tests. (Försöksuppställning i försöken.)

3 Material Properties

3.1 Concrete

A dry mixed concrete manufactured by OPTIROC, ("Reperationsbetong 0-12 mm," with d_{max}=12 mm), was used for the specimens. The compressive strength of the concrete was 63.0 MPa, measured in material tests on cylinders, diameter 150 mm and height 300 mm. The cylinders were wet stored, according to the Swedish standard SS 137230, see BST (1991). Young's modulus was tested on similar cylinders, according to the Swedish standard SS 137232, see BST (1991). It was evaluated to E_0 = 36.0 GPa. Both the compressive strength tests and the Young's modulus tests were done when the concrete had an age of 36 days.

3.2 Steel in the steel tubes

From the steel tube six test specimens with a geometry according to the Swedish Standards SS 11 21 19 as shown in Figure 4 were made. The steel had no marked yield plateau, instead the stiffness decreased gradually as shown in Figure 5. However, at low strains, up until about 1.5 ‰, the response was linear. Since the strains measured in the pull-out tests were always lower than 400 microstrain (0.4 ‰), only the modulus of elasticity is of interest. The results from tensile tests are presented in Table 1. The values are calculated from the measured area and load, and for the modulus of elasticity measurements of the strain with 20 mm long strain gauges are used.

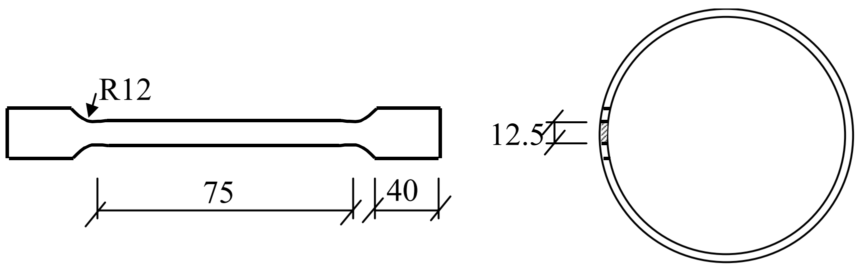


Figure 4 Test specimen for tensile tests of the steel tubes. (Försökskropp för dragprov av stålet i stålrören.)

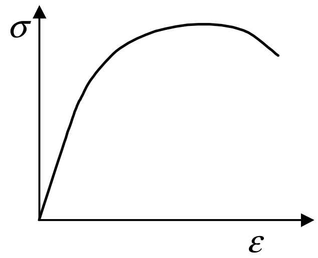


Figure 5 *Stress versus strain from tensile tests of the steel tubes. (Spänning – töjning från dragprov av stålet i stålrören.)*

Table 1 *Strength data of the steel tubes. Average of six tests.*

b [mm]	t [mm]	A [mm^2]	E [GPa]	f_u [MPa]
12.2	0.92	11.2	214	608

4 Test Results

All results from all the tests are given in appendix A-C. Here, similar tests are shown together, to ease a comparison between them.

4.1 Indented strands

Measured load versus slip for the indented strands is shown in Figure 6, where the effect of the indentation clearly can be seen in the wave pattern after the maximum load. The first part enlarged is shown in Figure 7. The measured tangential strain in the steel tubes is shown in Figure 8. As can be seen, the scatter is relatively low.

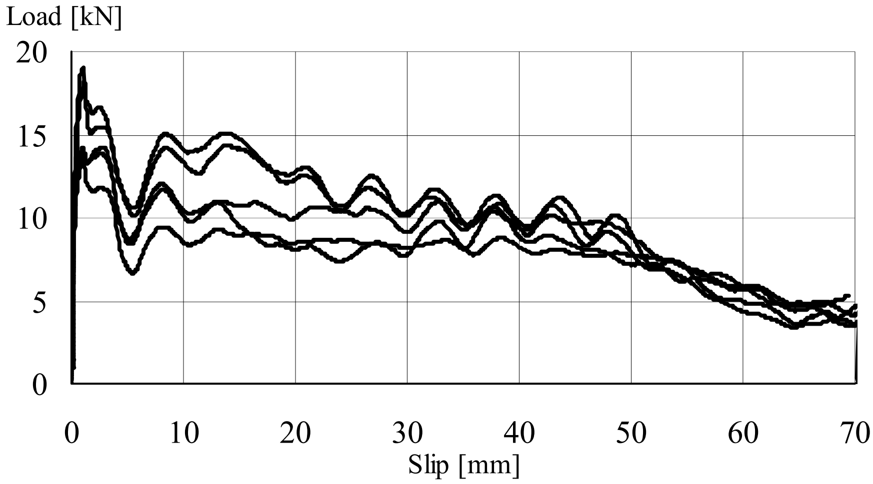


Figure 6 Load versus slip for the indented strands. (Last – glidning för indenterade linor.)

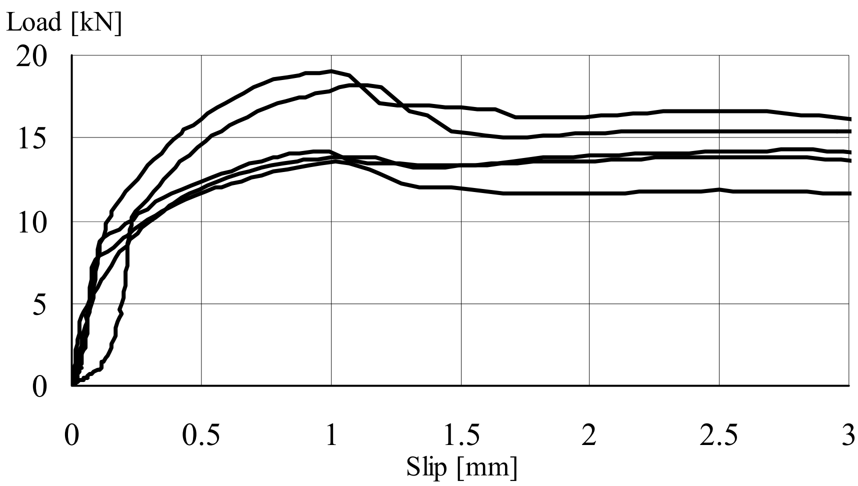


Figure 7 Load versus slip for the indented strands; first part enlarged. (Last – glidning för indenterade linor, första delen uppförstorad.)

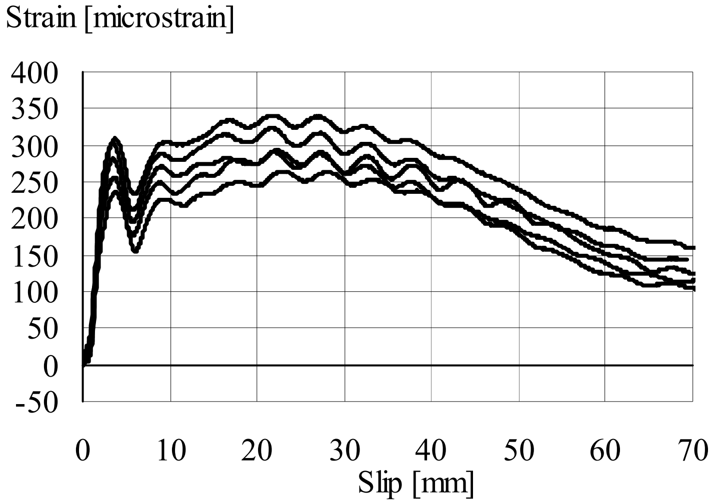


Figure 8 *Average measured tangential strain in the steel tubes versus slip for the indented strands. (Genomsnittliga uppmätta tangentiella töjningar i stålröret plottad mot glidningen, för indenterade linor.)*

4.2 Old smooth strands

Measured load versus slip for the strands of type "old smooth" is shown in Figure 9. The fist part enlarged is shown in Figure 10. The average measured tangential strain in the steel tubes for each of the tests is shown in Figure 11. As can be seen, the scatter is larger than for indented strands.

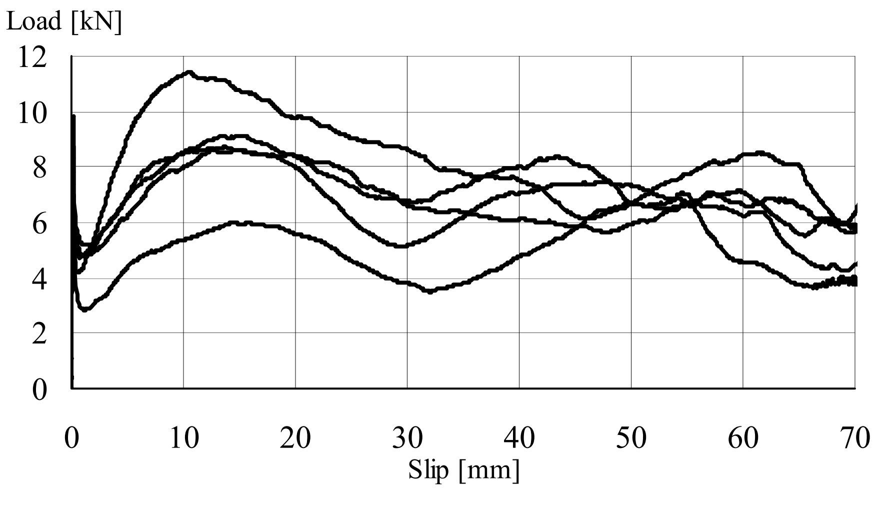


Figure 9 *Load versus slip for the strands of type "old smooth". (Last – glidning för linor av typen "gamla släta".)*

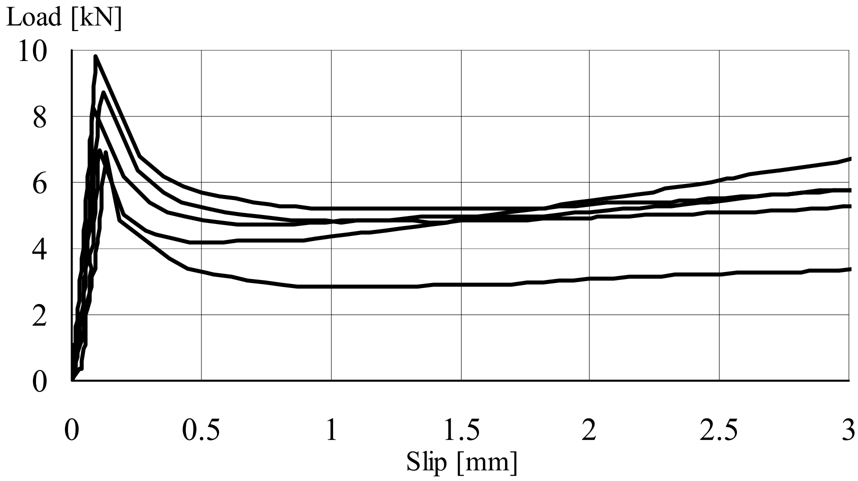


Figure 10 *Load versus slip for the strands of type "old smooth"; first part enlarged. (Last – glidning för linor av typen "gamla släta", första delen uppförstorad.)*

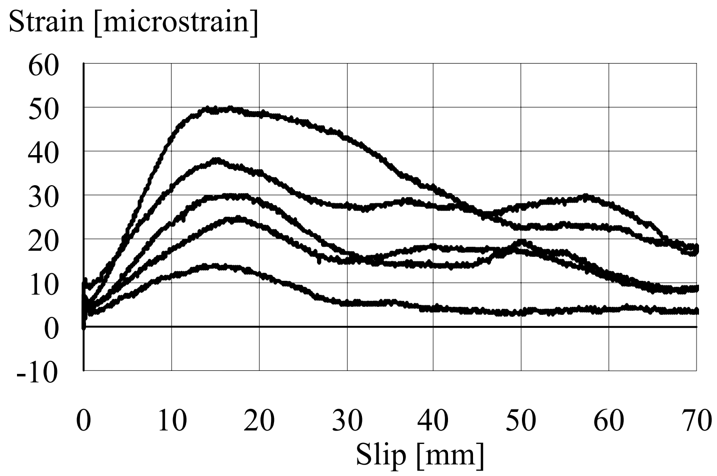


Figure 11 *Average measured tangential strain in the steel tubes versus slip for the strands of type "old smooth". (Genomsnittliga uppmätta tangentiella töjningar i stålröret plottad mot glidningen, för linor av typen "gamla släta".)*

4.3 New smooth strands

Measured load versus slip for the strands of type "new smooth" is shown in Figure 12. The fist part enlarged is shown in Figure 13. The average measured tangential strain in the steel tubes for each of the tests is shown in Figure 14. In one of the tests, No. b, the tangential stress was markedly larger than in the other ones. As can be seen in Appendix C, all three strain gauges in this test showed high values.

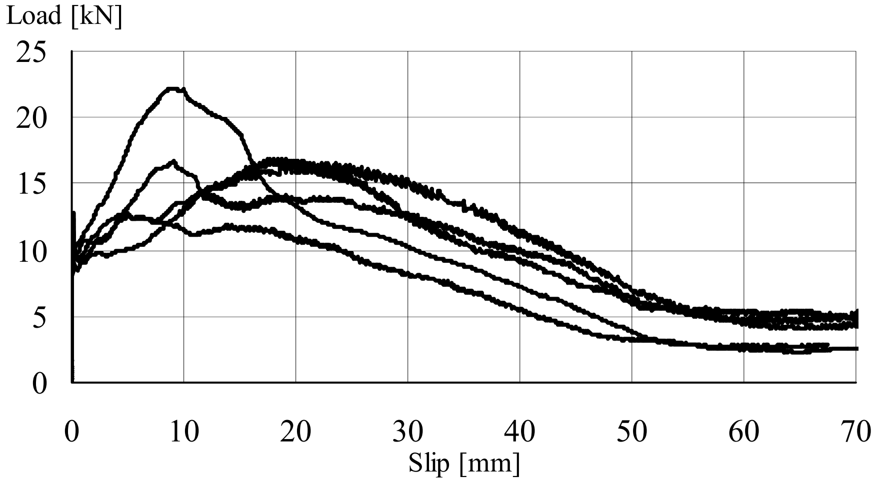


Figure 12 *Load versus slip for the strands of type "new smooth". (Last – glidning för linor av typen "nya släta".)*

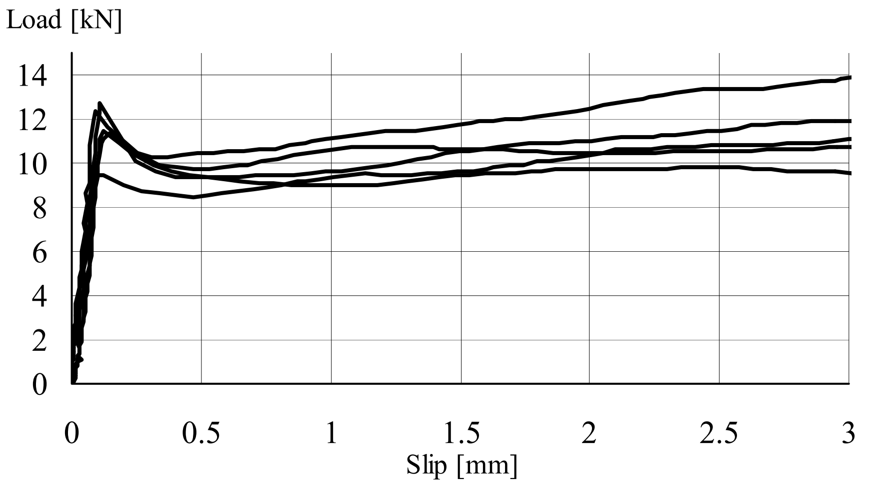


Figure 13 *Load versus slip for the strands of type "new smooth"; first part enlarged. (Last – glidning för linor av typen "nya släta", första delen uppförstorad.)*

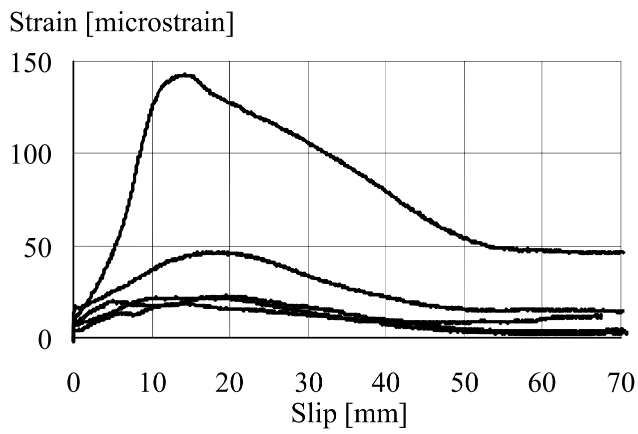


Figure 14 Average measured tangential strain in the steel tubes versus slip for the strands of type "new smooth". (Genomsnittliga uppmätta tangentiella töjningar i stålröret plottad mot glidningen, för linor av typen "nya släta".)

4.4 Comparison between different strand types

For each of the different strand types, one test showing a typical behaviour close to the average values was chosen. For the indented strands and the "old smooth", test No. e was chosen, and for the "new smooth", test No. d was chosen. The response in these tests are compared in Figs. 15 to 18. As can be seen in Figure 16, the smooth strands behave stiffer initially than the indented strand. The "new smooth" has a higher bond capacity than the "old smooth"; for large slip values the "new smooth" even has a higher capacity than the indented strand. For slip values between 0.3 to 4 mm, the indented strand has the highest capacity. However, the indented strands also causes the largest tangential strains in the steel tube, see Figs 17 and 18; i.e. the indented strands causes larger normal stresses than the smooth strands. The two different types of smooth strands appear to cause approximately the same normal stresses; in Figure 17 the "old smooth" causes slightly larger tangential strains than the "new smooth", but considering the scatter in the measured values, this is not for sure.

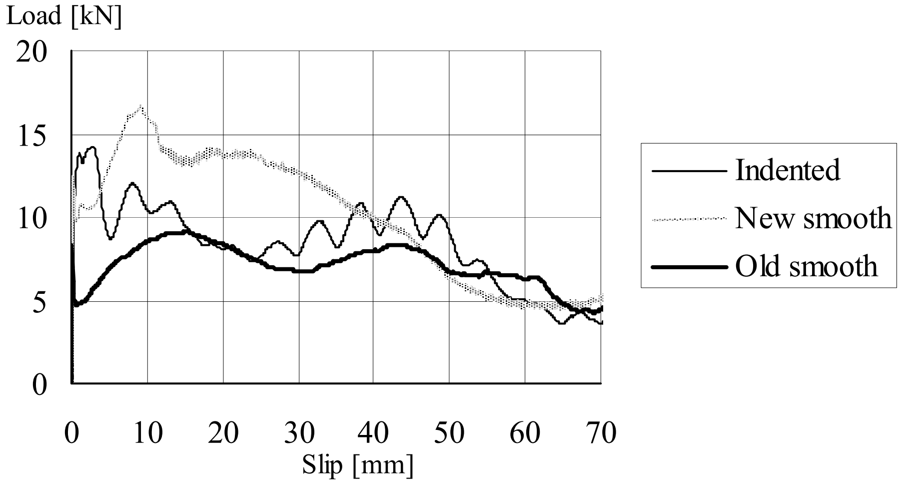


Figure 15 *Typical load versus slip for different strands types. (Typiska last-glidning för olika typer av linor.)*

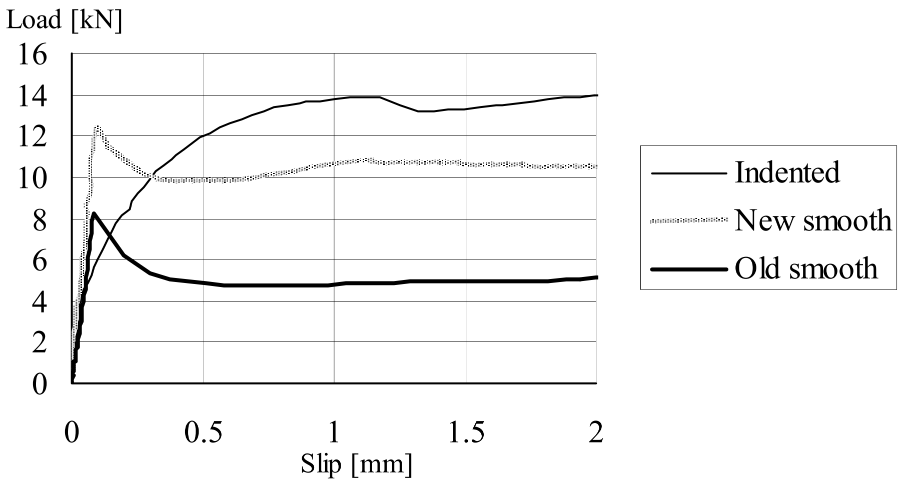


Figure 16 *Typical load versus slip for different strands types; first part enlarged. (Typiska last-glidning för olika typer av linor, första delen uppförstorad.)*

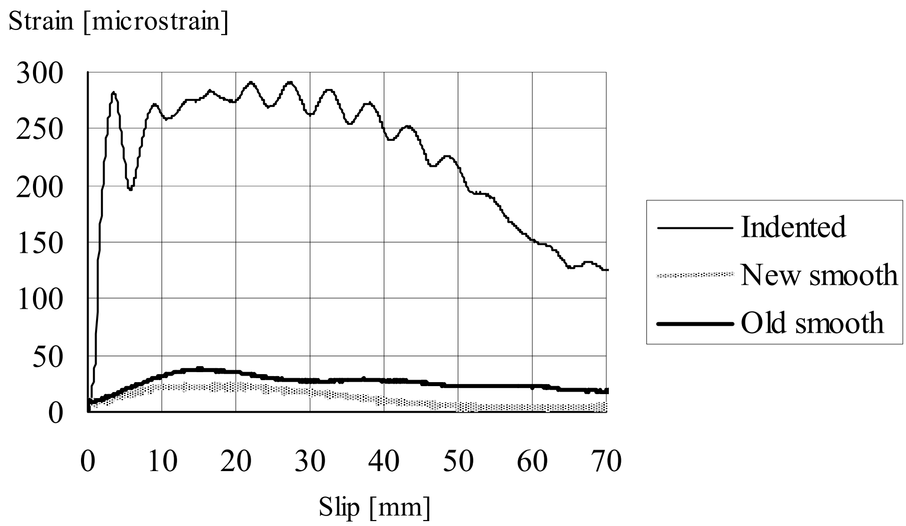


Figure 17 *Typical tangential strain in the steel tubes versus slip for different strands types. (Typiska tangentiella töjningar gentemot glidning för olika typer av linor.)*

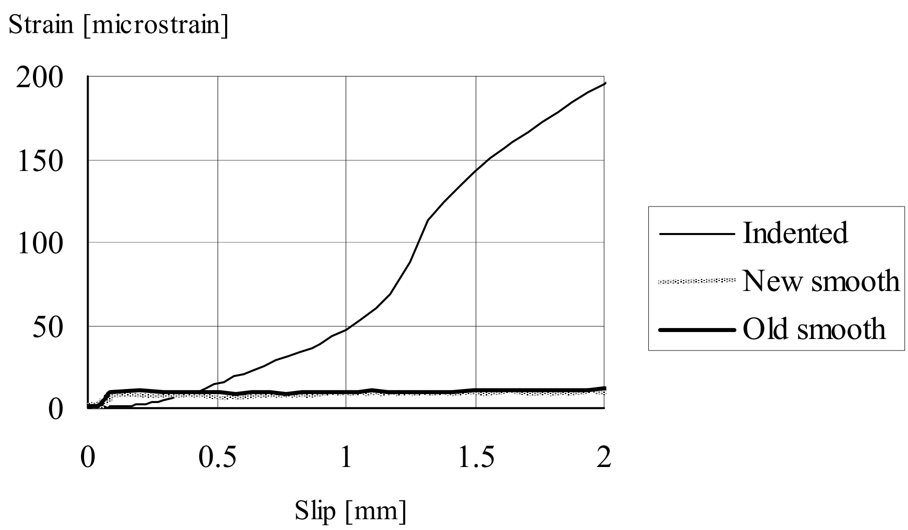


Figure 18 *Typical tangential strain in the steel tubes versus slip for different strands types; first part enlarged. (Typiska tangentiella töjningar gentemot glidning för olika typer av linor, uppförstoring av första delen.)*

5 Conclusions

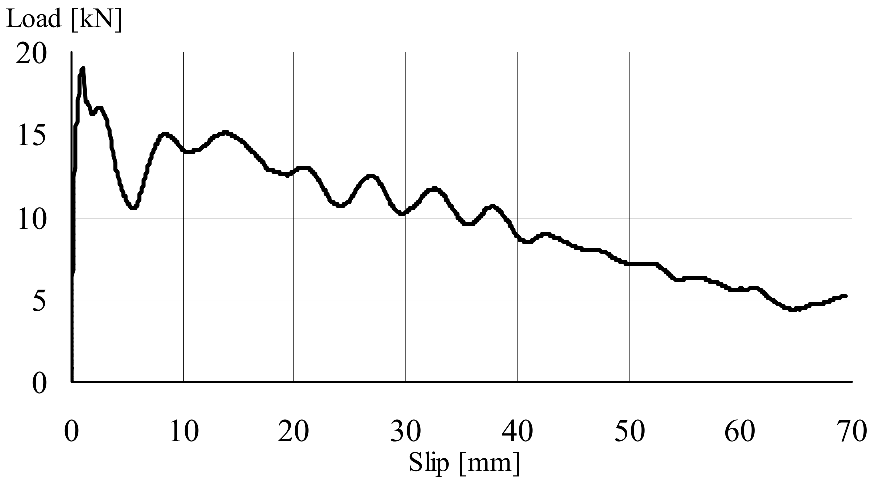
The tests show that the smooth strands behave stiffer initially than the indented strand. The "new smooth" has a higher bond capacity than the "old smooth"; for large slip values the "new smooth" even has a higher capacity than the indented strand. For slip values between 0.3 to 4 mm, the indented strand has the highest capacity. However, the indented strands also causes larger normal stresses than the smooth strands, which increases the risk for splitting failure. The two different types of smooth strands appear to cause approximately the same normal stresses.

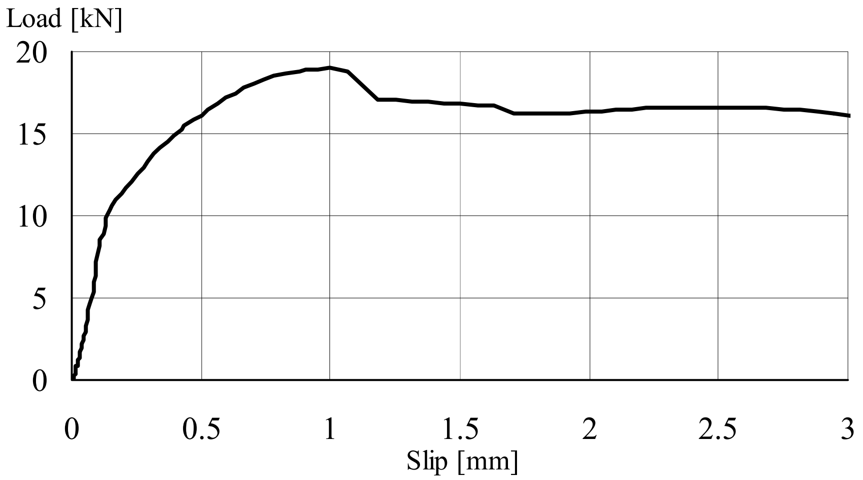
6 References

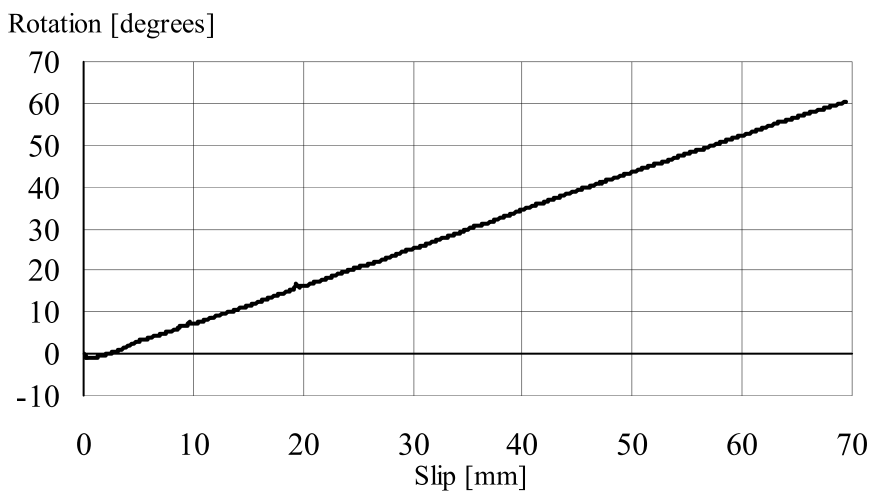
BST Byggstandardiseringen (1991): Betongprovning med Svensk Standard. BST handbok 12, utgåva 6 (Swedish Standards for Concrete Testing, BST handbook 12, sixth edition. In Swedish), SIS – Standardiseringskommissionen i Sverige och Svensk Byggtjänst, Stockholm, 286 pp.

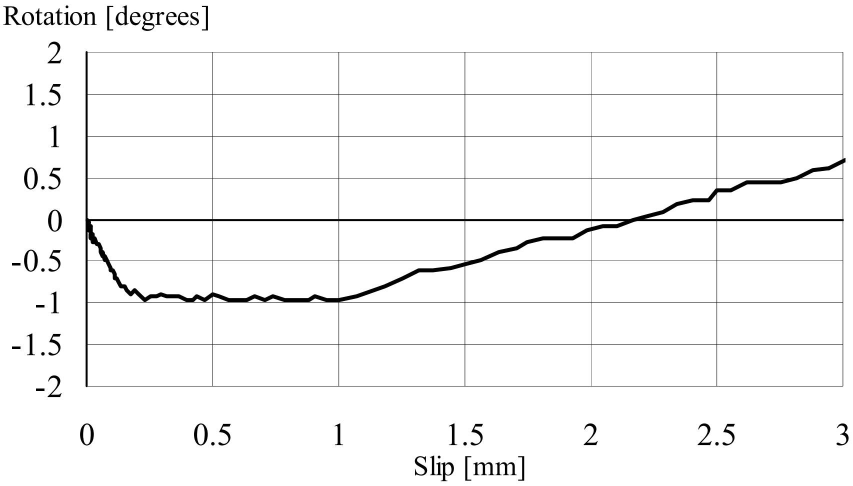
A1 Results for the indented strands

A1.1 Test indented a





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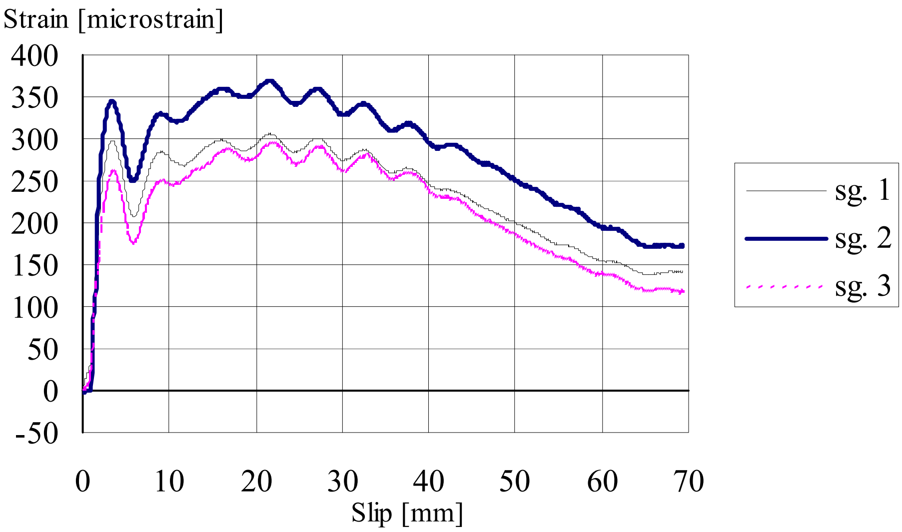
Slip [mm]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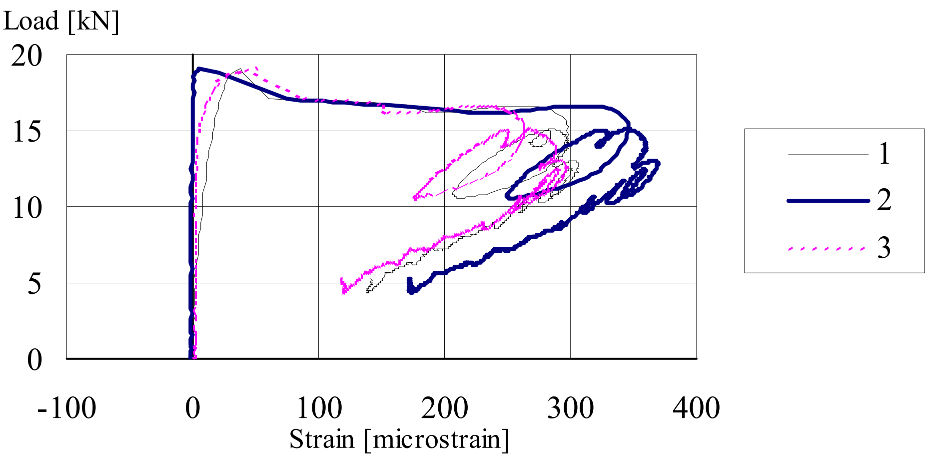
sg. 2
sg. 3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Strain [microstrain]
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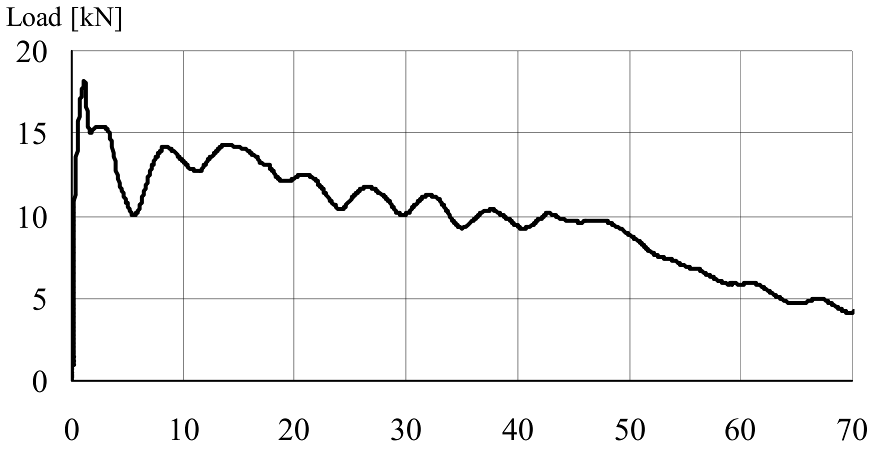

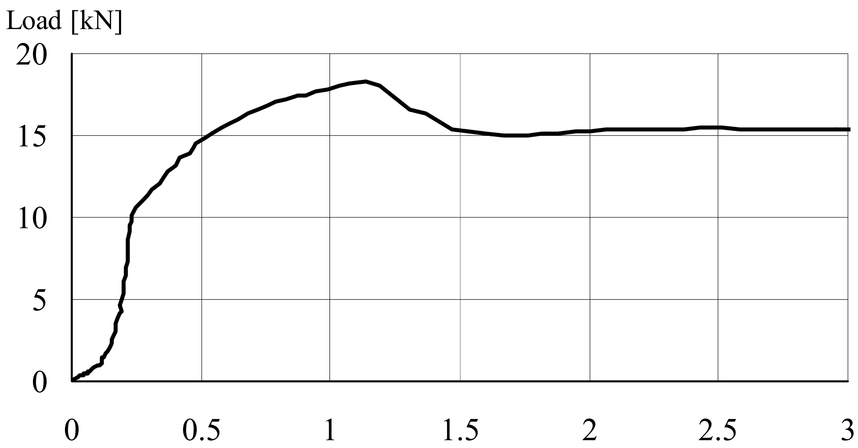

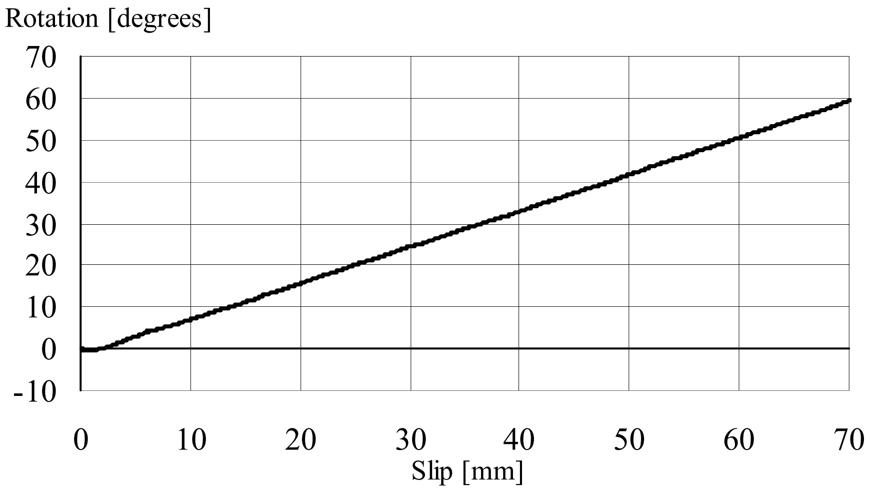

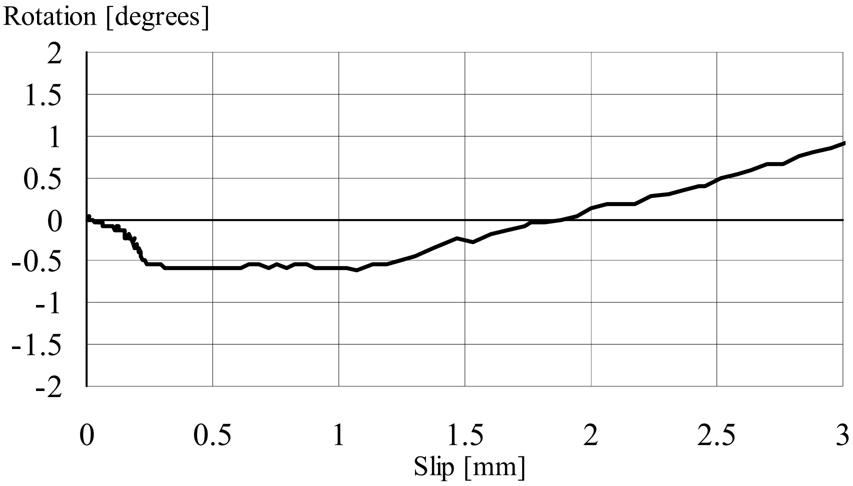
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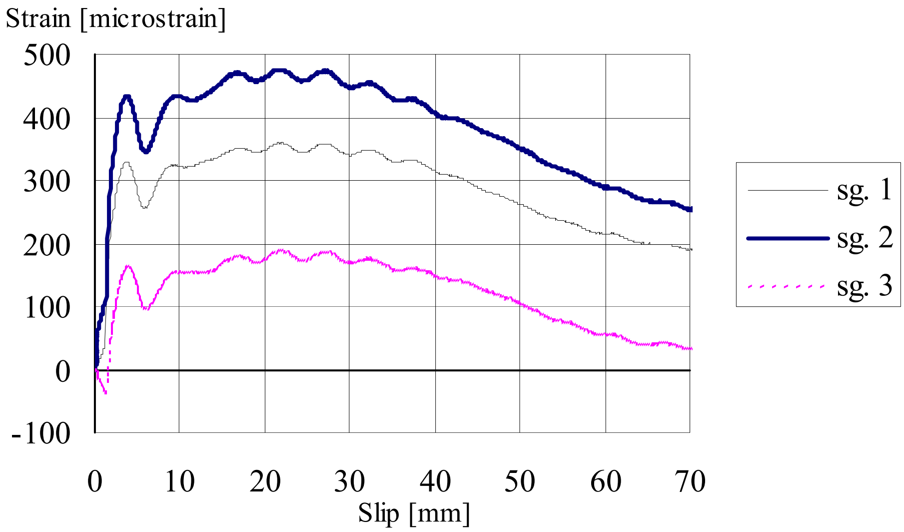
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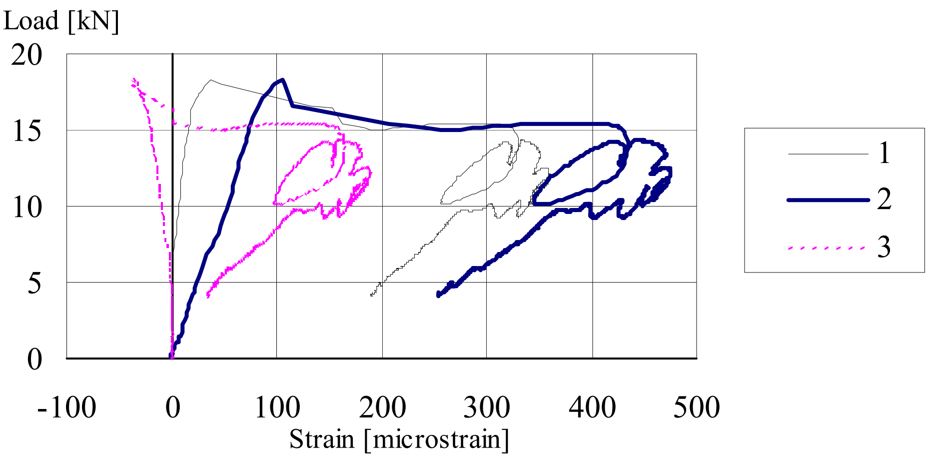
sg. 2
sg. 3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Strain [microstrain]
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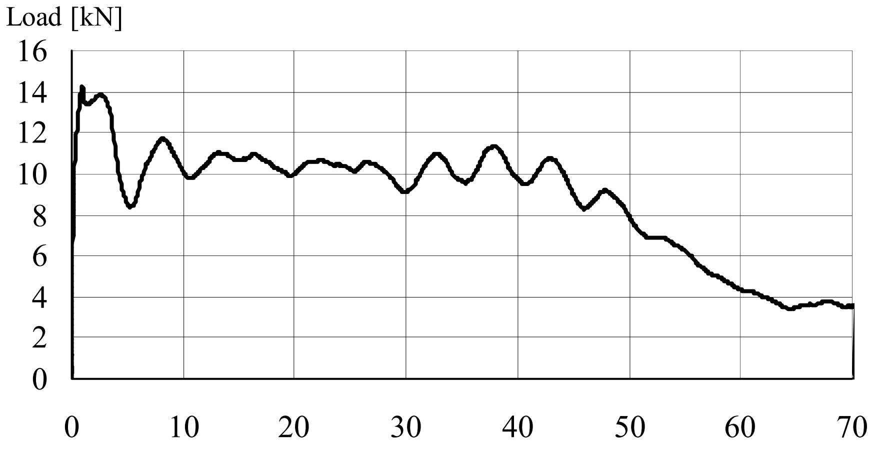
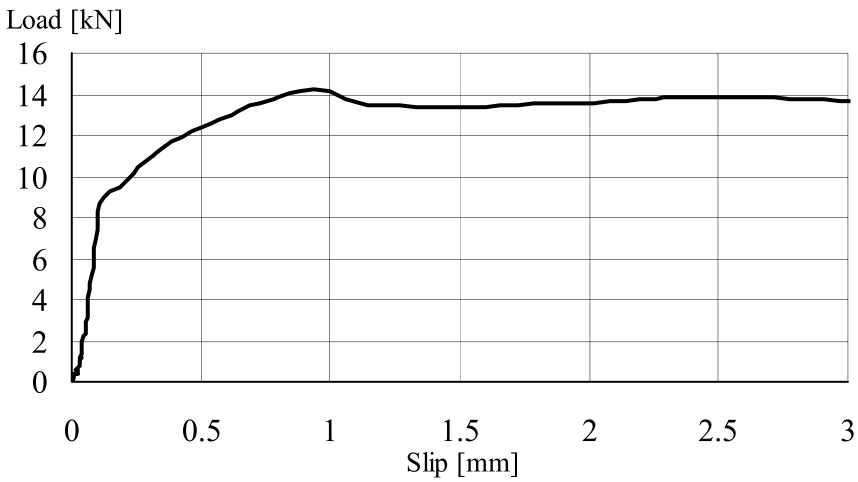
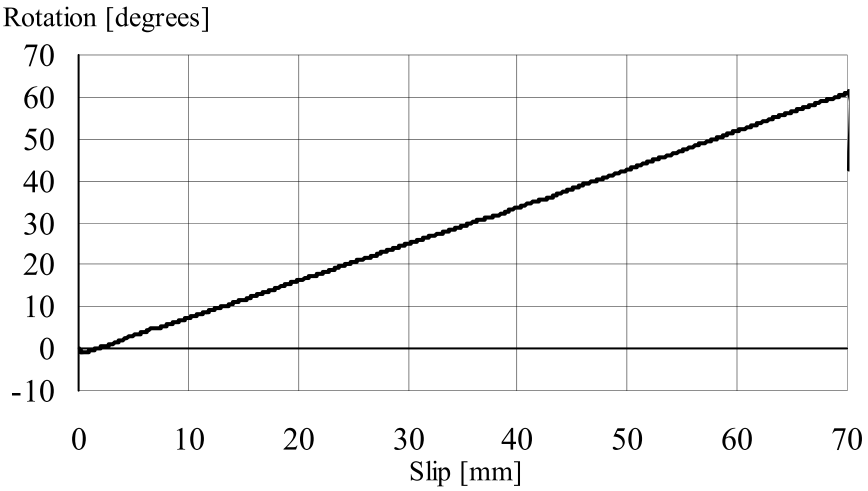
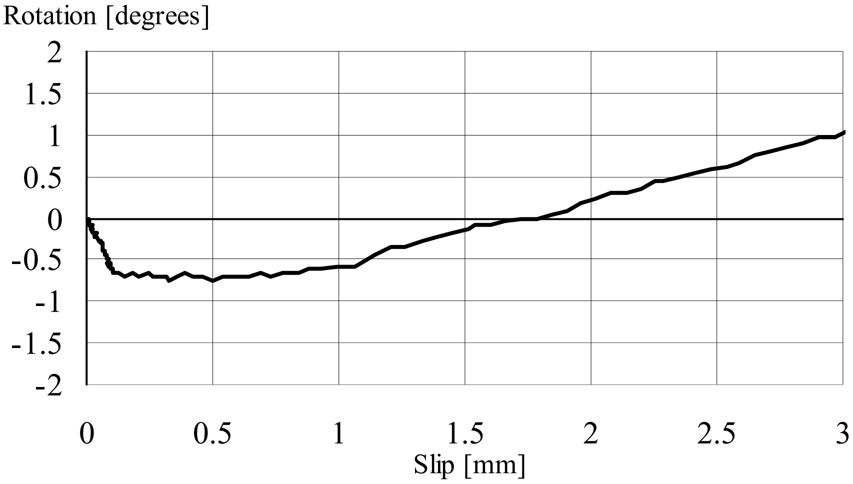
3

A1.3 Test indented c









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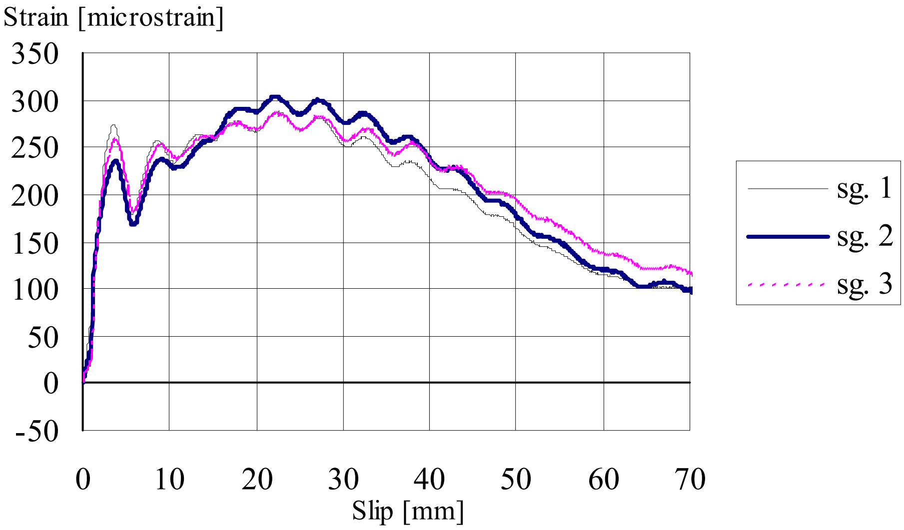
Slip [mm]



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60
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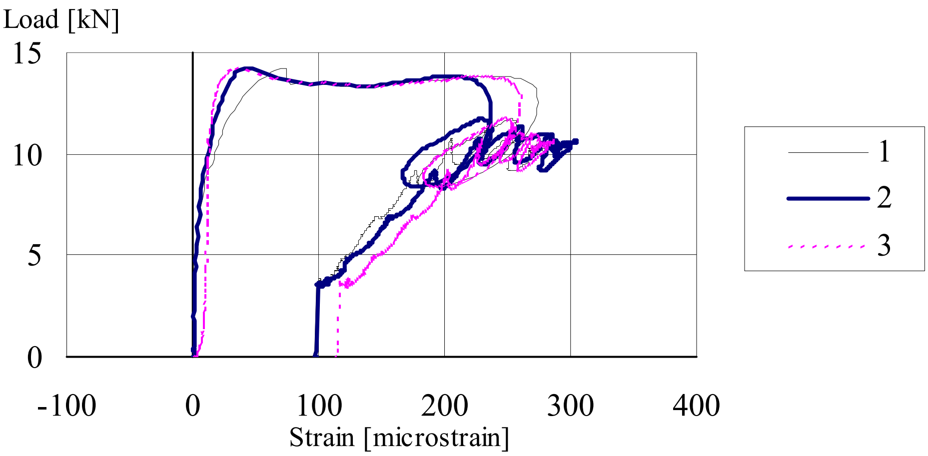
Slip [mm]
sg. 1
sg. 2
sg. 3



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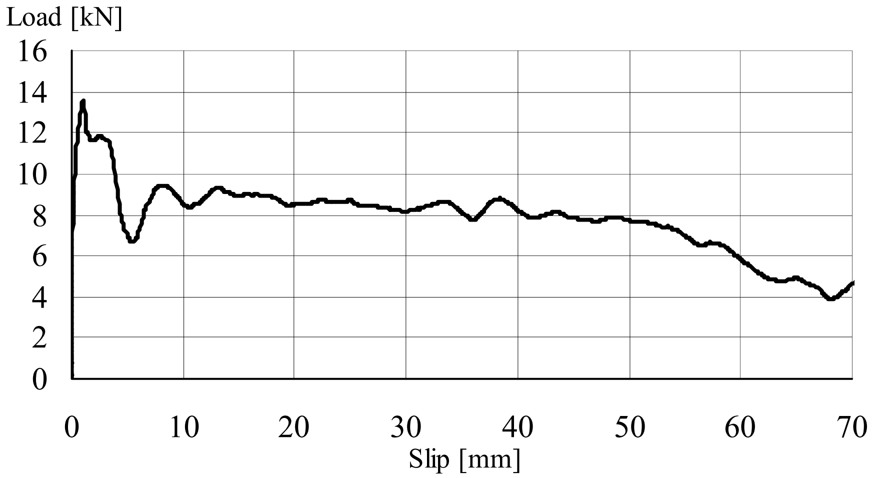
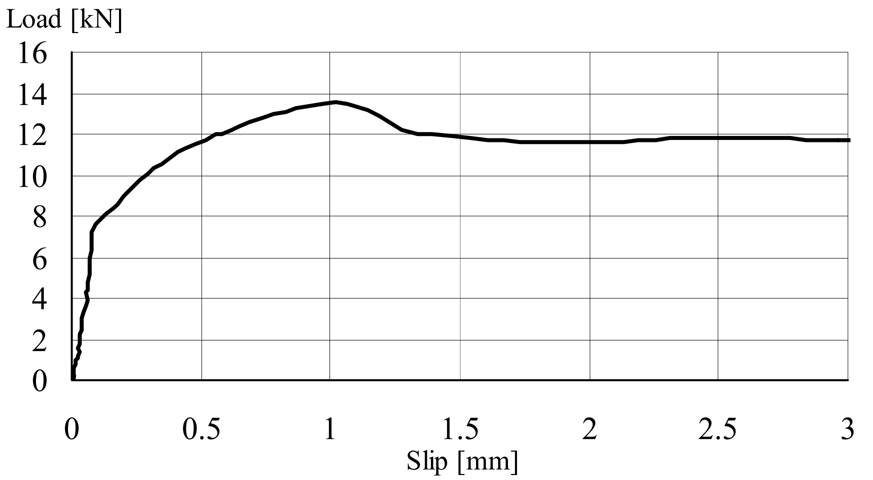
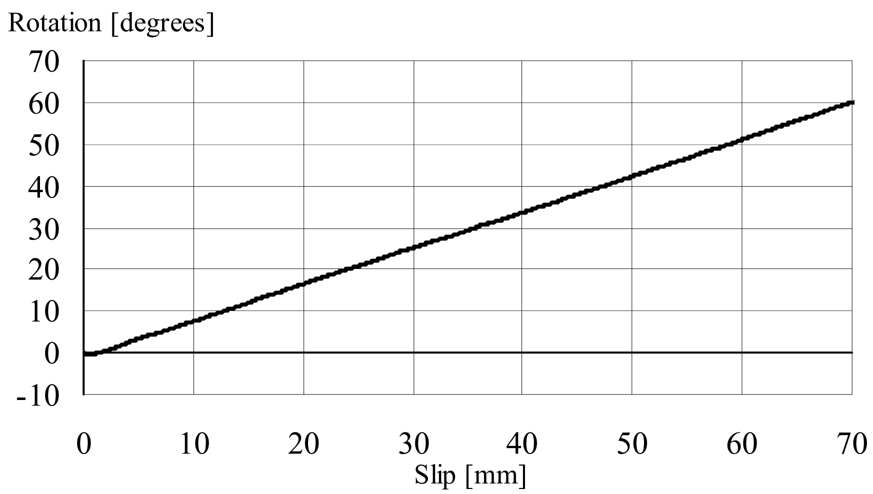
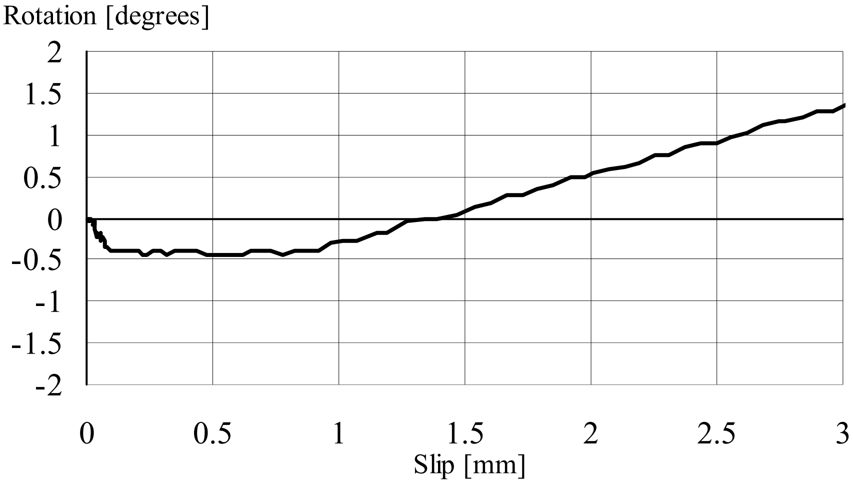
300
400
Strain [microstrain]
1
2
3

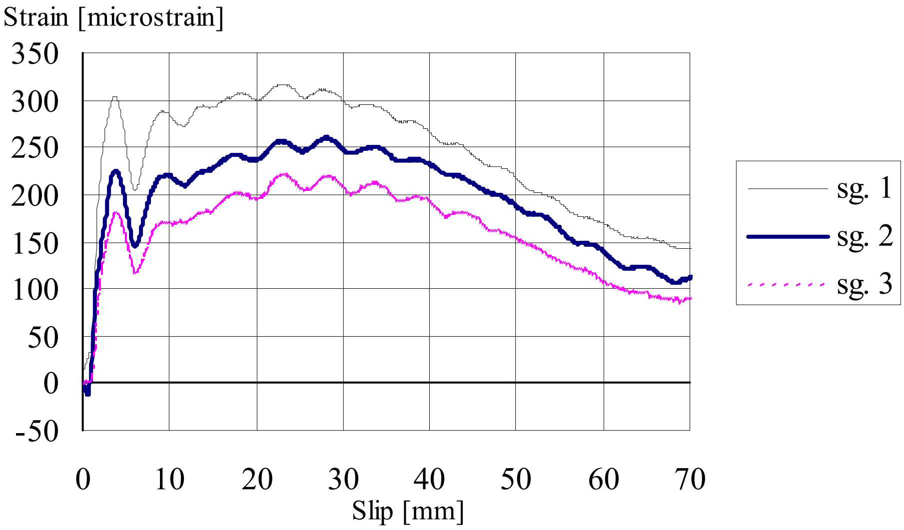
A1.4 Test indented d

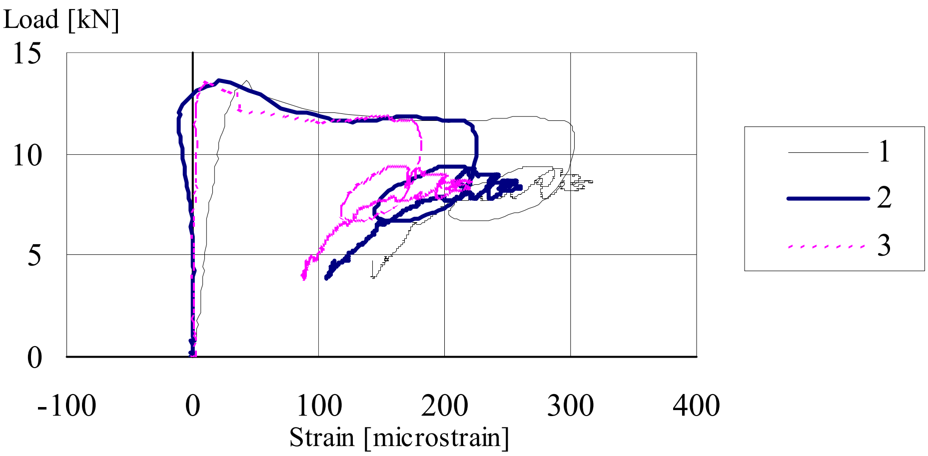




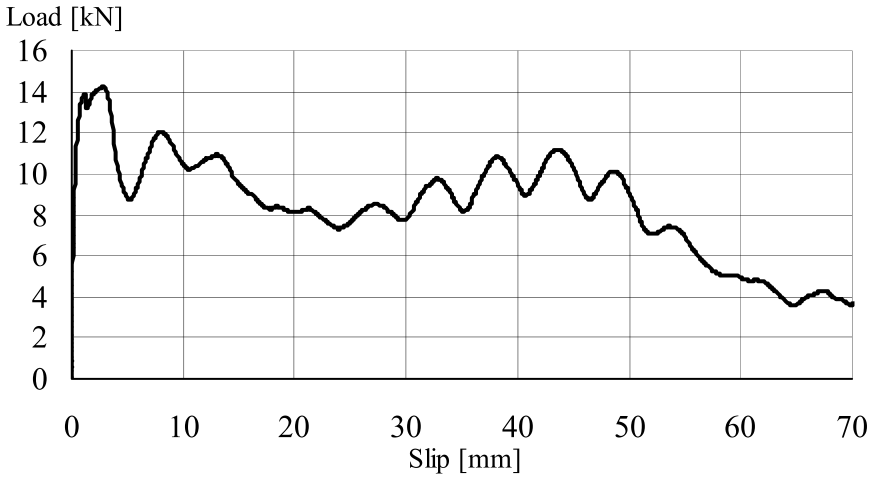


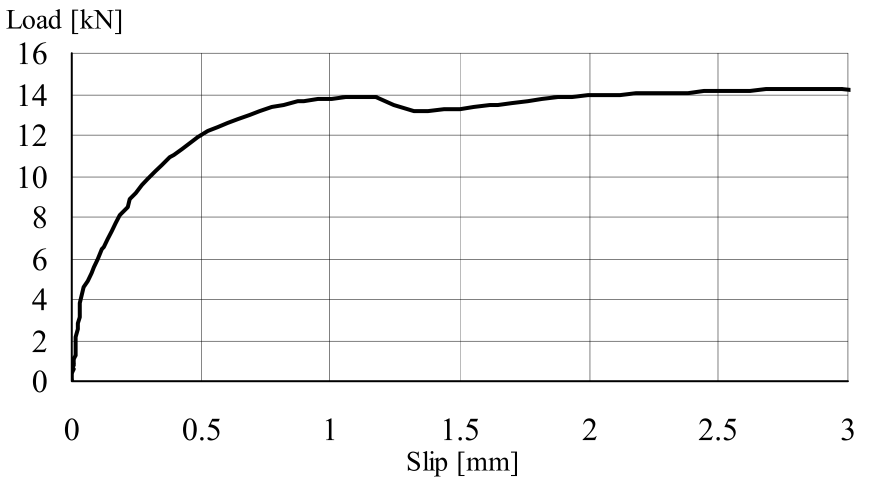

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

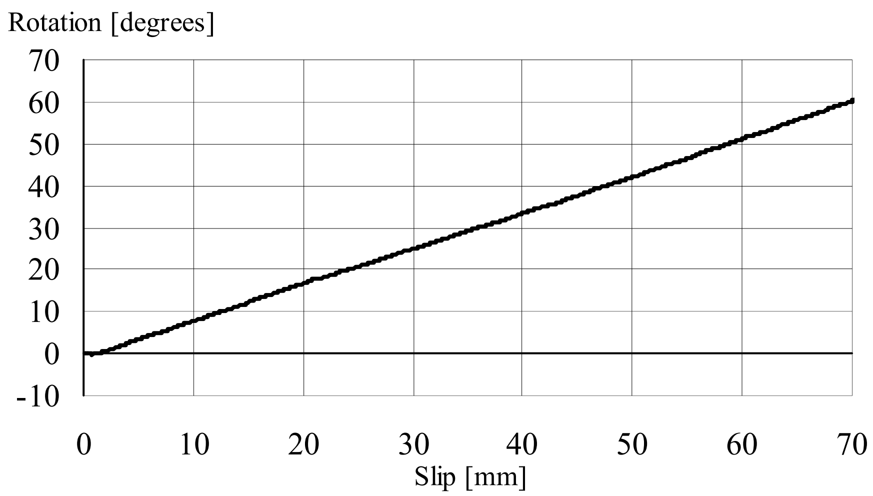

Strain [microstrain]
350
300
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

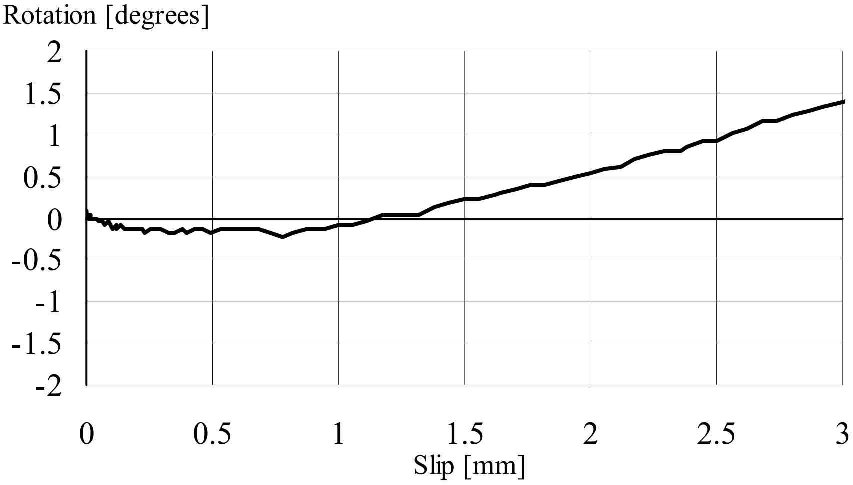

Load [kN]
15
10
5
0
-100
0
100
200
300
400
Strain [microstrain]
1
2
3

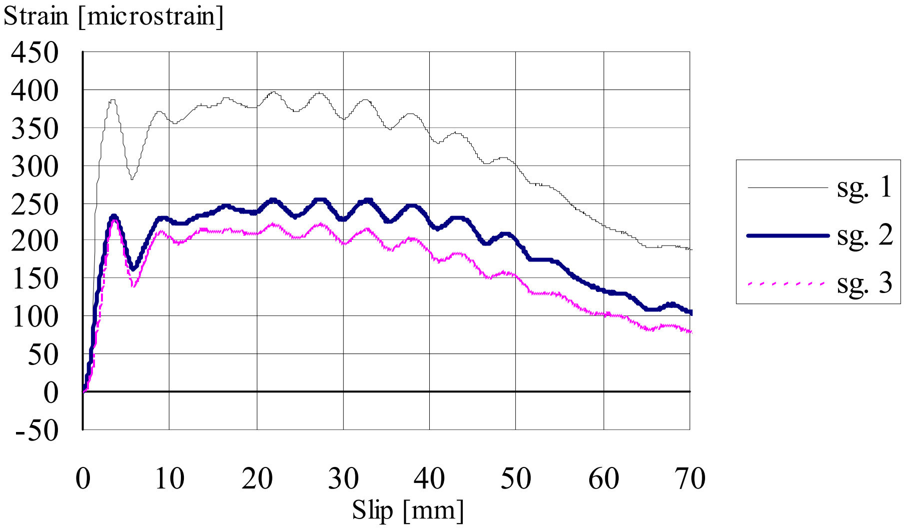
A1.5 Test indented e

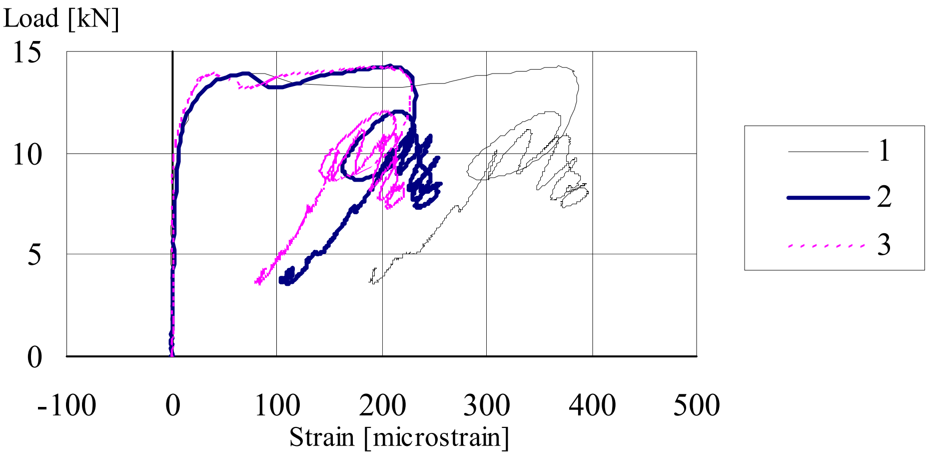






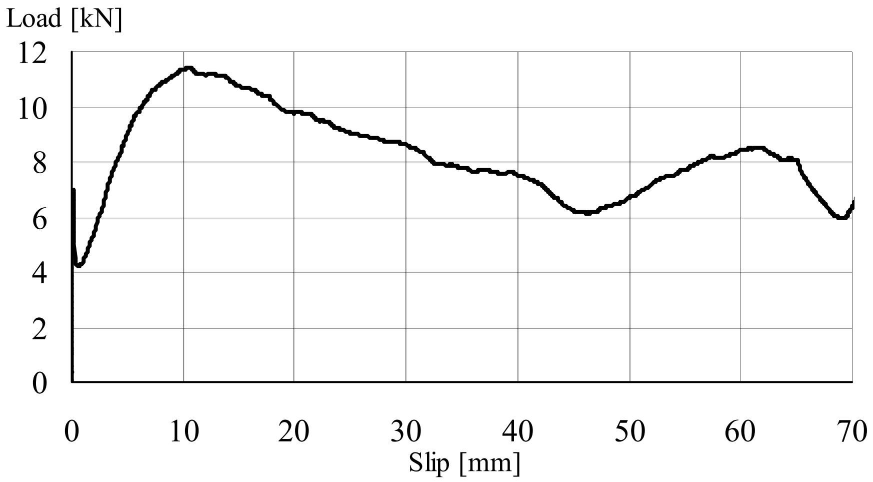

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

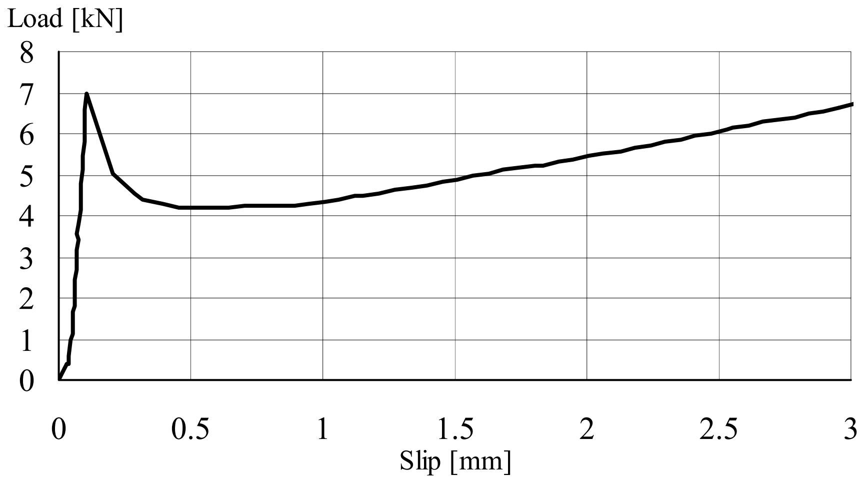

Strain [microstrain]
450
400
350
300
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

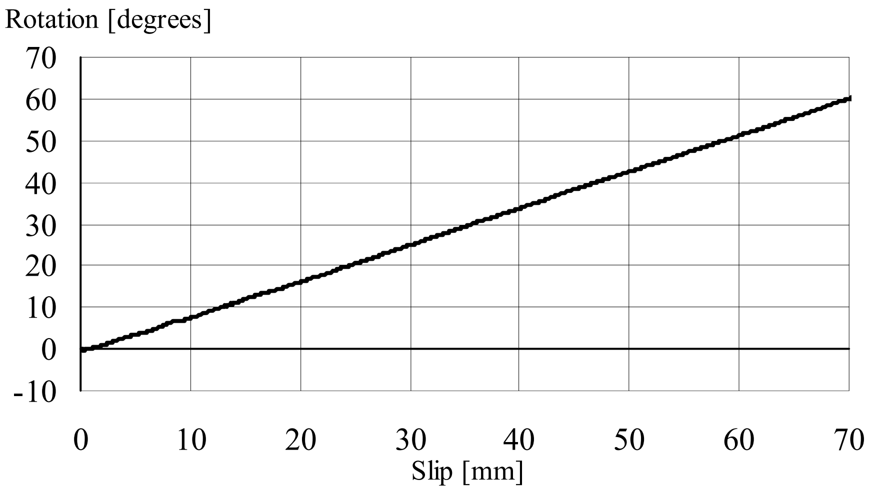

Load [kN]
15
10
5
0
-100
0
100
200
300
400
500
Strain [microstrain]
1
2
3

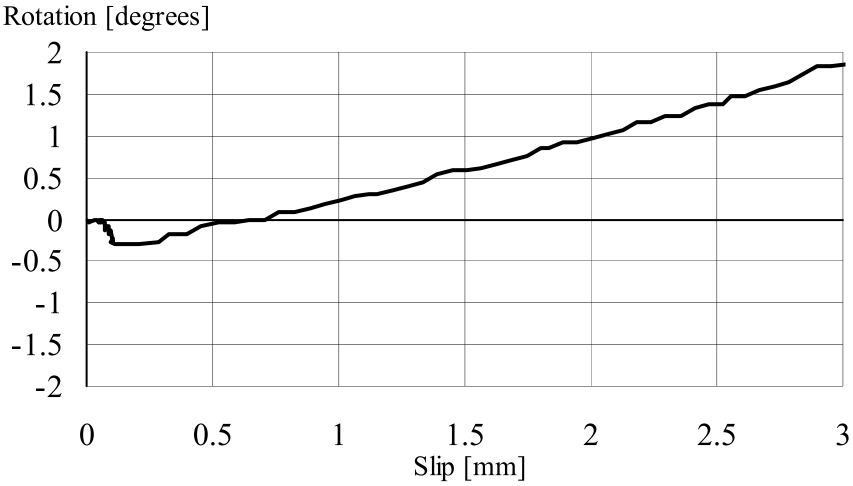
B1 Results for old smooth strands

B1.1 Test old smooth a

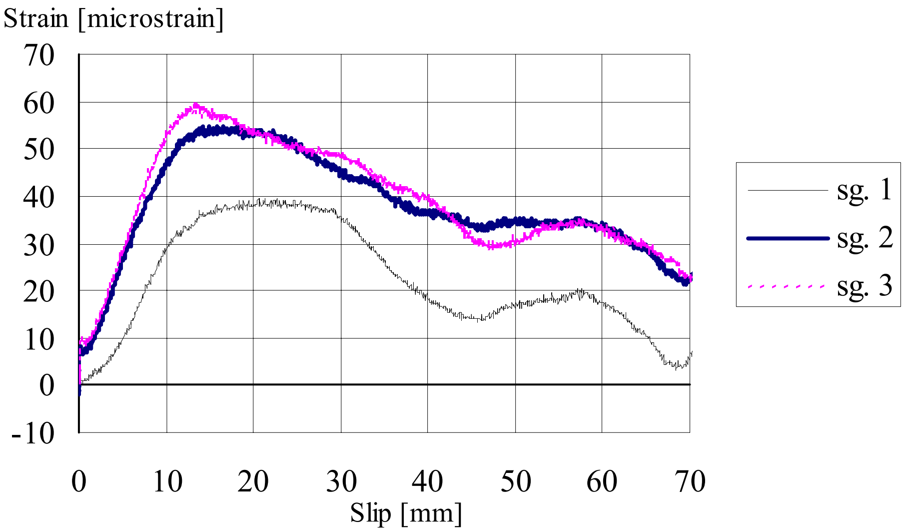




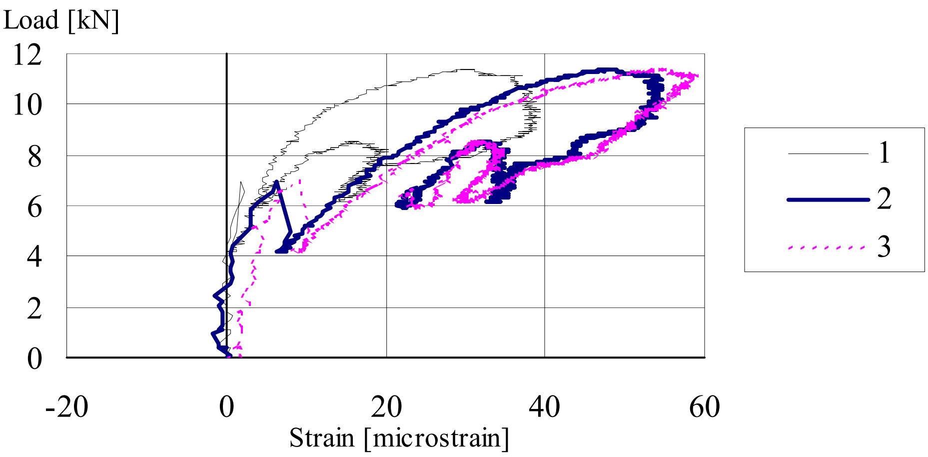




Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

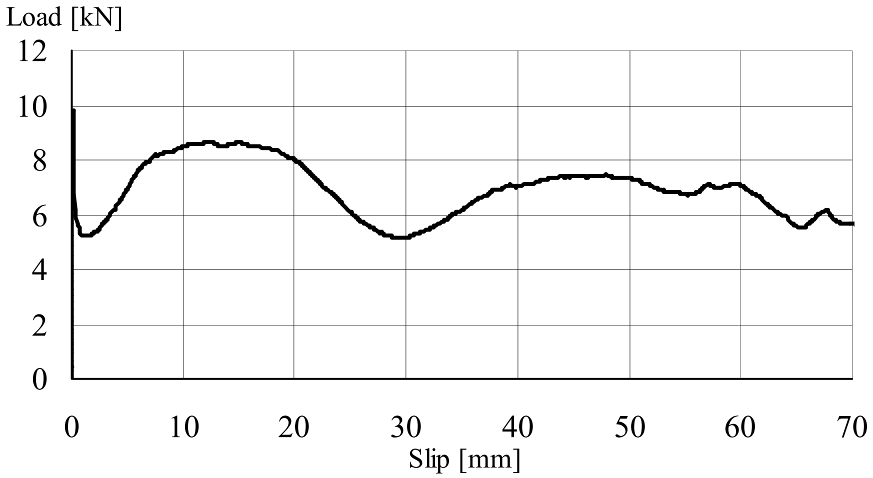


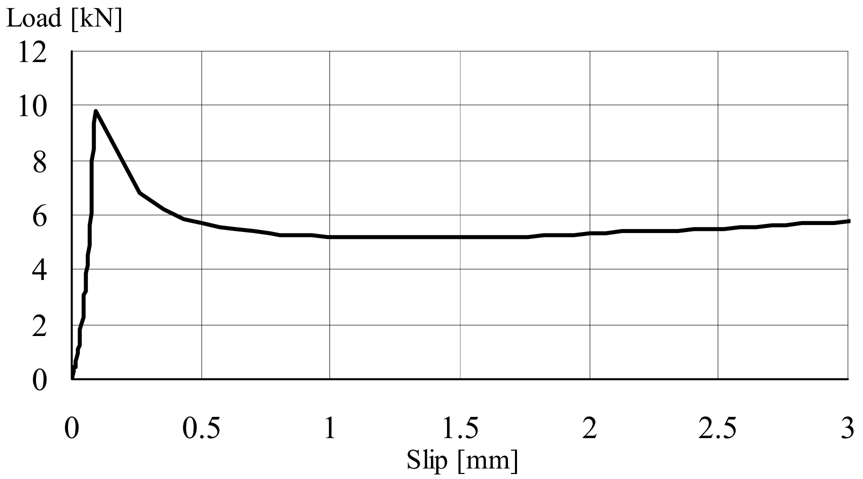
Strain [microstrain]
70
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

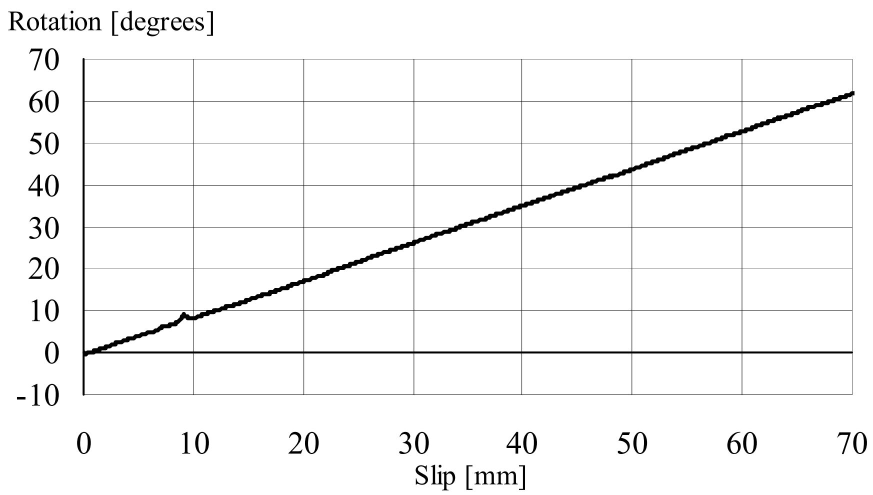


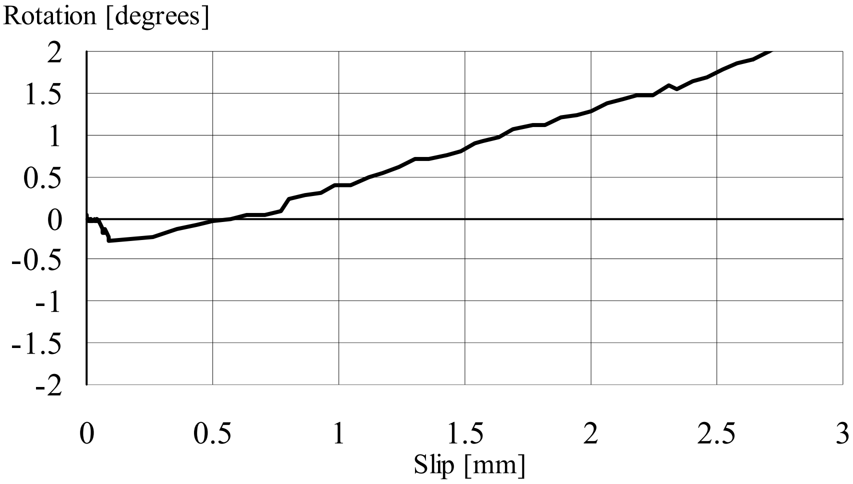
Load [kN]
12
10
8
6
4
2
0
-20
0
20
40
60
Strain [microstrain]
1
2
3

B1.2 Test old smooth b

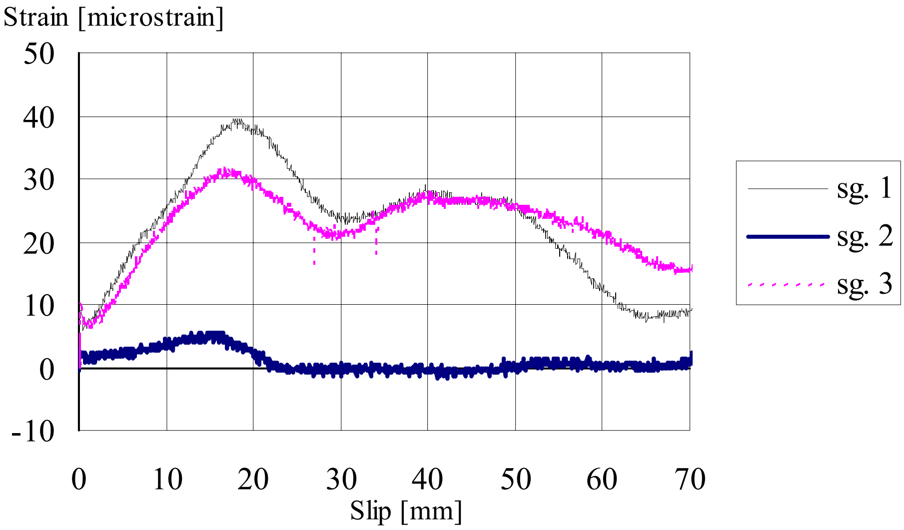




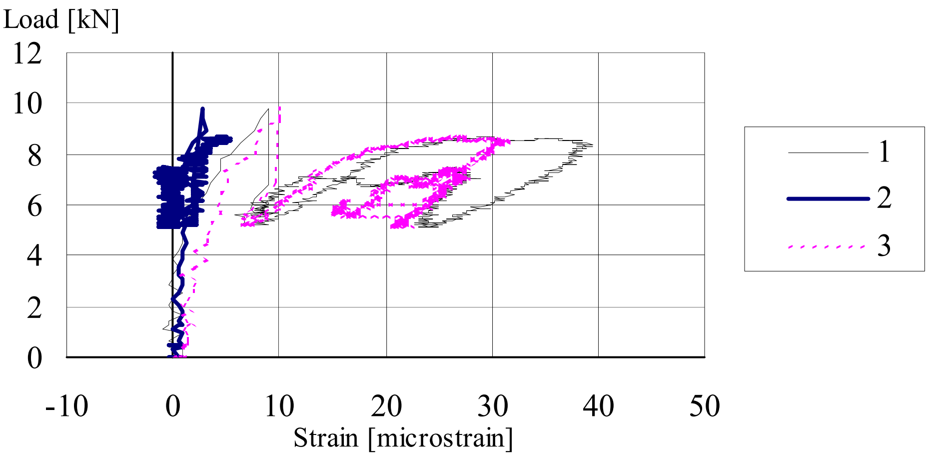




Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

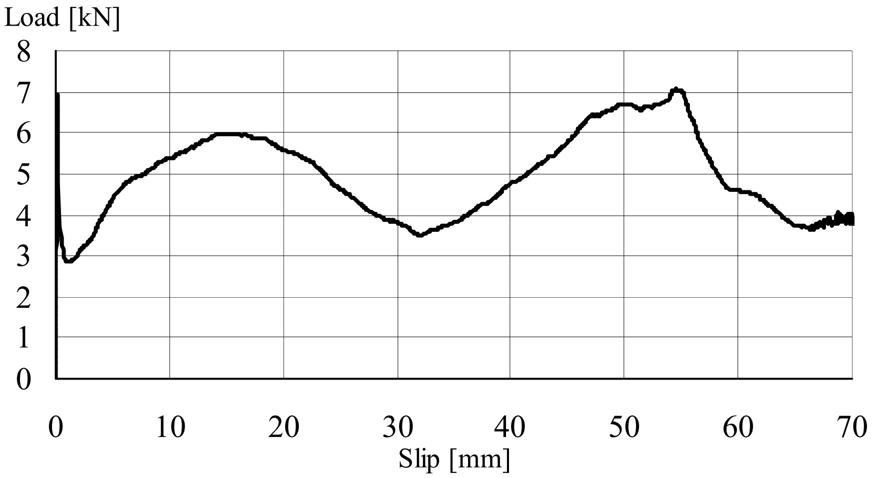


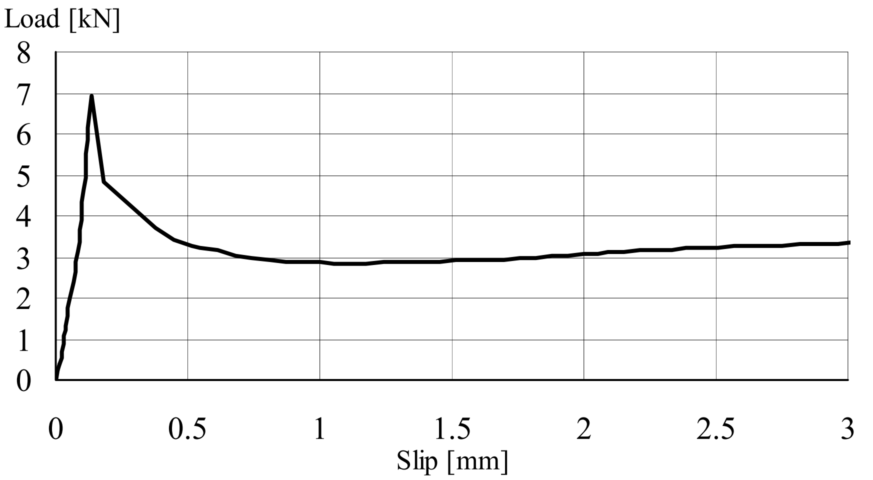
Strain [microstrain]
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

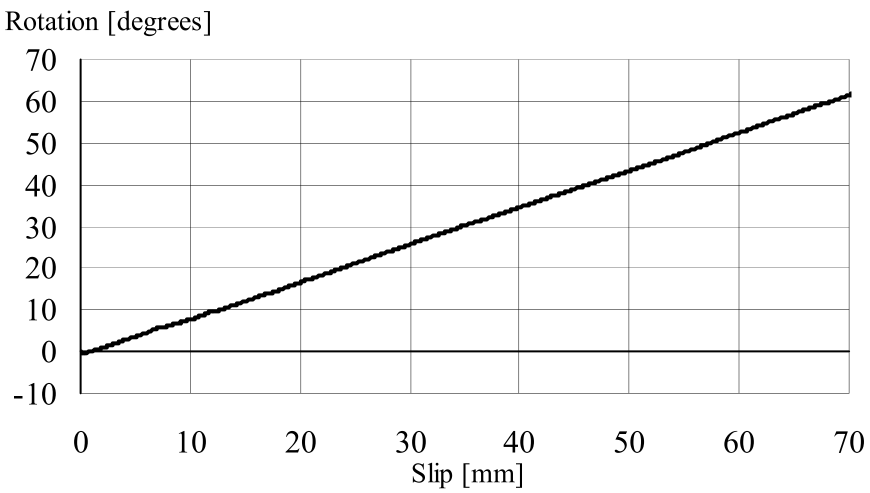


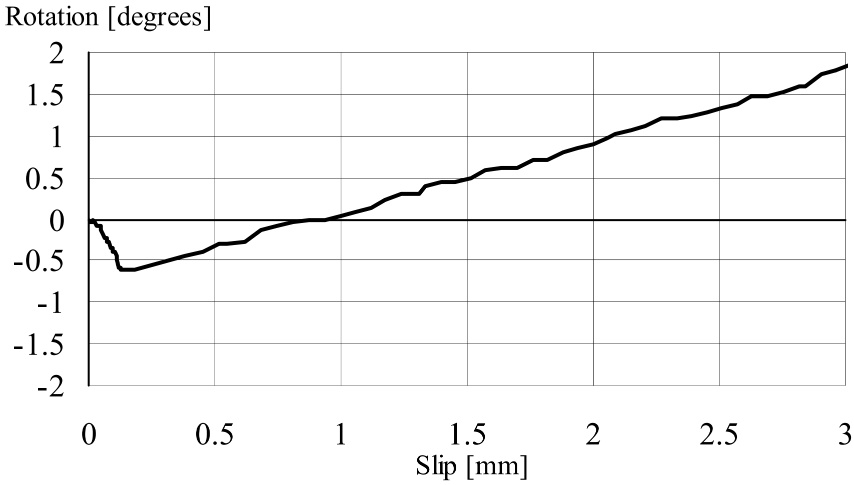
Load [kN]
12
10
8
6
4
2
0
-10
0
10
20
30
40
50
Strain [microstrain]
1
2
3

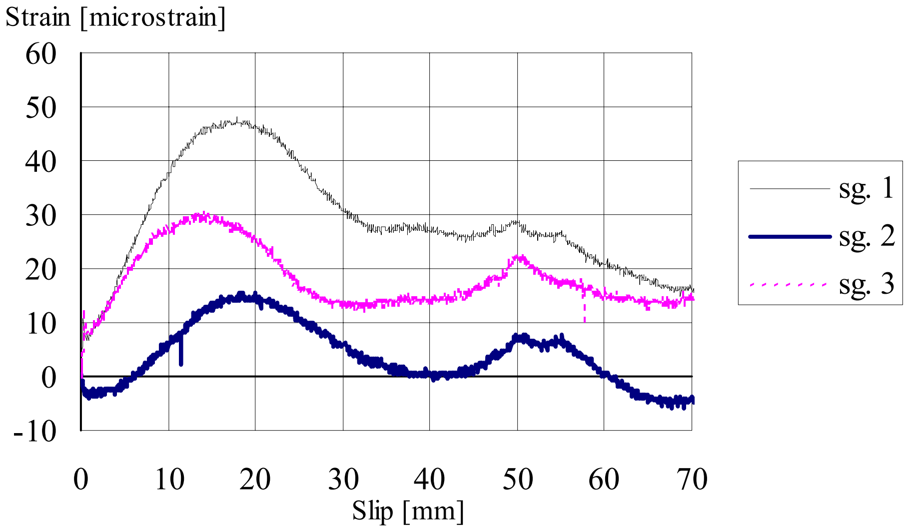
B1.3 Test old smooth c

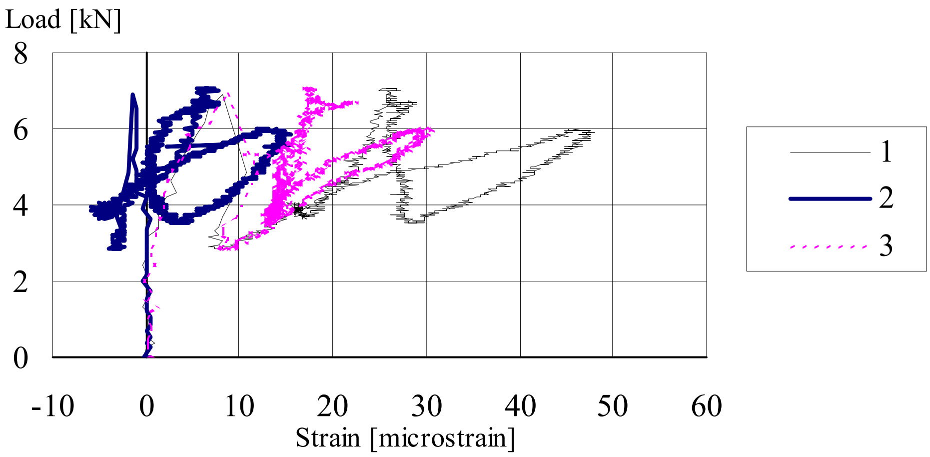




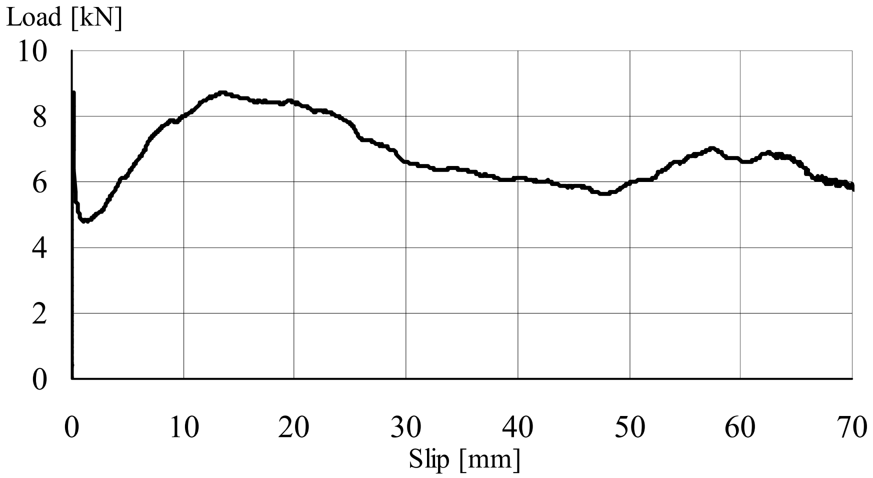


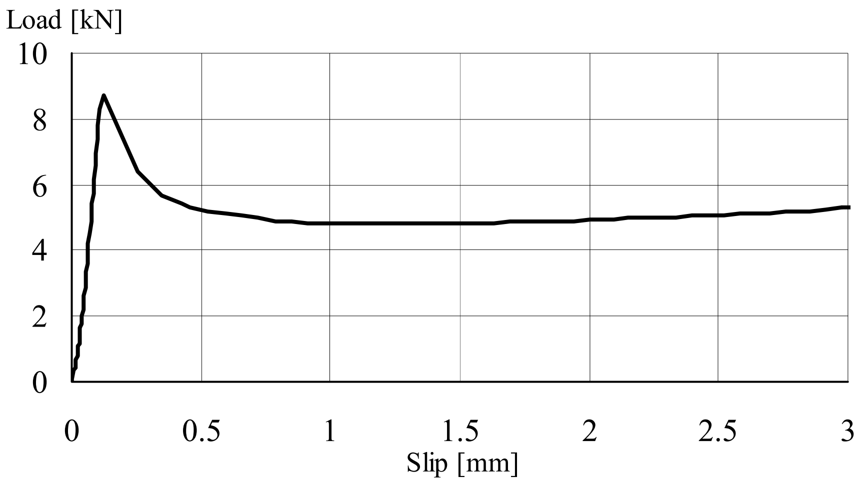

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

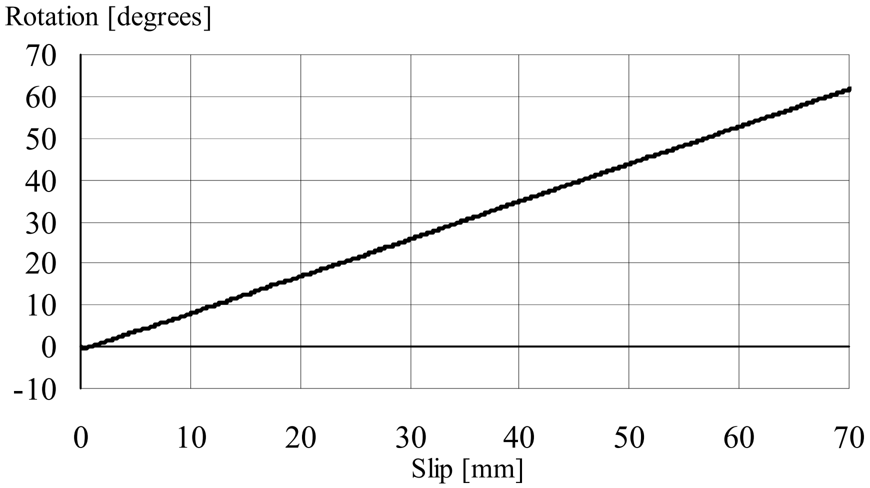

Strain [microstrain]
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

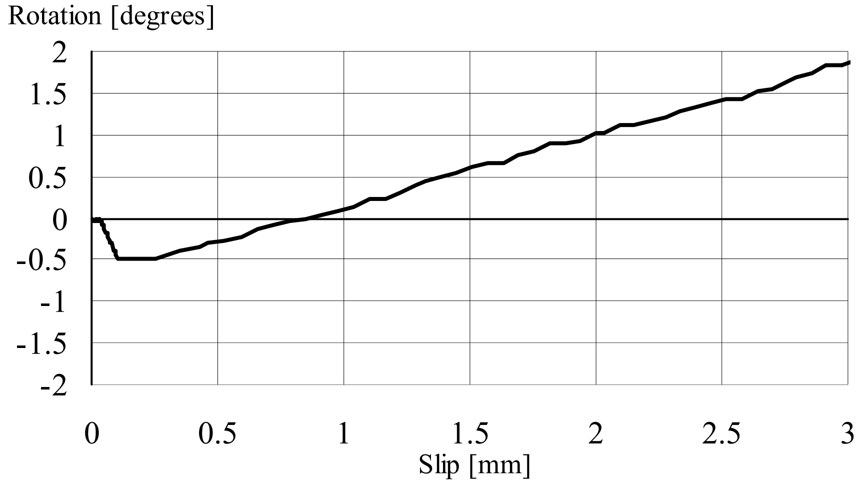

Load [kN]
8
6
4
2
0
-10
0
10
20
30
40
50
60
Strain [microstrain]
1
2
3

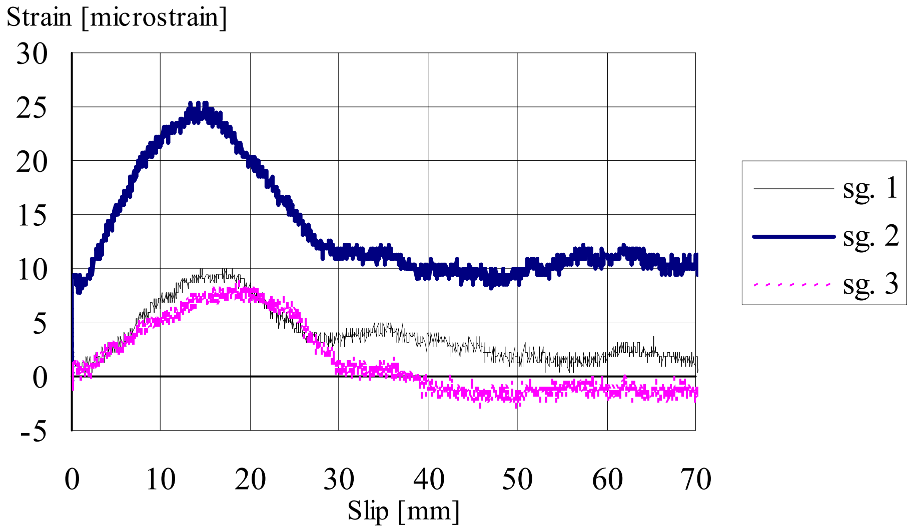
B1.4 Test old smooth d

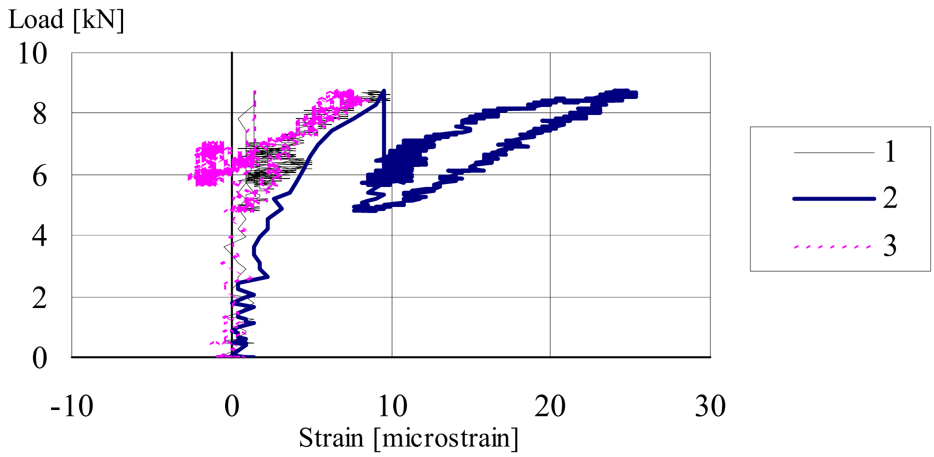




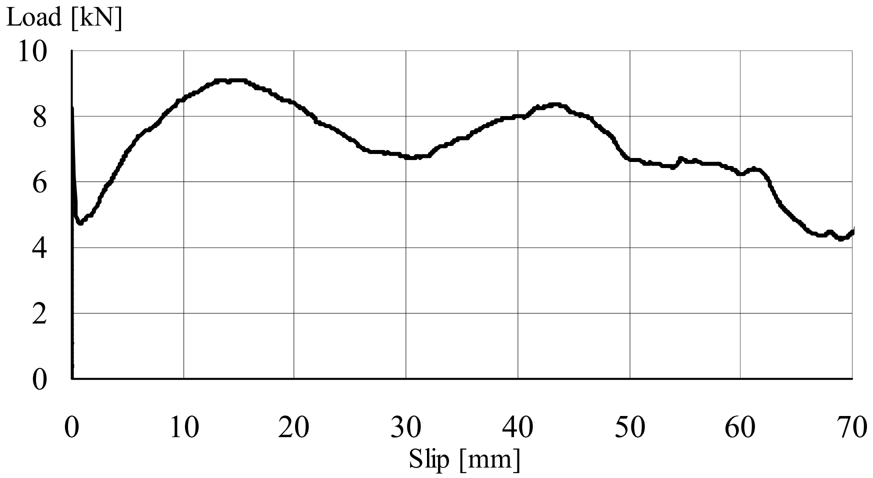


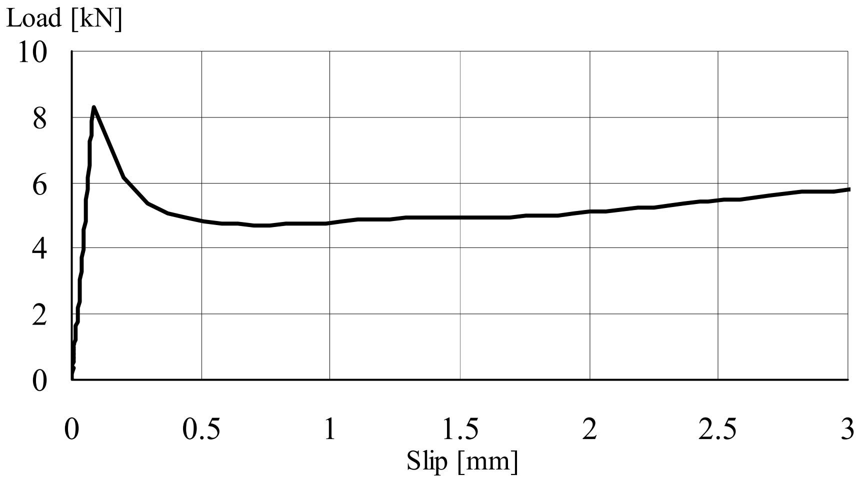

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

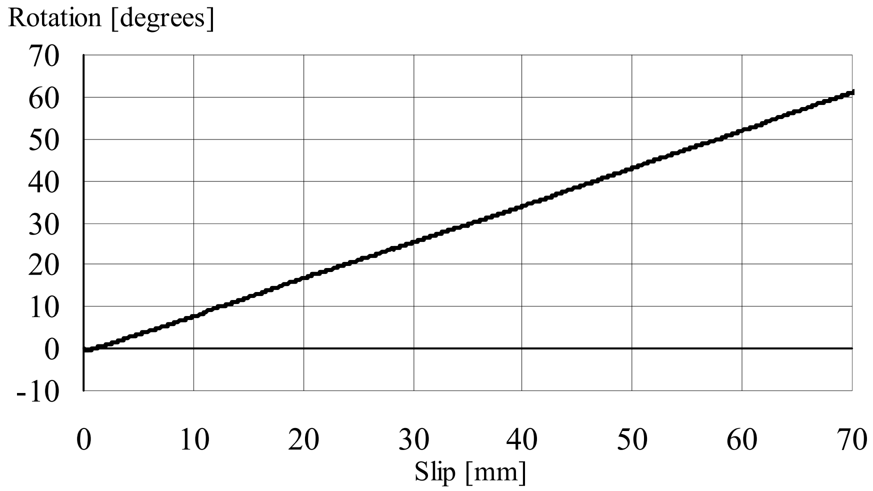

Strain [microstrain]
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

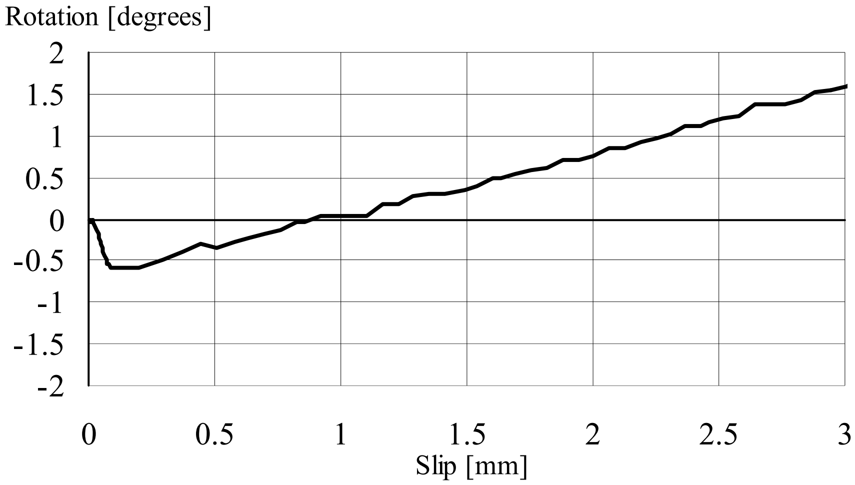

Load [kN]
10
8
6
4
2
0
-10
0
10
20
30
Strain [microstrain]
1
2
3

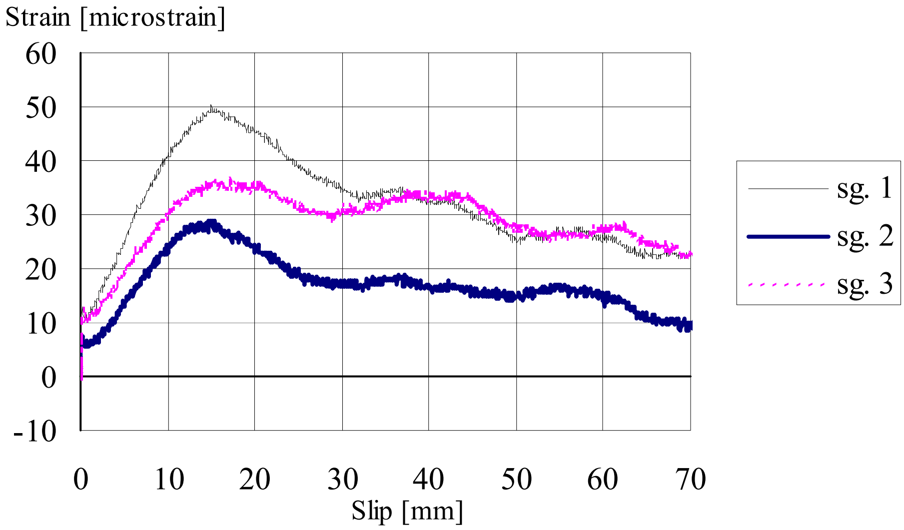
B1.5 Test old smooth e

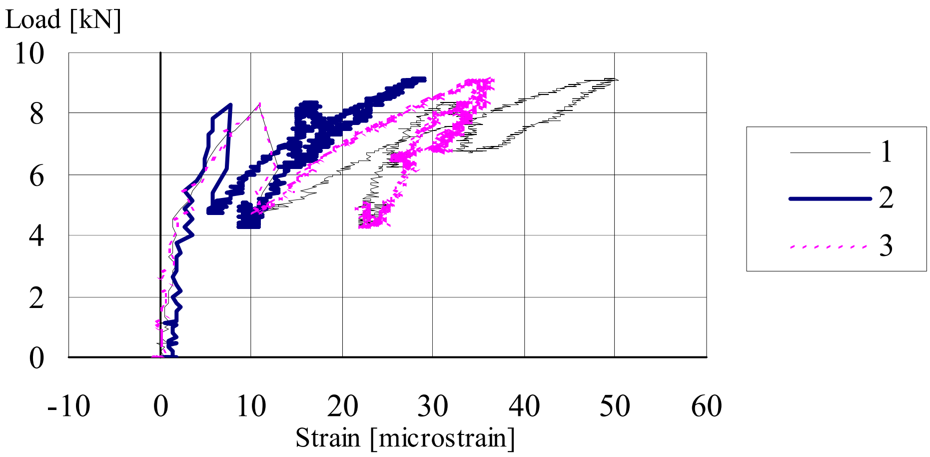






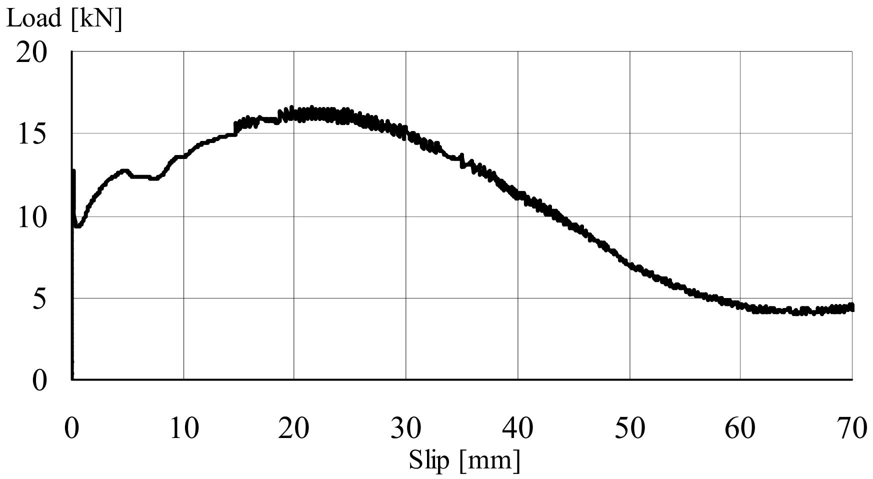

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

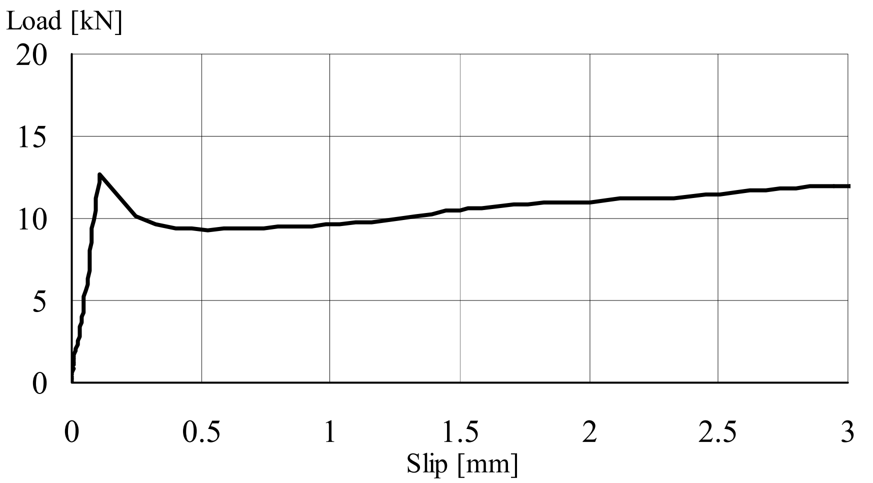

Strain [microstrain]
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

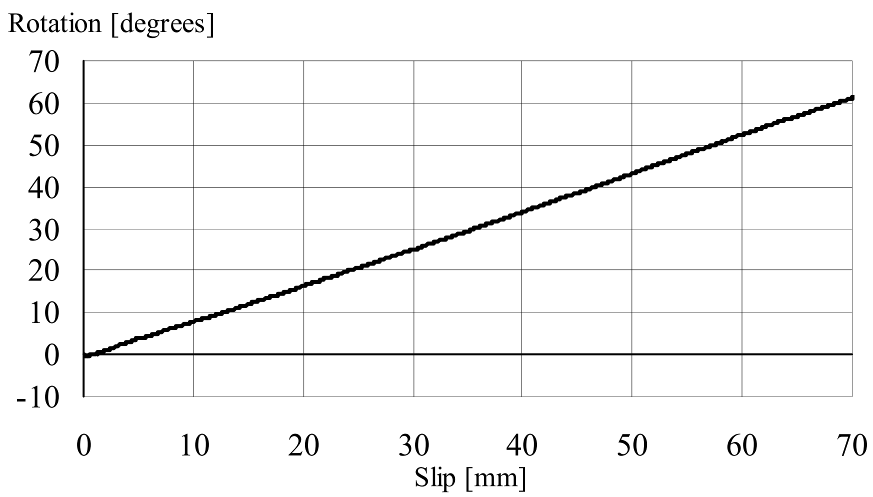

Load [kN]
10
8
6
4
2
0
-10
0
10
20
30
40
50
60
Strain [microstrain]
1
2
3

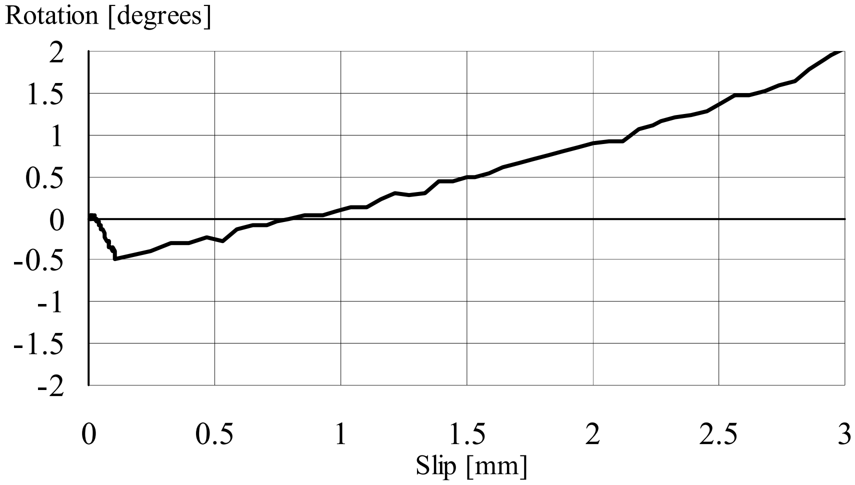
C1 Results for the new smooth strands

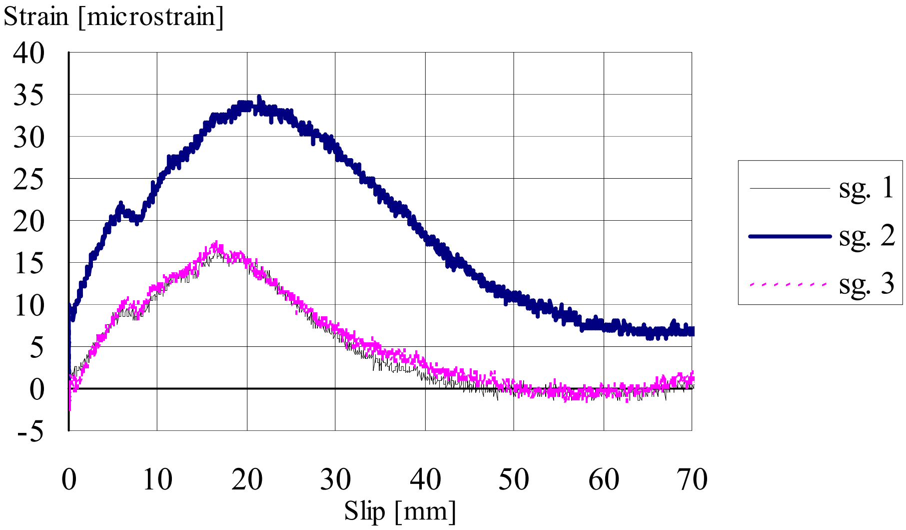
C1.1 Test new smooth a

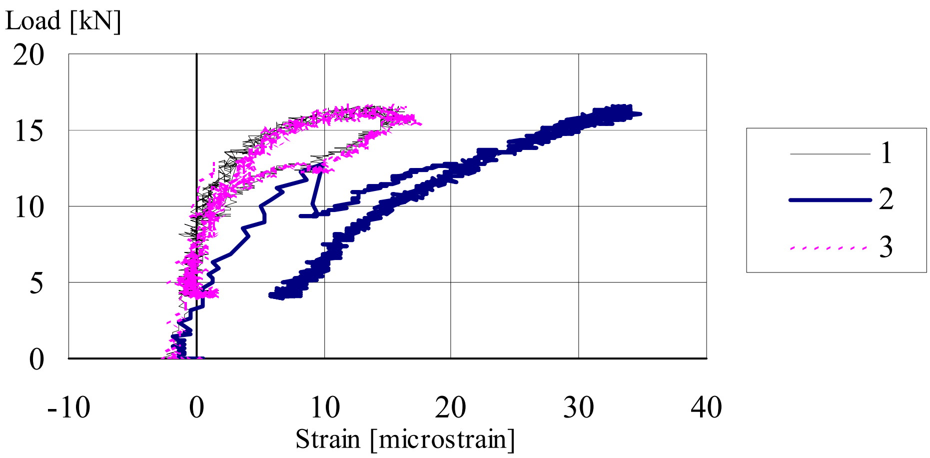




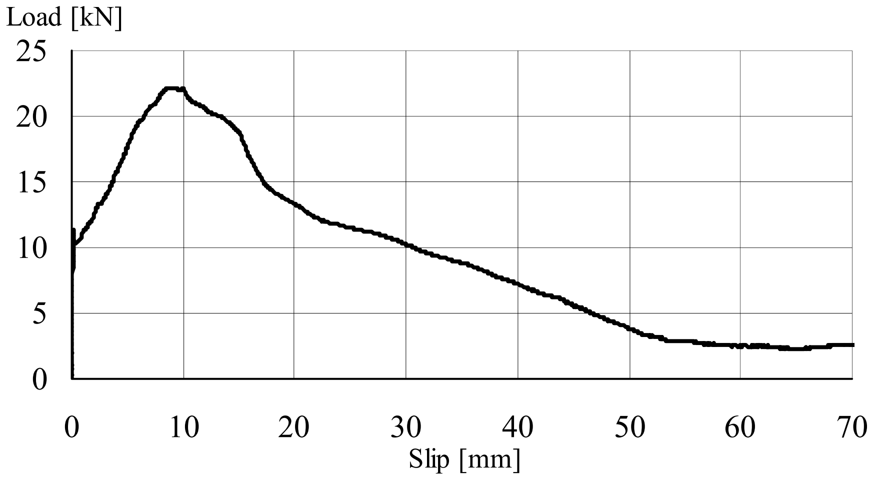


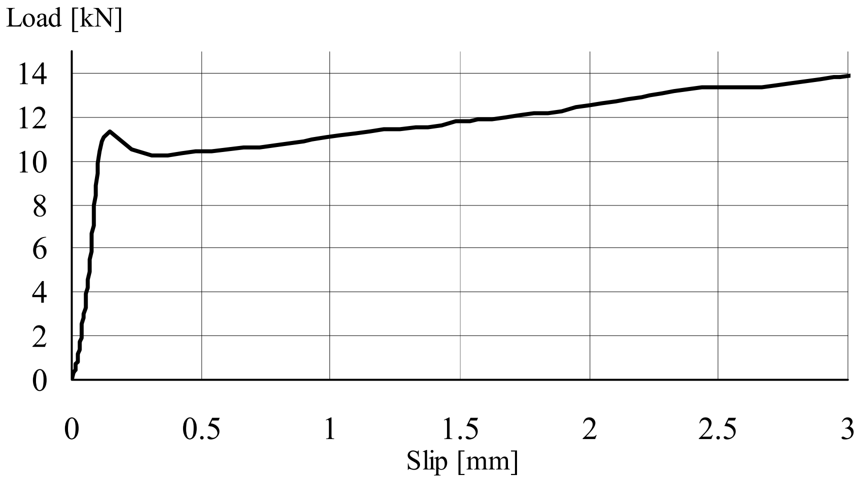

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

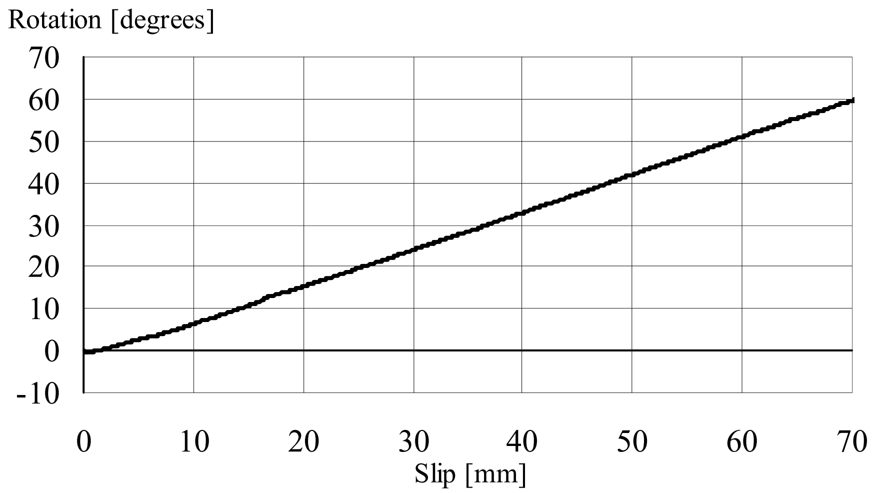

Strain [microstrain]
40
35
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

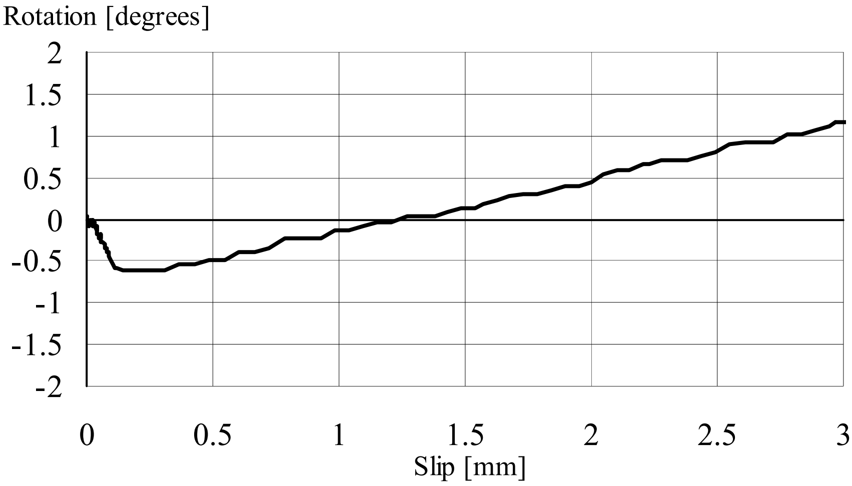

Load [kN]
20
15
10
5
0
-10
0
10
20
30
40
Strain [microstrain]
1
2
3

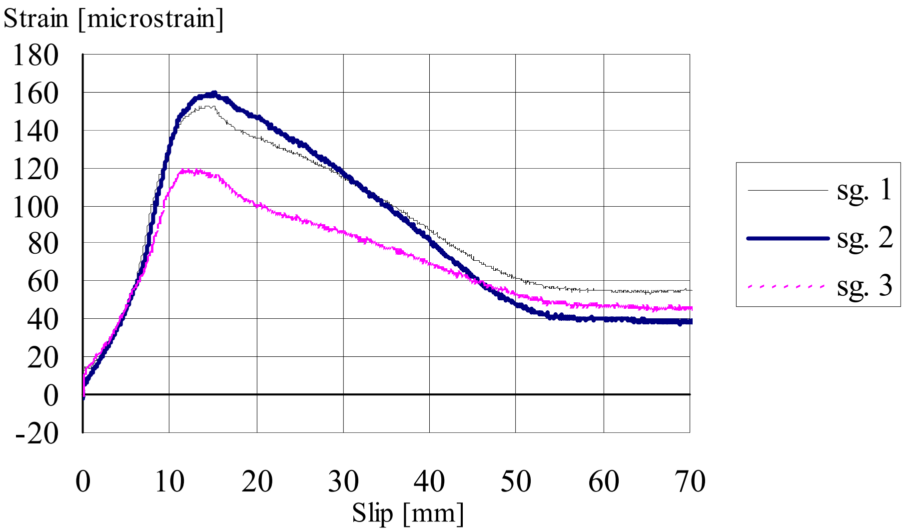
C1.2 Test new smooth b

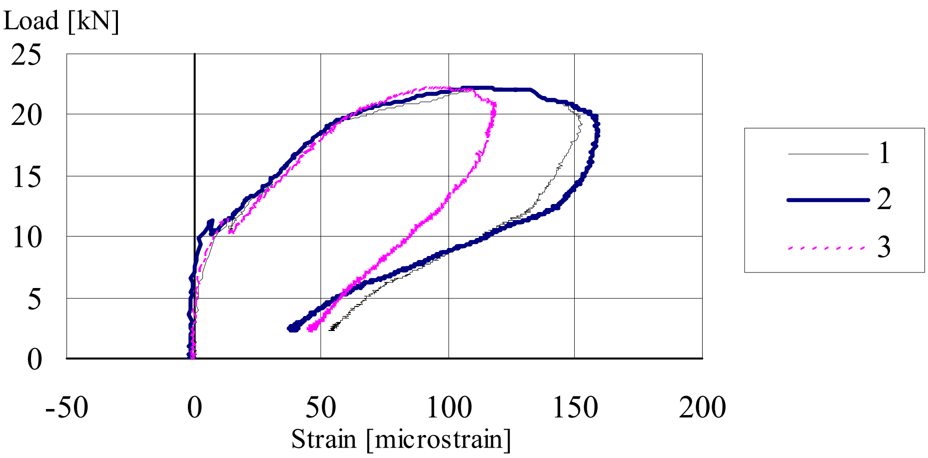




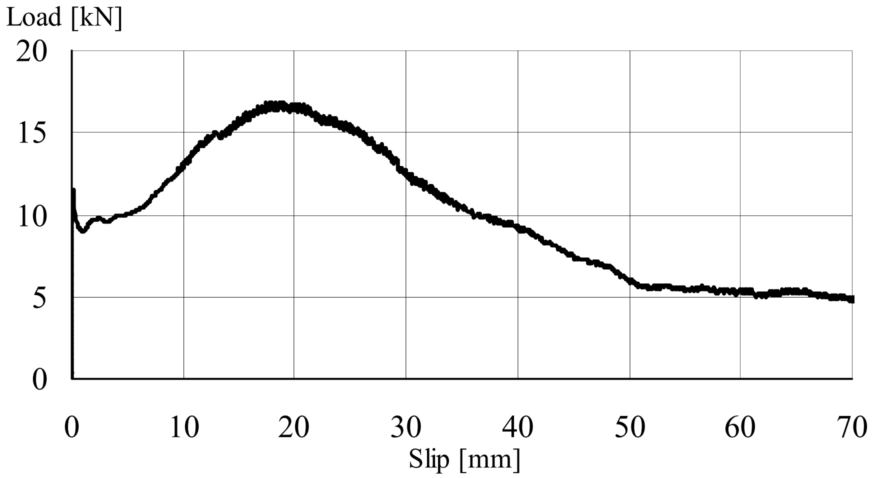


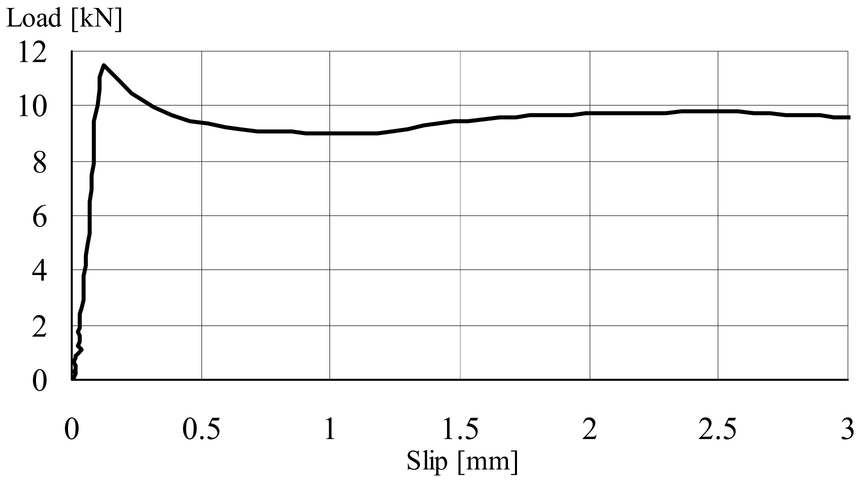

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

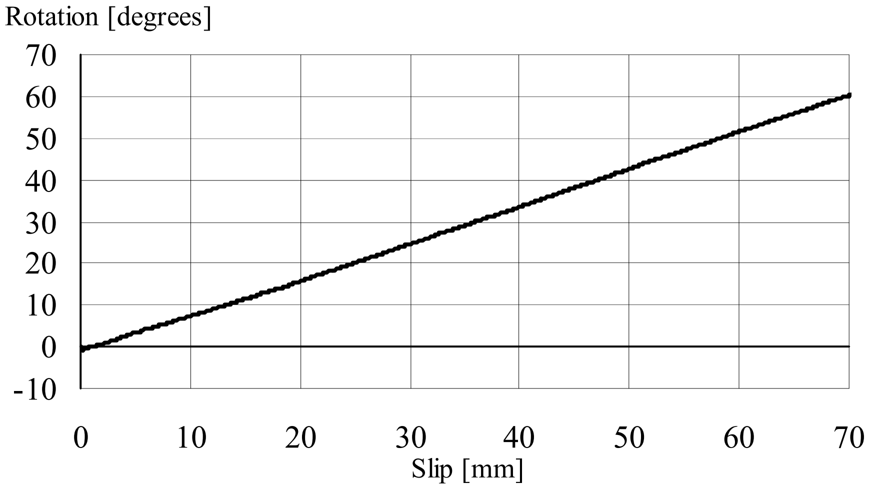

Strain [microstrain]
180
160
140
120
100
80
60
40
20
0
-20
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

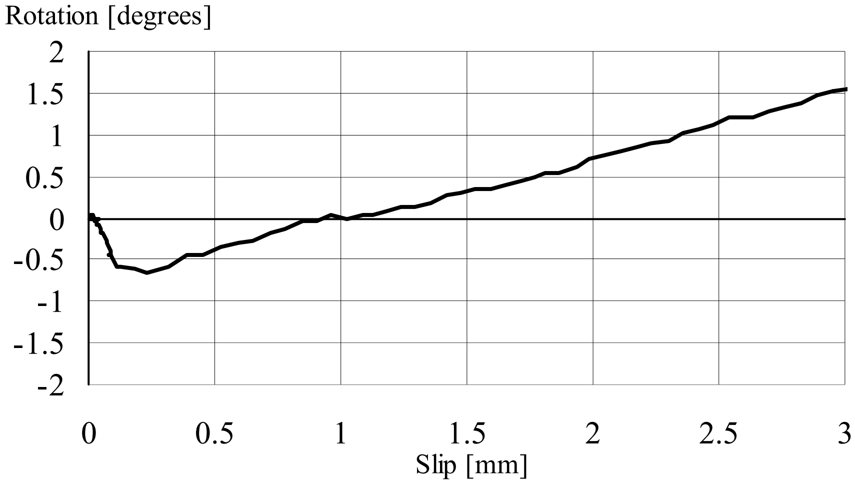

Load [kN]
25
20
15
10
5
0
-50
0
50
100
150
200
Strain [microstrain]
1
2
3

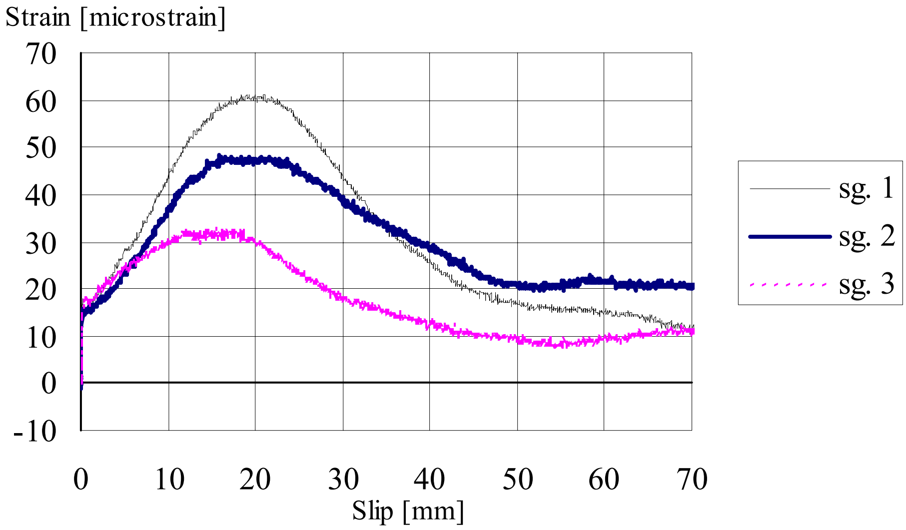
C1.3 Test new smooth c

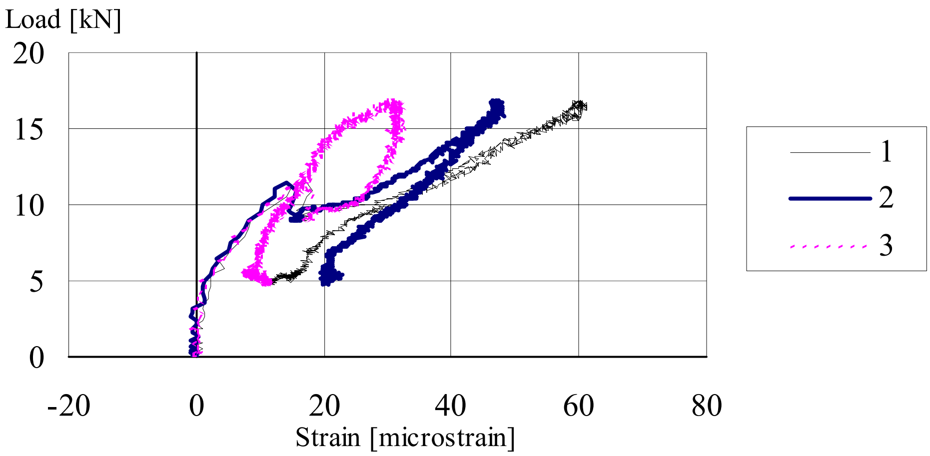




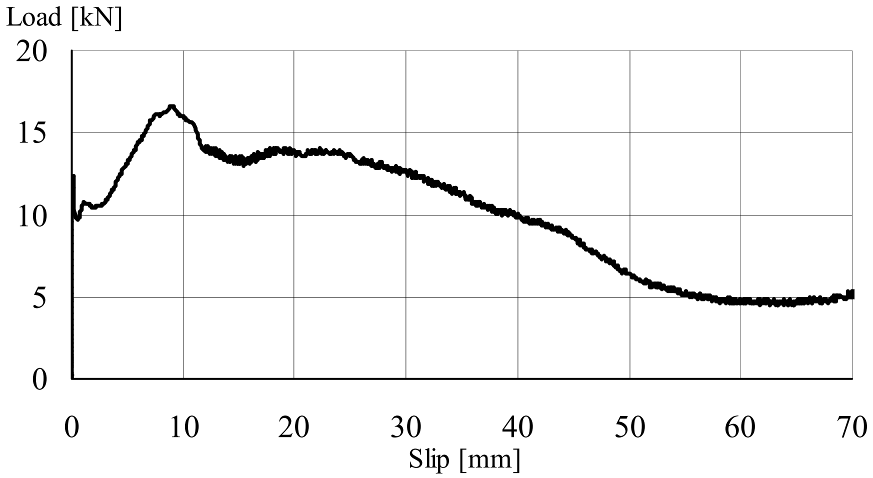


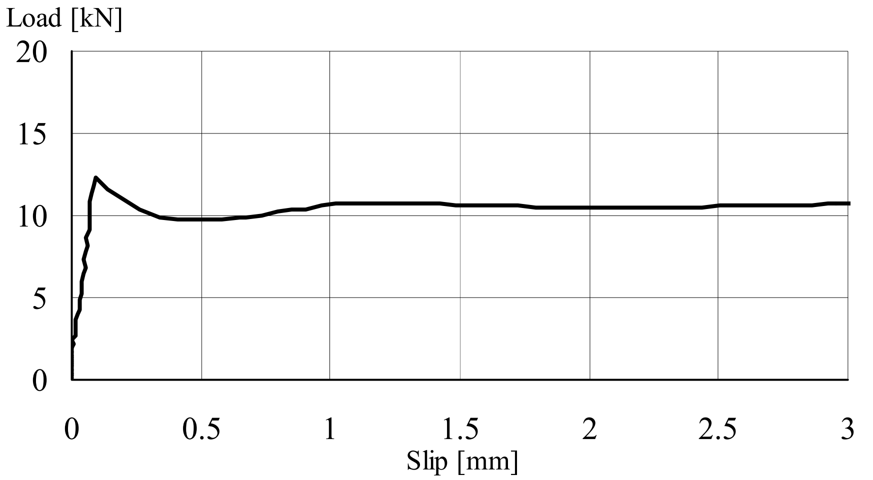

Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

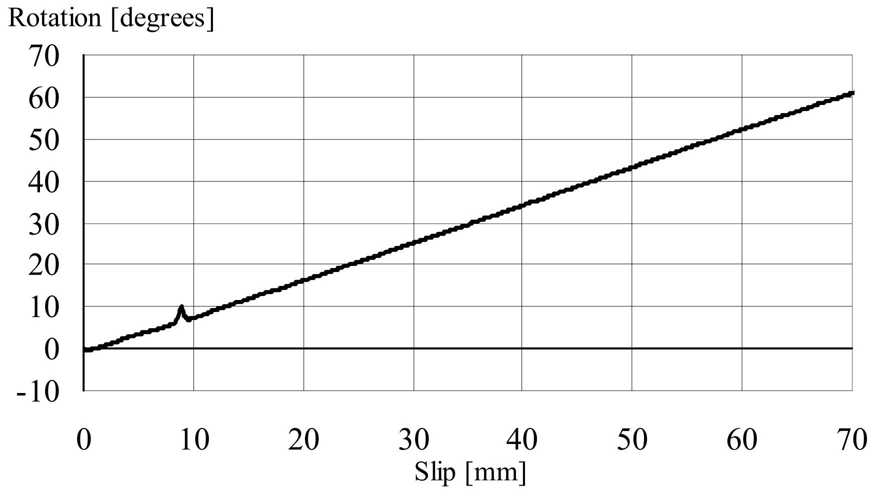

Strain [microstrain]
70
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

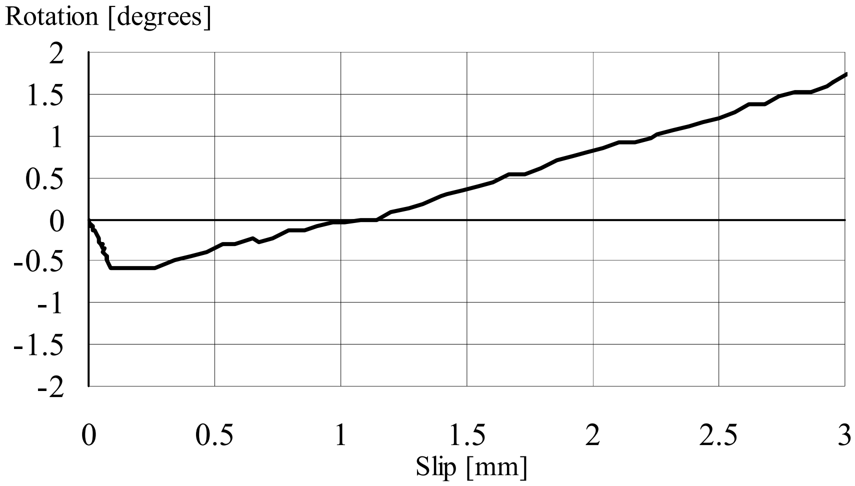

Load [kN]
20
15
10
5
0
-20
0
20
40
60
80
Strain [microstrain]
1
2
3

C1.4 Test new smooth d

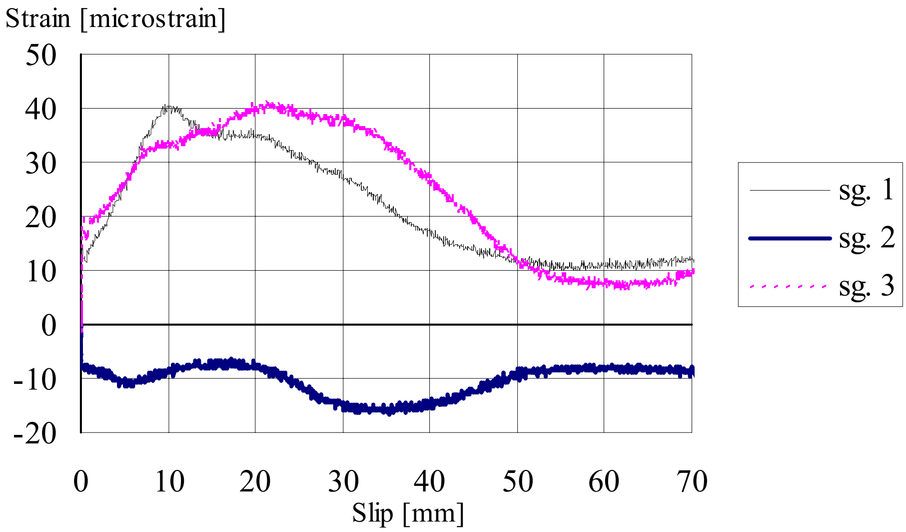




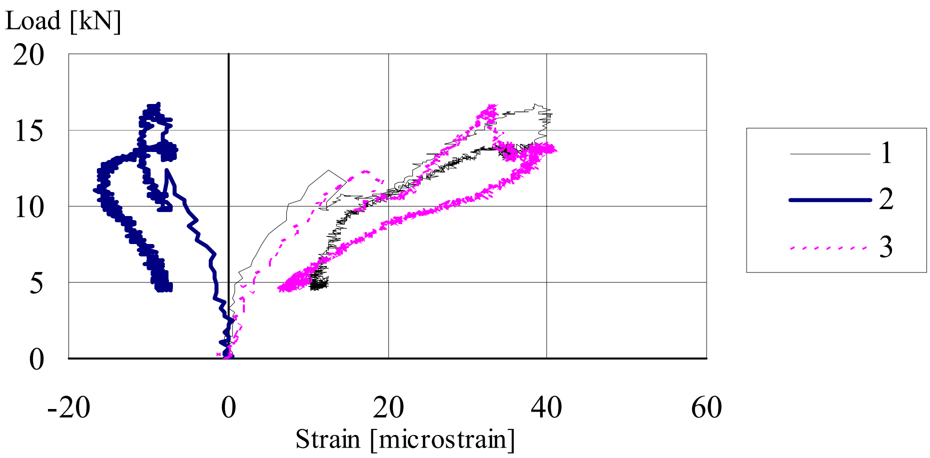




Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]

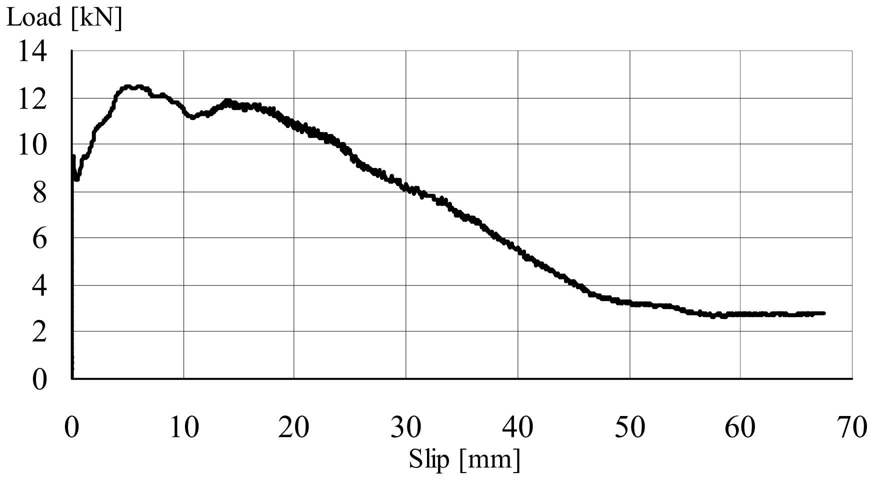


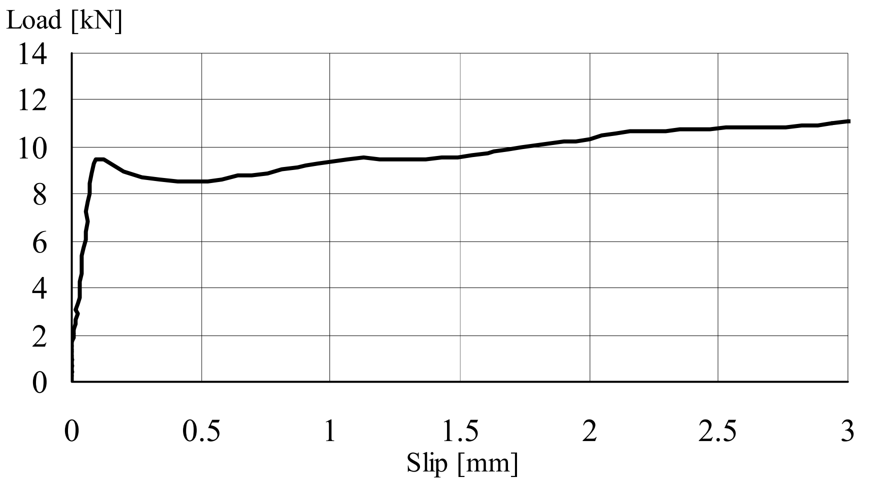
Strain [microstrain]
50
40
30
20
10
0
-10
-20
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3

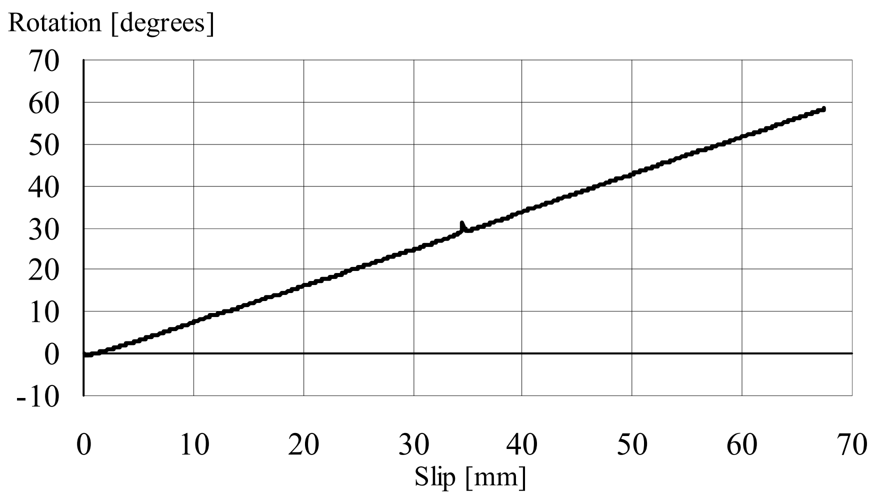


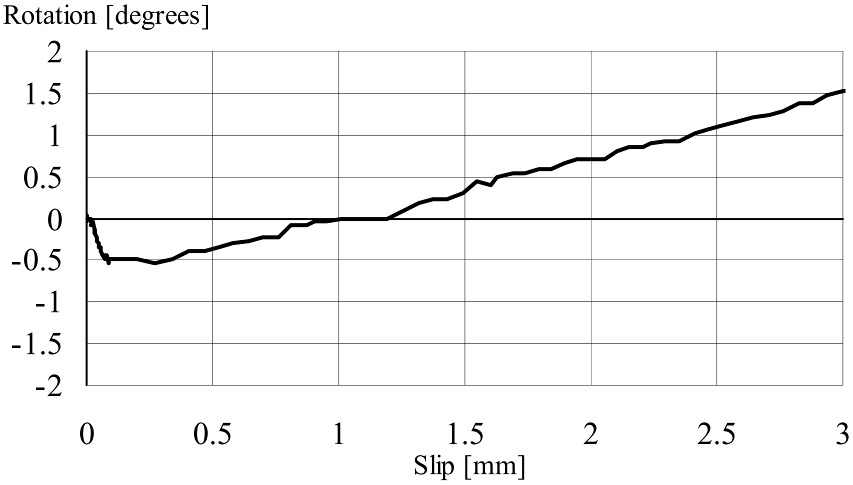
Load [kN]
20
15
10
5
0
-20
0
20
40
60
Strain [microstrain]
1
2
3

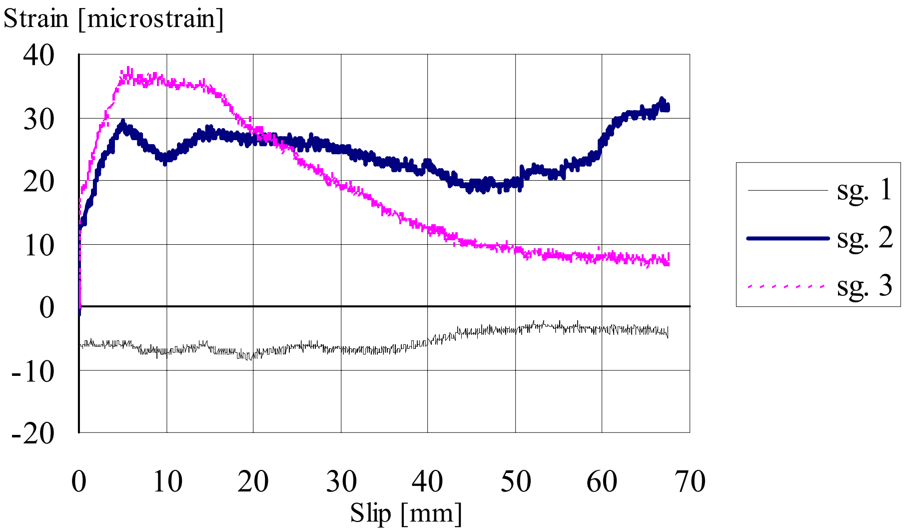
C1.5 Test new smooth e

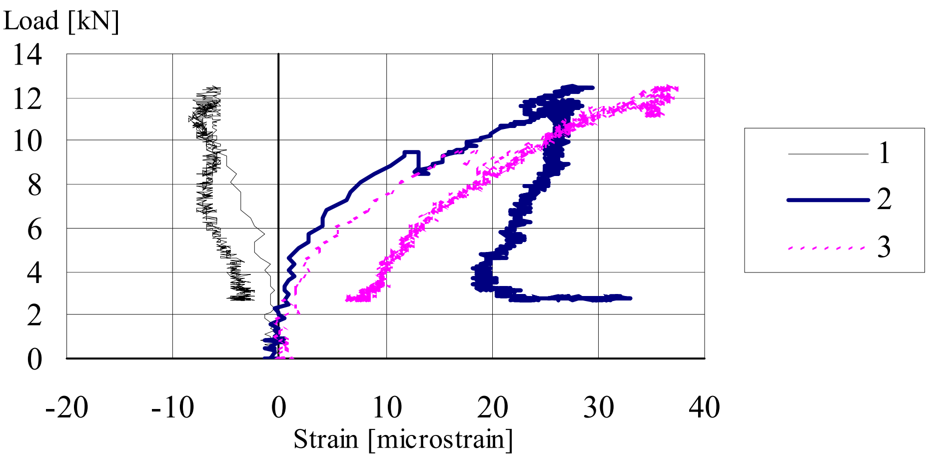







Rotation [degrees]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
Slip [mm]


Strain [microstrain]
40
30
20
10
0
-10
-20
0
10
20
30
40
50
60
70
Slip [mm]
sg. 1
sg. 2
sg. 3


Load [kN]
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
Strain [microstrain]
1
2
3

D1 Standard for the indents of the indented strands

From prEN 10138:

prEN 10138-3:2002(E)

The dimensions of the indentation shall be in accordance with Table 1 and Figure 1 of this Part of this European Standard. One line of indentations shall be at a contrary angle to the others.

NOTE 2 Alternative methods may be used to improve the bond between the strand and concrete.

Table 2 – Specified indentation

Nominal strand diameter *d*	Nominal depth *a*	Depth tolerance	Length *l*	Pitch *c*
≤ 12	0.06	± 0.03	3.5 ± 0.5	5.5 ± 0.5
> 12	0.07	± 0.03	3.5 ± 0.5	5.5 ± 0.5

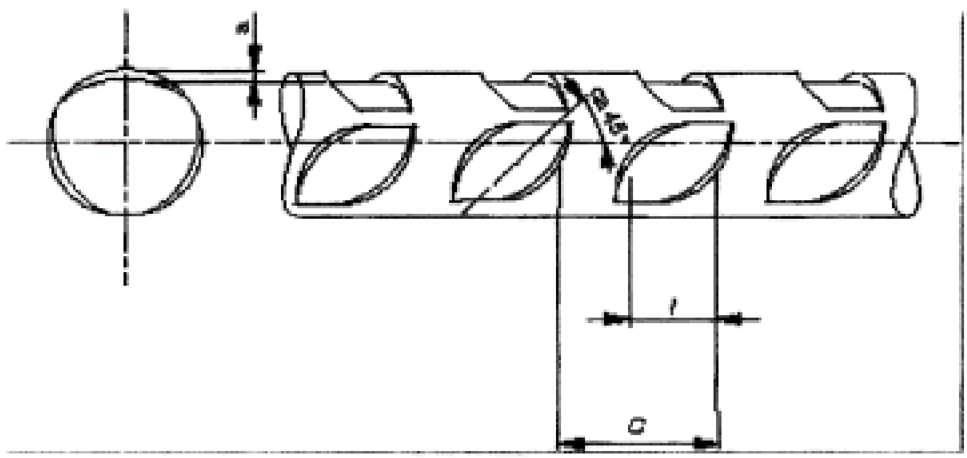


Figure 1 - Indentation