

# ***Guidelines on the design and execution of slip-resistant connections made of CS and amendments to Eurocode 3 and EN 1090-2 with background documentation***

## ***Deliverable report D7.1***

### ***WP 7 – Tasks 7.1/7.4***

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“SIROCO”

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## Guidelines on the design and execution of slip-resistant connections made of CS and amendments to Eurocode 3 and EN 1090-2 with background documentation

### 1 Scope of investigation

The scope of the guidelines on the design and execution of slip-resistant connections made of carbon steel including recommendations for testing is to serve designers of steel structures, fabricators, certifying authorities and to serve as a background document. The guidelines are primarily targeted at designers and its focus is on the determination of slip factors according to the slip factor test procedure, which was improved as a result of the investigations carried in the frame of SIROCO.

Proposed amendments and supporting background documents have been prepared for submission to the relevant Eurocode 3 Evolution Groups and CEN/TC 135 WG 2 for inclusion in revisions of EN 1993-1-8 [1] and EN 1090-2 [2]. Some conclusions of this research project have already been implemented in the revision EN 1090-2 which will be published in 2018.

These guidelines are based mainly on WP 1 and WP 2 of SIROCO as well as on [3].

### 2 Slip-resistant connections

Slip-resistant connections according to EN 1993-1-8 are a suitable choice for steel structures, such as radio masts, wind turbine towers and bridges, where joints are subjected to heavy impact loads, significant load reversal or fatigue and when slip must be limited at serviceability or ultimate limit state, see for example Figure 1.



**Figure 1** Radio masts with slip-resistant connections (photos: © CTeam)

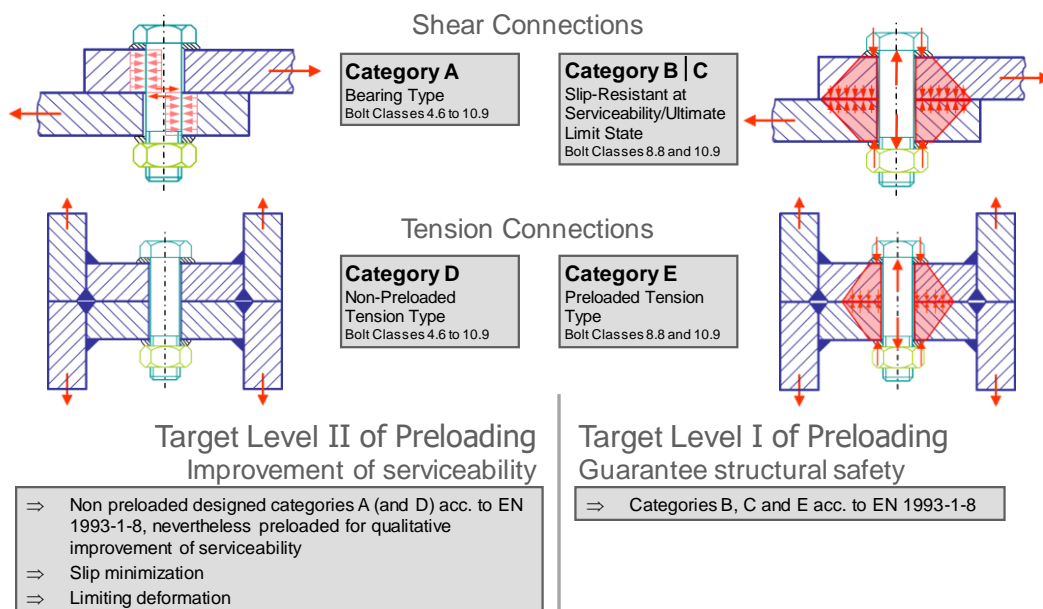
The slip-resistant behaviour of a slip-resistant connection is mainly influenced by the preload level of the bolt and the treatment of the faying surfaces of the clamped package. Slip factors for some specified surface conditions can be found in EN 1090-2 [2]. For deviating surface conditions which are not considered in EN 1090-2 or if higher slip factors are required, the slip factor can be determined experimentally

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according to the test procedure provided by Annex G of EN 1090-2. However, the practice has shown that the slip test procedure of Annex G needs careful consideration and was not clear in detail. Different interpretations may cause incomparable results for identical surface treatments. For this reason, special care has to be taken when comparing slip factors of different investigations. For these reasons, comprehensive investigations have been carried out in the frame of the European research project SIROCO to fill the gap in knowledge regarding their significance. As a result, the test procedure of Annex G, of EN 1090-2 could be significantly improved. Some of the resulting improvements from SIROCO have already been incorporated in the revision of EN 1090-2, which will be published in 2018. Some further improvements will be prepared as amendments for future implementation in revisions of EN 1993-1-8 and EN 1090-2, see also [3], [4], [5], [6], [7], [8].

### 3 Design of slip-resistant connections according to EN 1993-1-8

The design of slip-resistant connections made of carbon steel elements (plates and bolting assemblies) has to be carried out according to EN 1993-1-8 [1], in which the design of bolted connections is regulated in the frame of the Eurocode 3-family. EN 1993-1-8 distinguishes five categories of bolted connections which are subdivided in shear and tension connections, see Figure 2.



**Figure 2** Categories for bolted connections according to EN 1993-1-8

Slip-resistant connections are preloaded shear connections with high strength bolting assemblies of classes 8.8 and 10.9 conforming to the family of EN 14399 [9] for high strength structural bolting assemblies for preloading with controlled tightening in accordance with the requirements in EN 1090-2 [2].

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EN 1993-1-8 distinguishes in slip-resistant connections at serviceability and ultimate limit states which refer to Category B and Category C connections as follows, see also deliverable D7.2:

**Category B: Slip-resistant at serviceability limit state (SLS)**

Preloaded bolts in accordance with EN 14399 and EN 1090-2 should be used. The design serviceability shear load should not exceed the design slip resistance. The design ultimate shear load should not exceed the design shear resistance, nor the design bearing resistance.

*Category B is appropriate if slip after SLS but before ULS only produces some unsightly deflections (which may be very unwelcome), but crucially, does not reduce the ultimate resistance of the element or structure. An example might be a splice connection in a roof truss.*

The following design checks have to be carried out:

$$F_{v,Ed} \leq F_{v,Rd} \quad (1)$$

$$F_{v,Ed} \leq F_{b,Rd} \quad (2)$$

$$F_{v,Ed,ser} \leq F_{s,Rd,ser} \quad (3)$$

with

$F_{v,Ed}$  ultimate design shear force per fastener,

$F_{v,Ed,ser}$  design shear force per fastener at serviceability,

$F_{v,Rd}$  design shear resistance according to EN 1993-1-8,

$F_{b,Rd}$  design bearing resistance according to EN 1993-1-8,

$F_{s,Rd,ser}$  design slip resistance at serviceability according to EN 1993-1-8:

$$F_{s,Rd,ser} = \frac{k_s \cdot n \cdot \mu \cdot (F_{p,C} - 0,8 \cdot F_{t,Ed,ser})}{\gamma_{M3,ser} (= 1,1)} \quad (4)$$

$k_s$  factor considering the hole type (normal hole, oversized holes, long slotted hole etc.), see EN 1993-1-8, 3.9 and Table 1,

$n$  number of shear planes,

$\mu$  slip factor which can either be taken from specific slip factor tests in accordance with Annex G of EN 1090-2 or from tabulated values given in EN 1090-2, see Table 2 with slip factor values according to the final draft of the revised version of EN 1090-2, FprEN 1090-2 [10], which will be published in 2018,

$F_{p,C}$  preload in the bolt,

$F_{t,Ed,ser}$  design tensile force at serviceability, per fastener, including any force due to prying action.

$\gamma_{M3,ser}$  partial safety factor at serviceability limit state.

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background documentation****Category C: Slip-resistant at ultimate limit state (ULS)**

Preloaded bolts in accordance with EN 14399 and EN 1090-2 should be used. The design ultimate shear load should not exceed the design slip resistance. In addition for a connection in tension, the design plastic resistance of the net cross-section at bolt holes  $N_{net,Rd}$ , see 6.2 of EN 1993-1-1, should be checked at the ultimate limit state.

*Category C is appropriate when slip below ULS might reduce the ultimate resistance of the element or structure. An example of this might be a plan bracing restraint system to a compression member – for example in a heavily loaded transfer truss. Slippage within the restraint system might reduce the buckling resistance, so this must be prevented.*

The following design checks have to be carried out:

$$F_{v,Ed} \leq F_{s,Rd} \quad (5)$$

$$F_{v,Ed} \leq F_{b,Rd} \quad (6)$$

$$\Sigma F_{v,Ed} \leq N_{net,Rd} \quad (7)$$

with

$F_{v,Ed}$  ultimate design shear force per fastener,

$F_{s,Rd}$  design slip resistance at ultimate according to EN 1993-1-8:

$$F_{s,Rd} = \frac{k_s \cdot n \cdot \mu \cdot (F_{p,C} - 0,8 \cdot F_{t,Ed})}{\gamma_{M3} (= 1,25)} \quad (8)$$

$k_s$  factor considering the hole type (normal hole, oversized holes, long slotted hole etc.), see EN 1993-1-8, 3.9 and Table 1,

$n$  number of shear planes,

$\mu$  slip factor which can either be taken from specific slip factor tests in accordance with Annex G of EN 1090-2 or from tabulated values given in EN 1090-2, see Table 2 with slip factor values according to the final draft of the revised version of EN 1090-2, FprEN 1090-2 [10], which will be published in 2018,

$F_{p,C}$  preload in the bolt,

$F_{t,Ed}$  design ultimate tensile force, per fastener, including any force due to prying action,

$\gamma_{M3}$  partial safety factor at ultimate limit state.

$F_{b,Rd}$  design bearing resistance according to EN 1993-1-8,

$N_{net,Rd}$  design tension resistance of the net cross-section at bolt holes acc. to EN 1993-1-1, 6.2.

The design check of the slip resistance is carried out using Eq. (4) and (7) depending on the applied Category. The  $k_s$ -values and slip factors  $\mu$  are specified in Table 1 and Table 2.



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**Table 1** Values of  $k_s$  [1][10]

Description	$k_s$
Bolts in normal round holes.	1.0
Bolts in either oversized holes or short slotted holes with the axis of the slot perpendicular to the direction of force transfer.	0.85
Bolts in long slotted holes with the axis of the slot perpendicular to the direction of force transfer.	0.7
Bolts in short slotted holes with the axis of the slot parallel to the direction of force transfer.	0.76
Bolts in long slotted holes with the axis of the slot parallel to the direction of force transfer.	0.63

**Table 2** Slip factor for various surface treatments according to FprEN 1090-2 [10]

Surface Treatment	Class <sup>a</sup>	Slip Factor $\mu^\beta$
Surfaces blasted with shot or grit with loose rust removed, not pitted	A	0.5
Surfaces hot dip galvanized to EN ISO 1461 and flash (sweep) blasted <sup>d</sup> and with alkali-zinc silicate paint with a nominal thickness of 60 $\mu\text{m}$ <sup>c</sup> .	B	0.4
Surfaces blasted with shot or grit: a) coated with alkali-zinc silicate paint with a nominal thickness of 60 $\mu\text{m}$ <sup>c</sup> ; b) thermally sprayed with aluminium or zinc or a combination of both to a nominal thickness not exceeding 80 $\mu\text{m}$	B	0.4
Surfaces hot dip galvanized to EN ISO 1461 and flash (sweep) blasted (or equivalent abrasion method) <sup>d</sup>	C	0.35
Surfaces cleaned by wire-brushing or flame cleaning, with loose rust removed	C	0.3
Surfaces as rolled	D	0.2
<sup>a</sup> Classes as given in Annex G, G.6 of EN 1090-2. <sup>b</sup> The potential loss of preloading force from its initial value is considered in these slip factor values. <sup>c</sup> Dry thickness to be within 40 $\mu\text{m}$ 80 $\mu\text{m}$ range. <sup>d</sup> Unless alternative equivalent abrasion process capability can be demonstrated, flash (sweep) blasting of hot dip galvanized surfaces shall be carried out according to the procedures and conditions set out in EN 15773. After flash (sweep) blasting the appearance of a matt surface indicates that a soft surface layer of un-alloyed zinc has been removed.		

## 4 Determination of slip factors

### 4.1 General

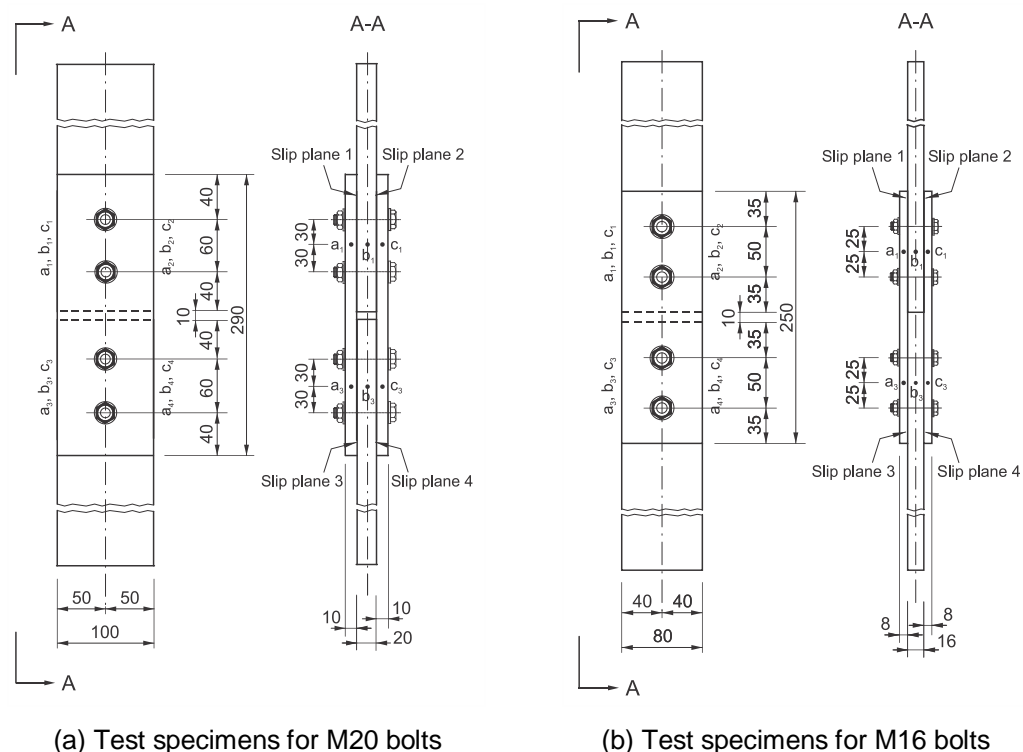
Annex G of EN 1090-2 prescribes a generalized experimental procedure to obtain the slip factor. This slip factor test procedure has been thoroughly investigated in the frame of SIROCO with the aim not only to clarify it but also to optimize it. The basics of the test procedure have not been changed in SIROCO. The clarification and optimization which could be achieved from the research results cover essentially

- the type of preload measurement,
- definition of the possible slip planes,
- the test speed,
- the position of slip measurement,
- the clamping length,
- the preload level,
- the evaluation of critical slip load and
- the performance of the extended creep test to cover creep effects.

In the following, the principle of the test procedure is described, already considering the improvements achieved in the frame of SIROCO. Most of the improvements have already been implemented in the revision of the current version of EN 1090-2 which should be published in 2018.

### 4.2 Test specimens

Slip factor tests shall be performed by using one of the two predefined standard specimens (M16 or M20) as shown in Figure 3. It has to be taken care, that both inner plates are cut from the same piece of material to ensure an identical thickness.

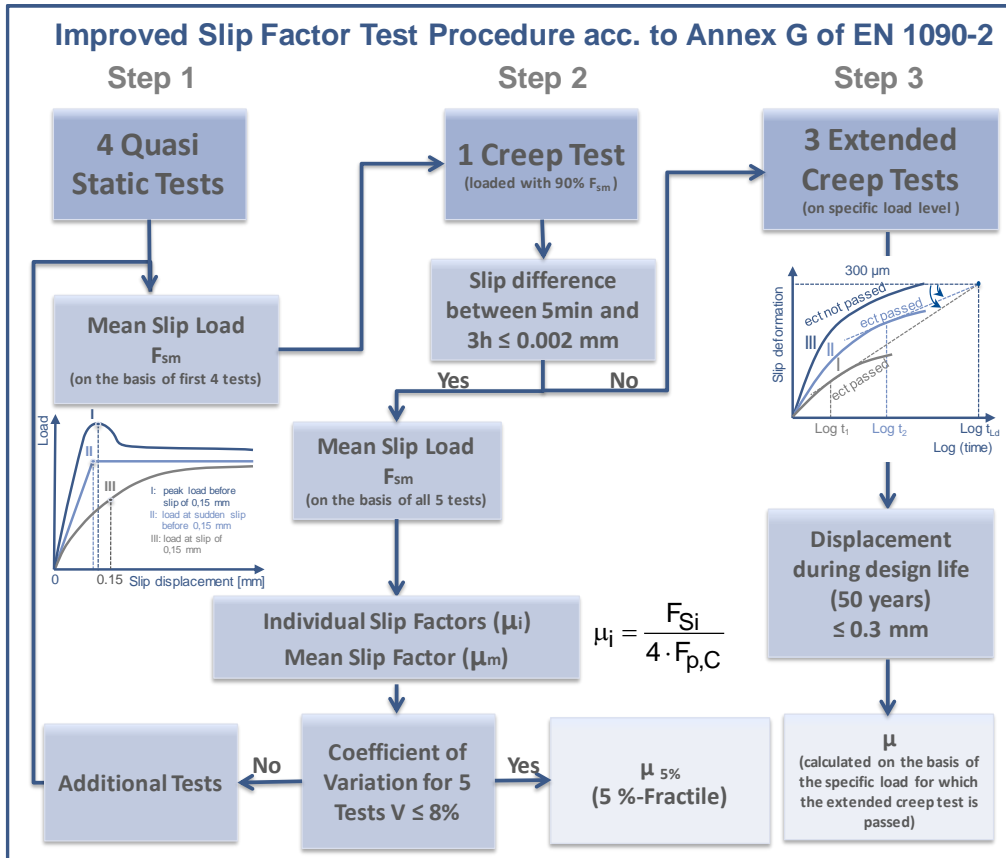


**Figure 3** M20 and M16 test specimen geometries for the determination of the slip factor according to EN 1090-2, Annex G

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### 4.3 Slip factor test procedure

The slip factor test consists of a three step test procedure, see Fig. 3. Four static tests shall be conducted at “normal speed”, followed by a creep test and in case the creep test is not passed, at least three extended creep tests.



**Figure 4** Improved three step test procedure of the slip factor test acc. to Annex G of EN 1090-2

### 4.4 Test speed

Unfortunately, EN 1090-2 gives no specific definition for normal speed; it is only mentioned that the duration of a static test should be about 10 to 15 minutes.

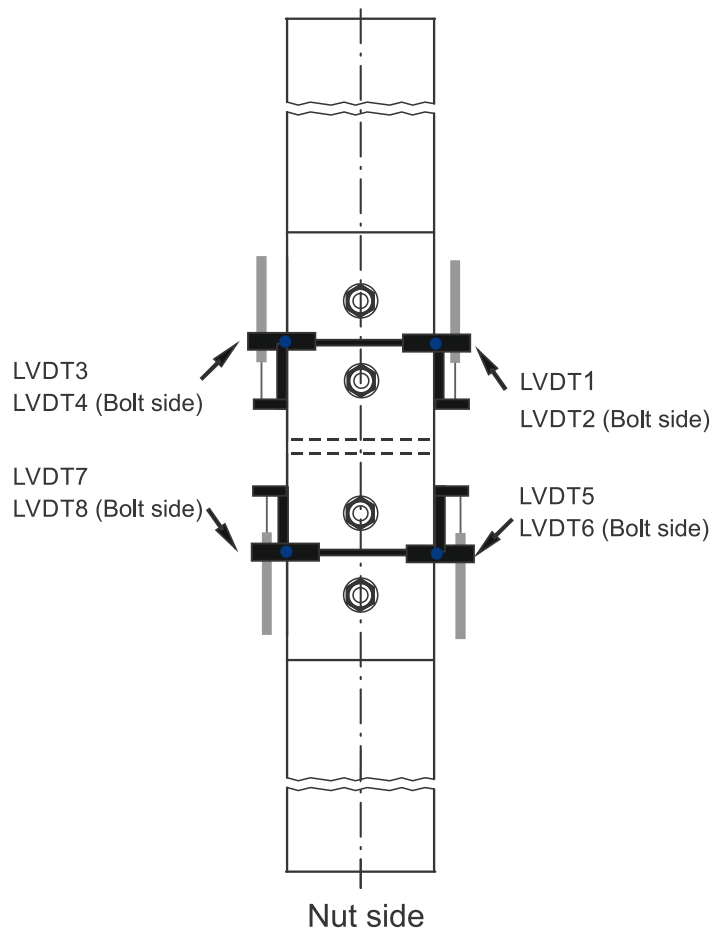
The first test specimens of a new surface roughness/coating series of static slip factor tests are necessary to determine the correct load head speed of a test rig. Unless the load duration of these initial tests are outside a time frame ranging from 5 to 20 min, the test results can be used as part of the series of 4 static slip factor tests.

The test duration has no influence on the scatter of the test results neither on the determination of the sensitivity of the investigated coating to creep.

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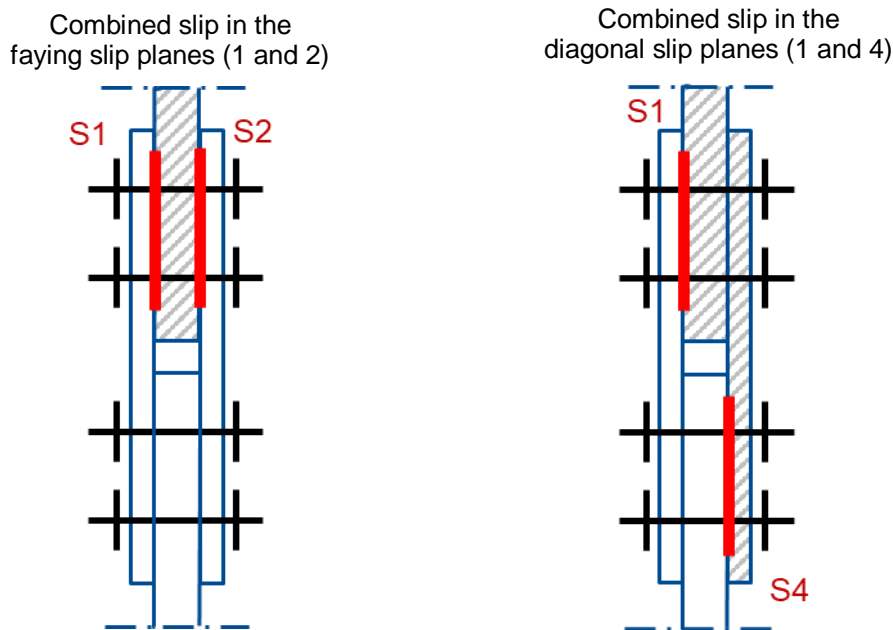
## 4.5 Measurement of the slip

The slip has to be measured in the direction of the applied load as the relative displacement between specific points on the inner (b) and cover plates (a and c), as shown in Figure 3 and Figure 5. The slip shall be measured in eight different positions for each end and each side of the specimen separately at points a, b and c in the centre of the upper and lower bolt group. Two slip values have to be determined based on eight measured displacements by considering the type of failure mode which can be a combination of slip in the faying slip planes (1 and 2) or (3 and 4) or diagonal in the slip planes (1 and 4) or (2 and 3), see Figure 3 and exemplary Figure 6.



**Figure 5** Positions of measurement of the slip

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**Figure 6** Exemplary two possible combined slip planes: faying slip planes (1 and 2) (left) and diagonal slip planes (1 and 4) (right)

#### 4.6 Measurement of the preload in the bolts

The determination of the slip factor according to EN 1090-2 is based on the nominal preload level. According to EN 1090-2, the preload in the bolts shall be directly measured with an equipment with an accuracy of  $\pm 5\%$ . Various possibilities exist to measure continuously during the testing time the preload in the bolts. It is recommended to use either

- instrumented bolts with implanted and calibrated strain gauges in the bolts or
- stiff calibrated load cells.

For detailed information regarding the production of instrumented bolts and stiff load cells as well as their calibration see deliverable D1.1 and exemplary [3], [5], [11].

It has to be mentioned that the use of load cells leads to a larger 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 initial 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. Furthermore, care has to be taken that the load cells are stiff enough.

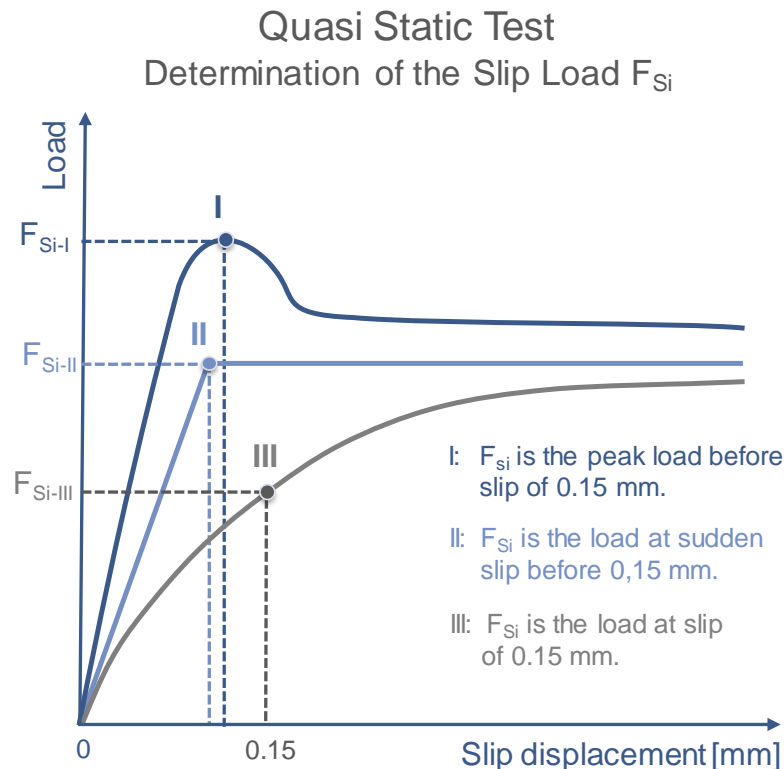
Due to the well-known fact that with smaller bolt length the preload losses in the bolts increase and due to a decrease in preload losses using larger load cells, higher slip load occurs using load cells which lead to an overestimation of the slip factor. For this reason, so far possible, the method using implanted strain gauges should be preferred.

#### 4.7 Determination of the slip load $F_{Si}$

The determination of the slip load  $F_{Si}$  depends on the various load-slip displacement behaviours as shown in Figure 7. The maximum allowable slip deformation is defined

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to 0.15 mm. If a peak load occurs below a slip deformation of 0.15 mm, the peak load can be chosen as the slip load. Does a sudden slip occur below a slip deformation of 0.15 mm, the load at sudden slip has to be chosen. In all other cases, the load at a slip deformation of 0.15 mm defines the slip load.



**Figure 7** Determination of the slip load  $F_{Si}$  in the quasi static slip factor test

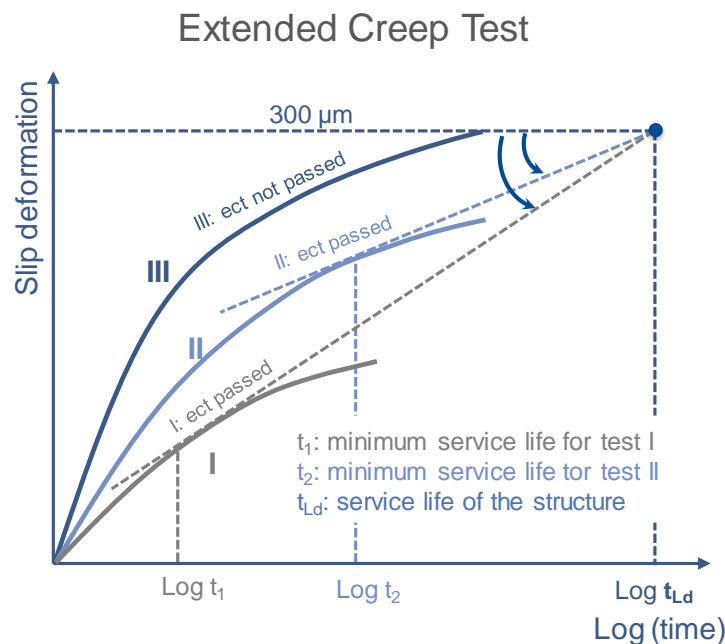
## 4.8 Execution of slip factor tests

In the first step, four static tests (st) are carried out which lead to eight individual slip factors. In the second step, a creep test (ct) has to be performed, whereby the specimen shall be loaded with a constant load level of 90 % of the mean slip load  $F_{Sm}$  from the first four static tests ( $0.9 \cdot F_{Sm}$ ) for at least 3 hours. The creep test is passed when the difference between the slip at 5 min and 3 hours after application of the constant load does not exceed 0.002 mm. If this is the case, the characteristic value of the slip factor  $\mu$  shall be calculated as the 5 % fractile value according to EN 1090-2, Annex G.

The standard deviation  $s_{F_s}$  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.

In case that the difference between the slip at 5 min and 3 hours exceeds 0.002 mm, at least three extended creep tests are foreseen. The long term creep behaviour is evaluated by using a displacement-log time curve for the results of the extended creep tests, see Figure 8. The slip displacement-log time curve may be extrapolated when a tangent can be determined with sufficient accuracy. For the extended creep tests, the testing load has to be decreased (exemplary to 75 %, 60 %, 50 % of  $F_{Sm}$ ) in such a way, that a total displacement of 0.3 mm may not be exceeded in the service life of the structure by extrapolating displacement-log time-curves.

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**Figure 8** Displacement-log time curves of extended creep tests for evaluating the creep behaviour

#### 4.9 Step test - Procedure to obtain an initial load level for the extended creep test

The main difficulty encountered in practice is the determination of the load level for a successful extended creep test when the creep test was not passed and extended creep tests are necessary. In the frame of SIROCO, a procedure with two different approaches for evaluating this load level was developed which will be presented in the following. Both approaches are applicable to obtain an initial load level for testing the creep sensitivity of a coating system with the extended creep test. At the obtained load level, the extended creep test will (most probably) pass, according to the requirements of Annex G of EN 1090-2.

The fundamentals of the load level that result from the new procedure are

- (1) the mean slip load  $F_{sm}$  (the result of the 4 static slip factor tests) and
- (2) a test procedure in which the load is increased stepwise and kept constant over a relatively short period.

The new test procedure has been developed in accordance to the long duration tests of ECCS No. 87 [12], which has been improved to a more time-efficient testing procedure. The new test procedure is a short-term stepwise loading test and denoted as “step test”.

The idea behind the step test is that the results of the static slip factor tests, combined with the results of the step test in which the load is increased stepwise and kept constant over a certain period, can be used to obtain an estimation of the initial load level to perform the extended creep tests for creep sensitive coatings.

The initial loading in the step test is set to a percentage of  $F_{sm}$ , e. g. 60 %. The value of this percentage is assumed on the basis that the investigated coating is suitable to be used in slip-resistant connections with a long term slip factor which is at least this

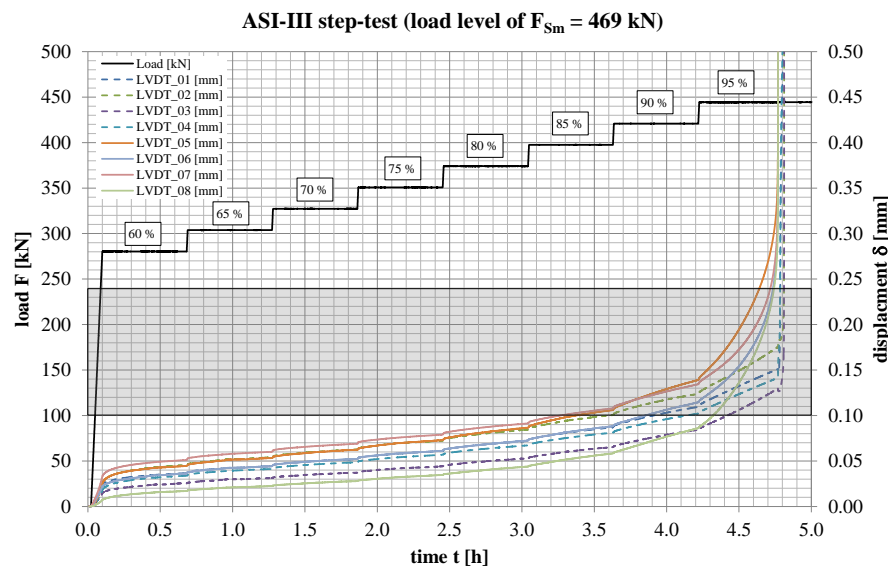
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percentage of the slip factor that results from the quasi static tests. In the ultimate step test procedure, the time over which the load has to be kept constant to a period of 30 min up to 90 min. The initial loading and load increments afterwards have to be kept unchanged. This means, that a step test normally takes 12 h to complete.

As already mentioned, in the frame of SIROCO, two approaches were adopted to use the results of the step test to obtain a sensible load level for the extended creep test.

First approach for evaluation of the step test

In the first approach, the hypothesis is that the load level at which the slip during the step test reaches the transition zone can be taken to perform the extended creep test for the coating system to be tested, see exemplary load-time/displacement-time diagram of a step test for an alkali zinc silicate coating (ASI) in Figure 9.



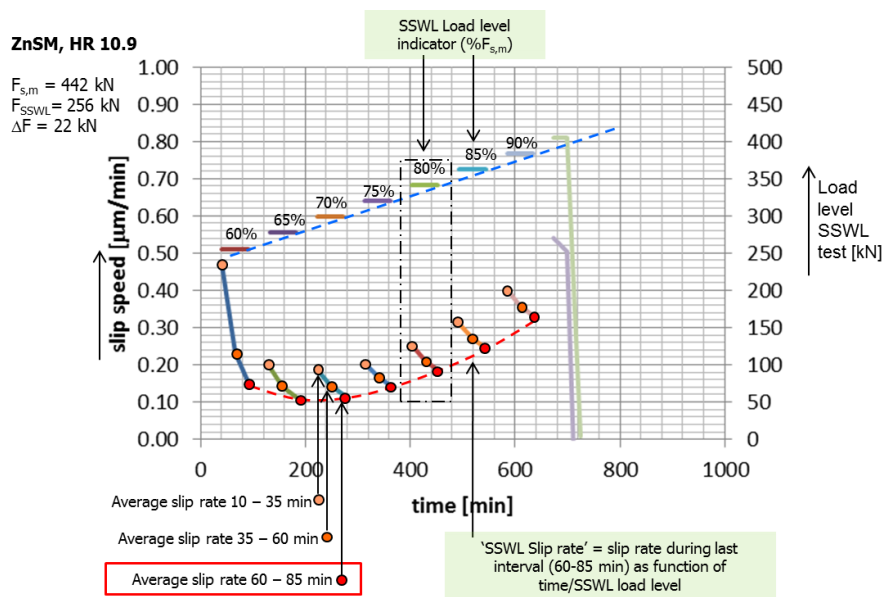
**Figure 9** 1<sup>st</sup> approach: step test of a slip-resistant connection with HV-M20x75 bolts and ASI-III faying surfaces

Second approach for evaluation of the step test

In the second approach, the starting point is that the evolution of the slip speed that is observed during the consecutive load steps of the step test can be used to obtain a sensible load level for the extended creep test. The hypothesis in this approach is that there is a 'critical step test slip speed', which is independent of the coating system that can be used to estimate the long duration slip load level for creep sensitive coatings, see exemplary Figure 10. Load levels with lower step test slip speed would pass the extended creep test, load levels for which a higher slip speed is found would not pass the extended creep test. The critical step test slip speed for all coatings was found to be in the order of magnitude of 0.1 – 0.15  $\mu\text{m}/\text{min}$ . To proof the hypothesis that this speed is critical for all possible coatings, further investigations are needed.



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**Figure 10** 2<sup>nd</sup> approach: step test of a slip-resistant connection with zinc spray metalized (Zn-SM) coating; dotted red line shows the evolution of the step test slip speed for consecutive load steps.

In the frame of SIROCO it could be shown that the developed step test procedure has definitively the potential to estimate the maximum load that can be applied to a creep sensitive coating system without causing displacements exceeding 300 µm during the lifetime of the structure. Nevertheless, additional research is needed to finally proof the value of the step test procedure to indicate the sensitivity to creep.

#### 4.10 Evaluation of the test results and determination of slip factors

The evaluation of the test results and determination of slip factors are carried out by the following equations.

**Individual values of the slip factor  $\mu_i$**

$$\mu_i = \frac{F_{Si}}{4 \cdot F_{p,C}} \quad (9)$$

$F_{Si}$ : individual slip load,

$F_{p,C}$ : specified preload level with

$$F_{p,C} = 0.7 f_{ub} A_s$$

and

$f_{ub}$ : tensile strength of the bolt,

$A_s$ : tensile stress area of the bolt

**Mean value of the slip load  $F_{Sm}$  and standard deviation of the slip load  $s_{Fs}$**

$$F_{Sm} = \frac{\sum F_{Si}}{n} \quad (10)$$

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$$s_{FS} = \sqrt{\frac{\sum (F_{Si} - F_{Sm})^2}{n-1}} \quad (11)$$

n: number of test specimens.

**Mean value of the slip factor  $\mu_m$  and standard deviation of the slip factor  $s_\mu$** 

$$\mu_m = \frac{\sum \mu_i}{n} \quad (12)$$

$$s_\mu = \sqrt{\frac{\sum (\mu_i - \mu_m)^2}{n-1}} \quad (13)$$

n: number of test specimens.

If the creep test is passed, the characteristic value of the slip factor  $\mu_k$  has to be calculated as the 5 % fractile value with a confidence level of 75 %.

**Characteristic value of the slip-factor  $\mu_k$  as 5 %-quantile from n = 10 results with a confidence level of 75 %**

$$\begin{aligned} \mu_k &= \mu_m - 2,05 \cdot s_\mu \\ &= \mu_m \cdot (1 - 2,05 \cdot V) \end{aligned} \quad (14)$$

$$\text{with } V = \frac{s_\mu}{\mu_m} \quad (15)$$

V: coefficient of variation,  
 $s_\mu$ : standard deviation of the slip factor,  
 $\mu_m$ : mean value of the slip factor from ten measurements.

**4.11 Hot-dip galvanized surfaces**

A hot-dip galvanized coating will typically comprise a series of Fe-Zn alloy layers covered with an outer layer of zinc. The Fe-Zn alloy layers are harder than the outer zinc layer and are often harder than the steel substrate. The Fe-Zn layers will control the slip behaviour. Higher levels of zinc layer removal will lead to higher slip factors, but the extent of blasting required will depend on the proportion of outer zinc layer within the original coating. Simple modifications of the zinc surface by needle gun treatment did not significantly increase the slip factor. Sweep blasting of a hot dip galvanized coating produces slip factors that are consistent with the values included in FprEN1090-2 and when blasting is combined with the application of an alkali-zinc silicate (ASl) coating higher slip factors are produced. As the slip factor highly depends on the creep sensitivity of the surfaces, extended creep tests are necessary for hot-dip galvanized surfaces and a final recommendation regarding the slip factors for hot-dip galvanized surfaces beyond those included in FprEN1090-2 cannot yet be drawn. Although higher slip factors than those included in FprEN1090-2 were achieved in static tests, further investigations are needed to complete extended creep tests. Further work may also consider different types of steels and post-treatments.

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## 4.12 Influence of different surface conditions on the slip factor

The surface condition has a great influence on the slip factor. The creep sensitivity is directly linked to the surface condition. Grit blasted surfaces are not creep sensitive at all whereas coated surfaces are usually creep sensitive. In general, it can be stated, that this leads to higher slip factors for grit blasted surfaces and lower slip factors for coated surfaces.

Table 3 comprises the finally resulting slip factors for carbon steel slip-resistant connections achieved in SIROCO. As far as possible, the values given in FprEN 1090-2 are given as well for comparison reason. It can be seen that especially for grit blasted surfaces alkali-zinc silicate coating (ASI) and thermally sprayed with aluminium (Al-SM) surfaces higher slip factors can be achieved than given in EN 1090-2.

It can be concluded that in special cases it might be of interest to determine the slip factor by testing in order to achieve higher slip factors than tabulated in EN 1090-2.

**Table 3** Slip factors for various surface treatments achieved in SIROCO and compared to FprEN 1090-2 [10]

Surface Treatment	Class <sup>a</sup>	Slip Factor $\mu$	Slip Factor $\mu$
	FprEN 1090-2		SIROCO
Grit blasted Sa 2½ / Rz = 80 $\mu$ m, $F_{p,C}$	A	0.5	0.75
Alkali-zinc silicate coating (ASI) Sa 2½ / Rz = 80 $\mu$ m, 60 $\mu$ m DFT, $F_{p,C}$	B	0.4	0.56
Alkali-zinc silicate coating (ASI) Sa 2½ / Rz = 80 $\mu$ m, 60 $\mu$ m DFT, $F_{p,C}^*$	-	-	0.63
Thermally sprayed with aluminium (Al-SM) 250 $\mu$ m DFT, $F_{p,C}$	B	0.4 (NDFT $\leq$ 80 $\mu$ m)	0.58
Thermally sprayed with zinc (Zn-SM) Sa 3 / Rz = 100 $\mu$ m, 140 $\mu$ m DFT, $F_{p,C}$	B	0.4 (NDFT $\leq$ 80 $\mu$ m)	0.44
Thermally sprayed with zinc (Zn-SM) Sa 3 / Rz = 100 $\mu$ m, 164 $\mu$ m DFT, $F_{p,C}^*$ and 0.9 $F_{p,C}^*$	-	-	0.48
Combination ASI – ZnSM Sa 2½ / Rz = 100 $\mu$ m, 55 $\mu$ m / 170 $\mu$ m DFT, $F_{p,C}$	-	-	0.44
Combination ASI – ZnSM Sa 3 / Rz = 100 $\mu$ m, 55 $\mu$ m / 170 $\mu$ m DFT, 0.9 $F_{p,C}^*$	-	-	0.55

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## 5 Proposed amendments to EN 1993-1-8 and EN 1090-2

### 5.1 EN 1993-1-8

The slip-resistance depends highly on the preload level of the bolting assemblies. It could be shown that with lower preload levels, higher slip factors can result for coated carbon steel slip-resistant connections. Furthermore, in some applications the re-use of components of the bolting assemblies might be necessary, e. g. bearings. For this reason, it should be possible to apply lower preload levels than  $F_{p,C}$ , which can be used not only for the determination of the slip-resistance of slip-resistant connections but also for preloaded tension connections. EN 1090-2 already allows lower preload levels than  $F_{p,C}$ .

### 5.2 EN 1090-2

Some findings of SIROCO have already been implemented in the latest draft of Annex G of FprEN 1090-2:2017 which will be published in 2018. These are:

- Clarification of wording
- Defining of the slip planes
- Determination of the slip load  $F_{Si}$
- Positioning of the displacement measurement.

Further amendments will be

- Enhancement of the slip factor for grit blasted surfaces
- Enhancement of slip factors for thermally sprayed with aluminium (Al-SM) surfaces
- Additional slip factors for surface treatments not covered yet, e. g. combinations as alkali-zinc silicate coating and thermally sprayed with zinc (ASI – ZnSM)
- Implementing the step test in order to be able to assume a load level for extended creep tests

The values of Table 4 will be used for formulating the amendment.

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background documentation****Table 4** Slip factors for various surface treatments achieved in SIROCO and compared to FprEN 1090-2 [10]

Surface Treatment	Class <sup>a</sup>	Slip Factor $\mu$	Slip Factor $\mu$
	FprEN 1090-2		SIROCO
Grit blasted Sa 2½ / Rz = 80 $\mu\text{m}$ , $F_{p,c}$	A	0.5	0.75
Alkali-zinc silicate coating (ASI) Sa 2½ / Rz = 80 $\mu\text{m}$ , 60 $\mu\text{m}$ DFT, $F_{p,c}$	B	0.4	0.56
Alkali-zinc silicate coating (ASI) Sa 2½ / Rz = 80 $\mu\text{m}$ , 60 $\mu\text{m}$ DFT, $F_{p,c}^*$	-	-	0.63
Thermally sprayed with aluminium (Al-SM) 250 $\mu\text{m}$ DFT, $F_{p,c}$	B	0.4 (NDFT $\leq$ 80 $\mu\text{m}$ )	0.58
Thermally sprayed with zinc (Zn-SM) Sa 3 / Rz = 100 $\mu\text{m}$ , 140 $\mu\text{m}$ DFT, $F_{p,c}$	B	0.4 (NDFT $\leq$ 80 $\mu\text{m}$ )	0.44
Thermally sprayed with zinc (Zn-SM) Sa 3 / Rz = 100 $\mu\text{m}$ , 164 $\mu\text{m}$ DFT, $F_{p,c}^*$ and 0.9 $F_{p,c}^*$	-	-	0.48
Combination ASI – ZnSM Sa 2½ / Rz = 100 $\mu\text{m}$ , 55 $\mu\text{m}$ / 170 $\mu\text{m}$ DFT, $F_{p,c}$	-	-	0.44
Combination ASI – ZnSM Sa 3 / Rz = 100 $\mu\text{m}$ , 55 $\mu\text{m}$ / 170 $\mu\text{m}$ DFT, 0.9 $F_{p,c}^*$	-	-	0.55

Essen, 24.03.2018



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