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# Recommendation of applicable methods for measuring the preload in bolts

## Deliverable report D1.1

## WP 1 – Task 1.1

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Part of the RFCS Research Project

"SIROCO"
*Execution and reliability of slip-resistant connections for steel structures using CS and SS*

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# Table of contents

Page

# 1 Introduction

## 1.1 General remarks

This deliverable deals with Work Package 1, Task 1.1 from the RFCS Research Project SIROCO, "Execution and reliability of slip resistant connections for steel structures using CS and SS". Work Package 1 of the project deals with improving test procedure for the determination of slip factors and closing the lack of undefined or unclear defined rules given in the test procedure of Annex G of EN 1090-2.

In this Work Package also regulations in other countries such as USA and Japan will be taken into account as well as experiences from our colleagues in those countries. Furthermore, of course, background information to the existing tightening methods and other data from literature will be part of the research.

## 1.2 Objectives

This deliverable deals with the work carried out in Task 1.1 "Comparative study regarding the accuracy of different kinds of methods for measuring the preload in the bolts (e.g. implanted strain gauges (SG), implanted strain gauges with a small adapter (SG + adapter), especially produced load cells (LC)) under experimental conditions (slip factor tests acc. to EN 1090-2, Annex G)".

# 2 State of the art

## 2.1 General

Bolted slip-resistant connections according to EN 1993-1-8 [1] are used in different type of steel structures such as lattice towers, cranes, bridges as well as wind turbine towers. The slip resistance of these connections is influenced by different parameters such as the condition of the faying surfaces, the preload level of the bolts, the geometry of the structural details etc. Slip factors for some specified surface conditions are given in EN 1090-2 [2] or can be found in literature.

For those surface conditions which have not been considered in EN 1090-2 or if higher slip factors are required, slip factor tests should be performed according to Annex G of EN 1090-2. However, the practice has shown that the current slip test procedure according to Annex G is not clear in detail. For this reason, as part of the European RFCS-research project SIROCO, Annex G shall be improved to an unambiguous, detailed description of a practical test procedure, which is applicable by testing laboratories for general classification purposes of surface conditions and adjustable for special cases [3, 4].

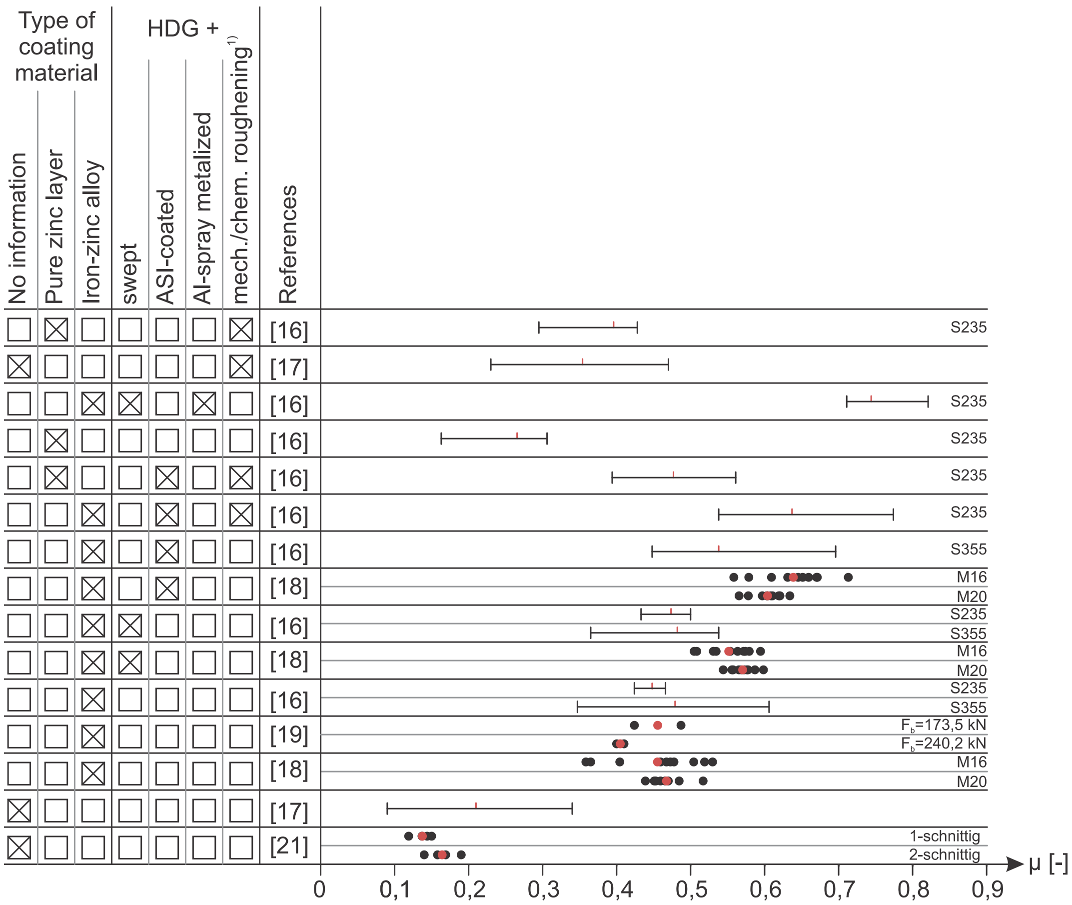
Blast-cleaned surfaces feature a high coefficient of static friction, however, they are not protected against corrosion. Therefore, they should only be applied in interior areas without specific corrosion exposure. Their use in outside areas is not recommended due to deficient corrosion protection in consequence of hazardous penetration of the construction by humidity and salts.

In order to achieve a high coefficient of static friction and an excellent effect of corrosion protection, different coating conditions have been used for slip-resistant connections for years.

In the literature results of several investigations and reviews on investigations can be found regarding evaluated and/or proposed slip factors of different coatings, e. g. [4, 5]. In some of these publications slip factors for ASI-Zn-, Zn-SM and HDG-coatings can be found which are summarized in Table 1, Figure 1 and 2. Comparing the slip factors from literature, special care has to be taken, see also [6, 7].

**Table 1**. Slip factors for ASI-coated faying surfaces, reviewed from literatures

| Reference | Surface condition | Slip factor μ [-] |
|---|---|---|
| | ASI-Zn-coating | |
| EN 1090-2 [2]<br>ECCS-TC 10 [8] | Surfaces blasted with shot or grit: …b) with alkali-zinc silicate paint with a thickness of 50 μm to 80 μm | 0.40 |
| ECCS-TC 10 [8] | Blasted and alkali-zinc silicate paint (thickness 20 to 50 μm) | 0.30 |
| DIN 18800-7 [9]/<br>TL/TP-KOR-Stahlbauten [10] | Surfaces painted with alkali-zinc-silicate (40 μm) | 0.50 |
| ECCS Recommendations [11] | Surfaces blasted with shot or grit and painted with alkali-zinc silicate coat (thickness 60 to 80 μm) | 0.35 |
| Cheal [12] | Grit or shot blasted and coated with zinc silicate primer | 0.35-0.65 |
| BS 5400-3 [13] | Surfaces treated with zinc silicate paint<br>(The slip factor should be reduced by 10 % where higher grade bolts in accordance with BS 4395-2 are used.) | 0.35 |
| Owens/Cheal [14] | Surfaces painted with alkali-zinc silicate (50 μm to 80 μm) | 0.46 |
| Kammel [15] | Surfaces blasted with shot or grit with alkali-zinc silicate paint | 0.51-0.54 |




1) Surfaces were roughened by sanding or brushing or treated by phosphate

**Figure 1:** Slip factors for hot-dip galvanized (HDG) faying surfaces reviewed from literature

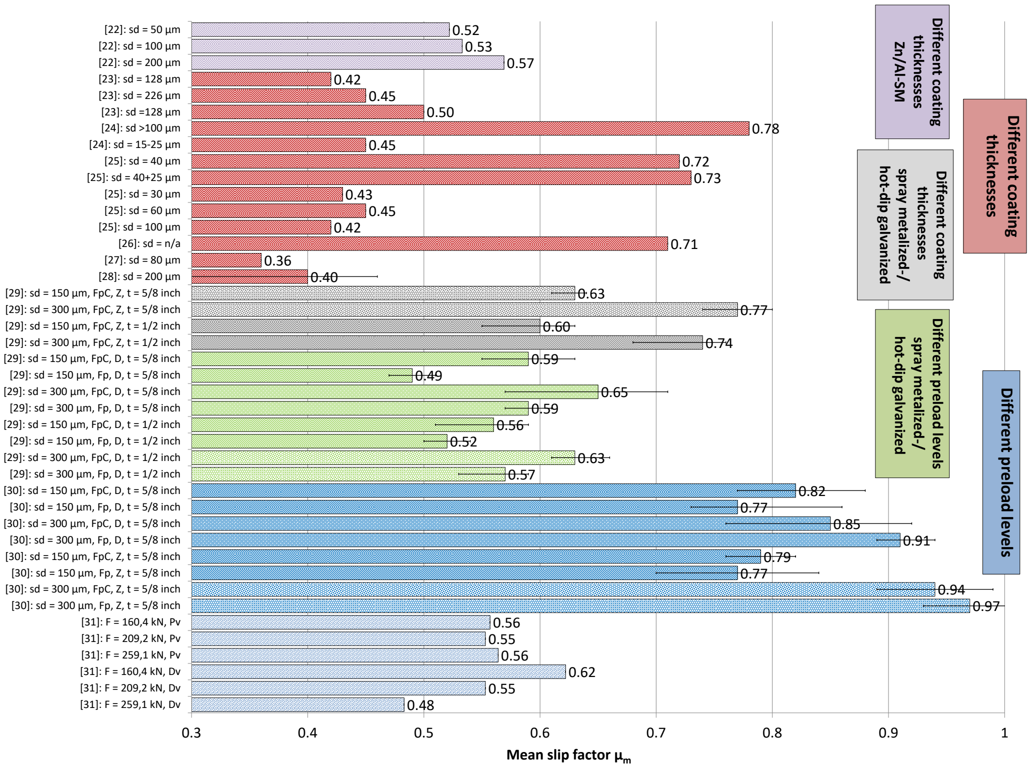



**Figure 2:** Slip factors for zinc spray metallized (Zn-SM) faying surfaces reviewed from literature

sd: coating thickness; D: compression test; Z: tensile test; F: preload; Fp,C: with 70 % $f_{ub}$; Fp: with 90 % $f_{ub}$; Pv: powder process; Dv: wire process

In the present deliverable, the following four questions will be clarified:

- Which methods ensure a measurement of the preload in the bolts with sufficient accuracy?
- How does the clamping length influence the slip resistance behaviour?
- How does the position of the displacement transducers influence the load-displacement-behaviour of a test specimen and herewith the slip factor?
- How do the different surface conditions influence the slip resistance behaviour?

## 2.2 Slip factor test procedure according to Annex G of EN 1090-2

EN 1090-2 prescribes a generalized experimental procedure to obtain the slip factor. Four static tests must be conducted under an incremental tensile loading condition at normal speed. The duration of the tests shall be 10 min to 15 min. The question arises: how much is the normal speed and how is it possible to predict the duration of the test before testing?

The individual slip value $\mu_i$, the mean value $\mu_m$ and the standard deviation $S_\mu$ shall be obtained by the following equations (1) to (3):

$$\mu_i = \frac{F_{Si}}{4F_{P,C}},\ \mu_m = \frac{\sum \mu_i}{n},\ S_\mu = \sqrt{\frac{\sum(\mu_i - \mu_m)^2}{n-1}}. \quad (1), (2), (3)$$

The slip loads $F_{Si}$ are defined as the load at which a slip of 0.15 mm is observed.

This evaluation criterion is different in other standards and recommendations. RCSC [32] and ECCS T10 [8] recommend 0.5 mm and 0.3 mm respectively to evaluate the slip load, see Figure 3.

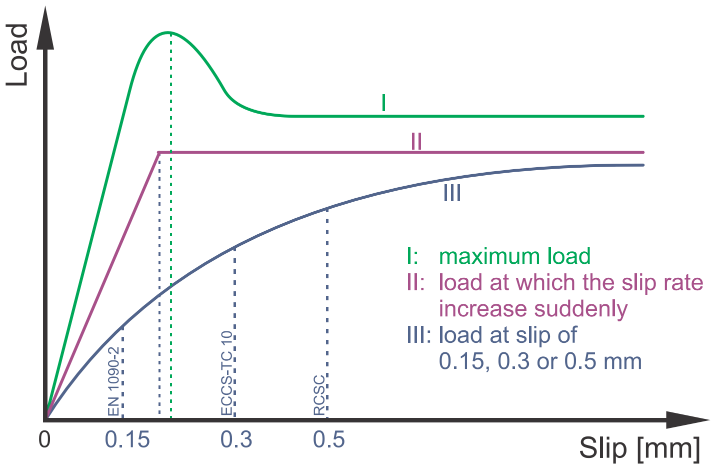



**Figure 3:** Definition of the slip load by various criteria acc. to [1, 8, 32]

Figure 4 shows significant differences for zinc spray metallized surface treatment at the three considered evaluation points. In the presented investigations the slip was determined at the peak before 0.15 mm slip or at the slip of 0.15 mm when no peak occurred before 0.15 mm.

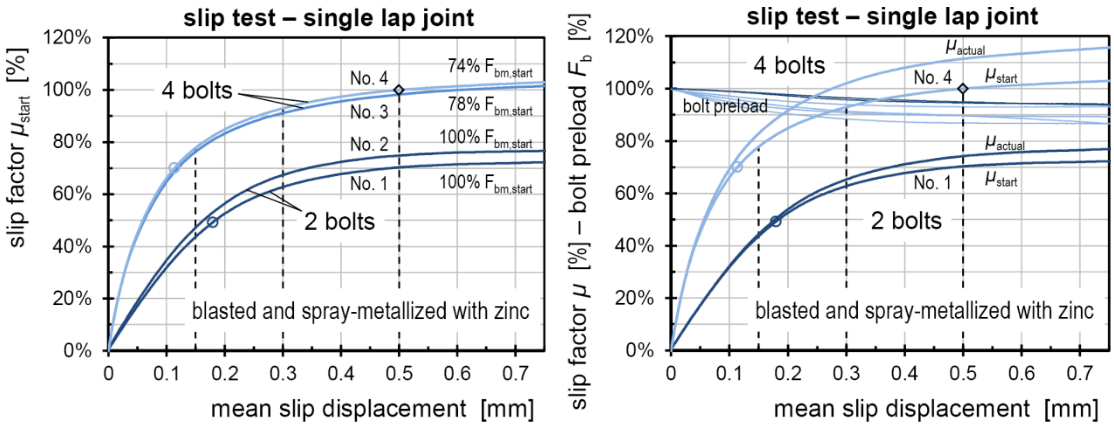



**Figure 4:** Slip factor-slip displacement-curves for slip tests of single lap joints [3]

With the fifth test specimen a creep test shall be carried out with a specific load of 90% of the mean slip load $F_{sm}$ from the first four static tests during 3 hour to investigate the behaviour of the joint under sustained loads. If the difference between the recorded slip at the end of 5 min and 3 hour after the full load application does not exceed 0.002 mm the slip load for the specimen under long term condition must be specified as for the previous four static tests. If the difference between the two slips at 5 min and 3 hour exceeds 0.002 mm, three extended creep tests must be performed.

The standard deviation $S_{Fs}$ of the ten slip load values obtained from the five specimens should not exceed 8% of the mean value, otherwise additional specimens shall be tested.

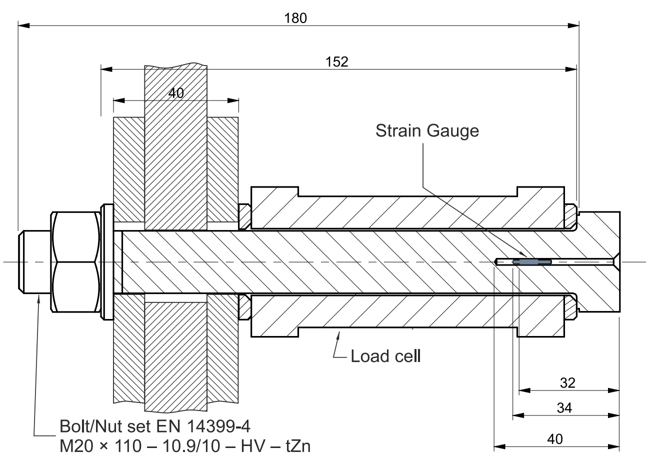
# 3 Experimental investigations

## 3.1 General

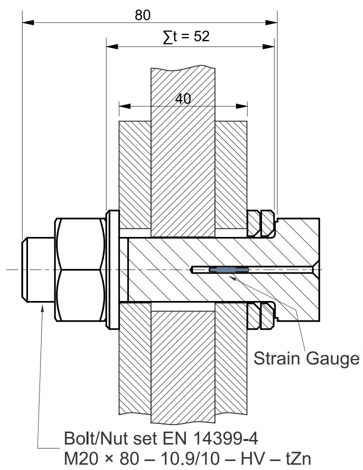
In this study three different kinds of methods for measuring the preload in the bolts and one further method in a preliminary study have been investigated, see Figure 5:

- instrumented bolts with implanted strain gauges without any adapter (SG),
- instrumented bolts with implanted strain gauges with a small adapter (SG + adapter),
- especially produced load cells (LC),
- small load cells (preliminary study).

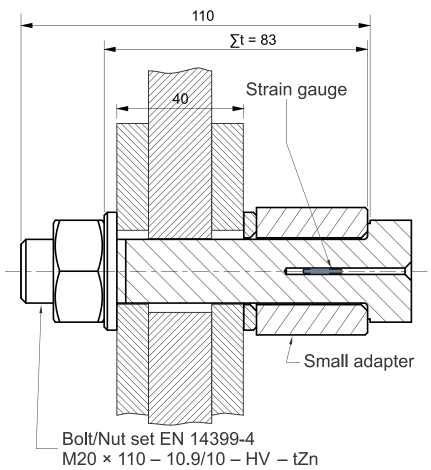
Different combinations of instrumented bolts with small adapters (with/without) and load cells resulting in three different clamping lengths have been considered in order to investigate the influence of the extension of the clamping length by the load cell and the small adapter on the determined slip factor.



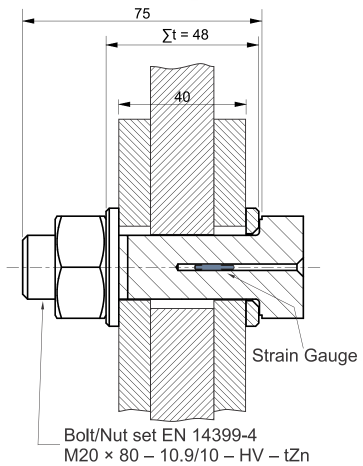

a) Instrumented bolt for application combined with the TUD-load cell (SG + LC)




b) Instrumented bolt for application without any adapter (SG) – two washers under the bolt head



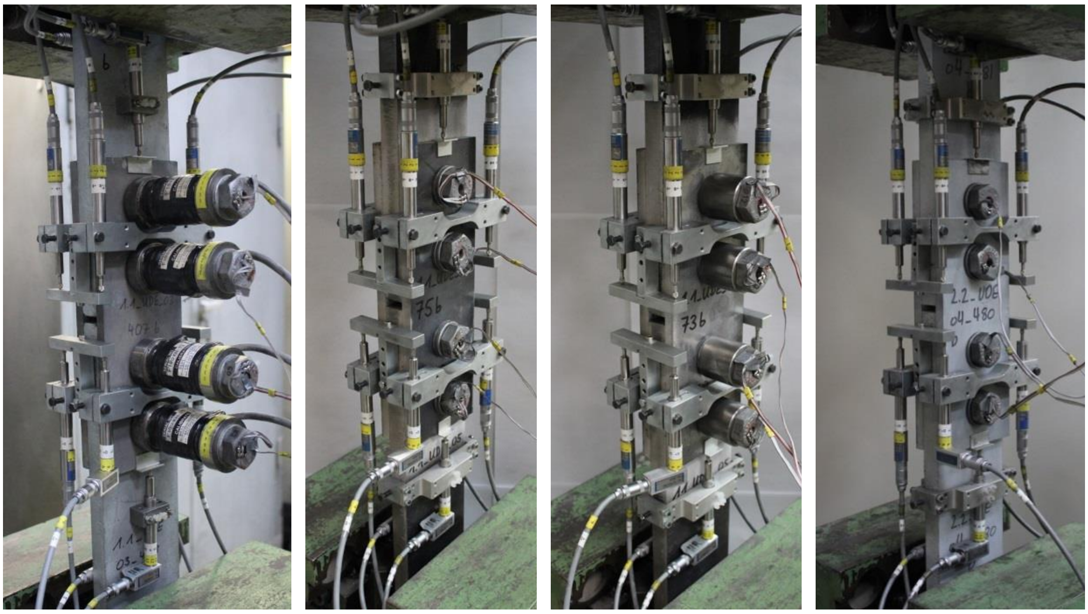

c) Instrumented bolt for application with an adapter (SG + adapter)




d) Instrumented bolt for application without any adapter (SG) – one washer under the bolt head

**Figure 5:** M20-Bolts with implanted strain gauges

For each test specimen four HV bolts M20, class 10.9 were instrumented with a strain gauge embedded in a 2 mm hole along the bolt shank. The bolts have been prepared in four different lengths 75mm, 80 mm, 110 mm and 180 mm for testing without any adapter, with a small adapter and combined with the load cells produced by the Delft University of Technology (TUD), see Figures 5 and 6.



a) LC and SG | b) only SG (two washer under the bolt head) | c) only SG with small adapter | d) only SG

**Figure 6**: Test setup, positions of displacement transducers (LVDTs) as well as clamped plates of a bolted connection with bolts with implanted strain gauge

Figure 6 shows the test setups used for the comparative study with 12 displacement transducers (LVDTs) numbered 1 to 12 using both preload measurement devices: instrumented bolts with implanted strain gauges (SG) and especially produced load cells (LC). By means of the LVDTs 1-8, positioned exactly at the centre of the upper resp. lower part of the test specimens, the exact slip of the upper resp. lower part can be measured excluding any strains resulting from the applied tensile force. Additionally, LVDTs 9-12 have been positioned on top of resp. beneath the outer plates for comparative reasons.

## 3.2 Bolts with implanted strain gauges (UDE)

Bolt with implanted strain gauges were manufactured by drilling a centric hole of 2 mm diameter along the bolt shank. After drilling, the holes were cleaned and degreased. In a next step, two components of an adhesive were mixed together to form the adhesive a short time before application. Afterward, the mixed adhesive was injected into the hole by using a syringe, see Figure 6.

BTM-6C (produced by Tokyo Sokki Kenkyujo Co., Ltd.) strain gauges were used for instrumentation of the bolts. The gauge lead was marked according to the required length and bended rectangularly at the mark without injuring the installation material. The strain gauge was inserted gently into the hole to a certain depth while holding the upper part of the lead. For a period of at least 12 hours, the bolts were left at room temperature to allow the adhesive to cure.

In the next step, the bolts were placed in a glass vacuum desiccator. For 15 to 20 minutes, a vacuum was created to get a level at 1 to 10 Pa. Thereafter, the bolts were placed in the electric furnace at 140 ° C for a period of three hours, see Figure 7.

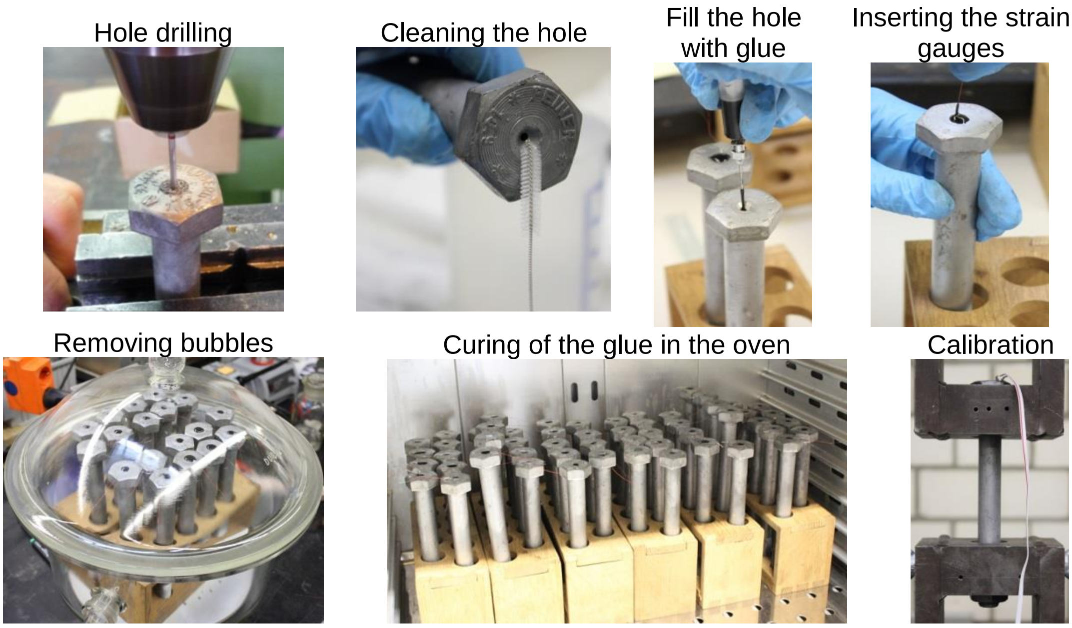



**Figure 7:** Production of the implanted strain gauges at UDE

The temperature was increased slowly to avoid appearance of air bubbles or crack in the adhesive. Afterwards, each instrumented bolt was calibrated under stepwise tensile loading, see Figure 8.

Figure 9 shows an example of the time-force / strain curve of a HV bolt (number 17) instrumented with strain gauges, which has completed the calibration successfully. Figure 10 presents an unsuccessful calibration test for bolt number 9.

Those bolts, which showed a linear load-strain behaviour, were selected for application within the slip tests, see Figure 11.

**Figure 8**: Calibration of instrumented bolts with strain gauge in a universal test machine (with a maximum load capacity of ±200 kN)

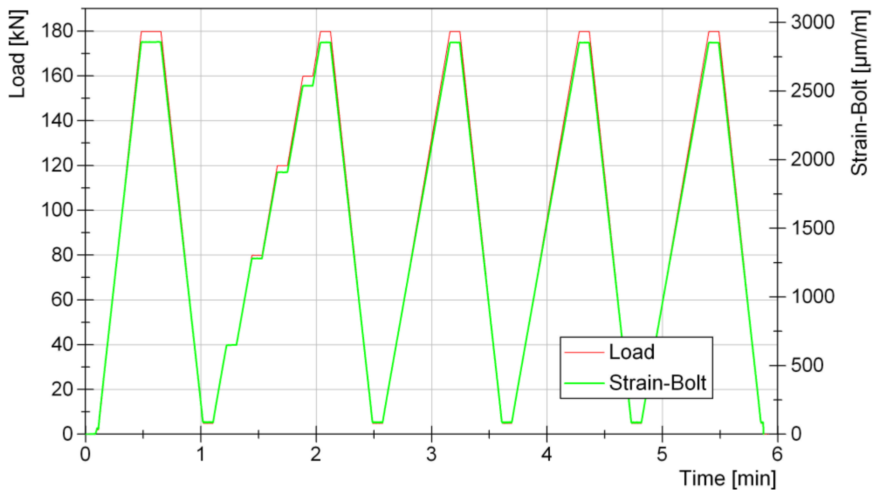



**Figure 9**: An example for a successful calibration test of a M20 x 110 instrumented bolt with a strain gauge: time-load/strain curve (Bolt number 17)

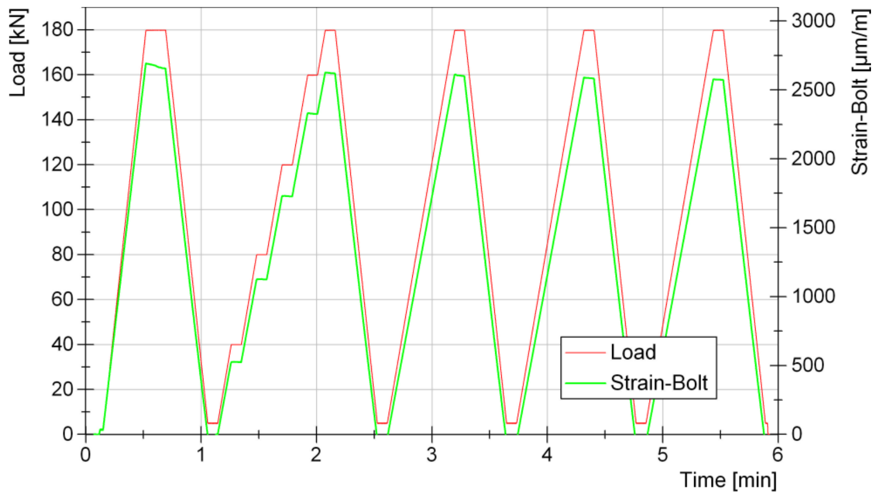



**Figure 10**: An example for an unsuccessful calibration test of a M20 x 110 instrumented bolt with a strain gauge: time-load/strain curve (Bolt number 9)

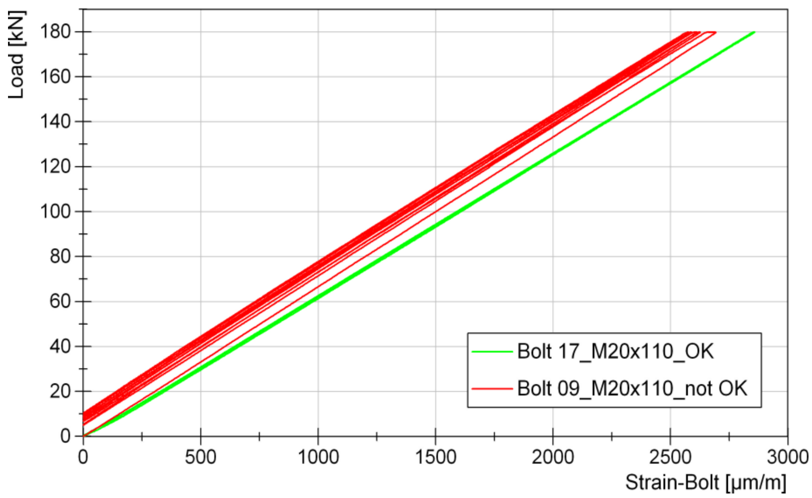


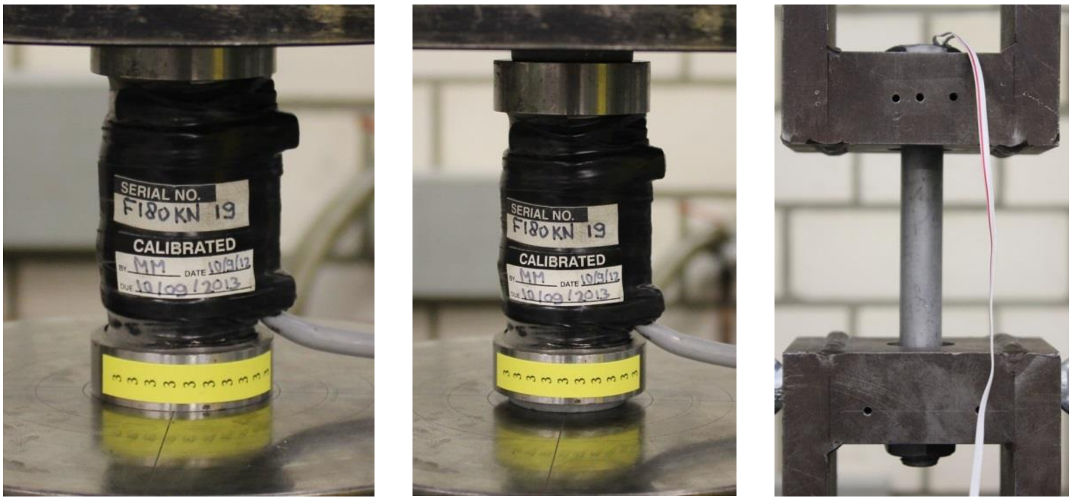

**Figure 11**: An example for a failed calibration test of a M20 x 110 instrumented bolt with a strain gauge: time-load/strain curve (Bolt number 9)

## 3.3 Especially produced load cells (TUD)

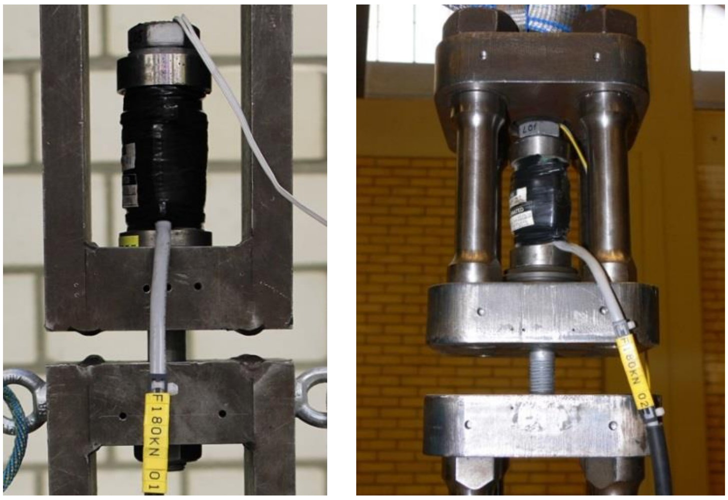
The accuracy of load cells that are used to measure bolt forces (preloads in the bolt) heavily depends on the effect of eccentricities between the bolt axis and the axis of the load cell. This eccentricity leads to bending strains in the load cell that are difficult to compensate for, especially when the measurement body of the load cell (the area of the load cell with the strain gauges) is short. The load cells that are used in the SIROCO project are 'home-made' instruments by TUD that are relatively long (100 mm) compared to the standard load cells that can be purchased on the market. As an additional measure to restrict eccentricities, the internal diameter of the home-made load cells is only 0.1 mm larger than the diameter of the bolts. The capacity of the especially produced load cells is 180 kN. The strain gauges used in the load cells are of type XY11-6/120 (produced by HBM), see Figure 12. Around the circumference of the measurement body of the load cells four XY11-6/120 gauges are placed, arranged at a 90° degree offset from each other. The four gauges are combined to a full bridge strain gauge configuration, which is fully compensated for temperature variations. After production, the load cells were calibrated in a certified calibration test rig in the Stevin lab of TU Delft. The calibration was carried out by loading the load cells in such a way that the loading of the cells during the slip factor tests is matched as much as possible. To achieve this, a long M20 bolt was placed into the load cell. Thereafter, the bolt was loaded in tension by the calibration test rig and the calibration factor for the load cell was determined. The calibration procedure confirmed the expected robustness and accuracy of the instruments (error <1% of the full scale), used in combination with M20 bolts.


**Figure 12:** Various phases of the production process of the load cells used in SIROCO (TUD)

The UDE bolts with implanted strain gauges as well as the TUD load cells have been independently pre-checked at both testing laboratories at UDE and TUD to verify 'common ground' between UDE and TUD labs with respect to the accuracy of the measured bolt forces, see Figure 13. This was carried out by applying the calibration load to the load cells using the instrumented bolts. By doing so, both instruments were calibrated in once. The differences between the calibration factor of the instrumented bolts determined in UDE and the results of the TUD calibration of the bolts was less than 3%.




a) Compression test – load cell only | b) Compression test – load cell with HV-washers | d) Tension test – bolt only



c) Tension test – load cell with bolt at UDE and TUD

**Figure 13:** Calibration of instrumented bolts and load cells at TUD and UDE

In the calibration process only tensile forces in the bolts are applied by the test rig. In practice, during the tests to determine the slip factor, the bolt force is applied by turning of the nut until the specified level of preloading is reached. Unlike during the calibration process, this practical method of applying the bolt force introduces a torsional moment in the load cells. To investigate the influence of torsion related strains on the accuracy of the load cell measurements, additional calibration procedures were conducted. For this part of the calibration procedure, the instrumented bolts produced were used to measure the actual bolt force (as the strain gauges in the instrumented bolts are in the center line of the bolts, these are not influenced by eventual torsional deformations of the bolt shaft). From this investigation it can be concluded that when standard hardened washers are used and when the thread of a bolt is unharmed and lubricated, the influence on the accuracy of the measurement of the bolt force of the torsion caused by the tightening of the bolt up to the maximum capacity of the load cells is negligible. This even holds when the nut is tightened from the load cell side (which is not the case during the tests).

## 3.4 Test program

The test specimen geometry was chosen to the standard test specimen with M20 bolts according to EN 1090-2, Annex G. Six surface conditions were considered, see Table 2: (1) grit-blasted (GB), (2) alkali-zinc silicate (ASI-Zn)-coating, (3) hot dip galvanized (HDG), (4) spray metallized with aluminium (SM-Al), (5) spray metallized with zinc (SM-Zn) and (6) a combination of alkali-zinc silicate and zinc spray metalized coating (ASI - Zn-SM).

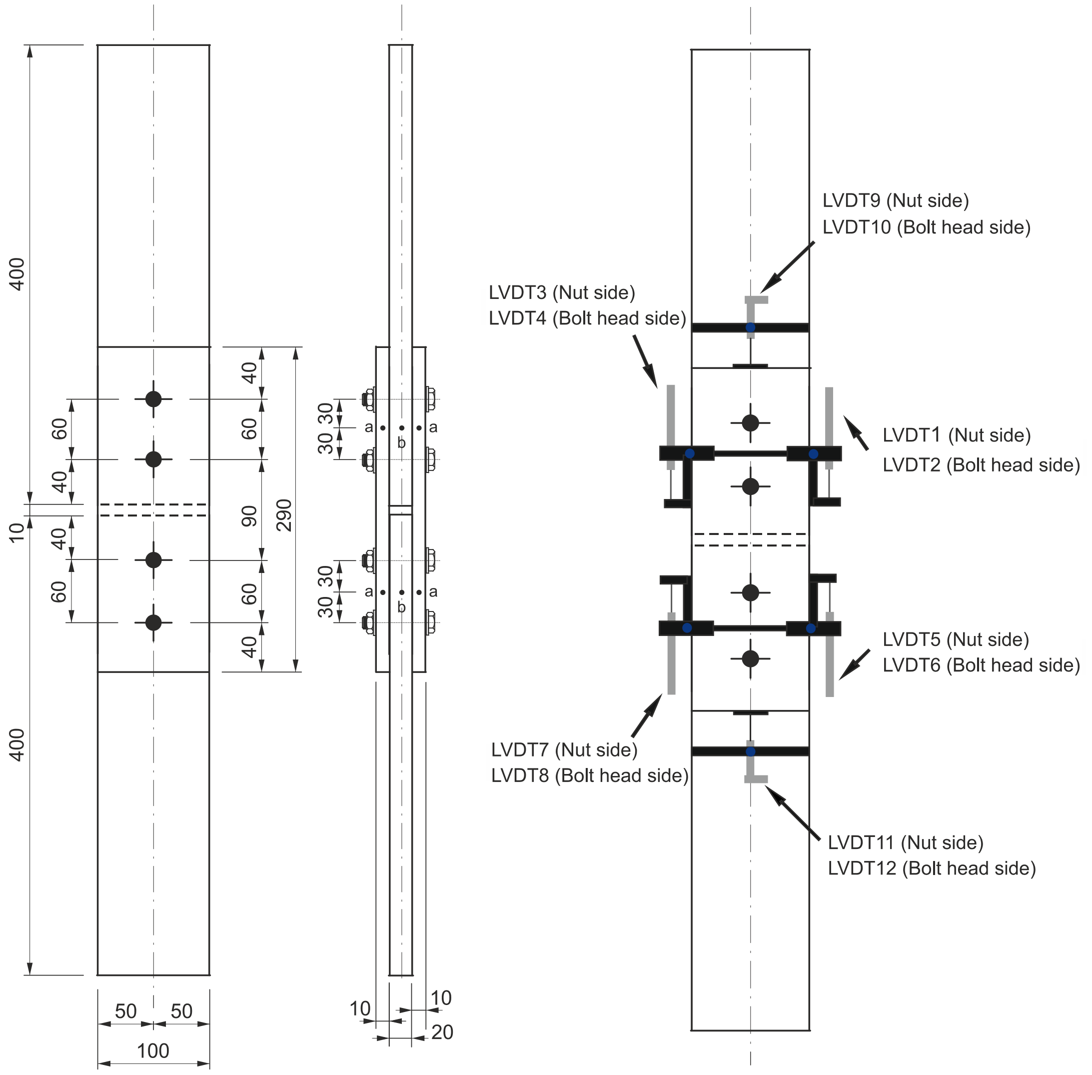
**Table 2**: Test programme

| Series ID | Surface preparation | | Σt[4)] [mm] | Bolt size (Md × l)[5)] [mm] | Preload [kN] | Number of tests |
|---|---|---|---|---|---|---|
| | Sa[1)] / Rz[2)] [µm] | DFT[3)] [µm] | | | | st/ct/ect[6)] |
| Grit blasted surfaces (GB) | | | | | | |
| GB-I | Sa 2½ / 80 | - | 152 | M20 × 180 | $F_{p,C}$/172 | 4/1/- |
| GB-II | | - | 83 | M20 × 110 | $F_{p,C}$/172 | 2/-/- |
| GB-III | | - | 52 | M20 × 80 | $F_{p,C}$/172 | 2/-/- |
| Alkali-zinc silicate coating (ASI) | | | | | | |
| ASI-I | Sa 2½ / 80 | 60 | 152 | M20 × 180 | $F_{p,C}$/172 | 4/1/- |
| ASI-II | | | 83 | M20 × 110 | $F_{p,C}$/172 | 2/-/- |
| ASI-III | | | 52 | M20 × 80 | $F_{p,C}$/172 | 2/-/- |
| Hot-dip galvanized surface (HDG) | | | | | | |
| HDG-I | - | 105 | 152 | M20 × 180 | $F_{p,C}$/172 | 4/1/- |
| HDG-II | - | 105 | 48 | M20 × 75 | $F_{p,C}$/172 | 2/-/- |
| HDG-III | - | 80 | 48 | M20 × 75 | $F_{p,C}$/172 | 4/-/- |
| Aluminium spray metalized coating (Al-SM) | | | | | | |
| Al-SM-I | - | 250 | 83 | M20 × 110 | $F_{p,C}$/172 | 2/-/- |
| Al-SM-II | | | 52 | M20 × 80 | $F_{p,C}$/172 | 4/1/- |
| Zinc spray metalized coating (Zn-SM) | | | | | | |
| Zn-SM-I | Sa 3 / 100 | 140 | 83 | M20 × 110 | $F_{p,C}$/172 | 4/-/1 |
| Zn-SM-II | | | 52 | M20 × 80 | $F_{p,C}$/172 | 2/-/- |
| Combination of alkali-zinc silicate and zinc spray metalized coating | | | | | | |
| ASI – Zn-SM-I | Sa 2½/100 – Sa 3/100 | 55 – 170 | 48 | M20 × 75 | $F_{p,C}$/172 | 4/1/2 |

[1)] Sa: surface preparation grade | [2)] Rz: roughness | [3)] DFT: dry film thickness (Coating thickness) | [4)] Σt: clamping length [5)] d: bolt diameter, l: bolt length | [6)] st: static test/ct: creep-/ect: extended creep test

The test specimens were made of S355J2C+N, for each plate thickness from one batch. In order to investigate different kinds of methods for measuring the preload in the bolts and the influence of different surface conditions and preload levels, the tests were performed by applying an incremental tensile displacement with a velocity of about 0.01 mm/s. The speed of the displacement controlled tests was selected in a way that the test duration was approximately 10 to 15 min.

The specimen geometry was chosen as M20-test-specimens according to EN 1090-2, see Figure 14. The slip displacements were measured in two different positions: CBG (center bolts group) and PE (plate edges) positions. CBG and PE positions consist of 8 (LVDTs 1-8) and 4 (LVDTs 9-12) displacement transducers respectively, as shown in Figure 14 and 15. In the presented investigation, the slip factors are evaluated based on the measured slip displacement in CBG position.




a) Test specimen geometry b) Positions of LVDTs

**Figure 14**: Test specimen geometry for the determination of the slip factor according to EN 1090-2, Annex G, test specimens for M20 bolts and positions of displacement transducers (LVDTs)

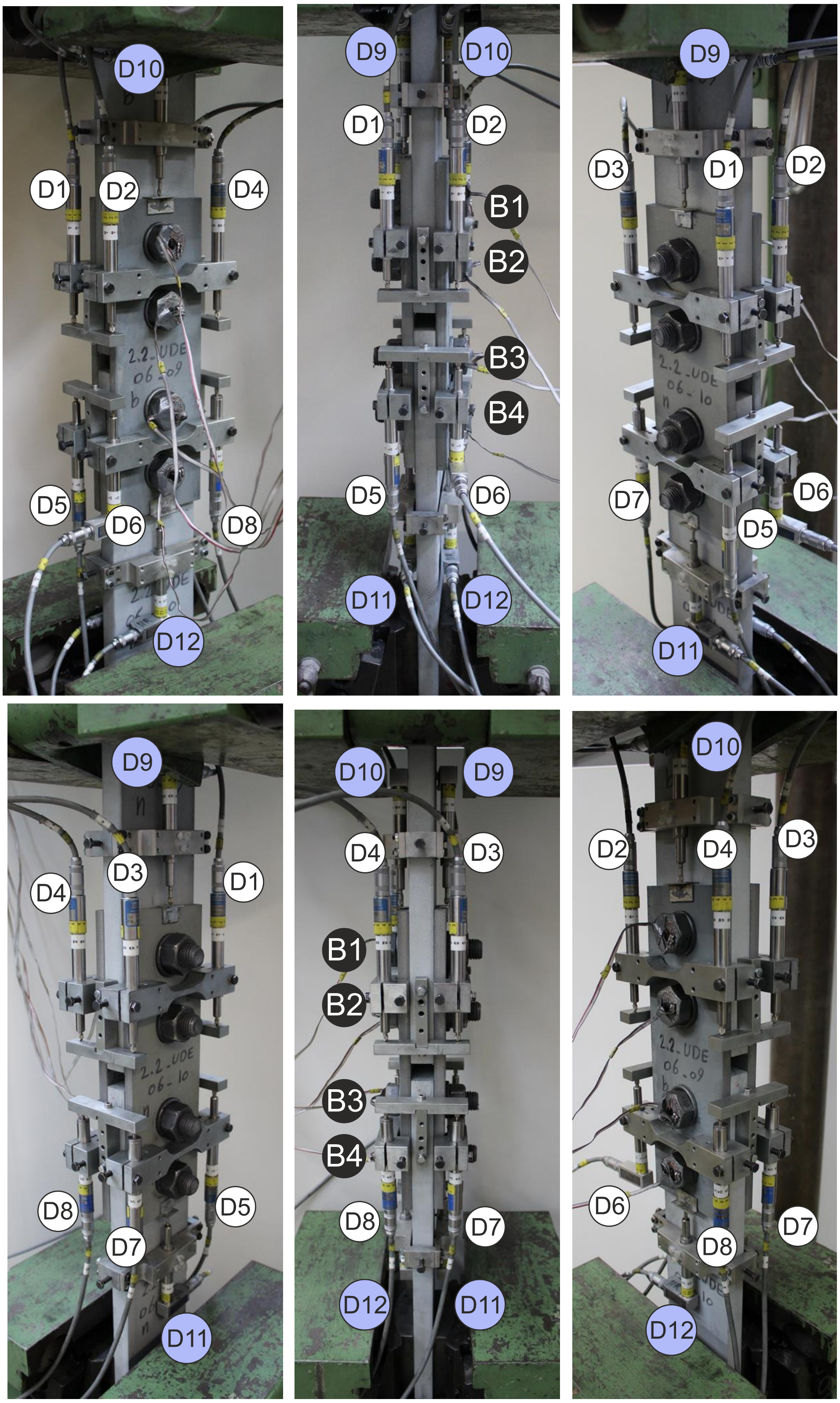
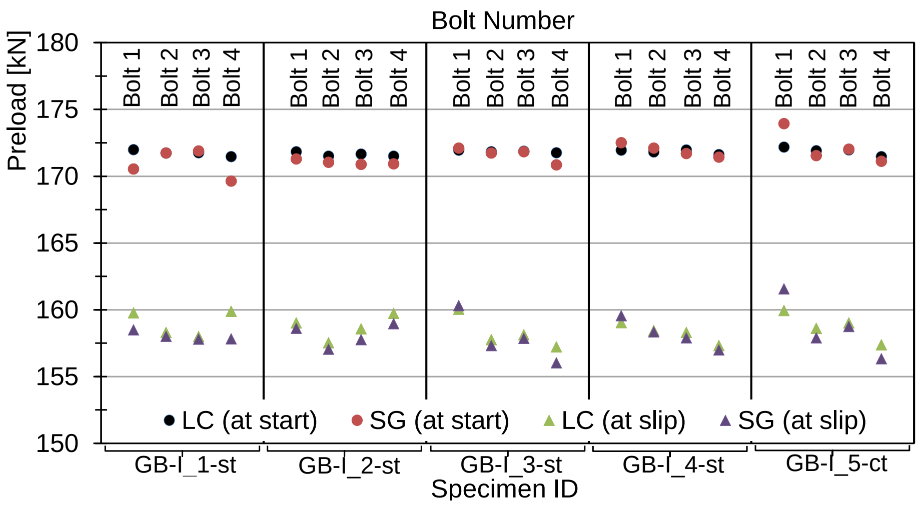



**Figure 15**: Positions of displacement transducers (LVDTs)
B: bolt │D: displacement transducers │Blue: PE position │White: CBG position

## 3.5 Results and Discussion

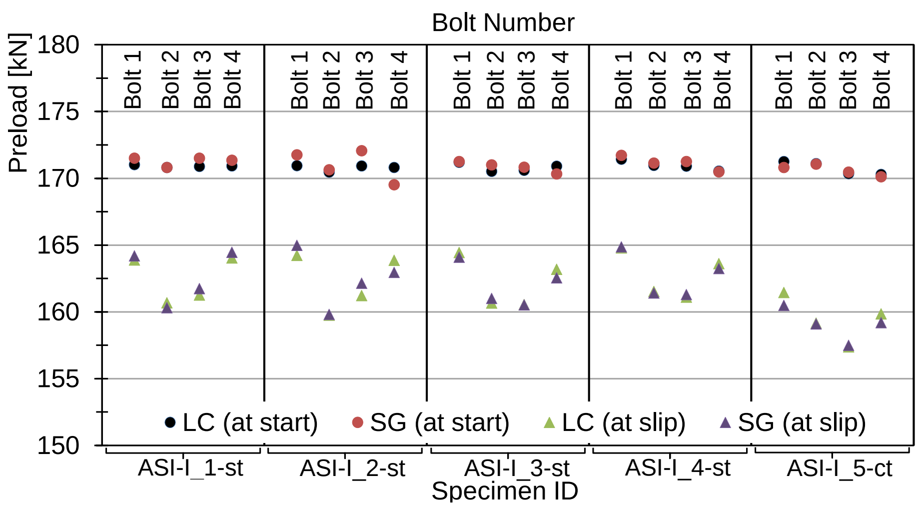
### 3.5.1 Methods for measuring the preload in the bolts

A comparative study regarding the accuracy of different kinds of methods for measuring the preload in the bolts has been performed. Figures 16, 17 and 18 present the initial preloads at beginning of testing and the actual preloads at slip in the bolts measured by SG and LC for the series GB-I, ASI-I and HDG-I. From these diagrams the preload losses due to creep and transversal contraction can be observed as well. It can be seen that the deviations between the measurement methods SG and LC are negligible small with a maximum deviation of 1.3%. Furthermore, the mean values of the losses of preload were detected to approximately 9% for GB-I, 7% for ASI-I and 3% for HDG-I.



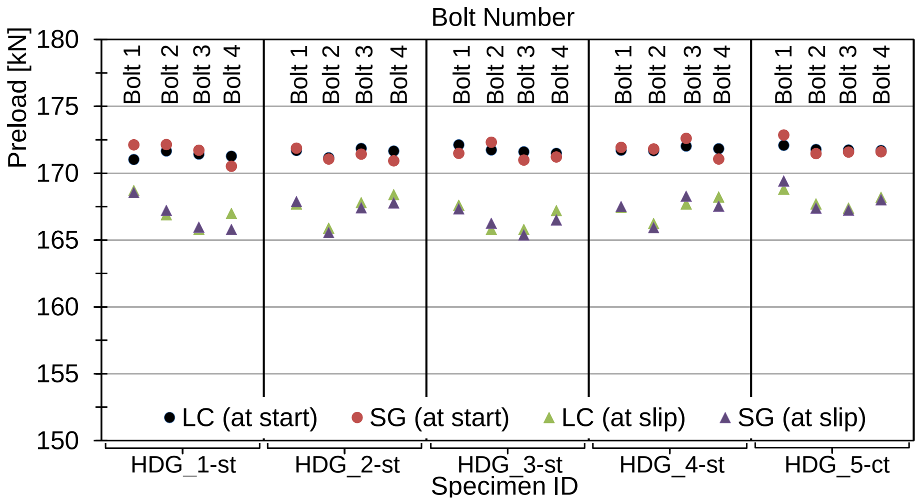

1) st: static test 2) ct: creep test

**Figure 16**: Comparison of preload measurements considering LC and SG for GB-I




1) st: static test 2) ct: creep test

**Figure 17**: Comparison of preload measurements considering LC and SG for ASI-I




[1)] st: static test [2)] ct: creep test

**Figure 18**: Comparison of preload measurements considering LC and SG for HDG-I

As the main part of the loss of preload is caused by transversal contraction (in static slip factor tests), the transversal contraction increases with increasing slip load, too, which results in preload losses corresponding to the level of the slip load.

Within additional, preliminary compression tests the ability to calibrate customary small load cells has been investigated with different setup configurations applying different types of washers, see figure 19.

Only the setup configuration without any additional washer showed a good agreement between the measured load of the load cell $F_{KMD}$ and the load of the testing machine F. For all setup configurations with additional washers significant deviations (up to 35 %) were observed.

The application of these customary small load cells in slip factor tests confirms the overestimation of the compression load, see Figure 19. The measured compression load is approximately 25 % higher than the preload in the instrumented bolts that were tightened according to the measuring signal of the implanted strain gauges. It was shown that the small customary load cells are very sensitive to irregularities of the clamped parts. Consequently, the use of these load cells within slip tests will lead to a wrong estimation of the slip factor. Therefore, it is highly recommended not to use these kinds of load cells for slip factor tests.

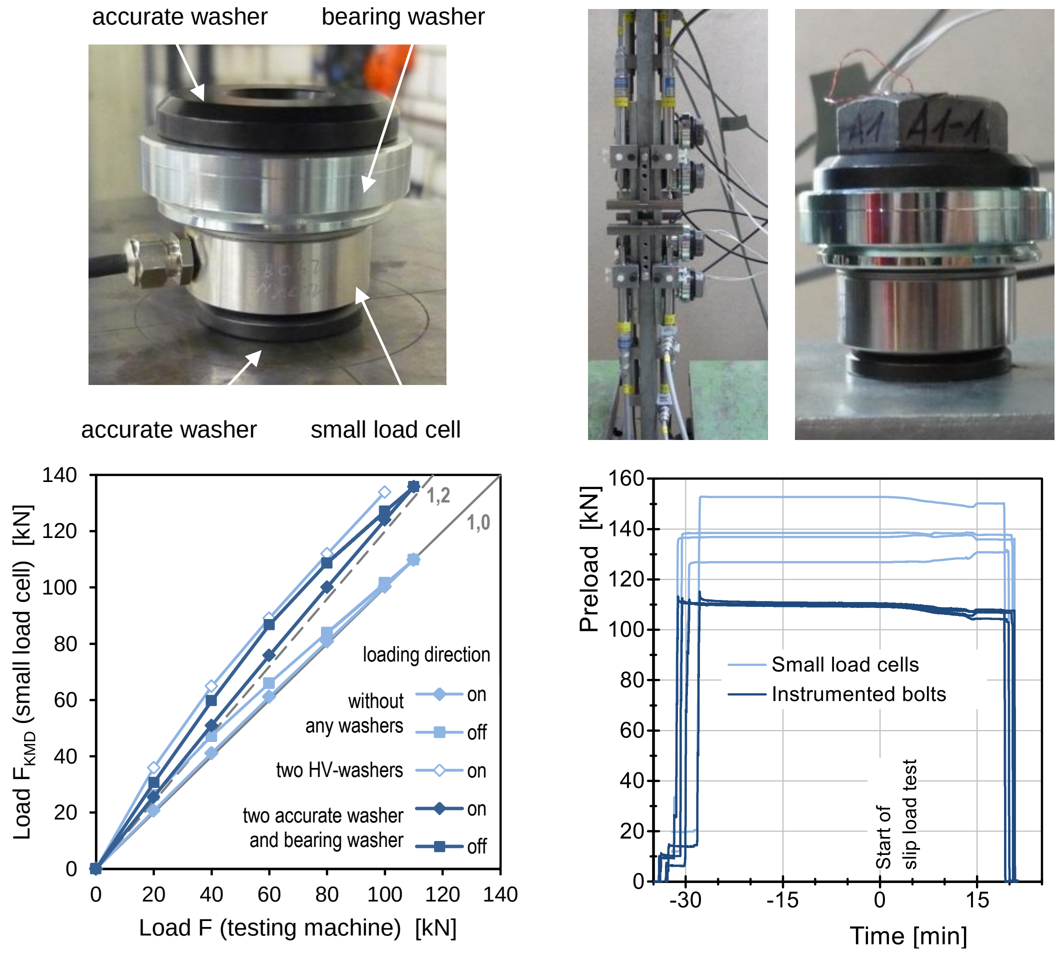



**Figure 19:** Results for the use of customary small load cells

### 3.5.2 Influence of different coating systems for the application in slip-resistant connections

The results of the static and creep tests based on LVDTs 1-8 (CBG position) are summarized in Table 3 for the static tests only and for the combined evaluation of the static and creep tests. Table 3 presents the calculated slip factors as mean values considering the nominal preload in the bolts $\mu_{nom,mean}$, the initial preload when the tests started $\mu_{init,mean}$ and the actual preload at slip $\mu_{actual,mean}$. In the latter one, the loss of preload is already considered. It represents the "real one" from mechanical point of view, but is not the one to be used for design purposes.

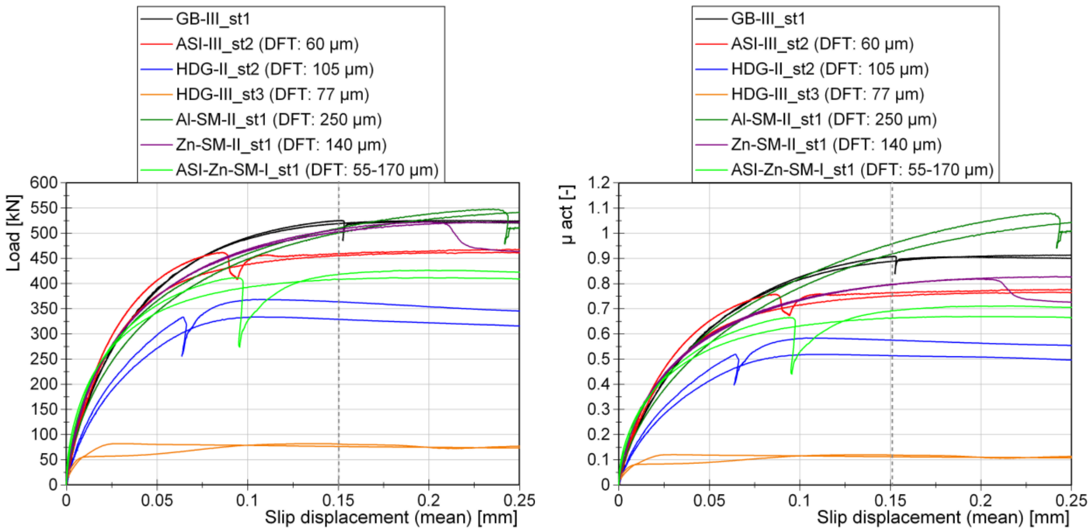
It can be seen from Table 3 that the highest initial and actual slip factors were achieved for GB- and Al-SM-surface conditions respectively. Figure 20a shows typical load-slip displacement curves. For each type of test series one typical test has been chosen, which is presented by two graphs to represent the behaviour of the upper and lower part of the connection. Approximately same slip loads ($F_{Si}$) are achieved for both GB and Al-SM-surfaces. The higher actual slip factor for Al-SM can be explained by significantly higher losses of preload for AL-SM-surfaces during the tests, see Figure 20b.

After the first series of testing on hot-dip galvanized specimens were carried out, the tested HDG-specimens were re-galvanized with a different procedure (HDG-III) compared to the previous galvanizing procedure (HDG-I and II). The specimens were galvanized in lower temperature and the centrifuge was not used in this procedure.

**Table 3**: Mean slip factor results based on LVDTs 1-8 (CBG position)

| Series ID | Surface preparation: Sa[1] / Rz[2] [µm] | Surface preparation: DFT[3] [µm] | Σt[4] [mm] | Number of tests st/ct/ect[5] | $\mu_{ini,mean}$[6] st/st+ct [-] | $\mu_{act,mean}$[7] st/st+ct [-] | V ($\mu_{act}$)[8] st/st+ct [%] |
|---|---|---|---|---|---|---|---|
| Grit blasted surfaces (GB) | | | | | | | |
| GB-I | Sa 2½ / 80 | - | 152 | 4/1/- | 0.80/0.79 | 0.87/0.86 | 1.9/3.0 |
| GB-II | | - | 83 | 2/-/- | 0.74/- | 0.83/- | 2.0/- |
| GB-III | | - | 52 | 2/-/- | 0.74/- | 0.86/- | 5.0/- |
| Alkali-zinc silicate coating (ASI) | | | | | | | |
| ASI-I | Sa 2½ / 80 | 60 | 152 | 4/1/- | 0.73/0.73 | 0.76/0.77 | 0.9/2.2 |
| ASI-II | | | 83 | 2/-/- | 0.72/- | 0.78/- | 3.5/- |
| ASI-III | | | 52 | 2/-/- | 0.70/- | 0.77/- | 2.9/- |
| Hot-dip galvanized surface (HDG) | | | | | | | |
| HDG-I | - | 105 | 152 | 4/1/- | 0.47/0.46 | 0.48/0.47 | 9.2/9.5 |
| HDG-II | - | 105 | 48 | 2/-/- | 0.47/- | 0.51/- | 14.6/- |
| HDG-III | - | 80 | 48 | 4/-/- | 0.12/- | 0.12/- | 6.6/- |
| Aluminium spray metalized coating (Al-SM) | | | | | | | |
| Al-SM-I | - | 250 | 83 | 2/-/- | 0.74/- | 0.89/- | 4.5/- |
| Al-SM-II | | | 52 | 4/1/- | 0.73/0.73 | 0.93/0.92 | 2.7/3.9 |
| Zinc spray metalized coating (Zn-SM) | | | | | | | |
| Zn-SM-I | Sa 3 / 100 | 140 | 83 | 4/-/1 | 0.75/- | 0.82/- | 2.9/- |
| Zn-SM-II | | | 52 | 2/-/- | 0.73/- | 0.82/- | 2.7/- |
| Combination of alkali-zinc silicate and zinc spray metalized coating | | | | | | | |
| ASI – Zn-SM-I | Sa 2½/100 – Sa 3/100 | 55 – 170 | 48 | 4/1/2 | 0.63/0.62 | 0.71/0.70 | 3.9/5.5 |

[1] Sa: surface preparation grade | [2] Rz: roughness | [3] DFT: dry film thickness (Coating thickness) [4] Σt: clamping length | [5] st: static test/ct: creep-/ect: extended creep test | [6] $\mu_{ini,mean}$: calculated slip factors as mean values considering the initial preload when the tests started | [7] $\mu_{act,mean}$: calculated slip factors as mean values considering the actual preload at slip | [8] V: Coefficient of variation for $\mu_{act}$




a) load-slip-displacement-curve b) $\mu_{act}$- slip-displacement-curve

**Figure 20:** Influence of different surface conditions on the slip-load behaviour and actual slip factors

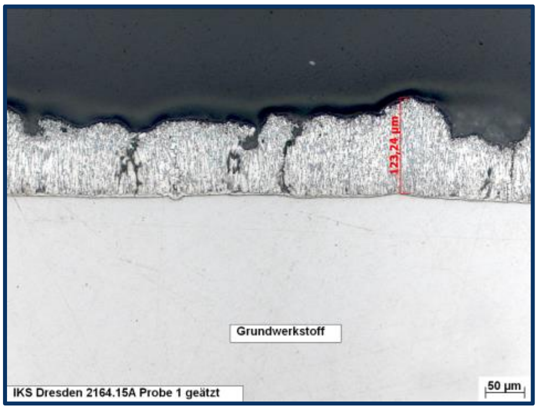
The metallographic tests were performed by Institut für Korrosionsschutz Dresden GmbH in order to investigate the structure of the HDG-coating.

Figure 21 and 22 show the results of metallographic cross section images of the HDG-specimens on reference panels for stressed and unstressed areas. Figure 22 shows the high content of pure zinc (white substance) in the coating material of the regalvanized specimens. The amount of pure zinc in the coating might have influence on the slip resistant behaviour of the connection.

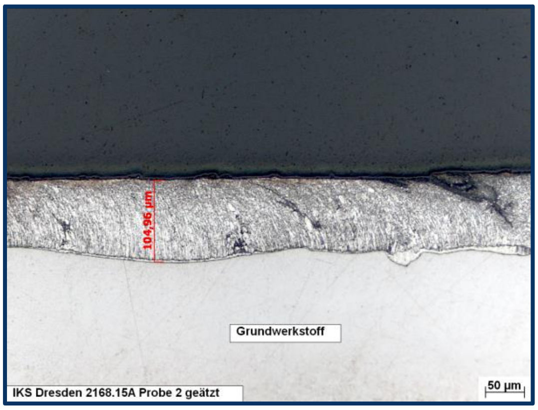
The coating thickness and the surface roughness after both procedures were measured and the results show lower coating thicknesses and surface roughnesses for the new specimens (DFT: 80 µm, Rz: 20 µm instead of DFT: 105 µm, Rz: 55 µm).

Four additional static slip tests (HDG-III) were performed in order to investigate the influence of the different galvanizing procedures. The results show that in the HDG-III series, the slip factor is significantly lower than the slip factor achieved in the HDG-II test series with the same clamping length, see Table 3 and Figure 20.

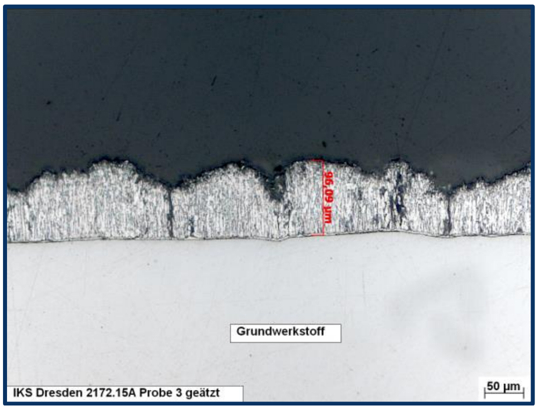
For design purposes, preload losses have to be considered implicitly in the slip factor itself – or in the design formula for the determination of the slip resistance – one of both. Practical recommendations and specifications regarding this topic must be ensured in codes and/or test guidelines.




a) unstressed area (Inner Plate)



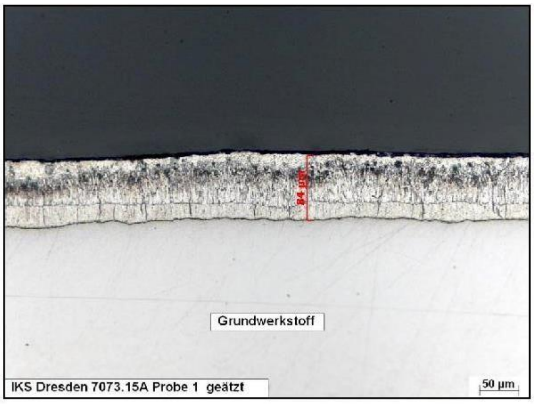

b) stressed area (Inner Plate)



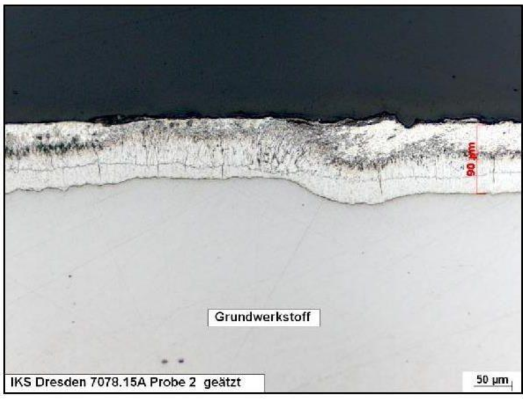

c) unstressed area (Cover Plate)


d) stressed area (Cover Plate)

**Figure 21:** Metallographic cross section images of HDG-I and HDG-II test specimens (Coating thickness (DFT): 105 µm)

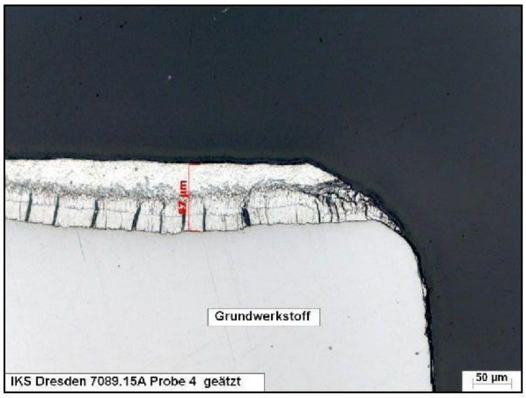



a) unstressed area (Inner Plate)




b) stressed area (Inner Plate)


c) unstressed area (Cover Plate)




d) stressed area (Cover Plate)

**Figure 22:** Metallographic cross section images of HDG-III test specimens (Coating thickness (DFT): 80 µm)

Regarding the creep tests it can be stated that they clearly failed for all coated surfaces and extended creep tests are necessary, see exemplary Figure 23. The creep test for grit blasted surfaces (GB-I) was passed, see Figure 23, and the characteristic value of the nominal and actual slip factor can be evaluated as 0.75 and 0.81 respectively (5 % fractile value with a confidence level of 75 %).

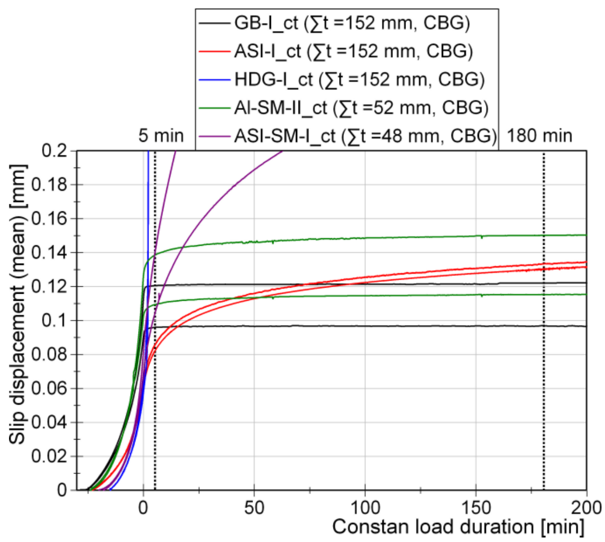



**Figure 23**: Time-displacement diagram of creep tests

### 3.5.3 Influence of the positioning of the displacement transducers on the slip measurement

Twelve displacement transducers were used in order to investigate the influence of the positioning of displacement transducers on the slip measurement. The results of the static and creep tests based on LVDTs 9-12 are summarized in Table 4.

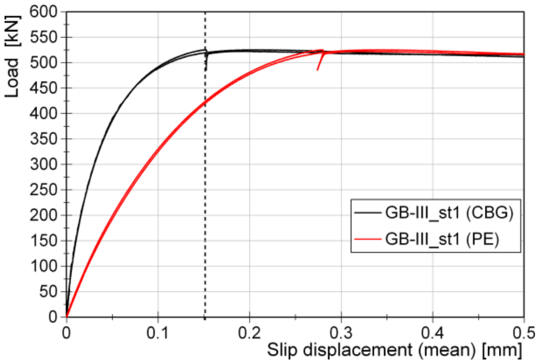
From Figure 24, it can be seen, that the stiffness of the slip-deformation behaviour is much higher when measured with LVDTs 1-8 (CBG position) than using the LVDTs 9-12 (PE position). Furthermore, large differences in the slip load result when the 0.15 mm slip criterion is used. Based on LVDTs 9-12, the maximum slip loads are reached far above 0.15 mm for GB-III, ASI-III, HDG-II, Al-SM-II, Zn-SM-II and ASI-Zn-SM-I. This is caused by the fact that using LVDTs 9-12, the elongation of the plates is implicitly measured as well. The influence of elongation can be more visible when the level of slip load is higher. On the other hand this phenomenon can be neglected when the slip happens in the lower load level, see Figure 24g and h.

Consequently, considering the 0.15 mm slip criterion and using a positioning of the LVDTs according to LVDTs 9-12 might lead to much lower slip factors than using the positioning at LVDT 1-8. This has to be kept in mind when comparing results from literature. For example, Cruz et al [4] performed slip factor tests with positions of displacement transducers comparable to those of LVDTs 9-12. The results of [4] fit quite well with the lower slip factors achieved with LVDTs 9-12, see Table 4.

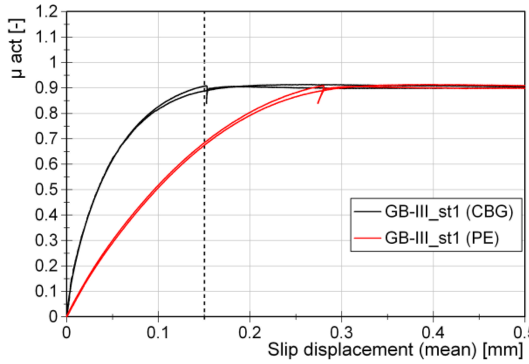
**Table 4**: Mean slip factor results based on LVDTs 9-12 (PE position)

| Series ID | Surface preparation: Sa[1] / Rz[2] [µm] | Surface preparation: DFT[3] [µm] | $\Sigma t$[4] [mm] | Number of tests st/ct/ect[5] | $\mu_{ini,mean}$[6] st/st+ct [-] | $\mu_{act,mean}$[7] st/st+ct [-] | V ($\mu_{act}$)[8] st/st+ct [%] |
|---|---|---|---|---|---|---|---|
| Grit blasted surfaces (GB) | | | | | | | |
| GB-I | | - | 152 | 4/1/- | 0.61/0.61 | 0.64/0.64 | 2.1/2.0 |
| GB-II | Sa 2½ / 80 | - | 83 | 2/-/- | 0.60/- | 0.64/- | 1.2/- |
| GB-III | | - | 52 | 2/-/- | 0.61/- | 0.67/- | 2.0/- |
| Cruz [7] | Sa 2½ / - | - | 48 | 4/1/- | -/0.56[9] | -/- | -/- |
| Alkali-zinc silicate coating (ASI) | | | | | | | |
| ASI-I | | | 152 | 4/1/- | 0.63/0.63 | 0.65/0.65 | 1.3/1.2 |
| ASI-II | Sa 2½ / 80 | 60 | 83 | 2/-/- | 0.62/- | 0.66/- | 2.6/- |
| ASI-III | | | 52 | 2/-/- | 0.61/- | 0.66/- | 1.7/- |
| Hot-dip galvanized surface (HDG) | | | | | | | |
| HDG-I | - | 105 | 152 | 4/1/- | 0.46/0.45 | 0.47/0.47 | 8.9/8.7 |
| HDG-II | - | 105 | 48 | 2/-/- | 0.47/- | 0.50/- | 14.1/- |
| HDG-III | - | 80 | 48 | 4/-/- | 0.12/- | 0.12/- | 6.6/- |
| Aluminium spray metalized coating (Al-SM) | | | | | | | |
| Al-SM-I | - | 250 | 83 | 2/-/- | 0.56/- | 0.62/- | 2.2/- |
| Al-SM-II | | | 52 | 4/1/- | 0.56/0.56 | 0.64/0.64 | 2.0/2.4 |
| Zinc spray metalized coating (Zn-SM) | | | | | | | |
| Zn-SM-I | Sa 3 / 100 | 140 | 83 | 4/-/1 | 0.58/- | 0.62/- | 4.8/- |
| Zn-SM-II | | | 52 | 2/-/- | 0.58/- | 0.62/- | 6.2/- |
| Combination of alkali-zinc silicate and zinc spray metalized coating | | | | | | | |
| ASI – Zn-SM-I | Sa 2½/100 – Sa 3/100 | 55 – 170 | 48 | 4/1/2 | 0.59/0.58 | 0.65/0.64 | 2.9/3.2 |

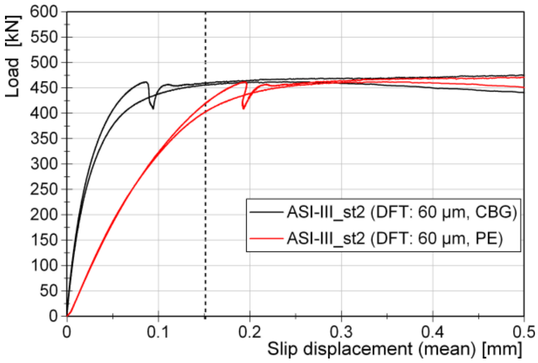
[1] Sa: surface preparation grade | [2] Rz: roughness | [3] DFT: dry film thickness (Coating thickness)
[4] $\Sigma t$: clamping length | [5] st: static test/ct: creep-/ect: extended creep test | [6] $\mu_{ini,mean}$: calculated slip factors as mean values considering the initial preload when the tests started | [7] $\mu_{act,mean}$: calculated slip factors as mean values considering the actual preload at slip | [8] V: Coefficient of variation for $\mu_{act}$
[9] reported as a nominal slip factor



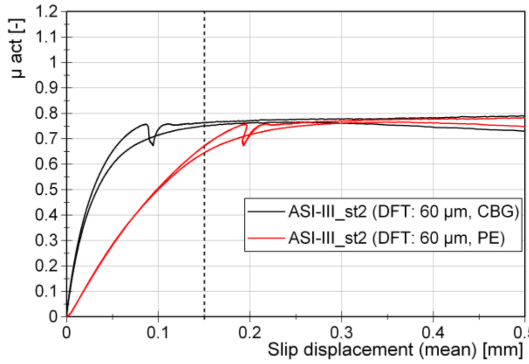

a) load-slip-displacement-curve:
GB-III_CBG vs. GB-III_PE



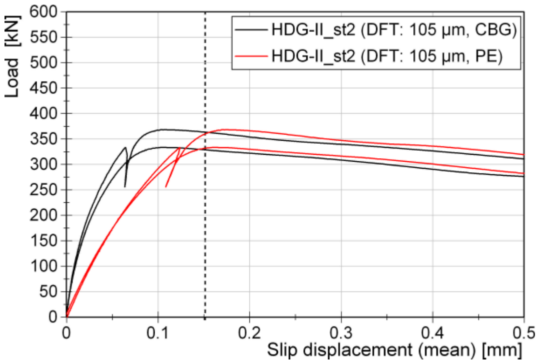

b) $\mu_{act}$- slip-displacement-curve
GB-III_CBG vs. GB-III_PE



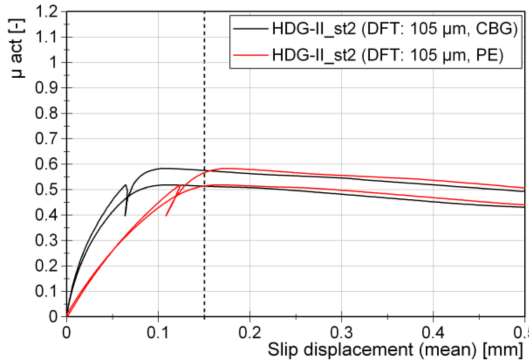

c) load-slip-displacement-curve:
ASI-III_CBG vs. ASI-III_PE



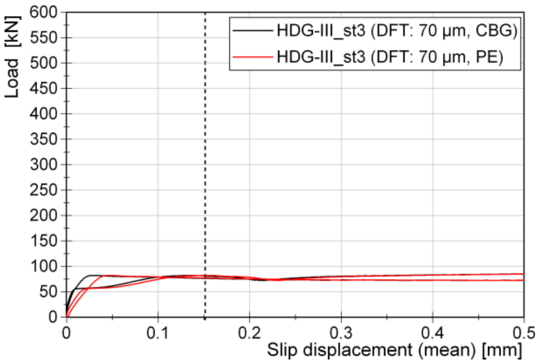

d) $\mu_{act}$- slip-displacement-curve
ASI-III_CBG vs. ASI-III_PE



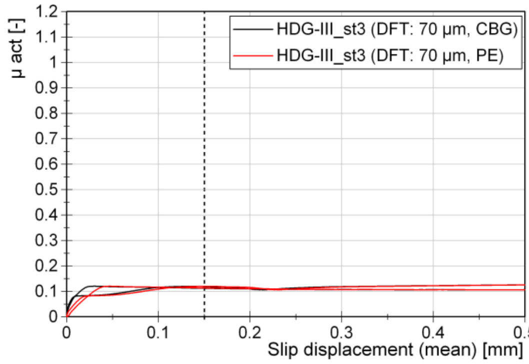

e) load-slip-displacement-curve:
HDG-II_CBG vs. HDG-II_PE




f) $\mu_{act}$- slip-displacement-curve
HDG-II_CBG vs. HDG-II_PE

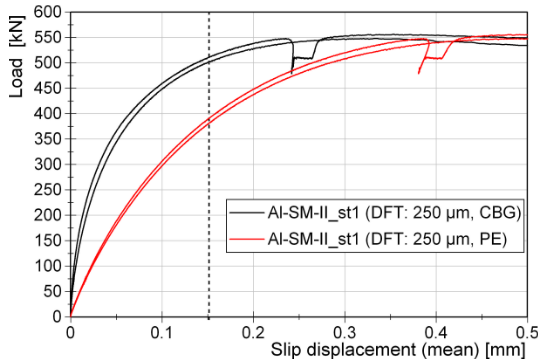



g) load-slip-displacement-curve:
HDG-III_CBG vs. HDG-III_PE

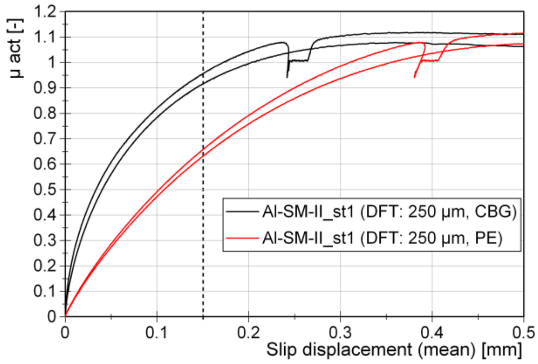



h) $\mu_{act}$- slip-displacement-curve
HDG-III_CBG vs. HDG-III_PE

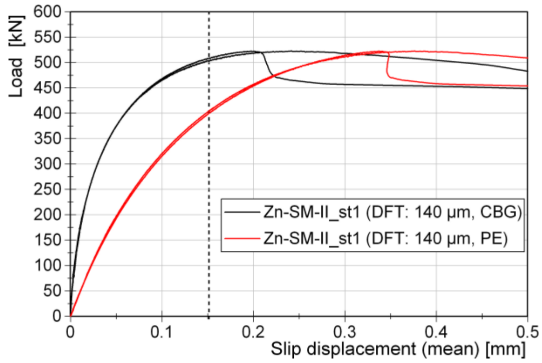
**Figure 24:** Influence of positioning the LVDTs: CBG vs. PE position



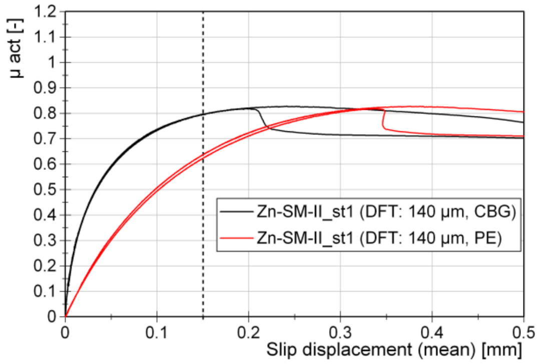

i) load-slip-displacement-curve:
Al-SM-II_CBG vs. Al-SM-II_PE



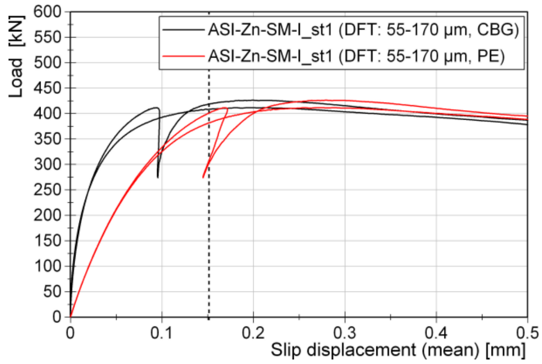

j) $\mu_{act}$- slip-displacement-curve
Al-SM-II_CBG vs. Al-SM-II_PE



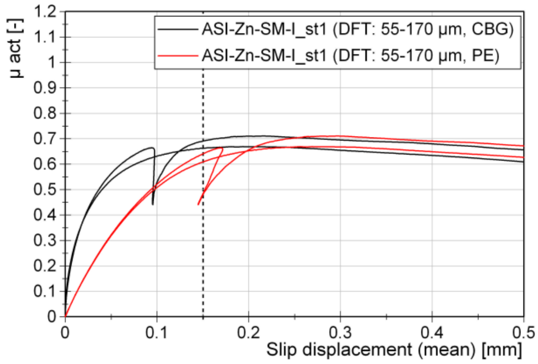

k) load-slip-displacement-curve:
Zn-SM-II_CBG vs. Zn-SM-II_PE




l) $\mu_{act}$- slip-displacement-curve
Zn-SM-II_CBG vs. Zn-SM-II_PE




m) load-slip-displacement-curve:
ASI-Zn-SM-I_CBG vs. ASI-Zn-SM-I_PE




n) $\mu_{act}$- slip-displacement-curve
ASI-Zn-SM-I_CBG vs. ASI-Zn-SM-I_PE

**Figure 24 (contin.):** Influence of positioning the LVDTs: CBG vs. PE position

Comparing the actual slip factors $\mu_{actual}$ from Table 4 with those given in Table 3 for LVDTs 1-8 it becomes obvious that in case of using the slip deformation measured with LVDTs 1-8, in most of the cases significantly higher slip factors are found. This cannot be neglected when cost effective slip-resistant connections shall be designed.

### 3.5.4 Influence of the clamping length on the slip resistance behaviour of the connection

Different test setups were chosen for a comparative study to investigate the effect of the clamping length on the slip resistance behaviour of the connection, see Table 2, Figures 5 and 6.

Using LCs leads to a relatively large clamping length of the bolts which influences the loss of preload and consequently the level of the slip load. Evaluating the slip factor considering the nominal preload in the bolts without taking into account the large clamping length might lead to an overestimation of the slip factor because the preload losses decrease and the slip load increases with increasing clamping length. The influence of the clamping length can be seen from Figure 25. If the slip factors are evaluated with the actual preload, the resulting slip factors of each surface condition do not vary significantly and are nearly on the same level for all three different clamping lengths.

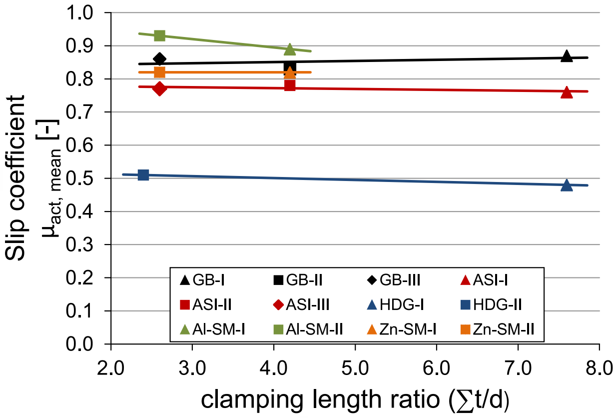



**Figure 25:** Influence of the clamping length ratio on the actual slip coefficient $\mu_{act,mean}$ (under consideration of the preloads at slip)

## 4 Conclusions

Slip resistant connections are required when the slip has to be prevented either for serviceability or ultimate limit state reasons. This study aims at investigating different kinds of methods for measuring the preload in the bolts.

The observations made from this study show that the deviations between the measurement methods SG and LC are negligible small with a maximum deviation of 1.3%. Furthermore, the mean values of the losses of preload were detected to approximately 9% for GB-I, 7% for ASI-I and 3% for HDG.

Comparative static slip factor and creep tests according to EN 1090-2 have been performed for six different surface condition and the highest initial and actual slip factors were achieved for GB- and Al-SM-surface conditions respectively.

The results also show that considering the 0.15 mm slip criterion and using a positioning of the LVDTs according to LVDTs 9-12 (PE position) might lead to much lower slip factors than using the positioning at LVDT 1-8 (CBG position).

The influence of the clamping length was investigated. It became obvious that if the slip factors are evaluated with the actual preload, the resulting slip factors of each surface condition do not vary significantly and are nearly on the same level for all three different clamping lengths. On the other side, evaluating the slip factor considering the nominal preload in the bolts without taking into account the larger clamping length resulting from length of the LC might lead to an overestimation of the slip factor because the preload losses decrease and the slip load increases with increasing clamping length.

Based on the results of task 1.1, it was decided to use instrumented bolts with implanted strain gauges without small adapters for the research project.

Essen, 24.03.2016

Univ.-Prof. Dr.-Ing. habil. Natalie Stranghöner

Nariman Afzali M.Sc.

Jörn Berg M.Sc.

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# Appendix A: Slip factor test results (static and creep tests) - based on LVDTs 1-8 (CBG position)

**Table A1** Test protocol GB-I test series based on LVDTs 1-8 (CBG position)

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**Test report** 24/11/2014

| Technical characteristics of the test | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 17.12.2014 & 18.12.2014 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| Coating | – |
| Coating composition | – |
| Surface treatment | **Grid blasted** Sa 2 1/2, Hartguss, edged |
| Maximum coating thickness | – |
| Mean coating thickness | – |
| Minimum coating thickness | – |
| Surface roughness (before coating) | about 80 µm |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 180 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 152 mm |
| Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172; $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_01_213-214 | 213 | 0.150 | 558.9 | 172.0 | 171.9 | 171.7 | 0.81 | 0.81 | 0.88 | 159.8 | 159.0 | 158.3 | 15.6 | | 17.12.14 12:25 |
| | | 214 | 0.150 | 555.8 | 171.5 | 171.6 | 171.8 | 0.81 | 0.81 | 0.87 | 159.9 | 158.9 | 158.0 | 15.4 | | |
| | 1.1_UDE_01_215-216 | 215 | 0.150 | 560.6 | 171.8 | 171.7 | 171.5 | 0.82 | 0.81 | 0.89 | 159.0 | 158.3 | 157.5 | 34.8 | | 17.12.14 17:05 |
| | | 216 | 0.150 | 534.9 | 171.5 | 171.6 | 171.7 | 0.78 | 0.78 | 0.84 | 159.7 | 159.2 | 158.6 | 14.7 | | |
| | 1.1_UDE_01_217-218 | 217 | 0.150 | 552.1 | 172.0 | 171.9 | 171.8 | 0.80 | 0.80 | 0.87 | 160.0 | 158.9 | 157.8 | 15.7 | | 17.12.14 19:40 |
| | | 218 | 0.150 | 553.2 | 171.8 | 171.8 | 171.9 | 0.80 | 0.80 | 0.88 | 157.2 | 157.7 | 158.1 | 15.8 | | |
| | 1.1_UDE_01_219-220 | 219 | 0.150 | 537.8 | 172.0 | 171.9 | 171.8 | 0.78 | 0.78 | 0.85 | 159.0 | 158.7 | 158.4 | 13.7 | | 18.12.14 10:00 |
| | | 220 | 0.147 | 554.8 | 171.6 | 171.8 | 172.0 | 0.81 | 0.81 | 0.88 | 157.3 | 157.8 | 158.3 | 15.1 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 560.6 | | | | 0.82 | 0.81 | 0.89 | | | | | | |
| | | *min* | Minimum | 534.9 | | | | 0.78 | 0.78 | 0.84 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **551.0** | | | | **0.80** | **0.80** | **0.87** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 25.7 | | | | 0.04 | 0.04 | 0.05 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 9.5 | | | | 0.014 | 0.014 | 0.016 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 1.7% | | | | 1.7% | 1.7% | 1.9% | | | | | *V* = *s* / *mean* | |
| | | **0.9 $F_{Sm}$** | | **495.9** | | | | | | | | | | | Load level for the creep test | |
| Creep test | 1.1_UDE_01_221-222 | 221 | Δ (5 min to 3 h): **0.001** | 493.6 | | | | | | | | | | | **Creep test is passed** Slip during the creep test < 0,002 mm (5 min to 3 h) | 18.12.14 13:15 |
| | | | 0.150 | 510.5 | 172.2 | 172.0 | 171.9 | 0.74 | 0.74 | 0.80 | 159.9 | 159.3 | 158.6 | 244.8 | | |
| | | 222 | Δ (5 min to 3 h): **0.001** | 493.6 | | | | | | | | | | | | |
| | | | 0.150 | 540.1 | 171.5 | 171.7 | 172.0 | 0.79 | 0.79 | 0.85 | 157.4 | 158.2 | 159.0 | 269.0 | | |
| | Statistics (5 specimens, 10 test results) | $n$ = 10 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 560.6 | | | | 0.82 | 0.81 | 0.89 | | | | | | |
| | | *min* | Minimum | 510.5 | | | | 0.74 | 0.74 | 0.80 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | 545.9 | | | | 0.79 | 0.79 | 0.86 | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 50.1 | | | | 0.07 | 0.07 | 0.08 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 15.4 | | | | 0.023 | 0.022 | 0.026 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | **2.8%** | | | | **2.9%** | **2.8%** | **3.0%** | | | | | *V* = *s* / *mean* ≤ 8% | |
| | | 0.9 $F_{Sm}$ | | 491.3 | | | | | | | | | | | | |
| | $\mu_k$ | | Characteristic value of the slip factor | | | | | 0.75 | 0.75 | 0.81 | | | | | Eq. (6) | |

**Table A2** Test protocol GB-II test series based on LVDTs 1-8 (CBG position)

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## Test report

03.03.2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 02/03/2015 & 03/03/2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | – |
| | Coating composition | – |
| | Surface treatment | **Grid blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | – |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload): Outer bolt | Mean value | Inner bolt | Slip factor: based on initial preload | based on nominal preload | based on preload at slip | Preload at slip: Outer bolt | Mean value | Inner bolt | Test duration | Comment | Date of test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $F_{p,C}$ [kN] 172 | | | | | | Eq. according to DIN EN 1090-2 | Start of the test |
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| Static test | 1.1_UDE_01_14-15 | 14 | 0.150 | 503.8 | 170.5 | 170.7 | 170.9 | 0.74 | 0.73 | 0.82 | 154.4 | 152.9 | 151.4 | 11.8 | | 02.03.15 17:40 |
| | | 15 | 0.140 | 519.8 | 171.2 | 171.0 | 170.8 | 0.76 | 0.76 | 0.85 | 154.3 | 153.0 | 151.8 | 13.0 | | |
| | 1.1_UDE_01_16-17 | 16 | 0.150 | 499.8 | 171.9 | 171.8 | 171.7 | 0.73 | 0.73 | 0.81 | 155.7 | 154.3 | 152.9 | 13.1 | | 03.03.15 13:05 |
| | | 17 | 0.111 | 513.8 | 172.0 | 171.9 | 171.8 | 0.75 | 0.75 | 0.82 | 157.4 | 156.1 | 154.8 | 13.5 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 519.8 | | | | 0.76 | 0.76 | 0.85 | | | | | | |
| | | *min* | Minimum | 499.8 | | | | 0.73 | 0.73 | 0.81 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **509.3** | | | | **0.74** | **0.74** | **0.83** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 20.0 | | | | 0.03 | 0.03 | 0.04 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{FS}$ | 9.1 | | | | 0.014 | 0.013 | 0.016 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 1.8% | | | | 1.9% | 1.8% | 2.0% | | | | | *V* = *s* / *mean* | |
| | | **0.9 $F_{Sm}$** | | **458.4** | | | | | | | | | | | Load level for the creep test | |

**Table A3** Test protocol GB-III test series based on LVDTs 1-8 (CBG position)

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## Test report

27.01.2015

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 26/01/2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | – |
| | Coating composition | – |
| | Surface treatment | **Grid blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | – |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| | Test speed | 0.6 mm/min |

| Static test | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value: mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | Slip factor based on nominal preload $F_{p,C}$ [kN] 172: $\mu_i = \mu_{i,nom}$ [–] | Slip factor based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value: mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.1_UDE_01_18-19 | 18 | 0.150 | 518.9 | 170.2 | 170.8 | 171.5 | 0.76 | 0.75 | 0.89 | 147.2 | 146.2 | 145.1 | 13.4 | | 26.01.15 14:30 |
| | | 19 | 0.150 | 525.3 | 170.9 | 171.0 | 171.0 | 0.77 | 0.76 | 0.91 | 146.4 | 144.7 | 143.1 | 14.0 | | |
| | 1.1_UDE_01_209-210 | 209 | 0.150 | 484.5 | 170.5 | 171.2 | 172.0 | 0.71 | 0.70 | 0.81 | 152.2 | 149.6 | 147.0 | 12.6 | | 26.01.15 17:25 |
| | | 210 | 0.150 | 500.9 | 170.7 | 171.2 | 171.7 | 0.73 | 0.73 | 0.85 | 149.3 | 147.3 | 145.3 | 29.5 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 525.3 | | | | 0.77 | 0.76 | 0.91 | | | | | | |
| | | *min* | Minimum | 484.5 | | | | 0.71 | 0.70 | 0.81 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **507.4** | | | | **0.74** | **0.74** | **0.86** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 40.8 | | | | 0.06 | 0.06 | 0.10 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 18.4 | | | | 0.028 | 0.027 | 0.043 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 3.6% | | | | 3.7% | 3.6% | 5.0% | | | | | *V* = *s* / *mean* | |
| | | 0.9 $F_{Sm}$ | | **456.7** | | | | | | | | | | | Load level for the creep test | |
| | $\mu_k$ | Characteristic value of the slip factor | | | | | | 0.68 | 0.68 | 0.78 | | | | | Eq. (6) | |

**Table A4** Test protocol ASI-I test series based on LVDTs 1-8 (CBG position)

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## Test report

24/11/2014

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 03.12.2014 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | **Alkali-zinc silicate coating (ASI), Type 2K-Interzinc 697** |
| | Coating composition | – |
| | Surface treatment | **Blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | 60 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 180 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 152 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment Eq. according to DIN EN 1090-2 | Date of test Start of the test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_02_153-154 | 153 | 0.121 | 498.9 | 171.0 | 170.9 | 170.8 | 0.73 | 0.73 | 0.77 | 163.9 | 162.3 | 160.7 | 17.9 | | 03.12.14 10:20 |
| | | 154 | 0.146 | 494.8 | 170.9 | 170.9 | 170.9 | 0.72 | 0.72 | 0.76 | 164.0 | 162.6 | 161.2 | 17.6 | | |
| | 1.1_UDE_02_155-156 | 155 | 0.150 | 493.5 | 170.9 | 170.7 | 170.5 | 0.72 | 0.72 | 0.76 | 164.2 | 162.0 | 159.8 | 18.4 | | 03.12.14 12:25 |
| | | 156 | 0.132 | 498.0 | 170.8 | 170.9 | 170.9 | 0.73 | 0.72 | 0.77 | 163.9 | 162.5 | 161.2 | 18.6 | | |
| | 1.1_UDE_02_159-160 | 159 | 0.150 | 497.0 | 171.2 | 170.9 | 170.5 | 0.73 | 0.72 | 0.76 | 164.5 | 162.6 | 160.7 | 18.5 | | 03.12.14 18:00 |
| | | 160 | 0.149 | 503.9 | 170.9 | 170.8 | 170.6 | 0.74 | 0.73 | 0.78 | 163.2 | 161.9 | 160.5 | 18.9 | | |
| | 1.1_UDE_02_161-162 | 161 | 0.130 | 496.3 | 171.4 | 171.2 | 171.0 | 0.72 | 0.72 | 0.76 | 164.8 | 163.2 | 161.5 | 17.5 | | 03.12.14 20:00 |
| | | 162 | 0.150 | 490.7 | 170.5 | 170.7 | 170.9 | 0.72 | 0.71 | 0.76 | 163.6 | 162.4 | 161.1 | 17.7 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 503.9 | | | | 0.74 | 0.73 | 0.78 | | | | | | |
| | | *min* | Minimum | 490.7 | | | | 0.72 | 0.71 | 0.76 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **496.7** | | | | **0.73** | **0.72** | **0.76** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 13.3 | | | | 0.02 | 0.02 | 0.02 | | | | | *R = max – min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 3.9 | | | | 0.006 | 0.006 | 0.007 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 0.8% | | | | 0.8% | 0.8% | 0.9% | | | | | *V = s / mean* | |
| | | **0.9 $F_{Sm}$** | | **447.0** | | | | | | | | | | | Load level for the creep test | |
| Creep test | 1.1_UDE_02_163-164 | 163 | Δ (5 min to 3 h): **0.07** | – | 171.3 | 171.2 | 171.1 | – | – | – | 161.5 | 160.3 | 159.1 | 585.6 | **Creep test failed** Slip during the creep test > 0.002 mm (5 min to 3 h) | 03.12.14 22:20 |
| | | 164 | Δ (5 min to 3 h): **0.07** | – | 170.3 | 170.3 | 170.3 | – | – | – | 159.9 | 158.6 | 157.4 | 586.5 | | |

**Table A5** Test protocol ASI-II test series based on LVDTs 1-8 (CBG position)

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## Test report

23.01.2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 22.01.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | **Alkali-zinc silicate coating (ASI), Type 2K-Interzinc 697** |
| | Coating composition | – |
| | Surface treatment | **Blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | 60 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload): Outer bolt | Mean value | Inner bolt | Slip factor: based on initial preload | based on nominal preload ($F_{p,C}$ [kN] 172) | based on preload at slip | Preload at slip: Outer bolt | Mean value | Inner bolt | Test duration | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| Static test | 1.1_UDE_02_165-166 | 165 | 0.150 | 505.3 | 170.3 | 170.6 | 170.9 | 0.74 | 0.73 | 0.80 | 158.8 | 157.6 | 156.4 | 18.0 | | 24.03.15 13:55 |
| | | 166 | 0.150 | 506.3 | 170.4 | 170.7 | 171.1 | 0.74 | 0.74 | 0.80 | 158.4 | 157.2 | 156.1 | 18.1 | | |
| | 1.1_UDE_02_239-240 | 239 | 0.150 | 478.7 | 172.0 | 172.0 | 171.9 | 0.70 | 0.70 | 0.75 | 160.9 | 158.9 | 156.9 | 17.5 | | 24.03.15 17:45 |
| | | 240 | 0.149 | 481.8 | 171.3 | 171.6 | 171.9 | 0.70 | 0.70 | 0.76 | 159.9 | 158.6 | 157.3 | 17.7 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 506.3 | | | | 0.74 | 0.74 | 0.80 | | | | | | |
| | | *min* | Minimum | 478.7 | | | | 0.70 | 0.70 | 0.75 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **493.0** | | | | **0.72** | **0.72** | **0.78** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 27.6 | | | | 0.05 | 0.04 | 0.05 | | | | | *R = max – min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 14.8 | | | | 0.024 | 0.022 | 0.027 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 3.0% | | | | 3.4% | 3.0% | 3.5% | | | | | *V = s / mean* | |
| | | **0.9 $F_{Sm}$** | | **443.7** | | | | | | | | | | | Load level for the creep test | |

**Table A6** Test protocol ASI-III test series based on LVDTs 1-8 (CBG position)

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## Test report

23.01.2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 22.01.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | **Alkali-zinc silicate coating (ASI), Type 2K-Interzinc 697** |
| | Coating composition | – |
| | Surface treatment | **Blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | 60 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| | Test speed | 0.6 mm/min |

| | Specimens | | Slip | Slip load | Preload at start of test (initial preload) | | | Slip factor | | | Preload at slip | | | Test duration | Comment | Date of test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mark | plate ID's | (average at CBG) | | Outer bolt | Mean value | Inner bolt | based on initial preload | based on nominal preload | based on preload at slip | Outer bolt | Mean value | Inner bolt | | Eq. according to DIN EN 1090-2 | Start of the test |
| | | | | | | | | | $F_{p,C}$ [kN] 172 | | | | | | | |
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| Static test | 1.1_UDE_02_241-242 | 241 | 0.150 | 478.6 | 167.6 | 168.0 | 168.4 | 0.71 | 0.70 | 0.79 | 154.1 | 151.2 | 148.4 | 17.9 | | 22.01.15 15:20 |
| | | 242 | 0.150 | 479.9 | 167.9 | 168.1 | 168.3 | 0.71 | 0.70 | 0.79 | 153.3 | 151.3 | 149.2 | 17.9 | | |
| | 1.1_UDE_02_243-244 | 243 | 0.150 | 455.7 | 167.9 | 167.7 | 167.5 | 0.68 | 0.66 | 0.75 | 153.8 | 151.8 | 149.8 | 16.8 | | 22.01.15 19:15 |
| | | 244 | 0.086 | 461.9 | 166.4 | 167.2 | 167.9 | 0.69 | 0.67 | 0.76 | 153.0 | 152.5 | 152.0 | 17.2 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 479.9 | | | | 0.71 | 0.70 | 0.79 | | | | | | |
| | | *min* | Minimum | 455.7 | | | | 0.68 | 0.66 | 0.75 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **469.0** | | | | **0.70** | **0.68** | **0.77** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 24.3 | | | | 0.03 | 0.04 | 0.04 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 12.1 | | | | 0.017 | 0.018 | 0.022 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 2.6% | | | | 2.4% | 2.6% | 2.9% | | | | | *V* = *s* / *mean* | |
| | | 0.9 $F_{Sm}$ | | 422.1 | | | | | | | | | | | Load level for the creep test | |

**Table A7** Test protocol HDG-I test series based on LVDTs 1-8 (CBG position)

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## Test report

27/11/2014

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 04.12.2014 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Hot-Dip Galvanized** |
| | Coating composition | – |
| | Surface treatment | chemical cleaning |
| | Maximum coating thickness | – |
| | Mean coating thickness | 104 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | – |
| | Surface roughness (after coating) | 55 µm |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 180 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 152 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_03_407-408 | 407 | 0.103 | 334.1 | 172.0 | 171.8 | 171.7 | 0.49 | 0.49 | 0.50 | 168.7 | 167.8 | 166.9 | 14.7 | | 04.12.14 11:00 |
| | | 408 | 0.105 | 334.1 | 171.3 | 171.4 | 171.4 | 0.49 | 0.49 | 0.50 | 167.0 | 166.4 | 165.8 | 14.7 | | |
| | 1.1_UDE_03_409-410 | 409 | 0.107 | 290.9 | 171.7 | 171.4 | 171.2 | 0.42 | 0.42 | 0.44 | 167.7 | 166.8 | 165.9 | 13.5 | | 04.12.14 12:55 |
| | | 410 | 0.150 | 278.2 | 171.7 | 171.8 | 171.8 | 0.40 | 0.40 | 0.41 | 168.4 | 168.1 | 167.8 | 12.8 | | |
| | 1.1_UDE_03_417-418 | 417 | 0.125 | 355.8 | 172.1 | 171.9 | 171.7 | 0.52 | 0.52 | 0.53 | 167.6 | 166.7 | 165.8 | 14.6 | | 04.12.14 15:30 |
| | | 418 | 0.105 | 355.8 | 171.5 | 171.5 | 171.6 | 0.52 | 0.52 | 0.53 | 167.2 | 166.5 | 165.8 | 14.6 | | |
| | 1.1_UDE_03_421-422 | 421 | 0.124 | 335.3 | 171.7 | 171.7 | 171.7 | 0.49 | 0.49 | 0.50 | 167.4 | 166.8 | 166.2 | 18.5 | | 04.12.14 17:35 |
| | | 422 | 0.150 | 304.5 | 171.8 | 171.9 | 172.0 | 0.44 | 0.44 | 0.45 | 168.2 | 168.0 | 167.7 | 12.8 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 355.8 | | | | 0.52 | 0.52 | 0.53 | | | | | | |
| | | *min* | Minimum | 278.2 | | | | 0.40 | 0.40 | 0.41 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **323.6** | | | | **0.47** | **0.47** | **0.48** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 77.6 | | | | 0.11 | 0.11 | 0.12 | | | | | *R = max – min* | |
| | | *s* | Standard deviation $s_{FS}$ | 29.1 | | | | 0.042 | 0.042 | 0.045 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 9.0% | | | | 9.0% | 9.0% | 9.2% | | | | | *V = s / mean* | |
| | | 0.9 $F_{Sm}$ | | **291.2** | | | | | | | | | | | Load level for the creep test | |
| Creep test | 1.1_UDE_03_423-424 | 423 | Δ (5 min to 3 h): - | – | 172.1 | 171.9 | 171.8 | – | – | – | 168.8 | 168.3 | 167.7 | 15.0 | **Creep test failed** Slip during the creep test > 0.002 mm (5 min to 3 h) | 04.12.14 19:30 |
| | | 424 | Δ (5 min to 3 h): - | – | 171.7 | 171.7 | 171.7 | – | – | – | 168.2 | 167.8 | 167.4 | 15.0 | | |

**Table A8** Test protocol HDG-II test series based on LVDTs 1-8 (CBG position)

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## Test report

24.07.2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 23.07.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | **Hot-Dip Galvanized** |
| | Coating composition | – |
| | Surface treatment | chemical cleaning |
| | Maximum coating thickness | – |
| | Mean coating thickness | about 100 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | – |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 48 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload): Outer bolt | Mean value | Inner bolt | Slip factor: based on initial preload | based on nominal preload $F_{p,C}$ [kN] 172 | based on preload at slip | Preload at slip: Outer bolt | Mean value | Inner bolt | Test duration | Comment: Eq. according to DIN EN 1090-2 | Date of test: Start of the test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| Static test | **1.1_UDE_03_413-414** | 413 | 0.128 | 338.3 | 172.9 | 172.1 | 171.3 | 0.49 | 0.49 | 0.52 | 160.8 | 161.3 | 161.8 | 20.2 | | 23.07.15 11:00 |
| | | 414 | 0.150 | 263.9 | 172.0 | 171.6 | 171.2 | 0.38 | 0.38 | 0.41 | 164.6 | 162.7 | 160.8 | 11.4 | | |
| | **1.1_UDE_03_415-416** | 415 | 0.104 | 368.3 | 172.4 | 172.1 | 171.7 | 0.54 | 0.54 | 0.58 | 157.6 | 157.8 | 158.0 | 22.0 | | 23.07.15 12:51 |
| | | 416 | 0.104 | 333.4 | 171.9 | 172.2 | 172.6 | 0.48 | 0.48 | 0.52 | 161.7 | 160.9 | 160.2 | 13.4 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 368.3 | | | | 0.54 | 0.54 | 0.58 | | | | | | |
| | | *min* | Minimum | 263.9 | | | | 0.38 | 0.38 | 0.41 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **326.0** | | | | **0.47** | **0.47** | **0.51** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 104.4 | | | | 0.15 | 0.15 | 0.18 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 44.2 | | | | 0.064 | 0.064 | 0.074 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 13.5% | | | | 13.4% | 13.5% | 14.6% | | | | | *V* = *s* / *mean* | |
| | | **0.9 $F_{Sm}$** | | **293.4** | | | | | | | | | | | Load level for the creep test | |

**Table A9** Test protocol HDG-III test series based on LVDTs 1-8 (CBG position)

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# Test report

15.10.2015

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 14.10.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Hot-Dip Galvanized (Recoated)** |
| | Coating composition | – |
| | Surface treatment | chemical cleaning |
| | Maximum coating thickness | – |
| | Mean coating thickness | 80 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | – |
| | Surface roughness (after coating) | 21 µm |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 48 mm |
| | Test speed | 0.6 mm/min |

| Static test | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment Eq. according to DIN EN 1090-2 | Date of test Start of the test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.1_UDE_03R_407-408 | 407 | 0.042 | 72.9 | 171.9 | 172.3 | 172.7 | 0.11 | 0.11 | 0.11 | 167.6 | 168.2 | 168.8 | 5.5 | | 14.10.15 11:25 |
| | | 408 | 0.150 | 80.4 | 172.1 | 172.2 | 172.2 | 0.12 | 0.12 | 0.12 | 170.2 | 170.3 | 170.3 | 7.9 | | |
| | 1.1_UDE_03R_409-410 | 409 | 0.107 | 83.0 | 172.2 | 172.2 | 172.3 | 0.12 | 0.12 | 0.12 | 171.4 | 170.1 | 168.7 | 8.6 | | 14.10.15 14:20 |
| | | 410 | 0.107 | 70.2 | 172.6 | 172.3 | 172.0 | 0.10 | 0.10 | 0.10 | 170.6 | 170.3 | 170.1 | 5.3 | | |
| | 1.1_UDE_03R_411-412 | 411 | 0.139 | 81.9 | 171.9 | 172.0 | 172.2 | 0.12 | 0.12 | 0.12 | 172.2 | 170.9 | 169.5 | 6.5 | | 14.10.15 15:50 |
| | | 412 | 0.030 | 81.9 | 172.8 | 172.4 | 172.0 | 0.12 | 0.12 | 0.12 | 170.9 | 170.5 | 170.1 | 6.5 | | |
| | 1.1_UDE_03R_417-418 | 417 | 0.054 | 85.5 | 172.7 | 172.7 | 172.6 | 0.12 | 0.12 | 0.12 | 173.2 | 172.4 | 171.5 | 5.7 | | 14.10.15 17:15 |
| | | 418 | 0.088 | 85.5 | 172.9 | 172.8 | 172.6 | 0.12 | 0.12 | 0.13 | 171.0 | 170.7 | 170.4 | 5.7 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | $max$ | Maximum | 85.5 | | | | 0.12 | 0.12 | 0.13 | | | | | | |
| | | $min$ | Minimum | 70.2 | | | | 0.10 | 0.10 | 0.10 | | | | | | |
| | | $mean$ | Mean value $F_{Sm}$ \| $\mu_m$ | **80.1** | | | | **0.12** | **0.12** | **0.12** | | | | | Eq. (2), Eq. (4) | |
| | | $R$ | Spread | 15.2 | | | | 0.02 | 0.02 | 0.02 | | | | | $R = max - min$ | |
| | | $s$ | Standard deviation $s_{Fs}$ | 5.6 | | | | 0.008 | 0.008 | 0.008 | | | | | Eq. (3), Eq. (5) | |
| | | $V$ | Coefficient of variation | 7.0% | | | | 7.0% | 7.0% | 6.6% | | | | | $V = s / mean$ | |
| | | **0.9 $F_{Sm}$** | | **72.1** | | | | | | | | | | | Load level for the creep test | |

**Table A10** Test protocol Al-SM-I test series based on LVDTs 1-8 (CBG position)

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## Test report

28.05.2015

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 20.05.2015 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| Coating | **Thermally sprayed with aluminium (Al-SM)** |
| Coating composition | – |
| Surface treatment | – |
| Maximum coating thickness | 470 µm (DFT) |
| Mean coating thickness | 250 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | – |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | Slip factor based on nominal preload $F_{p,C}$ [kN] 172; $\mu_i = \mu_{i,nom}$ [–] | Slip factor based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1_UDE_05_71-72 | 71 | 0.150 | 540.7 | 173.0 | 173.2 | 173.4 | 0.78 | 0.79 | 0.94 | 144.5 | 143.8 | 143.2 | 19.3 | | 20.05.15 14:40 |
| | 72 | 0.150 | 512.0 | 173.3 | 173.0 | 172.8 | 0.74 | 0.74 | 0.88 | 147.1 | 146.0 | 144.8 | 18.3 | | |
| 1.1_UDE_05_73-74 | 73 | 0.150 | 510.1 | 172.5 | 172.6 | 172.6 | 0.74 | 0.74 | 0.89 | 144.3 | 143.2 | 142.1 | 18.5 | | 20.05.15 16:45 |
| | 74 | 0.150 | 489.1 | 172.7 | 173.0 | 173.3 | 0.71 | 0.71 | 0.84 | 146.7 | 145.0 | 143.3 | 17.7 | | |
| Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | *max* | Maximum | 540.7 | | | | 0.78 | 0.79 | 0.94 | | | | | | |
| | *min* | Minimum | 489.1 | | | | 0.71 | 0.71 | 0.84 | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **513.0** | | | | **0.74** | **0.75** | **0.89** | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | 51.6 | | | | 0.07 | 0.08 | 0.10 | | | | | *R = max – min* | |
| | *s* | Standard deviation $s_{Fs}$ | 21.2 | | | | 0.030 | 0.031 | 0.040 | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | 4.1% | | | | 4.1% | 4.1% | 4.5% | | | | | *V = s / mean* | |
| | **0.9 $F_{Sm}$** | | **461.7** | | | | | | | | | | | Load level for the creep test | |

**Table A11** Test protocol AI-SM-II test series based on LVDTs 1-8 (CBG position)

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## Test report

28.05.2015

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 19.05.2015 - 20.05.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | **Thermally sprayed with aluminium (AI-SM)** |
| | Coating composition | – |
| | Surface treatment | – |
| | Maximum coating thickness | 470 µm (DFT) |
| | Mean coating thickness | 250 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | – |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172; $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_05_77-78 | 77 | 0.150 | 510.1 | 170.9 | 171.3 | 171.6 | 0.74 | 0.74 | 0.96 | 133.9 | 133.4 | 132.8 | 17.9 | | 19.05.15 15:25 |
| | | 78 | 0.150 | 500.5 | 171.6 | 171.9 | 172.2 | 0.73 | 0.73 | 0.92 | 138.7 | 136.7 | 134.6 | 18.8 | | |
| | 1.1_UDE_05_79-80 | 79 | 0.150 | 488.5 | 171.8 | 172.2 | 172.6 | 0.71 | 0.71 | 0.89 | 138.1 | 137.0 | 135.9 | 17.0 | | 19.05.15 17:30 |
| | | 80 | 0.149 | 504.5 | 172.6 | 172.8 | 173.0 | 0.73 | 0.73 | 0.91 | 139.7 | 137.9 | 136.2 | 17.8 | | |
| | 1.1_UDE_05_81-82 | 81 | 0.150 | 505.2 | 172.1 | 172.3 | 172.4 | 0.73 | 0.73 | 0.93 | 136.0 | 135.6 | 135.3 | 17.9 | | 20.05.15 10:35 |
| | | 82 | 0.150 | 528.3 | 173.1 | 172.9 | 172.7 | 0.76 | 0.77 | 0.95 | 141.2 | 138.7 | 136.3 | 18.8 | | |
| | 1.1_UDE_05_83-84 | 83 | 0.150 | 487.5 | 171.9 | 171.9 | 171.9 | 0.71 | 0.71 | 0.90 | 137.0 | 135.2 | 133.4 | 17.0 | | 20.05.15 12:45 |
| | | 84 | 0.150 | 508.7 | 171.9 | 172.0 | 172.1 | 0.74 | 0.74 | 0.95 | 136.0 | 133.8 | 131.6 | 17.8 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | $max$ | Maximum | 528.3 | | | | 0.76 | 0.77 | 0.96 | | | | | | |
| | | $min$ | Minimum | 487.5 | | | | 0.71 | 0.71 | 0.89 | | | | | | |
| | | $mean$ | Mean value $F_{Sm}$ \| $\mu_m$ | **504.2** | | | | **0.73** | **0.73** | **0.93** | | | | | Eq. (2), Eq. (4) | |
| | | $R$ | Spread | 40.8 | | | | 0.06 | 0.06 | 0.07 | | | | | $R = max - min$ | |
| | | $s$ | Standard deviation $s_{Fs}$ | 13.0 | | | | 0.018 | 0.019 | 0.025 | | | | | Eq. (3), Eq. (5) | |
| | | $V$ | Coefficient of variation | 2.6% | | | | 2.5% | 2.6% | 2.7% | | | | | $V = s / mean$ | |
| | | $0.9\ F_{Sm}$ | | 453.8 | | | | | | | | | | | Load level for the creep test | |
| Creep test | 1.1_UDE_05_75-76 | 75 | Δ (5 min to 3 h): - | | | | | | | | | | | | **Creep test failed** Slip during the creep test > 0.002 mm (5 min to 3 h) | 20.05.15 18:50 |
| | | | | – | 172.3 | 172.4 | 172.5 | – | – | – | 136.6 | 135.7 | 134.7 | 162.7 | | |
| | | 76 | Δ (5 min to 3 h): - | | | | | | | | | | | | | |
| | | | | – | 172.0 | 172.1 | 172.2 | – | – | – | 137.6 | 136.4 | 135.3 | 835.8 | | |

## Table A12 Test protocol Zn-SM-I test series based on LVDTs 1-8 (CBG position)

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### Test report

13.04.2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 08.04.15 - 10.04.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Thermally sprayed with zinc (Zn-SM)** |
| | Coating composition | – |
| | Surface treatment | Grit Blasted Sa 3, Hartguss |
| | Maximum coating thickness | – |
| | Mean coating thickness | 140 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 100 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) mean slip planes | $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172, $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip, upper part: Outer bolt $F_{bi,1,act}$ [kN] | Inner bolt $F_{bi,2,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | lower part: Inner bolt $F_{bi,3,act}$ [kN] | Outer bolt $F_{bi,4,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_04_35 | a | A \| B | 0.150 | 522.2 | 171.3 | 171.3 | 171.4 | 0.76 | 0.76 | 0.83 | 157.8 | 155.3 | 156.5 | | | 19.6 | | 08.04.15 16:50 |
| | | b | C \| D | 0.150 | 533.9 | 171.4 | 171.4 | 171.5 | 0.78 | 0.78 | 0.85 | | | 156.1 | 154.4 | 157.8 | 20.1 | | |
| | 1.1_UDE_04_36 | a | A \| B | 0.150 | 518.2 | 171.4 | 171.4 | 171.4 | 0.76 | 0.75 | 0.83 | 158.2 | 155.7 | 156.9 | | | 19.8 | | 08.04.15 18:45 |
| | | b | C \| D | 0.150 | 511.1 | 172.0 | 171.8 | 171.6 | 0.74 | 0.74 | 0.81 | | | 157.5 | 155.2 | 159.7 | 19.5 | | |
| | 1.1_UDE_04_37 | a | A \| B | 0.150 | 506.0 | 172.4 | 172.1 | 171.9 | 0.73 | 0.74 | 0.80 | 160.2 | 156.5 | 158.4 | | | 19.2 | | 09.04.15 10:40 |
| | | b | C \| D | 0.150 | 492.2 | 172.1 | 172.2 | 172.2 | 0.71 | 0.72 | 0.78 | | | 158.0 | 156.2 | 159.8 | 19.7 | | |
| | 1.1_UDE_04_38 | a | A \| D | 0.150 | 521.7 | 172.1 | 172.1 | 172.1 | 0.76 | 0.76 | 0.82 | 160.4 | 157.8 | 158.1 | 155.1 | 159.3 | 19.7 | | 09.04.15 13:00 |
| | | b | B \| C | 0.149 | 501.2 | 172.1 | 171.9 | 171.6 | 0.73 | 0.73 | 0.80 | 159.5 | 156.7 | 157.0 | 153.5 | 158.2 | 19.2 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | | | | |
| | | $max$ | Maximum | | 533.9 | | | | 0.78 | 0.78 | 0.85 | | | | | | | | |
| | | $min$ | Minimum | | 492.2 | | | | 0.71 | 0.72 | 0.78 | | | | | | | | |
| | | $mean$ | Mean value $F_{Sm}$ \| $\mu_m$ | | **513.3** | | | | **0.75** | **0.75** | **0.82** | | | | | | | Eq. (2), Eq. (4) | |
| | | $R$ | Spread | | 41.7 | | | | 0.06 | 0.06 | 0.08 | | | | | | | $R = max – min$ | |
| | | $s$ | Standard deviation $s_{FS}$ | | 13.3 | | | | 0.020 | 0.019 | 0.024 | | | | | | | Eq. (3), Eq. (5) | |
| | | $V$ | Coefficient of variation | | 2.6% | | | | 2.7% | 2.6% | 2.9% | | | | | | | $V = s / mean$ | |
| | | 0.9 $F_{Sm}$ | | | **462.0** | | | | | | | | | | | | | Load level for the creep test | |
| Creep test | 1.1_UDE_04_39 | a | Δ (5 min to 3 h): **–** | | | | | | | | | | | | | | | **Creep test failed** Slip during the creep test > 0.002 mm (5 min to 3 h) | 10.04.15 11:46 |
| | | | A \| B | | – | 172.3 | 172.2 | 172.0 | – | – | – | 155.2 | 154.2 | 155.2 | | | 19973.3 | | |
| | | b | Δ (5 min to 3 h): **–** | | | | | | | | | | | | | | | | |
| | | | C \| D | | – | 172.1 | 172.2 | 172.3 | – | – | – | | | 153.6 | 153.3 | 153.6 | 19974.5 | | |

**Table A13** Test protocol Zn-SM-II test series based on LVDTs 1-8 (CBG position)

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## Test report

11.05.2015

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 24.04.2015 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| Coating | **Thermally sprayed with zinc (Zn-SM)** |
| Coating composition | – |
| Surface treatment | Grit Blasted Sa 3, Hartguss |
| Maximum coating thickness | – |
| Mean coating thickness | 140 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | about 100 µm |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) mean slip planes | $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172, $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip, upper part: Outer bolt $F_{bi,1,act}$ [kN] | Inner bolt $F_{bi,2,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | lower part: Inner bolt $F_{bi,3,act}$ [kN] | Outer bolt $F_{bi,4,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1_UDE_04_40 | a | A \| D | 0.150 | 508.7 | 170.8 | 171.0 | 171.3 | 0.74 | 0.74 | 0.83 | 154.5 | 151.8 | 153.1 | 150.7 | 155.6 | 19.4 | | 24.04.15 12:05 |
| | b | C \| B | 0.150 | 502.1 | 171.4 | 171.5 | 171.5 | 0.73 | 0.73 | 0.82 | 154.8 | 152.4 | 153.6 | 151.3 | 156.0 | 19.1 | | |
| 1.1_UDE_04_41 | a | A \| B | 0.150 | 485.3 | 170.6 | 170.4 | 170.3 | 0.71 | 0.71 | 0.78 | 157.2 | 152.5 | 154.8 | | | 18.4 | | 24.04.15 14:25 |
| | b | C \| D | 0.150 | 508.8 | 170.6 | 170.7 | 170.7 | 0.75 | 0.74 | 0.83 | | | 153.1 | 151.4 | 154.8 | 19.6 | | |
| Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | | | | |
| | *max* | Maximum | | 508.8 | | | | 0.75 | 0.74 | 0.83 | | | | | | | | |
| | *min* | Minimum | | 485.3 | | | | 0.71 | 0.71 | 0.78 | | | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | | **501.2** | | | | **0.73** | **0.73** | **0.82** | | | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | | 23.6 | | | | 0.03 | 0.03 | 0.05 | | | | | | | *R = max – min* | |
| | *s* | Standard deviation $s_{Fs}$ | | 11.1 | | | | 0.015 | 0.016 | 0.022 | | | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | | 2.2% | | | | 2.1% | 2.2% | 2.7% | | | | | | | *V = s / mean* | |
| | 0.9 $F_{Sm}$ | | | **451.1** | | | | | | | | | | | | | Load level for the creep test | |

**Table A14** Test protocol ASI – Zn-SM-I test series based on LVDTs 1-8 (CBG position)

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## Test report

30.07.2014

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 28.07.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Inner plate: thermally sprayed with zinc - Zn-SM; cover plate: alkali-zinc silicate (ASI)** |
| | Coating composition | – |
| | Surface treatment | **Zn-SM:** blasted Sa 3, Hartguss, edged; **ASI:** blasted Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | Zn-SM: 170 µm (DFT); ASI: 55 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 100 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 48 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment Eq. according to DIN EN 1090-2 | Date of test Start of the test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 2.2_UDE_06_01-02 | 1 | 0.150 | 418.3 | 170.6 | 170.3 | 169.9 | 0.61 | 0.61 | 0.69 | 154.6 | 151.3 | 148.0 | 25.5 | | 28.07.15 10:10 |
| | | 2 | 0.150 | 408.0 | 170.9 | 170.7 | 170.5 | 0.60 | 0.59 | 0.66 | 158.3 | 154.1 | 149.8 | 16.7 | | |
| | 2.2_UDE_06_03-04 | 3 | 0.117 | 431.8 | 172.3 | 171.7 | 171.0 | 0.63 | 0.63 | 0.70 | 156.9 | 153.2 | 149.5 | 17.3 | | 28.07.15 12:00 |
| | | 4 | 0.150 | 428.4 | 171.7 | 171.3 | 171.0 | 0.63 | 0.62 | 0.70 | 156.8 | 152.9 | 148.9 | 17.1 | | |
| | 2.2_UDE_06_05-06 | 5 | 0.150 | 428.9 | 171.2 | 171.1 | 170.9 | 0.63 | 0.62 | 0.71 | 153.3 | 151.0 | 148.7 | 18.0 | | 28.07.15 13:45 |
| | | 6 | 0.150 | 438.0 | 170.6 | 170.6 | 170.7 | 0.64 | 0.64 | 0.72 | 155.1 | 152.5 | 149.8 | 27.3 | | |
| | 2.2_UDE_06_07-08 | 7 | 0.150 | 452.9 | 171.1 | 171.0 | 171.0 | 0.66 | 0.66 | 0.75 | 152.6 | 150.0 | 147.3 | 26.9 | | 28.07.15 16:15 |
| | | 8 | 0.150 | 444.2 | 170.9 | 170.8 | 170.6 | 0.65 | 0.65 | 0.73 | 155.4 | 151.7 | 148.0 | 17.6 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 452.9 | | | | 0.66 | 0.66 | 0.75 | | | | | | |
| | | *min* | Minimum | 408.0 | | | | 0.60 | 0.59 | 0.66 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **431.3** | | | | **0.63** | **0.63** | **0.71** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 45.0 | | | | 0.06 | 0.07 | 0.09 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{FS}$ | 14.2 | | | | 0.020 | 0.021 | 0.028 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 3.3% | | | | 3.2% | 3.3% | 3.9% | | | | | *V* = *s* / *mean* | |
| | | 0.9 $F_{Sm}$ | | 388.2 | | | | | | | | | | | Load level for the creep test | |
| Creep test | 2.2_UDE_06_09-10 | 9 | Δ (5 min to 3 h): **4.511** | | | | | | | | | | | | **Creep test failed** Slip during the creep test > 0.002 mm (5 min to 3 h) | 28.07.15 18:00 |
| | | | | – | 172.1 | 171.8 | 171.5 | – | – | – | 156.9 | 152.6 | 148.2 | 26.5 | | |
| | | 10 | Δ (5 min to 3 h): **0.191** | | | | | | | | | | | | | |
| | | | | – | 171.1 | 171.2 | 171.4 | – | – | – | 154.4 | 151.4 | 148.5 | 41.1 | | |

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# Appendix B: Slip factor test results (static and creep tests) - based on LVDTs 9-12 (PE position)

**Table B1** Test protocol GB-I test series based on LVDTs 9-12 (PE position)

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## Test report

30/01/2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 17.12.2014 & 18.12.2014 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | – |
| | Coating composition | – |
| | Surface treatment | **Grid blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | – |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 180 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 152 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment: Eq. according to DIN EN 1090-2 | Date of test: Start of the test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_01_213-214 | 213 | 0.150 | 436.1 | 172.0 | 171.9 | 171.7 | 0.63 | 0.63 | 0.66 | 164.4 | 164.1 | 163.7 | 10.5 | | 17.12.14 12:25 |
| | | 214 | 0.150 | 426.4 | 171.5 | 171.6 | 171.8 | 0.62 | 0.62 | 0.65 | 164.6 | 164.3 | 164.0 | 10.2 | | |
| | 1.1_UDE_01_215-216 | 215 | 0.150 | 425.8 | 171.8 | 171.7 | 171.5 | 0.62 | 0.62 | 0.65 | 164.5 | 164.1 | 163.6 | 10.3 | | 17.12.14 17:05 |
| | | 216 | 0.150 | 420.8 | 171.5 | 171.6 | 171.7 | 0.61 | 0.61 | 0.64 | 164.0 | 163.8 | 163.6 | 10.1 | | |
| | 1.1_UDE_01_217-218 | 217 | 0.151 | 421.0 | 172.0 | 171.9 | 171.8 | 0.61 | 0.61 | 0.64 | 164.8 | 164.3 | 163.9 | 10.2 | | 17.12.14 19:40 |
| | | 218 | 0.150 | 414.3 | 171.8 | 171.8 | 171.9 | 0.60 | 0.60 | 0.63 | 163.9 | 164.0 | 164.1 | 10.0 | | |
| | 1.1_UDE_01_219-220 | 219 | 0.150 | 412.8 | 172.0 | 171.9 | 171.8 | 0.60 | 0.60 | 0.63 | 164.5 | 164.3 | 164.1 | 8.9 | | 18.12.14 10:00 |
| | | 220 | 0.150 | 409.9 | 171.6 | 171.8 | 172.0 | 0.60 | 0.60 | 0.62 | 164.1 | 164.3 | 164.4 | 8.8 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 436.1 | | | | 0.63 | 0.63 | 0.66 | | | | | | |
| | | *min* | Minimum | 409.9 | | | | 0.60 | 0.60 | 0.62 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **420.9** | | | | **0.61** | **0.61** | **0.64** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 26.2 | | | | 0.04 | 0.04 | 0.04 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{FS}$ | 8.6 | | | | 0.013 | 0.012 | 0.013 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 2.0% | | | | 2.1% | 2.0% | 2.1% | | | | | *V* = *s* / *mean* | |
| | | 0.9 $F_{Sm}$ | | **378.8** | | | | | | | | | | | Load level for the creep test | |

**Table B2** Test protocol GB-II test series based on LVDTs 9-12 (PE position)

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# Test report

03.03.2015

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 02/03/2015 & 03/03/2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | – |
| | Coating composition | – |
| | Surface treatment | **Grid blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | – |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| | Test speed | 0.6 mm/min |

| Static test | Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload) | | | Slip factor based on initial preload | Slip factor based on nominal preload | Slip factor based on preload at slip | Preload at slip | | | Test duration | Comment | Date of test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Outer bolt | Mean value | Inner bolt | | $F_{p,C}$ [kN] 172 | | Outer bolt | Mean value | Inner bolt | | Eq. according to DIN EN 1090-2 | Start of the test |
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| | 1.1_UDE_01_14-15 | 14 | 0.150 | 402.3 | 170.5 | 170.7 | 170.9 | 0.59 | 0.58 | 0.63 | 160.0 | 159.4 | 158.8 | 8.3 | | 02.03.15 17:40 |
| | | 15 | 0.150 | 413.0 | 171.2 | 171.0 | 170.8 | 0.60 | 0.60 | 0.65 | 160.1 | 159.5 | 158.9 | 8.7 | | |
| | 1.1_UDE_01_16-17 | 16 | 0.150 | 413.6 | 171.9 | 171.8 | 171.7 | 0.60 | 0.60 | 0.65 | 160.8 | 159.9 | 159.1 | 10.0 | | 03.03.15 13:05 |
| | | 17 | 0.150 | 415.3 | 172.0 | 171.9 | 171.8 | 0.60 | 0.60 | 0.65 | 161.7 | 160.9 | 160.1 | 10.0 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 415.3 | | | | 0.60 | 0.60 | 0.65 | | | | | | |
| | | *min* | Minimum | 402.3 | | | | 0.59 | 0.58 | 0.63 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **411.1** | | | | **0.60** | **0.60** | **0.64** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 12.9 | | | | 0.01 | 0.02 | 0.02 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 5.9 | | | | 0.007 | 0.009 | 0.008 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 1.4% | | | | 1.2% | 1.4% | 1.2% | | | | | *V* = *s* / *mean* | |
| | | **0.9 $F_{Sm}$** | | **370.0** | | | | | | | | | | | Load level for the creep test | |

**Table B3** Test protocol GB-III test series based on LVDTs 9-12 (PE position)

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## Test report

30/01/2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 26/01/2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | – |
| | Coating composition | – |
| | Surface treatment | **Grid blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | – |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload): Outer bolt | Mean value | Inner bolt | Slip factor: based on initial preload | based on nominal preload ($F_{p,C}$ [kN] 172) | based on preload at slip | Preload at slip: Outer bolt | Mean value | Inner bolt | Test duration | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| Static test | 1.1_UDE_01_18-19 | 18 | 0.150 | 417.9 | 170.2 | 170.8 | 171.5 | 0.61 | 0.61 | 0.67 | 155.0 | 155.1 | 155.1 | 9.4 | | 26.01.15 14:30 |
| | | 19 | 0.150 | 422.2 | 170.9 | 171.0 | 171.0 | 0.62 | 0.61 | 0.68 | 154.8 | 154.2 | 153.6 | 9.5 | | |
| | 1.1_UDE_01_209-210 | 209 | 0.150 | 408.0 | 170.5 | 171.2 | 172.0 | 0.60 | 0.59 | 0.65 | 157.4 | 156.1 | 154.8 | 9.6 | | 26.01.15 17:25 |
| | | 210 | 0.150 | 419.8 | 170.7 | 171.2 | 171.7 | 0.61 | 0.61 | 0.68 | 155.7 | 155.0 | 154.4 | 10.0 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 422.2 | | | | 0.62 | 0.61 | 0.68 | | | | | | |
| | | *min* | Minimum | 408.0 | | | | 0.60 | 0.59 | 0.65 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **417.0** | | | | **0.61** | **0.61** | **0.67** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 14.2 | | | | 0.02 | 0.02 | 0.03 | | | | | *R = max – min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 6.2 | | | | 0.010 | 0.009 | 0.013 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 1.5% | | | | 1.6% | 1.5% | 2.0% | | | | | *V = s / mean* | |
| | | **0.9 $F_{Sm}$** | | **375.3** | | | | | | | | | | | Load level for the creep test | |

**Table B4** Test protocol ASI-I test series based on LVDTs 9-12 (PE position)

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## Test report

30/01/2015

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 03.12.2014 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| Coating | **Alkali-zinc silicate coating (ASI), Type 2K-Interzinc 697** |
| Coating composition | – |
| Surface treatment | **Blasted** Sa 2 1/2, Hartguss, edged |
| Maximum coating thickness | – |
| Mean coating thickness | 60 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | about 80 µm |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 180 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 152 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | Slip factor based on nominal preload $F_{p,C}$ [kN] = 172; $\mu_i = \mu_{i,nom}$ [–] | Slip factor based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1_UDE_02_153-154 | 153 | 0.150 | 434.9 | 171.0 | 170.9 | 170.8 | 0.64 | 0.63 | 0.66 | 165.8 | 164.8 | 163.8 | 15.6 | | 03.12.14 10:20 |
| | 154 | 0.150 | 427.0 | 170.9 | 170.9 | 170.9 | 0.62 | 0.62 | 0.65 | 165.8 | 164.9 | 164.0 | 15.3 | | |
| 1.1_UDE_02_155-156 | 155 | 0.150 | 419.4 | 170.9 | 170.7 | 170.5 | 0.61 | 0.61 | 0.64 | 166.2 | 164.8 | 163.5 | 15.8 | | 03.12.14 12:25 |
| | 156 | 0.150 | 431.8 | 170.8 | 170.9 | 170.9 | 0.63 | 0.63 | 0.65 | 165.8 | 165.3 | 164.7 | 16.3 | | |
| 1.1_UDE_02_159-160 | 159 | 0.150 | 425.7 | 171.2 | 170.9 | 170.5 | 0.62 | 0.62 | 0.64 | 166.3 | 165.1 | 163.8 | 16.0 | | 03.12.14 18:00 |
| | 160 | 0.150 | 434.4 | 170.9 | 170.8 | 170.6 | 0.64 | 0.63 | 0.66 | 165.2 | 164.6 | 163.9 | 16.3 | | |
| 1.1_UDE_02_161-162 | 161 | 0.150 | 431.7 | 171.4 | 171.2 | 171.0 | 0.63 | 0.63 | 0.65 | 166.6 | 165.5 | 164.5 | 15.3 | | 03.12.14 20:00 |
| | 162 | 0.150 | 423.6 | 170.5 | 170.7 | 170.9 | 0.62 | 0.62 | 0.64 | 165.5 | 164.8 | 164.1 | 15.0 | | |
| Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | *max* | Maximum | 434.9 | | | | 0.64 | 0.63 | 0.66 | | | | | | |
| | *min* | Minimum | 419.4 | | | | 0.61 | 0.61 | 0.64 | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **428.6** | | | | **0.63** | **0.62** | **0.65** | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | 15.5 | | | | 0.02 | 0.02 | 0.02 | | | | | *R = max – min* | |
| | *s* | Standard deviation $s_{FS}$ | 5.5 | | | | 0.008 | 0.008 | 0.008 | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | 1.3% | | | | 1.2% | 1.3% | 1.3% | | | | | *V = s / mean* | |
| | **0.9 $F_{Sm}$** | | **385.7** | | | | | | | | | | | Load level for the creep test | |

**Table B5** Test protocol ASI-II test series based on LVDTs 9-12 (PE position)

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## Test report

23.01.2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 22.01.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| | Coating | **Alkali-zinc silicate coating (ASI), Type 2K-Interzinc 697** |
| | Coating composition | – |
| | Surface treatment | **Blasted** Sa 2 1/2, Hartguss, edged |
| | Maximum coating thickness | – |
| | Mean coating thickness | 60 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 80 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor: based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment: Eq. according to DIN EN 1090-2 | Date of test: Start of the test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_02_165-166 | 165 | 0.150 | 435.5 | 170.3 | 170.6 | 170.9 | 0.64 | 0.63 | 0.67 | 162.1 | 161.6 | 161.2 | 15.6 | | 24.03.15 13:55 |
| | | 166 | 0.150 | 432.3 | 170.4 | 170.7 | 171.1 | 0.63 | 0.63 | 0.67 | 162.0 | 161.7 | 161.4 | 15.4 | | |
| | 1.1_UDE_02_239-240 | 239 | 0.150 | 413.4 | 172.0 | 172.0 | 171.9 | 0.60 | 0.60 | 0.64 | 163.5 | 162.4 | 161.2 | 15.3 | | 24.03.15 17:45 |
| | | 240 | 0.149 | 421.8 | 171.3 | 171.6 | 171.9 | 0.61 | 0.61 | 0.65 | 162.5 | 161.9 | 161.3 | 15.5 | | |
| | Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 435.5 | | | | 0.64 | 0.63 | 0.67 | | | | | | |
| | | *min* | Minimum | 413.4 | | | | 0.60 | 0.60 | 0.64 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **425.8** | | | | **0.62** | **0.62** | **0.66** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 22.1 | | | | 0.04 | 0.03 | 0.04 | | | | | *R = max – min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 10.1 | | | | 0.017 | 0.015 | 0.017 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 2.4% | | | | 2.8% | 2.4% | 2.6% | | | | | *V = s / mean* | |
| | | **0.9 $F_{Sm}$** | | 383.2 | | | | | | | | | | | Load level for the creep test | |

**Table B6** Test protocol ASI-III test series based on LVDTs 9-12 (PE position)

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## Test report

23.01.2015

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 22.01.2015 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| Coating | **Alkali-zinc silicate coating (ASI), Type 2K-Interzinc 697** |
| Coating composition | – |
| Surface treatment | **Blasted** Sa 2 1/2, Hartguss, edged |
| Maximum coating thickness | – |
| Mean coating thickness | 60 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | about 80 µm |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload): Outer bolt | Mean value | Inner bolt | Slip factor: based on initial preload | based on nominal preload | based on preload at slip | Preload at slip: Outer bolt | Mean value | Inner bolt | Test duration | Comment | Date of test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $F_{p,C}$ [kN] 172 | | | | | | Eq. according to DIN EN 1090-2 | Start of the test |
| | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| **1.1_UDE_02_241-242** | 241 | 0.150 | 415.5 | 167.6 | 168.0 | 168.4 | 0.62 | 0.60 | 0.67 | 157.9 | 156.0 | 154.2 | 15.7 | | 22.01.15 15:20 |
| | 242 | 0.150 | 410.7 | 167.9 | 168.1 | 168.3 | 0.61 | 0.60 | 0.66 | 157.3 | 156.2 | 155.2 | 15.5 | | |
| **1.1_UDE_02_243-244** | 243 | 0.150 | 401.4 | 167.9 | 167.7 | 167.5 | 0.60 | 0.58 | 0.64 | 157.3 | 155.6 | 153.9 | 16.8 | | 22.01.15 19:15 |
| | 244 | 0.150 | 417.4 | 166.4 | 167.2 | 167.9 | 0.62 | 0.61 | 0.67 | 155.4 | 155.5 | 155.5 | 17.2 | | |
| **Statistics** (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | *max* | Maximum | 417.4 | | | | 0.62 | 0.61 | 0.67 | | | | | | |
| | *min* | Minimum | 401.4 | | | | 0.60 | 0.58 | 0.64 | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **411.3** | | | | **0.61** | **0.60** | **0.66** | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | 16.1 | | | | 0.03 | 0.02 | 0.03 | | | | | *R* = *max* – *min* | |
| | *s* | Standard deviation $s_{Fs}$ | 7.2 | | | | 0.011 | 0.010 | 0.012 | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | 1.7% | | | | 1.8% | 1.7% | 1.7% | | | | | *V* = *s* / *mean* | |
| | **0.9 $F_{Sm}$** | | **370.1** | | | | | | | | | | | Load level for the creep test | |

**Table B7** Test protocol HDG-I test series based on LVDTs 9-12 (PE position)

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## Test report

30/01/2015

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 04.12.2014 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Hot-Dip Galvanized** |
| | Coating composition | – |
| | Surface treatment | chemical cleaning |
| | Maximum coating thickness | – |
| | Mean coating thickness | about 100 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | – |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 180 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 152 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment Eq. according to DIN EN 1090-2 | Date of test Start of the test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Static test | 1.1_UDE_03_407-408 | 407 | 0.150 | 330.1 | 172.0 | 171.8 | 171.7 | 0.48 | 0.48 | 0.49 | 168.8 | 167.9 | 167.0 | 14.6 | | 04.12.14 11:00 |
| | | 408 | 0.150 | 330.7 | 171.3 | 171.4 | 171.4 | 0.48 | 0.48 | 0.50 | 167.1 | 166.5 | 165.9 | 14.6 | | |
| | 1.1_UDE_03_409-410 | 409 | 0.150 | 287.8 | 171.7 | 171.4 | 171.2 | 0.42 | 0.42 | 0.43 | 167.9 | 167.0 | 166.1 | 13.3 | | 04.12.14 12:55 |
| | | 410 | 0.150 | 274.8 | 171.7 | 171.8 | 171.8 | 0.40 | 0.40 | 0.41 | 168.6 | 168.3 | 168.0 | 12.6 | | |
| | 1.1_UDE_03_417-418 | 417 | 0.150 | 336.0 | 172.1 | 171.9 | 171.7 | 0.49 | 0.49 | 0.50 | 168.1 | 167.3 | 166.5 | 13.8 | | 04.12.14 15:30 |
| | | 418 | 0.150 | 353.4 | 171.5 | 171.5 | 171.6 | 0.52 | 0.51 | 0.53 | 167.2 | 166.6 | 165.9 | 14.4 | | |
| | 1.1_UDE_03_421-422 | 421 | 0.150 | 325.6 | 171.7 | 171.7 | 171.7 | 0.47 | 0.47 | 0.49 | 167.6 | 166.9 | 166.2 | 17.9 | | 04.12.14 17:35 |
| | | 422 | 0.150 | 295.5 | 171.8 | 171.9 | 172.0 | 0.43 | 0.43 | 0.44 | 168.4 | 168.3 | 168.1 | 12.4 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | $max$ | Maximum | 353.4 | | | | 0.52 | 0.51 | 0.53 | | | | | | |
| | | $min$ | Minimum | 274.8 | | | | 0.40 | 0.40 | 0.41 | | | | | | |
| | | $mean$ | Mean value $F_{Sm}$ \| $\mu_m$ | **316.7** | | | | **0.46** | **0.46** | **0.47** | | | | | Eq. (2), Eq. (4) | |
| | | $R$ | Spread | 78.6 | | | | 0.12 | 0.11 | 0.12 | | | | | $R = max – min$ | |
| | | $s$ | Standard deviation $s_{Fs}$ | 27.3 | | | | 0.040 | 0.040 | 0.042 | | | | | Eq. (3), Eq. (5) | |
| | | $V$ | Coefficient of variation | 8.6% | | | | 8.6% | 8.6% | 8.9% | | | | | $V = s / mean$ | |
| | | 0.9 $F_{Sm}$ | | 285.1 | | | | | | | | | | | Load level for the creep test | |
| Creep test | 1.1_UDE_03_423-424 | 423 | Δ (5 min to 3 h): - | – | 172.1 | 171.9 | 171.8 | – | – | – | 168.3 | 167.8 | 167.3 | 17.0 | **Creep test failed** Slip during the creep test > 0.002 mm (5 min to 3 h) | 04.12.14 19:30 |
| | | 424 | Δ (5 min to 3 h): - | – | 171.7 | 171.7 | 171.7 | – | – | – | 168.0 | 167.5 | 167.0 | 16.5 | | |

**Table B8** Test protocol HDG-II test series based on LVDTs 9-12 (PE position)

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## Test report

24.07.2015

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 23.07.2015 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| Coating | **Hot-Dip Galvanized** |
| Coating composition | – |
| Surface treatment | chemical cleaning |
| Maximum coating thickness | – |
| Mean coating thickness | about 100 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | – |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 48 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload) | | | Slip factor based on initial preload | Slip factor based on nominal preload | Slip factor based on preload at slip | Preload at slip | | | Test duration | Comment | Date of test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Outer bolt | Mean value | Inner bolt | | $F_{p,C}$ [kN] 172 | | Outer bolt | Mean value | Inner bolt | | Eq. according to DIN EN 1090-2 | Start of the test |
| | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| 1.1_UDE_03_413-414 | 413 | 0.150 | 331.6 | 172.9 | 172.1 | 171.3 | 0.48 | 0.48 | 0.51 | 163.1 | 162.2 | 161.2 | 19.8 | | 23.07.15 11:00 |
| | 414 | 0.150 | 261.4 | 172.0 | 171.6 | 171.2 | 0.38 | 0.38 | 0.40 | 165.5 | 163.5 | 161.5 | 11.2 | | |
| 1.1_UDE_03_415-416 | 415 | 0.150 | 358.8 | 172.4 | 172.1 | 171.7 | 0.52 | 0.52 | 0.57 | 159.0 | 158.4 | 157.9 | 21.5 | | 23.07.15 12:51 |
| | 416 | 0.150 | 331.9 | 171.9 | 172.2 | 172.6 | 0.48 | 0.48 | 0.51 | 162.1 | 161.2 | 160.4 | 13.3 | | |
| Statistics (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | *max* | Maximum | 358.8 | | | | 0.52 | 0.52 | 0.57 | | | | | | |
| | *min* | Minimum | 261.4 | | | | 0.38 | 0.38 | 0.40 | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **320.9** | | | | **0.47** | **0.47** | **0.50** | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | 97.4 | | | | 0.14 | 0.14 | 0.17 | | | | | *R = max – min* | |
| | *s* | Standard deviation $s_{FS}$ | 41.7 | | | | 0.060 | 0.061 | 0.070 | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | 13.0% | | | | 12.9% | 13.0% | 14.1% | | | | | *V = s / mean* | |
| | **0.9 $F_{Sm}$** | | **288.8** | | | | | | | | | | | Load level for the creep test | |

**Table B9** Test protocol HDG-III test series based on LVDTs 9-12 (PE position)

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## Test report

15.10.2015

| | | |
|---|---|---|
| Technical characteristics of the test | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 14.10.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Hot-Dip Galvanized (Recoated)** |
| | Coating composition | – |
| | Surface treatment | chemical cleaning |
| | Maximum coating thickness | – |
| | Mean coating thickness | 80 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | – |
| | Surface roughness (after coating) | 21 µm |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 48 mm |
| | Test speed | 0.6 mm/min |

| | Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload): Outer bolt | Mean value | Inner bolt | Slip factor: based on initial preload | based on nominal preload $F_{p,C}$ [kN] 172 | based on preload at slip | Preload at slip: Outer bolt | Mean value | Inner bolt | Test duration | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | | |
| Static test | **1.1_UDE_03R_407-408** | 407 | 0.150 | 72.5 | 171.9 | 172.3 | 172.7 | 0.11 | 0.11 | 0.11 | 167.4 | 168.0 | 168.6 | 5.4 | | 14.10.15 11:25 |
| | | 408 | 0.054 | 80.4 | 172.1 | 172.2 | 172.2 | 0.12 | 0.12 | 0.12 | 170.5 | 170.6 | 170.6 | 7.9 | | |
| | **1.1_UDE_03R_409-410** | 409 | 0.125 | 70.2 | 172.2 | 172.2 | 172.3 | 0.10 | 0.10 | 0.10 | 171.4 | 170.1 | 168.7 | 8.6 | | 14.10.15 14:20 |
| | | 410 | 0.122 | 83.0 | 172.6 | 172.3 | 172.0 | 0.12 | 0.12 | 0.12 | 170.6 | 170.3 | 170.1 | 5.3 | | |
| | **1.1_UDE_03R_411-412** | 411 | 0.150 | 81.7 | 171.9 | 172.0 | 172.2 | 0.12 | 0.12 | 0.12 | 172.3 | 170.9 | 169.5 | 6.5 | | 14.10.15 15:50 |
| | | 412 | 0.046 | 81.9 | 172.8 | 172.4 | 172.0 | 0.12 | 0.12 | 0.12 | 170.9 | 170.5 | 170.1 | 6.5 | | |
| | **1.1_UDE_03R_417-418** | 417 | 0.068 | 85.5 | 172.7 | 172.7 | 172.6 | 0.12 | 0.12 | 0.12 | 173.3 | 172.4 | 171.5 | 5.7 | | 14.10.15 17:15 |
| | | 418 | 0.103 | 85.5 | 172.9 | 172.8 | 172.6 | 0.12 | 0.12 | 0.13 | 170.9 | 170.6 | 170.3 | 5.7 | | |
| | **Statistics** (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 85.5 | | | | 0.12 | 0.12 | 0.13 | | | | | | |
| | | *min* | Minimum | 70.2 | | | | 0.10 | 0.10 | 0.10 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **80.1** | | | | **0.12** | **0.12** | **0.12** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 15.2 | | | | 0.02 | 0.02 | 0.02 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 5.7 | | | | 0.008 | 0.008 | 0.008 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 7.1% | | | | 7.0% | 7.1% | 6.6% | | | | | *V* = *s* / *mean* | |
| | | **0.9 $F_{Sm}$** | | **72.1** | | | | | | | | | | | Load level for the creep test | |

**Table B10** Test protocol Al-SM-I test series based on LVDTs 9-12 (PE position)

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## Test report

28.05.2015

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 20.05.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Thermally sprayed with aluminium (Al-SM)** |
| | Coating composition | – |
| | Surface treatment | – |
| | Maximum coating thickness | 470 µm (DFT) |
| | Mean coating thickness | 250 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | – |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| | Test speed | 0.6 mm/min |

| Static test | Specimens mark | plate ID's | Slip (average at CBG) | Slip load | Preload at start of test (initial preload): Outer bolt | Mean value | Inner bolt | Slip factor: based on initial preload | based on nominal preload, $F_{p,C}$ [kN] 172 | based on preload at slip | Preload at slip: Outer bolt | Mean value | Inner bolt | Test duration | Comment | Date of test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $u_i$ [mm] | $F_{Si}$ [kN] | $F_{bi,o,ini}$ [kN] | mean $F_{bi,ini}$ [kN] | $F_{bi,i,ini}$ [kN] | $\mu_{i,ini}$ [–] | $\mu_i = \mu_{i,nom}$ [–] | $\mu_{i,act}$ [–] | $F_{bi,o,act}$ [kN] | mean $F_{bi,act}$ [kN] | $F_{bi,i,act}$ [kN] | t [min] | Eq. according to DIN EN 1090-2 | Start of the test |
| | **1.1_UDE_05_71-72** | 71 | 0.150 | 396.0 | 173.0 | 173.2 | 173.4 | 0.57 | 0.58 | 0.64 | 155.5 | 155.9 | 156.3 | 14.6 | | 20.05.15 14:40 |
| | | 72 | 0.150 | 391.4 | 173.3 | 173.0 | 172.8 | 0.57 | 0.57 | 0.63 | 156.4 | 155.6 | 154.8 | 14.4 | | |
| | **1.1_UDE_05_73-74** | 73 | 0.150 | 378.3 | 172.5 | 172.6 | 172.6 | 0.55 | 0.55 | 0.61 | 155.6 | 155.4 | 155.1 | 14.1 | | 20.05.15 16:45 |
| | | 74 | 0.150 | 376.7 | 172.7 | 173.0 | 173.3 | 0.54 | 0.55 | 0.61 | 155.6 | 154.8 | 154.1 | 14.1 | | |
| | **Statistics** (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | | *max* | Maximum | 396.0 | | | | 0.57 | 0.58 | 0.64 | | | | | | |
| | | *min* | Minimum | 376.7 | | | | 0.54 | 0.55 | 0.61 | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **385.6** | | | | **0.56** | **0.56** | **0.62** | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | 19.3 | | | | 0.03 | 0.03 | 0.03 | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | 9.6 | | | | 0.013 | 0.014 | 0.014 | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | 2.5% | | | | 2.4% | 2.5% | 2.2% | | | | | *V* = *s* / *mean* | |
| | | **0.9 $F_{Sm}$** | | **347.0** | | | | | | | | | | | Load level for the creep test | |

**Table B11** Test protocol Al-SM-II test series based on LVDTs 9-12 (PE position)

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## Test report

28.05.2015

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 19.05.2015 - 20.05.2015 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355JR +N (hot rolled) |
| Coating | **Thermally sprayed with aluminium (Al-SM)** |
| Coating composition | – |
| Surface treatment | – |
| Maximum coating thickness | 470 µm (DFT) |
| Mean coating thickness | 250 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | – |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172, $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.1_UDE_05_77-78** | 77 | 0.150 | 388.9 | 170.9 | 171.3 | 171.6 | 0.57 | 0.57 | 0.66 | 147.4 | 147.9 | 148.4 | 14.1 | | 19.05.15 15:25 |
| | 78 | 0.150 | 379.5 | 171.6 | 171.9 | 172.2 | 0.55 | 0.55 | 0.63 | 151.2 | 150.1 | 149.0 | 13.7 | | |
| **1.1_UDE_05_79-80** | 79 | 0.150 | 378.4 | 171.8 | 172.2 | 172.6 | 0.55 | 0.55 | 0.63 | 149.4 | 149.4 | 149.5 | 13.4 | | 19.05.15 17:30 |
| | 80 | 0.150 | 388.9 | 172.6 | 172.8 | 173.0 | 0.56 | 0.57 | 0.65 | 150.9 | 150.1 | 149.4 | 13.8 | | |
| **1.1_UDE_05_81-82** | 81 | 0.150 | 384.1 | 172.1 | 172.3 | 172.4 | 0.56 | 0.56 | 0.64 | 149.4 | 149.6 | 149.8 | 13.8 | | 20.05.15 10:35 |
| | 82 | 0.150 | 403.0 | 173.1 | 172.9 | 172.7 | 0.58 | 0.59 | 0.66 | 152.7 | 151.6 | 150.6 | 14.4 | | |
| **1.1_UDE_05_83-84** | 83 | 0.150 | 375.1 | 171.9 | 171.9 | 171.9 | 0.55 | 0.55 | 0.63 | 149.8 | 148.9 | 148.1 | 13.1 | | 20.05.15 12:45 |
| | 84 | 0.150 | 380.3 | 171.9 | 172.0 | 172.1 | 0.55 | 0.55 | 0.64 | 149.9 | 149.1 | 148.3 | 13.4 | | |
| **Statistics** (4 specimens, 8 test results) | *n* = 8 | Number of tests | | | | | | | | | | | | | |
| | *max* | Maximum | 403.0 | | | | 0.58 | 0.59 | 0.66 | | | | | | |
| | *min* | Minimum | 375.1 | | | | 0.55 | 0.55 | 0.63 | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **384.8** | | | | **0.56** | **0.56** | **0.64** | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | 27.8 | | | | 0.04 | 0.04 | 0.03 | | | | | *R* = *max* – *min* | |
| | *s* | Standard deviation $s_{Fs}$ | 8.8 | | | | 0.012 | 0.013 | 0.013 | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | 2.3% | | | | 2.2% | 2.3% | 2.0% | | | | | *V* = *s* / *mean* | |
| | **0.9 $F_{Sm}$** | | **346.3** | | | | | | | | | | | Load level for the creep test | |

**Table B12** Test protocol Zn-SM-I test series based on LVDTs 9-12 (PE position)

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## Test report

13.04.2015

| Technical characteristics of the test | | |
|---|---|---|
| | Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| | Test date | 08.04.15 - 10.04.2015 |
| | Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| | Project No. | 410410007 20003 |
| | Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| | Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| | Coating | **Thermally sprayed with zinc (Zn-SM)** |
| | Coating composition | – |
| | Surface treatment | Grit Blasted Sa 3, Hartguss |
| | Maximum coating thickness | – |
| | Mean coating thickness | 140 µm (DFT) |
| | Minimum coating thickness | – |
| | Surface roughness (before coating) | about 100 µm |
| | Surface roughness (after coating) | – |
| | Curing procedure | – |
| | Duration of curing | – |
| | Time between application of coating and testing | – |
| | Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| | Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 110 – 10.9/10 – tZn) |
| | Nominal preload level | 172 kN = $F_{p,C}$ |
| | Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 83 mm |
| | Test speed | 0.6 mm/min |

| Static test | Specimens mark | plate ID's | Slip (average at CBG) mean slip planes | $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172; $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip, upper part: Outer bolt $F_{bi,1,act}$ [kN] | upper part: Inner bolt $F_{bi,2,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | lower part: Inner bolt $F_{bi,3,act}$ [kN] | lower part: Outer bolt $F_{bi,4,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.1_UDE_04_35 | a | A \| B | 0.150 | 410.5 | 171.3 | 171.3 | 171.4 | 0.60 | 0.60 | 0.64 | 162.2 | 160.6 | 161.4 | | | 15.8 | | 08.04.15 16:50 |
| | | b | C \| D | 0.150 | 417.7 | 171.4 | 171.4 | 171.5 | 0.61 | 0.61 | 0.65 | | | 161.4 | 160.5 | 162.4 | 16.1 | | |
| | 1.1_UDE_04_36 | a | A \| B | 0.150 | 395.9 | 171.4 | 171.4 | 171.4 | 0.58 | 0.58 | 0.61 | 162.9 | 161.5 | 162.2 | | | 15.5 | | 08.04.15 18:45 |
| | | b | C \| D | 0.150 | 398.8 | 172.0 | 171.8 | 171.6 | 0.58 | 0.58 | 0.61 | | | 162.2 | 161.0 | 163.5 | 15.6 | | |
| | 1.1_UDE_04_37 | a | A \| B | 0.150 | 398.2 | 172.4 | 172.1 | 171.9 | 0.58 | 0.58 | 0.61 | 163.8 | 161.6 | 162.7 | | | 15.9 | | 09.04.15 10:40 |
| | | b | C \| D | 0.150 | 387.3 | 172.1 | 172.2 | 172.2 | 0.56 | 0.56 | 0.60 | | | 162.6 | 161.6 | 163.5 | 15.5 | | |
| | 1.1_UDE_04_38 | a | **A \| D** | 0.150 | 369.9 | 172.1 | 172.1 | 172.1 | 0.54 | 0.54 | 0.56 | 164.9 | 163.6 | 163.7 | 161.9 | 164.5 | 14.5 | | 09.04.15 13:00 |
| | | b | **B \| C** | 0.150 | 425.5 | 172.1 | 171.9 | 171.6 | 0.62 | 0.62 | 0.66 | 163.2 | 161.1 | 161.5 | 159.3 | 162.5 | 16.3 | | |
| | Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | | | | |
| | | *max* | Maximum | | 425.5 | | | | 0.62 | 0.62 | 0.66 | | | | | | | | |
| | | *min* | Minimum | | 369.9 | | | | 0.54 | 0.54 | 0.56 | | | | | | | | |
| | | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | | **400.5** | | | | **0.58** | **0.58** | **0.62** | | | | | | | Eq. (2), Eq. (4) | |
| | | *R* | Spread | | 55.7 | | | | 0.08 | 0.08 | 0.09 | | | | | | | *R* = *max* – *min* | |
| | | *s* | Standard deviation $s_{Fs}$ | | 17.6 | | | | 0.026 | 0.026 | 0.030 | | | | | | | Eq. (3), Eq. (5) | |
| | | *V* | Coefficient of variation | | 4.4% | | | | 4.5% | 4.4% | 4.8% | | | | | | | *V* = *s* / *mean* | |
| | | **0.9 $F_{Sm}$** | | | **360.4** | | | | | | | | | | | | | Load level for the creep test | |

**Table B13** Test protocol Zn-SM-II test series based on LVDTs 9-12 (PE position)

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## Test report

11.05.2015

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 24.04.2015 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| Coating | **Thermally sprayed with zinc (Zn-SM)** |
| Coating composition | – |
| Surface treatment | Grit Blasted Sa 3, Hartguss |
| Maximum coating thickness | – |
| Mean coating thickness | 140 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | about 100 µm |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 80 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 52 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) mean slip planes | $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload) Outer bolt $F_{bi,o,ini}$ [kN] | Mean value mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172 $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip, upper part, Outer bolt $F_{bi,1,act}$ [kN] | upper part, Inner bolt $F_{bi,2,act}$ [kN] | Mean value mean $F_{bi,act}$ [kN] | lower part, Inner bolt $F_{bi,3,act}$ [kN] | lower part, Outer bolt $F_{bi,4,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1_UDE_04_40 | a | A \| D | 0.150 | 382.3 | 170.8 | 171.0 | 171.3 | 0.56 | 0.56 | 0.60 | 159.8 | 159.0 | 159.6 | 158.6 | 160.8 | 15.1 | | 24.04.15 12:05 |
| | b | C \| B | 0.150 | 418.7 | 171.4 | 171.5 | 171.5 | 0.61 | 0.61 | 0.66 | 158.4 | 157.1 | 157.9 | 156.5 | 159.4 | 16.3 | | |
| 1.1_UDE_04_41 | a | A \| B | 0.150 | 369.8 | 170.6 | 170.4 | 170.3 | 0.54 | 0.54 | 0.58 | 161.5 | 158.6 | 160.0 | | | 14.5 | | 24.04.15 14:25 |
| | b | C \| D | 0.150 | 405.2 | 170.6 | 170.7 | 170.7 | 0.59 | 0.59 | 0.64 | | | 159.0 | 157.7 | 160.3 | 15.7 | | |
| Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | | | | |
| | *max* | Maximum | | 418.7 | | | | 0.61 | 0.61 | 0.66 | | | | | | | | |
| | *min* | Minimum | | 369.8 | | | | 0.54 | 0.54 | 0.58 | | | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | | **394.0** | | | | **0.58** | **0.57** | **0.62** | | | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | | 49.0 | | | | 0.07 | 0.07 | 0.09 | | | | | | | *R = max – min* | |
| | *s* | Standard deviation $s_{Fs}$ | | 22.1 | | | | 0.031 | 0.032 | 0.038 | | | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | | 5.6% | | | | 5.4% | 5.6% | 6.2% | | | | | | | *V = s / mean* | |
| | **0.9 $F_{Sm}$** | | | **354.6** | | | | | | | | | | | | | Load level for the creep test | |

**Table B14** Test protocol ASI – Zn-SM-I test series based on LVDTs 9-12 (PE position)

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## Test report

30.07.2014

**Technical characteristics of the test**

| | |
|---|---|
| Tested according to | DIN EN 1090-2:2011-10 – Annex G |
| Test date | 28.07.2015 |
| Test performed by | N. Afzali, M.Sc. – Dipl.-Ing. M. Schiborr – J. Berg, M.Sc. |
| Project No. | 410410007 20003 |
| Quotation No. | RFSR-CT-2014-00024 (SIROCO) |
| Steel grade | Structural Steel EN 10025-2 – S355J2C +N (hot rolled) |
| Coating | **Inner plate: thermally sprayed with zinc - Zn-SM; cover plate: alkali-zinc silicate (ASI)** |
| Coating composition | – |
| Surface treatment | **Zn-SM: blasted** Sa 3, Hartguss, edged; **ASI: blasted** Sa 2 1/2, Hartguss, edged |
| Maximum coating thickness | – |
| Mean coating thickness | Zn-SM: 170 µm (DFT); ASI: 55 µm (DFT) |
| Minimum coating thickness | – |
| Surface roughness (before coating) | about 100 µm |
| Surface roughness (after coating) | – |
| Curing procedure | – |
| Duration of curing | – |
| Time between application of coating and testing | – |
| Specimen size | Standard specimens M20 (EN 1090-2, Figure G.1 b) |
| Bolt class, bolt type | 10.9 (Set EN 14399-4 – HV – M20 x 75 – 10.9/10 – tZn) |
| Nominal preload level | 172 kN = $F_{p,C}$ |
| Preload measuring method | implanted SG, measured continuously, clamping length $\Sigma t$ = 48 mm |
| Test speed | 0.6 mm/min |

**Static test**

| Specimens mark | plate ID's | Slip (average at CBG) $u_i$ [mm] | Slip load $F_{Si}$ [kN] | Preload at start of test (initial preload): Outer bolt $F_{bi,o,ini}$ [kN] | Mean value: mean $F_{bi,ini}$ [kN] | Inner bolt $F_{bi,i,ini}$ [kN] | Slip factor based on initial preload $\mu_{i,ini}$ [–] | based on nominal preload $F_{p,C}$ [kN] 172: $\mu_i = \mu_{i,nom}$ [–] | based on preload at slip $\mu_{i,act}$ [–] | Preload at slip: Outer bolt $F_{bi,o,act}$ [kN] | Mean value: mean $F_{bi,act}$ [kN] | Inner bolt $F_{bi,i,act}$ [kN] | Test duration t [min] | Comment (Eq. according to DIN EN 1090-2) | Date of test (Start of the test) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.2_UDE_06_01-02 | 1 | 0.150 | 399.9 | 170.6 | 170.3 | 169.9 | 0.59 | 0.58 | 0.64 | 159.3 | 156.0 | 152.7 | 16.4 | | 28.07.15 10:10 |
| | 2 | 0.150 | 380.7 | 170.9 | 170.7 | 170.5 | 0.56 | 0.55 | 0.61 | 159.9 | 156.3 | 152.7 | 15.7 | | |
| 2.2_UDE_06_03-04 | 3 | 0.150 | 409.1 | 172.3 | 171.7 | 171.0 | 0.60 | 0.59 | 0.66 | 159.3 | 155.8 | 152.3 | 16.3 | | 28.07.15 12:00 |
| | 4 | 0.150 | 398.8 | 171.7 | 171.3 | 171.0 | 0.58 | 0.58 | 0.64 | 159.7 | 156.2 | 152.7 | 16.0 | | |
| 2.2_UDE_06_05-06 | 5 | 0.150 | 399.7 | 171.2 | 171.1 | 170.9 | 0.58 | 0.58 | 0.65 | 157.0 | 154.5 | 152.1 | 16.9 | | 28.07.15 13:45 |
| | 6 | 0.150 | 409.7 | 170.6 | 170.6 | 170.7 | 0.60 | 0.60 | 0.66 | 156.3 | 154.1 | 151.8 | 17.2 | | |
| 2.2_UDE_06_07-08 | 7 | 0.150 | 417.6 | 171.1 | 171.0 | 171.0 | 0.61 | 0.61 | 0.67 | 158.6 | 155.6 | 152.6 | | | 28.07.15 16:15 |
| | 8 | 0.150 | 403.1 | 170.9 | 170.8 | 170.6 | 0.59 | 0.59 | 0.65 | 159.1 | 155.6 | 152.1 | | | |
| Statistics (4 specimens, 8 test results) | $n$ = 8 | Number of tests | | | | | | | | | | | | | |
| | *max* | Maximum | 417.6 | | | | 0.61 | 0.61 | 0.67 | | | | | | |
| | *min* | Minimum | 380.7 | | | | 0.56 | 0.55 | 0.61 | | | | | | |
| | *mean* | Mean value $F_{Sm}$ \| $\mu_m$ | **402.3** | | | | **0.59** | **0.58** | **0.65** | | | | | Eq. (2), Eq. (4) | |
| | *R* | Spread | 36.9 | | | | 0.05 | 0.05 | 0.06 | | | | | *R = max – min* | |
| | *s* | Standard deviation $s_{Fs}$ | 10.9 | | | | 0.016 | 0.016 | 0.019 | | | | | Eq. (3), Eq. (5) | |
| | *V* | Coefficient of variation | 2.7% | | | | 2.6% | 2.7% | 2.9% | | | | | *V = s / mean* | |
| | 0.9 $F_{Sm}$ | | **362.1** | | | | | | | | | | | Load level for the creep test | |