Empa
Überlandstrasse 129
CH-8600 Dübendorf
T +41 58 765 11 11
F +41 58 765 62 44
www.empa.ch

Materials Science & Technology

FiReP International AG
Mr. Hamid Ahari Hashemi
Alte Jonastrasse 83
8640 Rapperswil

# Test Report No. 456495

| | |
|---|---|
| **Test assignment:** | **Testing of Spinmax J65-32 and accessories** |
| Client: | FiReP International AG, Rapperswil, Switzerland |
| Test objects: | 5 Bolts: Tensile maximum force |
| | 5 Bolts: Torsion maximum force |
| | 5 Bolts with GRP Nut |
| | 5 Bolts with 1 Steel Nut (1 x L=45 mm) |
| | 5 Bolts with 2 Steel Nuts (2 x L=45 mm) |
| | 5 Bolts with Steel Coupler L=200 mm |
| | 5 Bolts with Steel Coupler L=120 mm |
| Client’s ref: | Mr. H. Ahari Hashemi |
| Order dated of: | 05.11.2010 |
| Test performed: | 27.01.2011 – 18.02.2011 |
| Number of pages: | 16 |
| Attachments: | Appendix A and B |

Empa, Swiss Federal Laboratories for Materials Science and Technology
Laboratory for Structural Engineering
Dübendorf, March 24, 2011

Expert:
Dr. Andrin Herwig

Head of Laboratory:
Prof. Dr. Masoud Motavalli

SWISS TESTING
STS

# Contents

# 0 Units and symbols

### Units

| | |
|---|---|
| area: | $mm^2$ |
| deformation: | mm |
| displacement: | mm |
| force: | kN |
| length: | mm, cm, m |
| strain: | % |
| stress: | $N/mm^2$ |
| temperature: | °C |
| rotation: | ° |
| time: | min. |
| volume: | $mm^3$ |
| Young's modulus: | $N/mm^2$ |

### Latin upper case symbols

| | |
|---|---|
| A | cross section area |
| $A_s$ | stress section area |
| D | diameter |
| $D_s$ | stress section diameter |
| E | Young's modulus |
| $F_u$ | maximum force |
| L | length |
| $L_m$ | length of the field for the image correlation measurements in bolt direction |
| N | number of test pieces |
| $T_u$ | maximum torsion moment |

### Latin lower case symbols

| | |
|---|---|
| $f_u$ | maximum stress |
| $\bar{x}$ | mean value |
| $x_i$ | sampling data |

### Greek upper case symbols

| | |
|---|---|
| $\Delta\varepsilon$ | difference between the strains at 50% and 20% of the maximum tensile force |
| $\Delta F$ | difference between the forces at 50% and 20% of the maximum tensile force |

### Greek lower case symbols

| | |
|---|---|
| $\varepsilon$ | strain |
| $\sigma$ | standard deviation |

# 1 Introduction

FiReP International AG (Switzerland) commissioned Empa to conduct tests on 4 types of glass fiber reinforced polymer (GRP) bolt and accessories under short term loading. These bolt systems are used in mining, tunneling and ground stabilization.

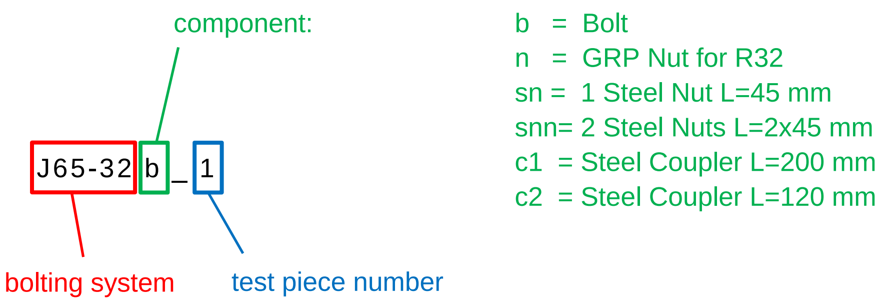
The test method is based on ISO 10406-1 standard.

This test report describes tensile and torsion tests and its test results for Spinmax J65-32 (D=32 mm, EP resin) and related accessories.

# 2 Tests

## 2.1 Test piece names

Using the following example the explanation is given on how the test piece name is built up:




## 2.2 Overview of the tests

The test pieces were delivered to Empa on January 24, 2011. All tested objects are listed in Table 1. The loading was applied with a 1000 kN machine (Log-No 60.220) cross head displacement controlled. The measurement uncertainty was smaller than 1% of the load over the 1000 kN measuring domain.

This machine allows for a maximum test piece length of 2.0 m.

The strain rate listed in the table corresponds to the constant cross head displacement velocity divided by the free length of the GRP bolt.

The torsion tests were conducted with the 2000 Nm testing machine (I-1343) of the Laboratory Mechanical Systems Engineering of Empa. The temperature was 20° C for all tests.

Table 1: Components to be tested for fracture load

| Component to be tested | Number of test pieces | Test piece designation | GRP strain rate [% / min.] |
|---|---|---|---|
| Bolt: Fracture load and tensile modulus | 5 | J65-32b_1…5 | 0.8 |
| Normal Nut (GRP) | 5 | J65-32n_1…5 | 0.9 |
| 1 Steel Nut (1x45 mm) | 5 | J65-32sn_1…5 | 0.9 |
| 2 Steel Nuts (2x45 mm) | 5 | J65-32snn_1…5 | 0.9 |
| Steel Coupler L=200 mm | 5 | J65-32c1_1…5 | 0.9 |
| Steel Coupler L=120 mm | 5 | J65-32c2_1…5 | 0.9 |

| Component to be tested | Number of test pieces | Name | Loading rate [°/min.] |
|---|---|---|---|
| Bolt: Torsion resistance | 5 | J65-32t_1…5 | 30 |

## 2.3 Tensile tests with bolts

### 2.3.1 Test piece

Figure 1 shows the test piece geometry. The free GRP bolt length was 1000 mm. Both ends of the 2000 mm long GRP bolt were glued into steel sleeves in the factory.

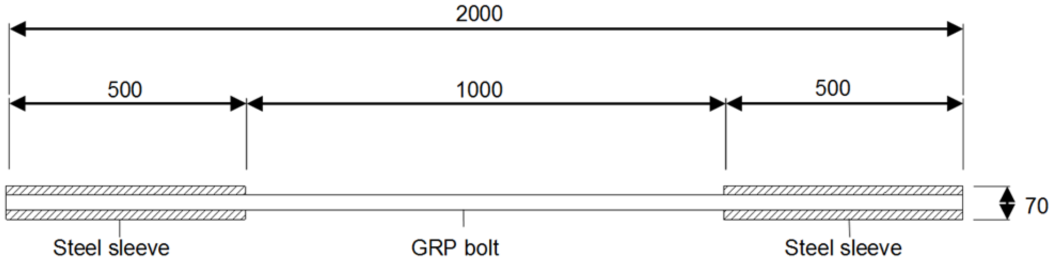



Figure 1: Test piece for the bolt tensile tests [mm].

### 2.3.2 Test set up

The test set up is shown in Figure 2. The cross head displacement and the force were measured. The measurement of the cross head displacement is subsequently designated as ‚test machine displacement reading’. The strain was measured contactless with an image correlation system within a field with a length of $L_m$ = 300 mm. The image correlation system took pictures with a frequency of 0.4 Hz. The software calculated the surface profile and the displacements in three orthogonal directions. The accuracy of the measured displacements was ±0.005 mm. The strain was calculated using the relative displacement between two selected points along the bolt axis.

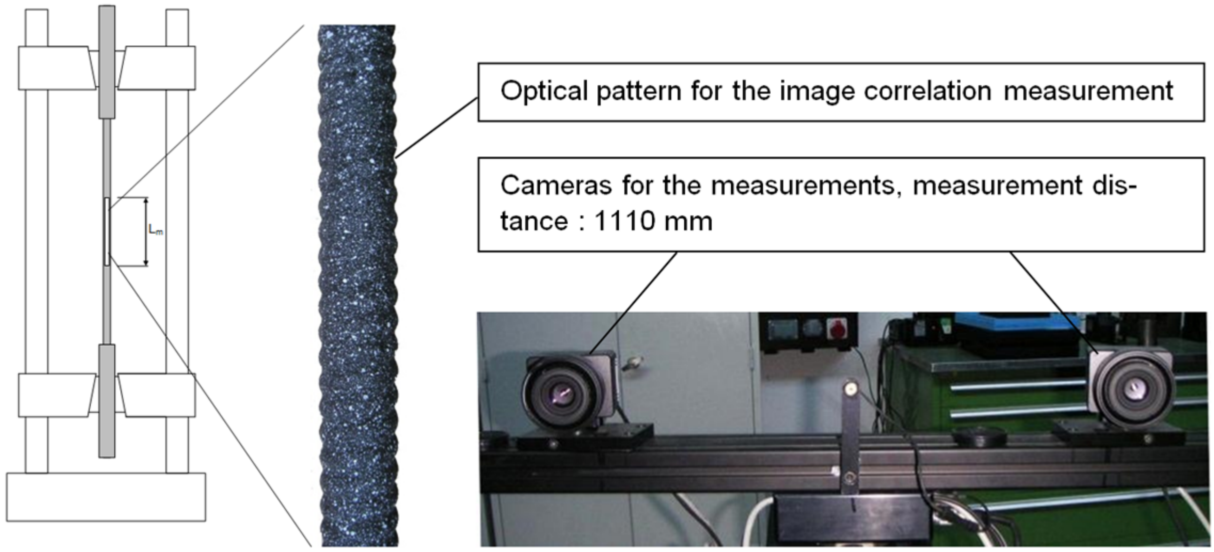



Figure 2: Test set up for the bolt tensile tests with image correlation system.

### 2.3.3 Test results

Figure 3a) shows the force-displacement relationships and Figure 3b) the stress – strain relationships of the bolts. The stress – strain relations have a linear and coincident course.

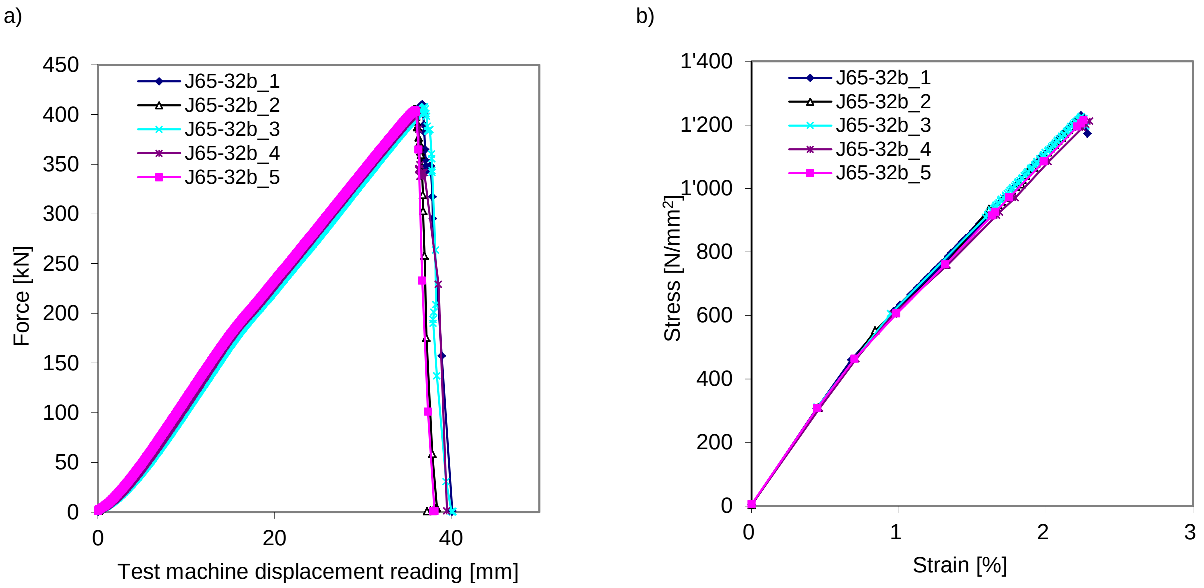



Figure 3: Relationships for a) force – machine displacement reading, b) stress – strain (from the image correlation system).

Figure 4 shows examples of the displacement and strain fields close to maximum force for J65-32b_1.

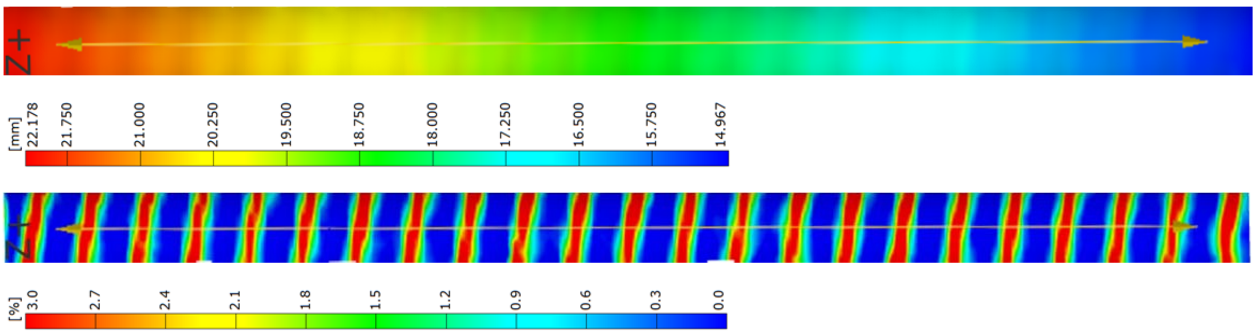



Figure 4: Displacement and strain fields of the image correlation measurement for J65-32b_1 close to maximum force. The arrow line represents the distance for the strain measurements.

Table 2 shows the results of the tensile tests and the Young's moduli. The maximum stress and the Young's modulus were calculated using the stress area shown. Explanations of this area are provided in Appendix 1.

Table 2: Test results for the bolt. Test date: 18.02.2011.

| Name | Stress area $A_s$ *) [mm²] | Maximum force $F_u$ [kN] | Maximum stress $f_u$ [N/mm²] | Strain $\varepsilon$ @ $F_u$ [%] | Strain $\varepsilon$ @ 20 % $F_u$ [%] | Strain $\varepsilon$ @ 50 % $F_u$ [%] | Young's modulus [N/mm²] |
|---|---|---|---|---|---|---|---|
| J65-32b_1 | | 410.1 | 1,235 | 2.24 | 0.35 | 0.98 | 59,314 |
| J65-32b_2 | | 405.5 | 1,221 | 2.22 | 0.35 | 0.97 | 59,345 |
| J65-32b_3 | 332 | 407.7 | 1,228 | 2.24 | 0.35 | 0.96 | 60,037 |
| J65-32b_4 | | 403.8 | 1,216 | 2.30 | 0.36 | 0.97 | 59,828 |
| J65-32b_5 | | 404.1 | 1,217 | 2.26 | 0.35 | 0.99 | 57,141 |
| Mean value: $\bar{x}$ | | **406.3** | **1,217** | **2.25** | **0.35** | **0.97** | **59,133** |
| Standard dev.: $\sigma$ | | **2.4** | | | | | |

*) Stress area specified by the client. See also explanations in Appendix 1.

The maximum stress is calculated according to Equation (1)

$$f_u = \frac{F_u}{A_s}. \tag{1}$$

The mean values were calculated according to Equation (2):

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{2}$$

where N is the number of test pieces and $x_i$ are the sampling data. The standard deviation is defined as given in Equation (3):

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}. \tag{3}$$

The Young’s modulus was calculated according to [ISO 10406-1, 2008] by dividing the difference between the stresses by the difference between the strains at 50% and 20% of the maximum tensile force. The Young’s modulus was calculated according to Equation (4).

$$E = \frac{\Delta F}{\Delta\varepsilon \cdot A_s}. \tag{4}$$

Figure 5 shows the bolts after the tests.

Figure 5: Photograph of failure patterns. The black color was applied for the image correlation measurements.

#### 2.3.4 Failure mechanism and fracture pattern

Failure occurred in a brittle manner with a sequence of loud banging noises. The bolts were partially separated. The bolts experienced a fibrous fracture pattern (Figure 5).

## 2.4 Tensile tests with nuts

#### 2.4.1 Test pieces

Figures 6 und 7 show the geometry of the test pieces for the tests with the nuts. One end of the test piece was glued into a steel sleeve in the factory and the other end was equipped with either (1) a GRP nut plus a GRP plate (Figure 6) or (2) one or two Steel Nuts (Figure 7). The free end of the bolt had a length of 40 mm. In the case where 2 Steel Nuts have been applied, the nuts have been tightened together by hand before testing.

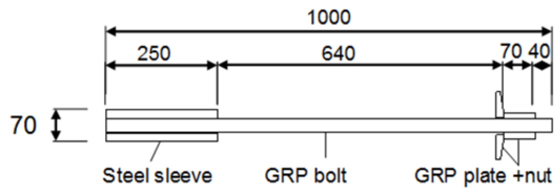



Figure 6: Test piece for the tests with GRP Nuts [mm].

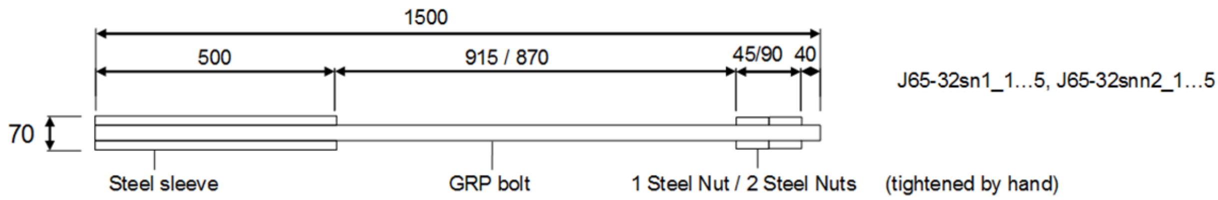



Figure 7: Test piece for the tests with steel nuts [mm].

### 2.4.2 Test set up

Figure 8 shows the test set up. To prevent eccentric loads from acting on the test pieces a steel plate with a hole diameter of 34 mm was placed underneath the nuts. This plate was protected by a washer in the case where steel nuts were tested. The steel sleeve at the other end was clamped.

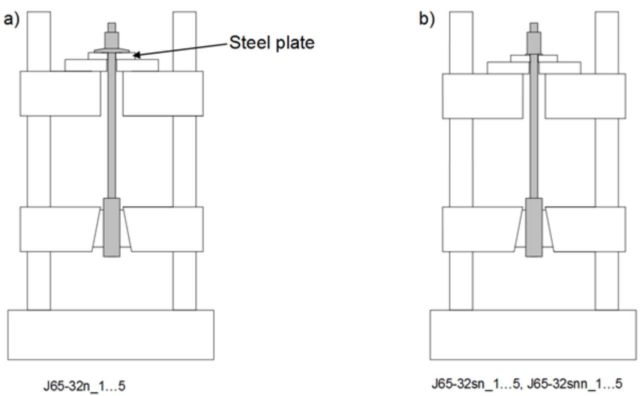



Figure 8: Test set up for the tensile tests a) with GRP nuts plus GRP – plates, b) with steel nuts.

### 2.4.3 Test results

Figure 9 shows the force – test machine displacement relationships for the tests with nuts.

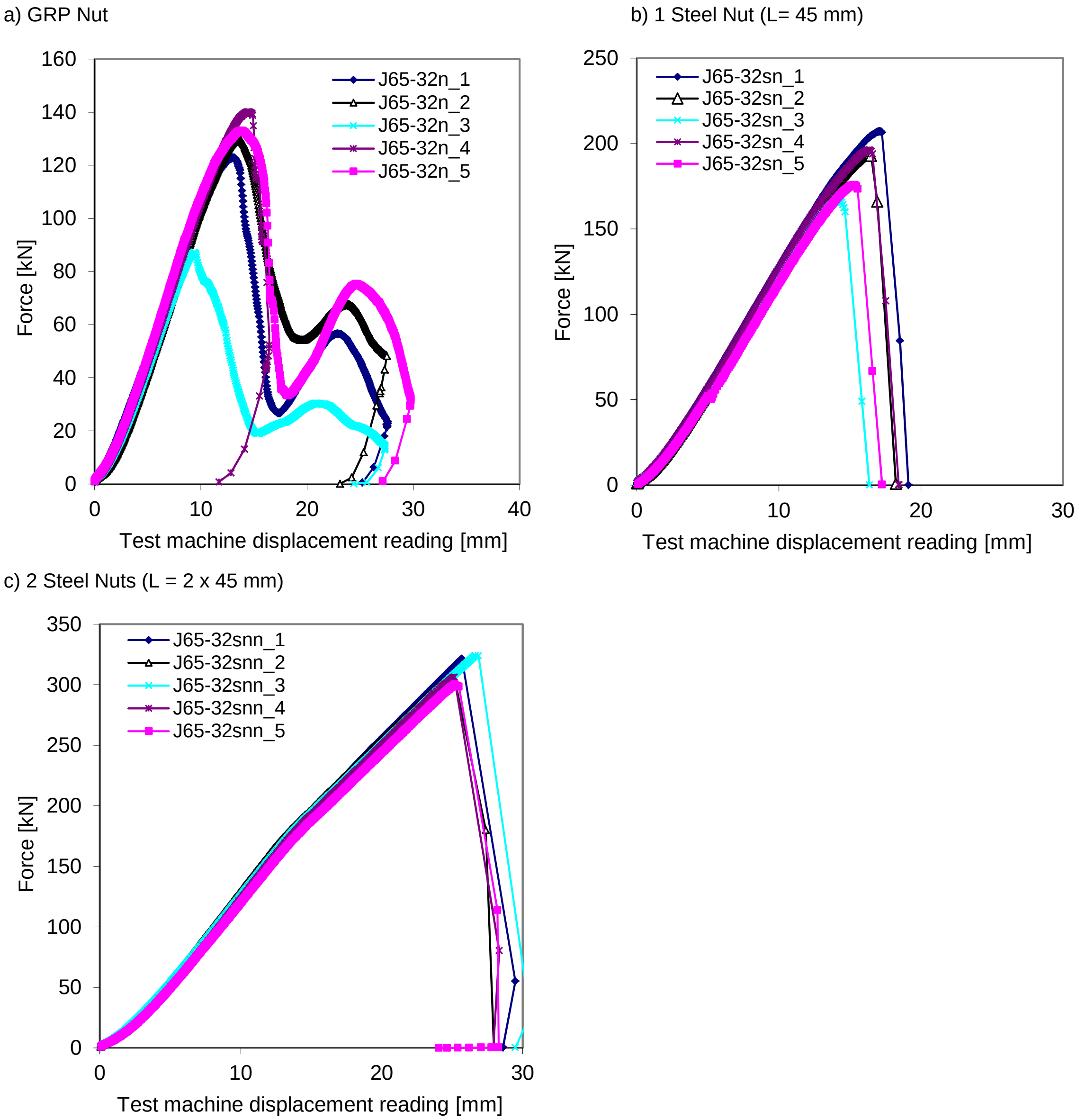



Figure 9: Force – displacement relation for the nuts.

The maximum forces of the GRP Nuts are listed in Table 3. Figure 10 shows the anchorage heads after the tests.

Table 3: Breaking loads of the GRP Nuts.

| GRP Nut | Breaking load [kN] |
|---|---|
| J65-32n_1 | 122.9 |
| J65-32n_2 | 129.7 |
| J65-32n_3 | 87.2 |
| J65-32n_4 | 140.0 |
| J65-32n_5 | 132.9 |
| mean value $\bar{x}$ | **122.5** |
| standard deviation $\sigma$ | **18.5** |
| test date | 31.01.11 |

Figure 10: GRP Nuts and plates after the test. Since the nuts could not be loosened, the bolts were cut after the tests.

The maximum forces for the Steel Nuts are listed in Tables 4a) and b). The Figures 11a) und b) show the anchorage heads after the tests.

Table 4: Breaking loads of the Steel Nuts, a) L=45 mm and b) L=2x45 mm.

a)

| 1 Steel Nut (L= 45 mm) | Breaking load [kN] |
|---|---|
| J65-32sn_1 | 207.2 |
| J65-32sn_2 | 194.2 |
| J65-32sn_3 | 166.4 |
| J65-32sn_4 | 196.2 |
| J65-32sn_5 | 175.6 |
| mean value: $\bar{x}$ | **187.9** |
| standard deviation: $\sigma$ | **14.8** |
| test date | 28.01.2011 |

b)

| 2 Steel Nut (L= 2x45 mm) | Breaking load [kN] |
|---|---|
| J65-32snn_1 | 321.5 |
| J65-32snn_2 | 308.9 |
| J65-32snn_3 | 324.0 |
| J65-32snn_4 | 306.3 |
| J65-32snn_5 | 300.3 |
| mean value: $\bar{x}$ | **312.2** |
| standard deviation: $\sigma$ | **9.1** |
| test date | 16.02.2011 |

a)


b)


Figure 11: Steel Nuts after the tests. a) L = 1 x 45 mm and b) L = 2 x 45 mm. Since the nuts could not be loosened, the bolts were cut after the tests.

### 2.4.4 Failure mechanism and fracture pattern

With the GRP Nut, a softening behavior could be observed (Figure 9a). The free bolt length above the nut was distinctly smaller than the initial 4 cm, except with test piece 4 (Figure 10), but there the nut was crushed.

The test pieces failed in a brittle manner accompanied by a banging noise. The bolts were pulled out the nuts (Figure 11a und b).

## 2.5 Tensile tests with Steel Couplers

### 2.5.1 Test piece

Figure 12 shows the geometry of the test pieces with couplers. One end was equipped with an over-the-bolt glued steel sleeve and the other end with a steel nut. The free end of the GRP bolt 2 had a length of 110 mm. The two GRP bolts (bolt 1 and bolt 2) were joined with the Steel Coupler, which was centrically attached to both bolt ends with the ends touching each other. Two different lengths have been chosen for the couplers (L = 200 and L = 120 mm).

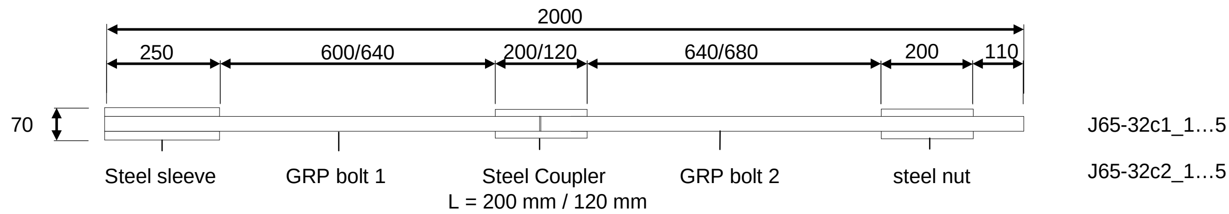



Figure 12: Test piece for the coupler tests [mm].

### 2.5.2 Test set up

Figure 13 shows the test set up. To prevent eccentric loads from acting on the test pieces a steel plate with a hole diameter of 34 mm was placed underneath the nuts. This plate was protected by a washer in the case where steel nuts were tested. The steel sleeve at the other end was clamped.

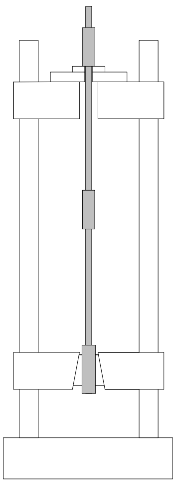


Figure 13: Test set up for the couplers.

### 2.5.3 Test results

Figure 14 shows the force – displacement relationships for the tests with the Steel Couplers.

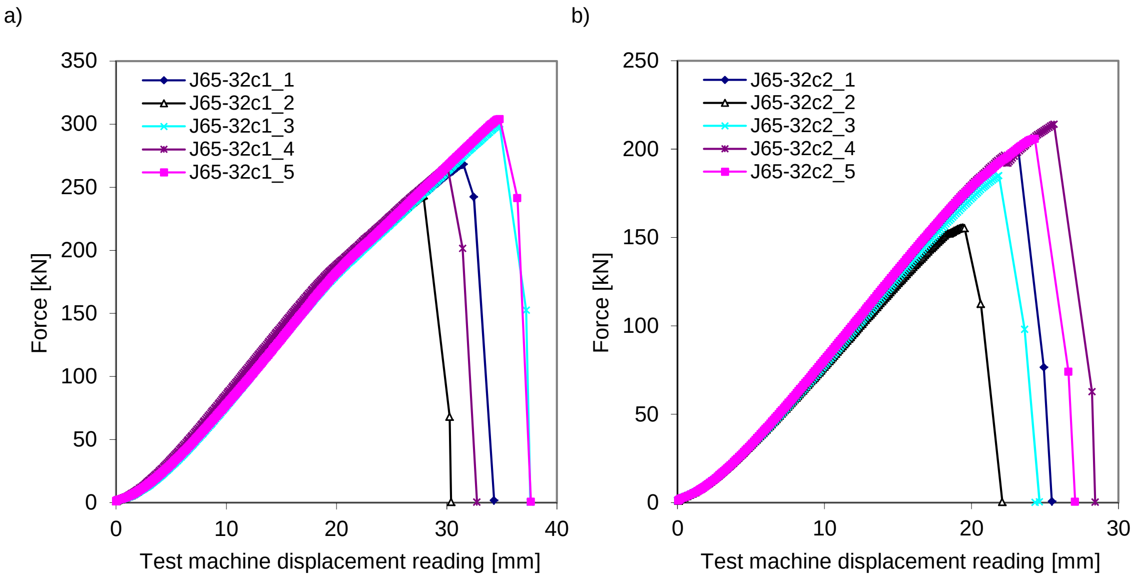



Figure 14: Force – displacement relationships for the tests with couplers. a) L=200 mm and b) L=120 mm.

The maximum forces are listed in Table 5.

Table 5: Breaking loads for the Steel Couplers, a) L=200 mm and b) L=120 mm

a)

| Steel Coupler<br>L = 200 mm | Breaking load [kN] |
|---|---|
| J65-32c1_1 | 268.1 |
| J65-32c1_2 | 243.4 |
| J65-32c1_3 | 300.0 |
| J65-32c1_4 | 266.5 |
| J65-32c1_5 | 303.8 |
| mean value $\bar{x}$ | **276.4** |
| standard deviation $\sigma$ | **22.6** |
| test date | 02.02.2011 |

b)

| Steel Coupler<br>L = 120 mm | Breaking load [kN] |
|---|---|
| J65-32c2_1 | 199.2 |
| J65-32c2_2 | 155.6 |
| J65-32c2_3 | 184.9 |
| J65-32c2_4 | 214.0 |
| J65-32c2_5 | 205.7 |
| mean value $\bar{x}$ | **191.9** |
| standard deviation $\sigma$ | **20.5** |
| test date | 14.02.2011 |

Figure 15 shows the Steel Couplers after the tests.

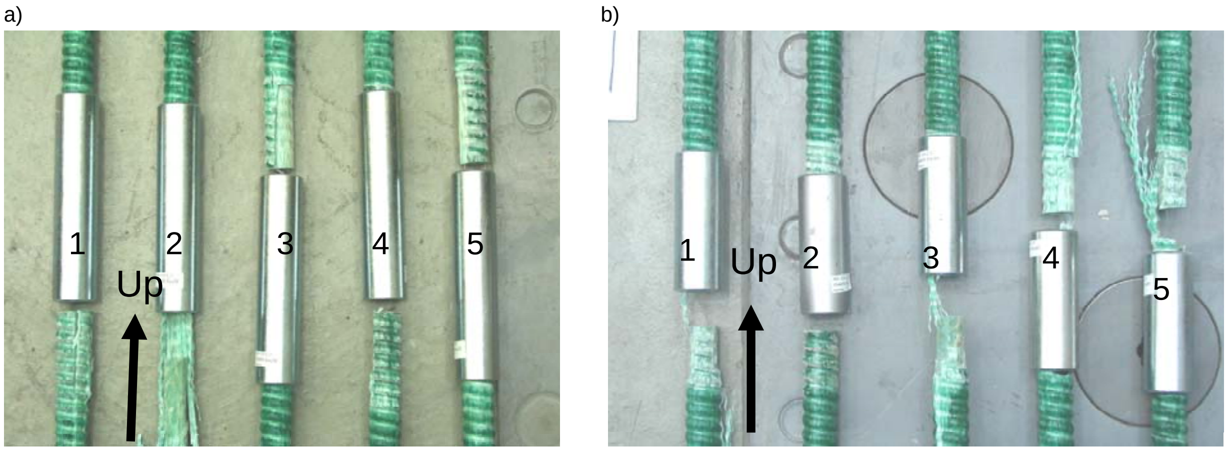



Figure 15: Steel Couplers, a) L = 200 mm and b) L = 120 mm with pulled out bolts.

#### 2.5.4 Failure mechanism and fracture pattern

The test pieces failed in a brittle manner accompanied by a banging noise. The bolts were pulled out of the couplers (Figure 15).

## 2.6 Torsion tests with Bolts

### 2.6.1 Test piece

Figure 12 shows the geometry of the test pieces. The free GRP length was 250 mm. Both ends of the 410 mm long GRP bolt were glued into steel nuts 50x50mm in the factory.

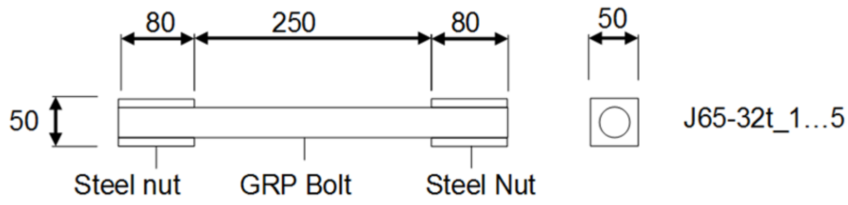



Figure 16: Test pieces for the torsion tests [mm].

### 2.6.2 Test set up and measuring system

The test piece was clamped with its both nuts in the 2000 Nm test machine (Figure 17). The rotation angle and the torsion moment were measured. The measurement uncertainty for the torsion moment was smaller than 1% of the load over the 2’000 Nm measuring domain.


Figure 17: Torsion test machine with clamped test piece prior to the test.

### 2.6.3 Test results

Figure 18a shows the torsion moment rotation angle relation of the Bolts. Since the length of the bolts decresed, an axial force appeared, due to the stiffness of the testing machine (Figure 18b). In order to minimise the axial force, the control system was programmed to correct the position of the clamping as soon as the threshold value of 2.5 kN, which was the minimum possible value, was exceeded.

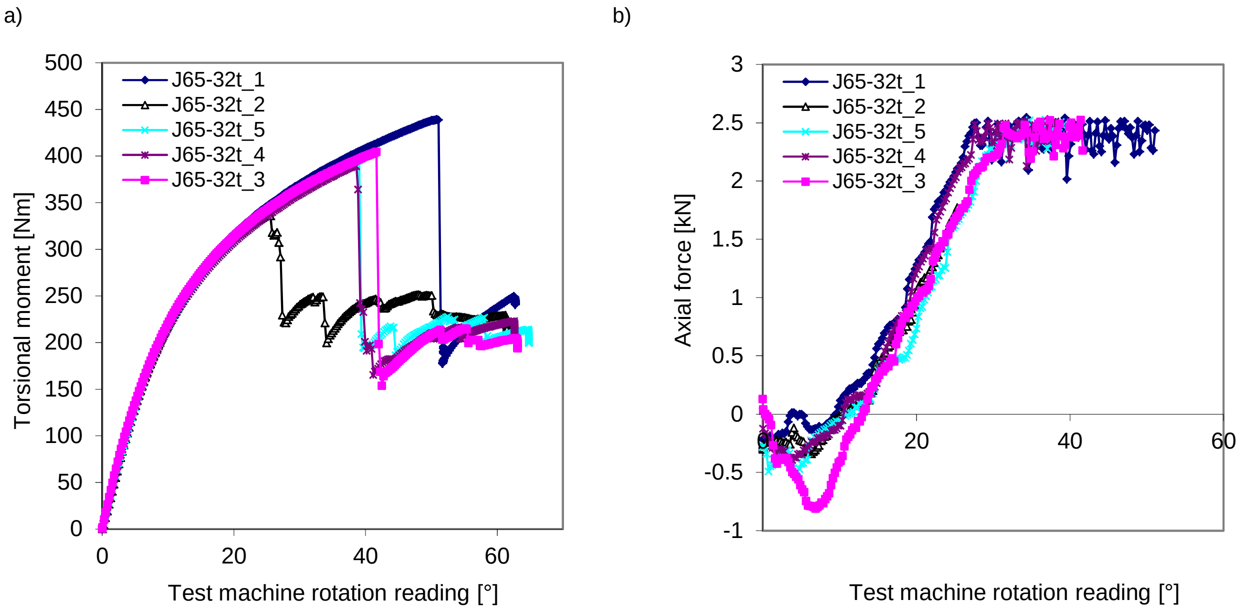



Figure 18: Relationships a) torsion moment – test machine rotation reading, b) normal force – test machine rotation reading for the control of the to 2.5 kN limited tensile force.

Table 6 shows the test results.

Table 6: Test results for the torsion resistance of the Bolts

| Name | Maximum torsion moment $T_u$ [Nm] |
|---|---|
| J65-32t_1 | 439.2 |
| J65-32t_2 | 337.3 |
| J65-32t_3 | 404.1 |
| J65-32t_4 | 389.4 |
| J65-32t_5 | 395.2 |
| mean value $\overline{x}$ | **393.0** |
| standard deviation $\sigma$ | **32.8** |
| test date | 11.02.2011 |

Figure 19 shows the test pieces after the tests. The white lines have been painted prior to the tests as straight lines parallel to the bolt axis, in order to control the bolt rotation distribution.

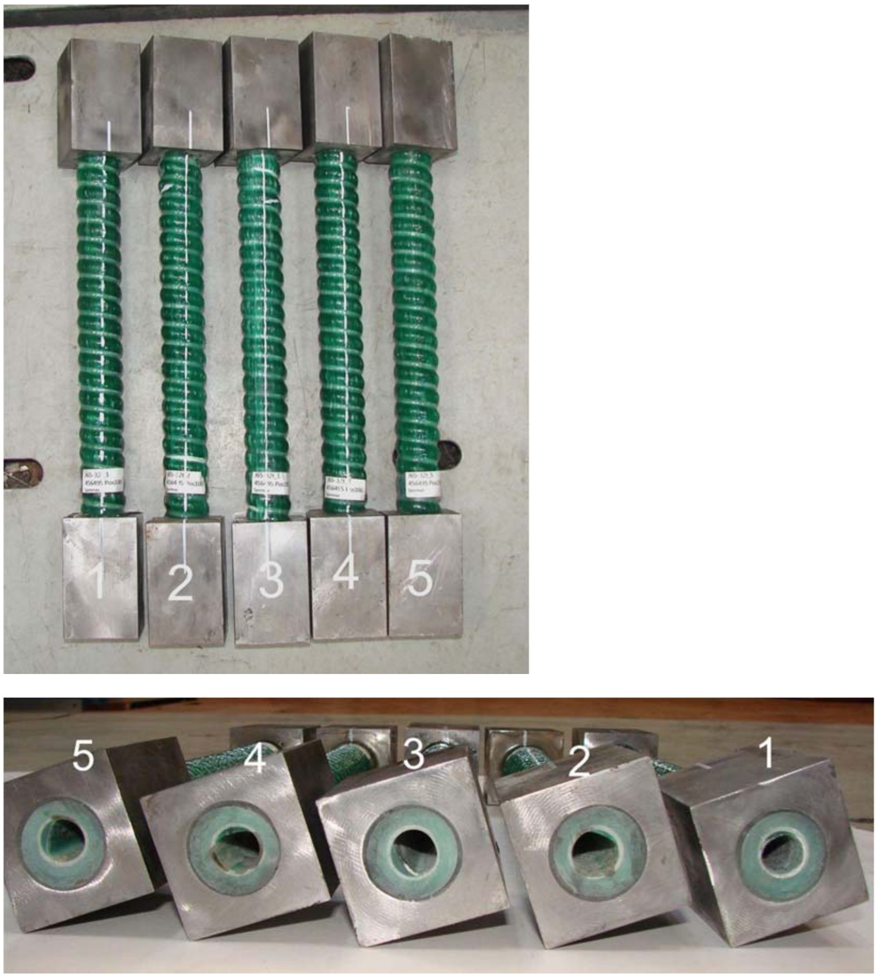



Figure 19: Test pieces after the torsion tests with remaining relative rotation.

#### 2.6.4 Failure mechanism and fracture pattern

The torsion moment – test machine rotation reading (Figure 18a) shows an abrupt drop of the force after the breaking torsion moment. The failure was accompanied by a short clicking noise. The bolts weren't considerably damaged (Figure 19). Only a remaining relative rotation between the nuts with an uniform rotation distribution along the Bolt and some visible cracks along the whole bolt length appeared.

# 3 Summary of the maximum forces

The mean maximum forces of all tested components are listed in Table 7.

Table 7: Mean maximum forces for J65-32 components.

| Component | Mean maximum force [kN] | Mean maximum torsion moment [Nm] |
|---|---|---|
| Spinmax J65-32 | 406 | |
| Bolt with GRP Nut | 123 | |
| Bolt with 1 Steel Nut (1x45 mm) | 188 | |
| Bolt with 2 Steel Nut (2x45 mm) | 312 | |
| Bolt with Steel Coupler L=200 mm | 276 | |
| Bolt with Steel Coupler L=120 mm | 192 | |
| Spinmax J65-32 | | 393 |

# 4 Reference

ISO 10406-1 (2008) Fibre reinforced polymer (FRP) reinforcement of concrete – Test methods, Part 1: FRP bars and grids, International Standard.

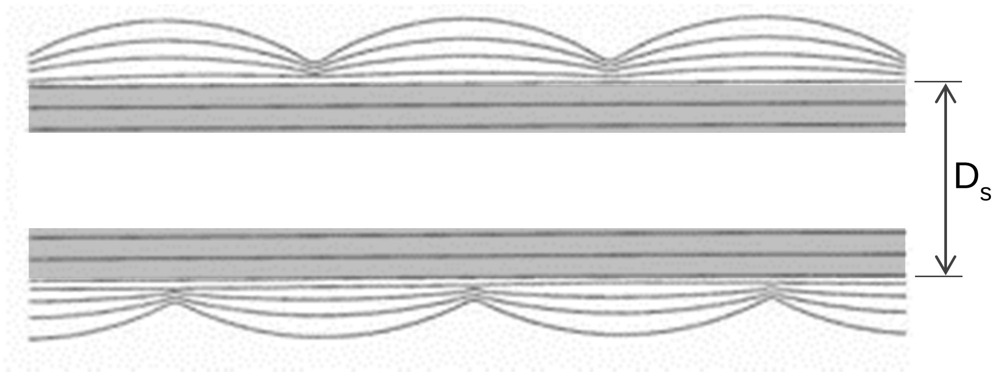
# Appendix 1

**Explanations for the stress area**

Figure 20 schematically shows a longitudinal section of the GRP bolt. The cross section of the anisotropic GRP bolt is composed of a portion of unidirectional fibers within the core cross section, plus a portion of undulated fibers in the outer layer.

The stress section $A_s$ is related to the core cross section with unidirectional fibers.

The stress section in the figure lies within the grey highlighted area of the height $D_s$.




$D_s$: Relevant diameter for the determination of the stress section $A_s$

Figure 20: Schematic longitudinal section of a GRP Bolt.

# Appendix 2

**Mean bolt cross sectional area**

3 bolt test pieces (J65-32A_1, J65-32A_2 und J65-32A_3) were trimmed to the length of about 200 mm for the determination of the mean cross sectional area. Subsequently, the lengths were exactly measured and the volume of water displaced was measured using a 250 ml measuring cup (Figure 21). No air bullets were observed at the test piece surface.


Figure 21: Test pieces with hollow section and measuring cup.

The cross sectional area was calculated by dividing the displaced volume of water by the test piece length. Table 8 shows the measured water volumes and the calculated cross sectional areas.

Table 8: Measured water volumes and the calculated cross sectional areas.

| | | | |
|---|---|---|---|
| Date | | | 31.01.2011 |
| pure water volume | [mm$^3$] | Vw | 110'000 |
| water + test piece volume | [mm$^3$] | Vtot_1 | 214'000 |
| | | Vtot_2 | 215'000 |
| | | Vtot_3 | 215'000 |
| test piece volume (V = Vtot - Vw) | [mm$^3$] | V_1 | 104'000 |
| | | V_2 | 105'000 |
| | | V_3 | 105'000 |
| test piece length | [mm] | L_1 | 200.1 |
| | | L_2 | 200 |
| | | L_3 | 199.9 |
| net section area | [mm$^2$] | A_1 net | 519.7 |
| | | A_2 net | 525.0 |
| | | A_3 net | 525.3 |
| **mean net section area** | **[mm$^2$]** | **A_mean** | **523.3** |