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# *Behaviour of slip-resistant stainless steel bolted connections*

**5th International Experts Seminar**
**Stainless Steel in Structures**
18-19 September 2017
London, UK

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- Conclusions


RFCS-Project SIROCO
Execution and reliability of slip-resistant connections for steel structures using CS and SS



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# Categories of Bolted Connections acc. to EN 1993-1-8

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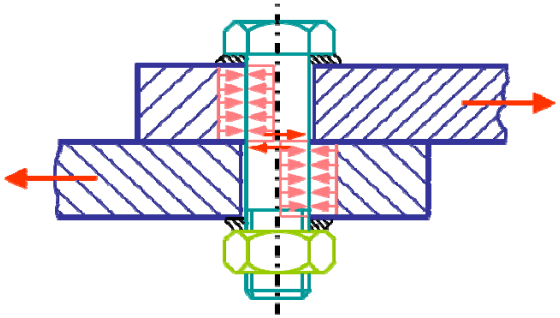
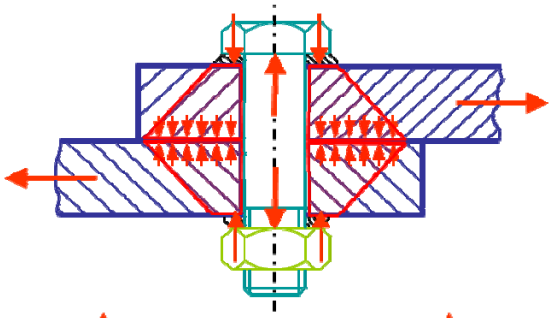
## Shear Connections

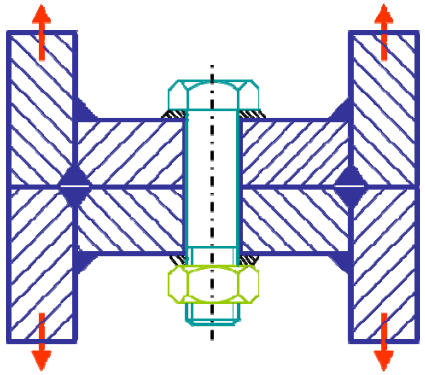


**Category A**
Bearing Type
Bolt Classes 4.6 to 10.9

**Category B | C**
Slip-Resistant at Serviceability/Ultimate Limit State
Bolt Classes 8.8 and 10.9

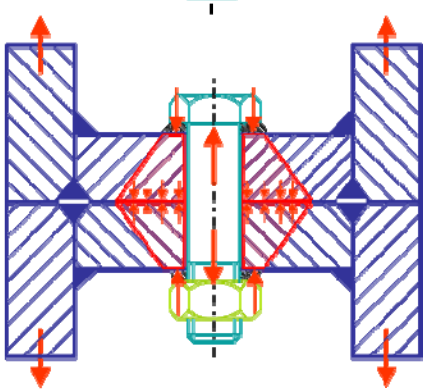


## Tension Connections



**Category D**
Non-Preloaded Tension Type
Bolt Classes 4.6 to 10.9

**Category E**
Preloaded Tension Type
Bolt Classes 8.8 and 10.9



## Target Level II
### Improvement of serviceability

- ⇒ Non preloaded designed categories A (and D) acc. to EN 1993-1-8, nevertheless preloaded for qualitative improvement of serviceability
- ⇒ Slip minimization
- ⇒ Limiting deformation

## Target Level I
### Guarantee structural safety

- ⇒ Categories B, C und E acc. to EN 1993-1-8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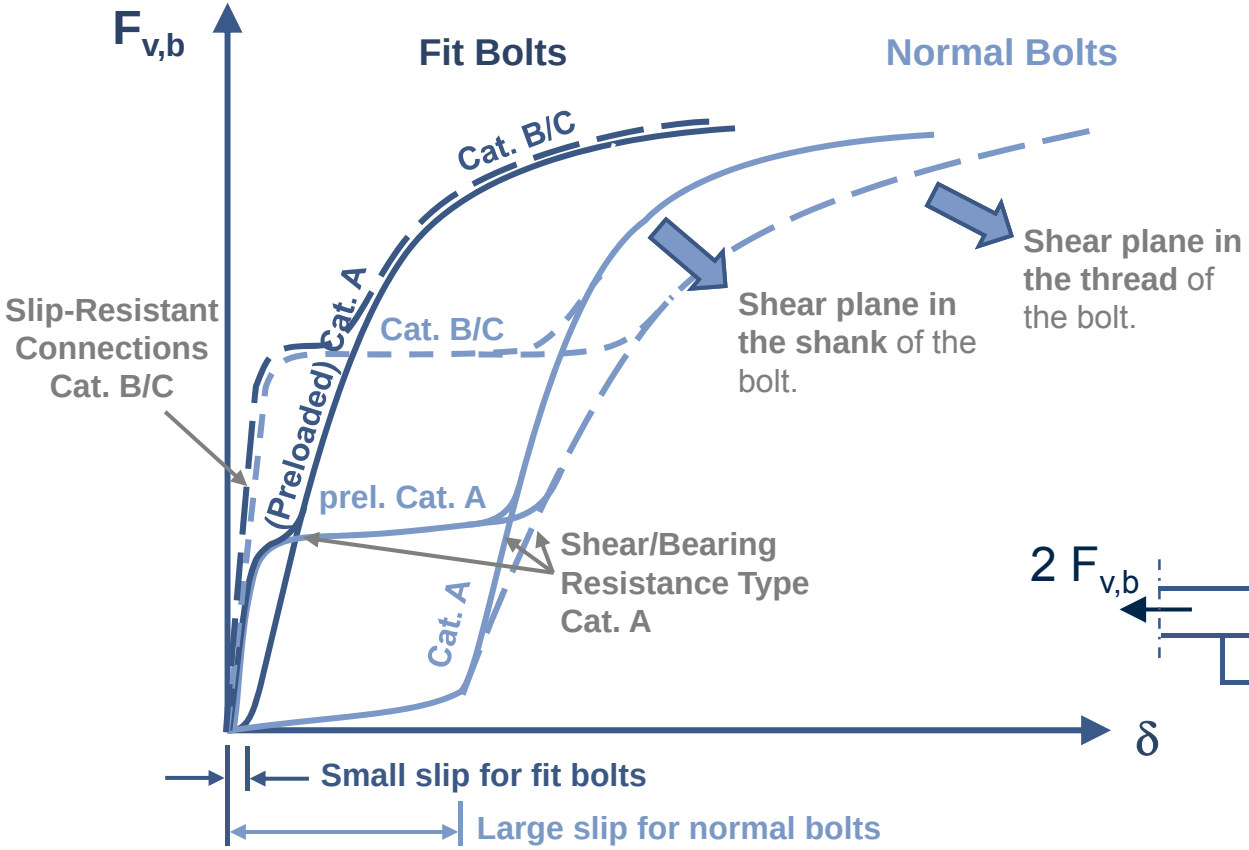
# Slip-Resistant Bolted Connections …

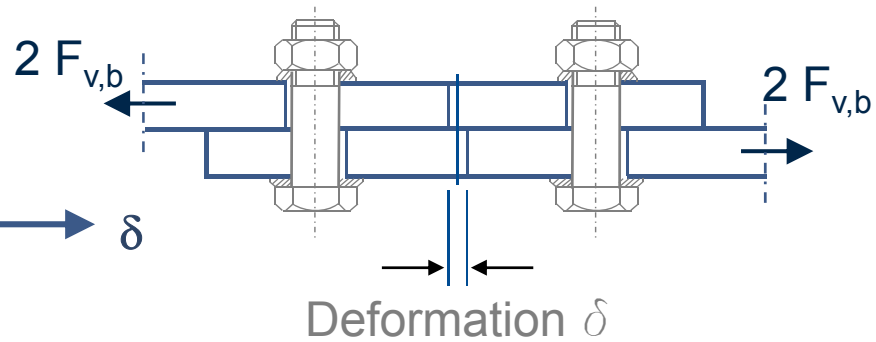
…are required, when

**deformations in bolted connections must be limited**

to pre-defined values either for serviceability or ultimate limit reasons.



© Cteam



# Slip-Resistant Connections acc. to EN 1993-1-8

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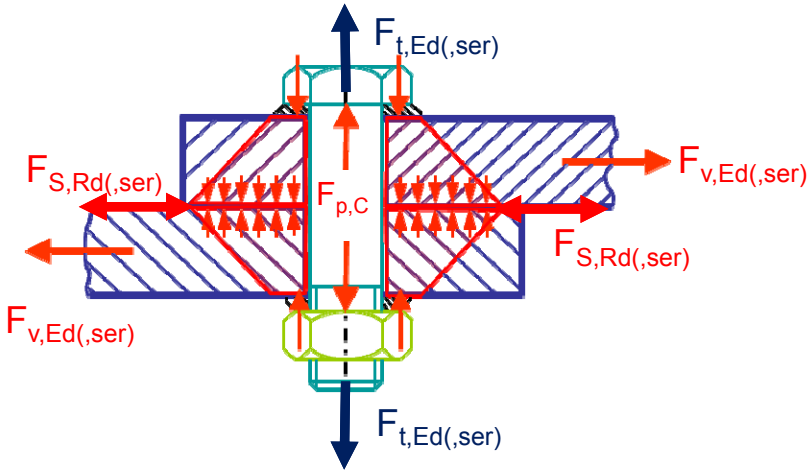
## Slip-Resistant Connection - Categories B | C

Slip-resistant at serviceability (Cat. B) and at ultimate (Cat. C) Bolt grades 8.8 and 10.9

Slip-Resistant at ULS




Factor for the hole detail $k_s$
Normal hole: $k_s = 1{,}0$

Number of Friction Surfaces

Preload $F_{p,C}$

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

Slip Factor $\mu$

External Load $F_{t,Ed}$

Partial Safety Factor $\gamma_{M3}$

| Surface Treatment | Class | Slip Factor $\mu$ |
|---|---|---|
| **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 b and with alkali-zinc silicate paint with a nominal thickness of 40 µm to 80 µm. | B | 0.4 |
| Surfaces blasted with shot or grit:<br>a) coated with alkali-zinc silicate paint with a nominal thickness of 40 µm to 80 µm;<br>b) thermally sprayed with aluminium or zinc or a combination of both to a nominal thickness not exceeding 80 µm | B | 0.4 |
| Surfaces hot dip galvanized to EN ISO 1461 and flash (sweep) blasted | C | 0.35 |
| Surfaces cleaned by wire brushing or flame cleaning, with loose rust removed | C | 0.3 |
| **Surfaces as rolled** | **D** | **0.2** |

EN 1090-2, 8.4

# Slip Factor Test acc. to Annex G of EN 1090-2

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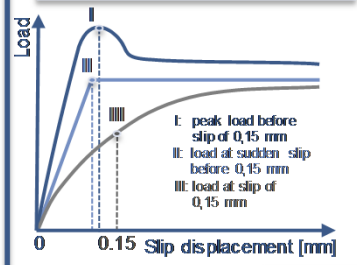
Test Specimen Geometry M20 acc. to EN 1090-2

## Improved Slip Factor Test Procedure acc. to Annex G of EN 1090-2

**Step 1**

**4 Quasi Static Tests**

**Mean Slip Load $F_{sm}$ (on the basis of first 4 tests)**




**Step 2**

**1 Creep Test** (loaded with 90% $F_{sm}$)

**Slip difference between 5min and 3h ≤ 0.002 mm**

Yes / No

**Mean Slip Load $F_{sm}$ (on the basis of all 5 tests)**

**Individual Slip Factors ($\mu_i$)**
**Mean Slip Factor ($\mu_m$)**

$$\mu_i = \frac{F_{Si}}{4 \cdot F_{p,C}}$$

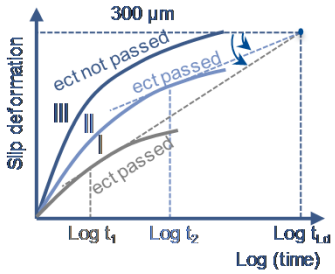
**Coefficient of Variation for 5 Tests V ≤ 8%**

No → **Additional Tests**

Yes → **$\mu_{5\%}$ (5 %-Fractile)**

**Step 3**

**3 Extended Creep Tests** (on specific load level)




**Displacement during design life (50 years) ≤ 0.3 mm**

**$\mu$** (calculated on the basis of the specific load for which the extended creep test is passed)

# Determination of the Slip Factor acc. to EN 1090-2

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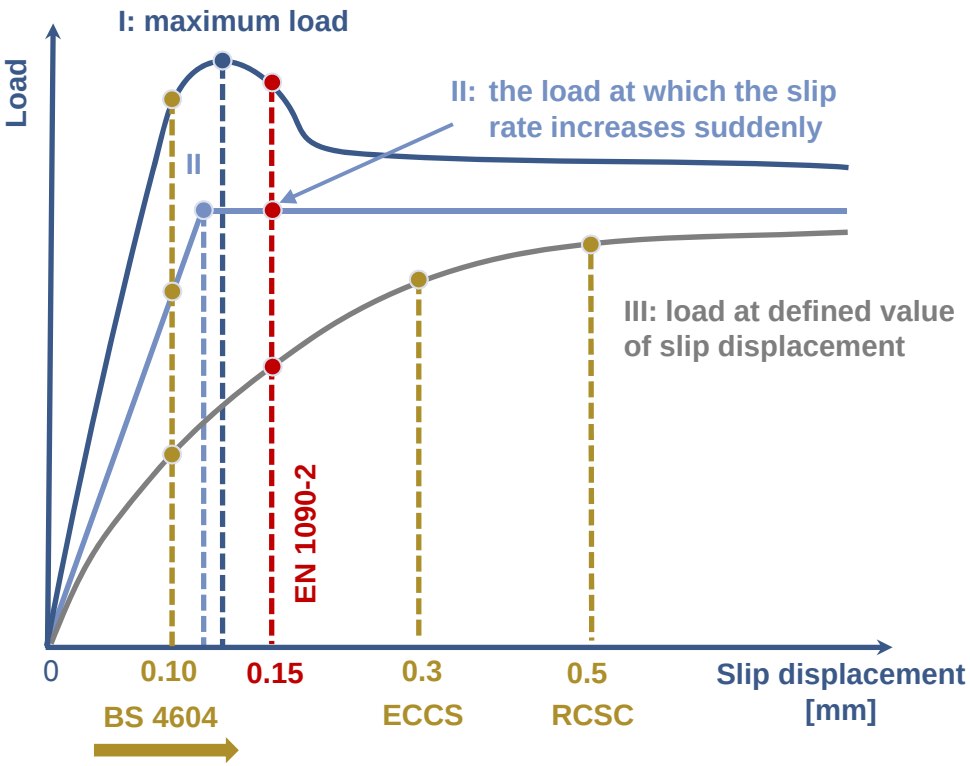
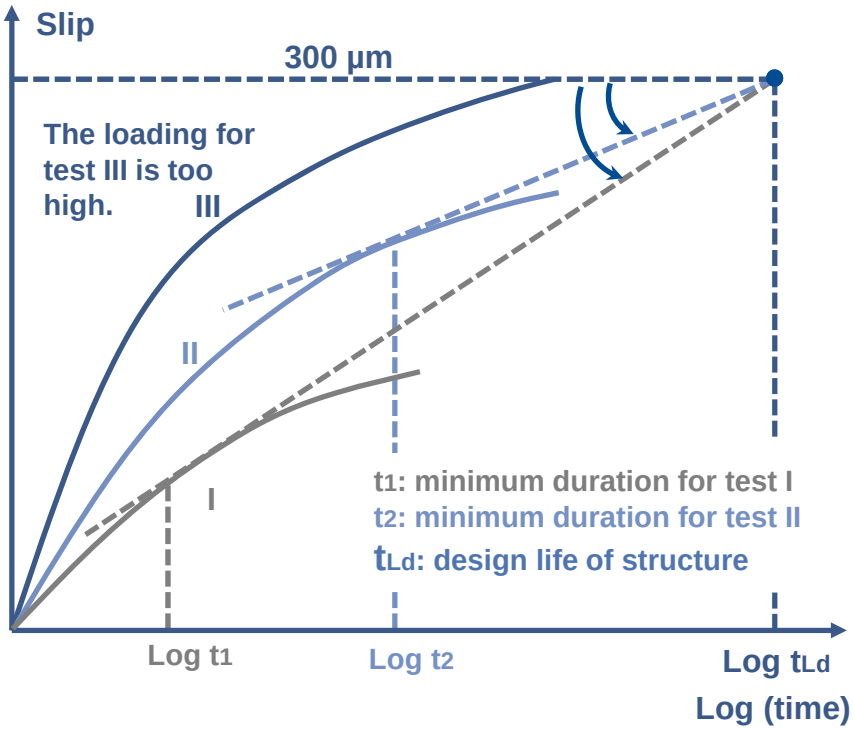
## Quasi Static Test
Determination of the Slip Load $F_{Si}$




## Extended Creep Test



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# Measurement of the Preload in the Bolts by Load Cell

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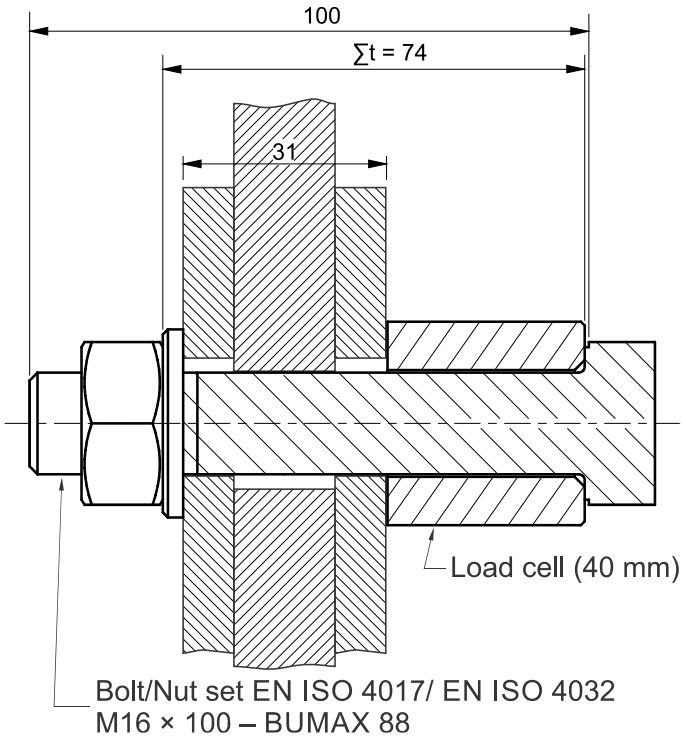


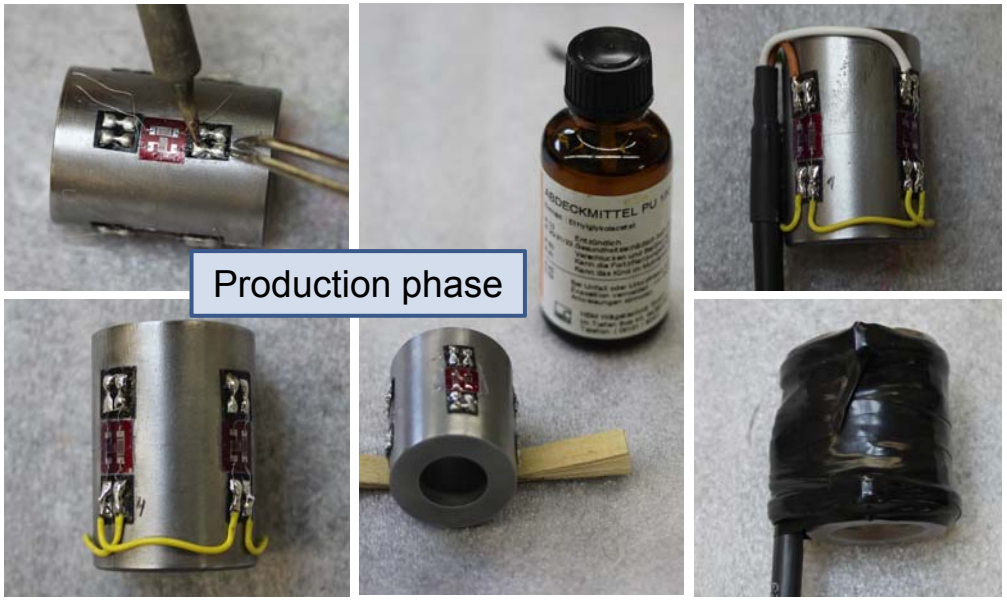


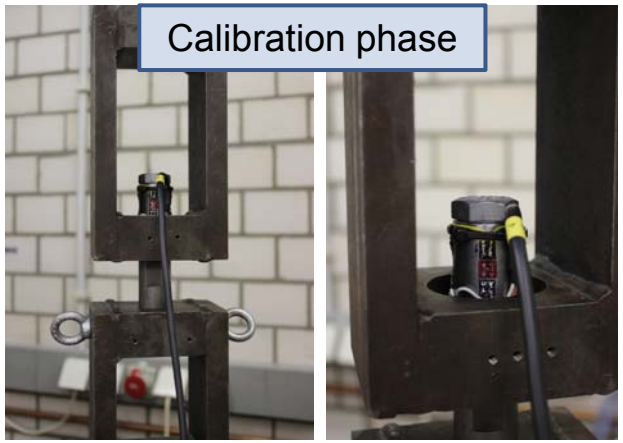


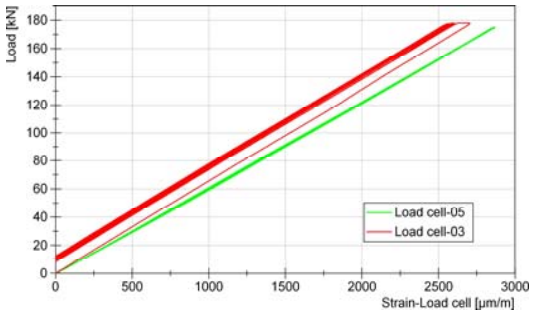


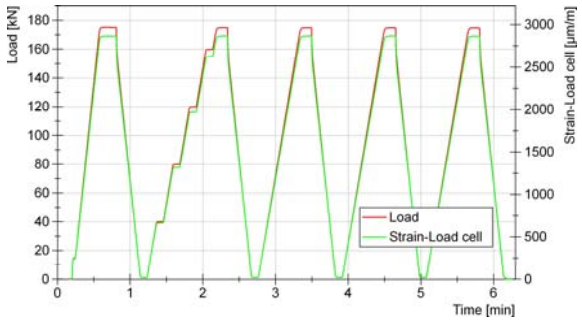





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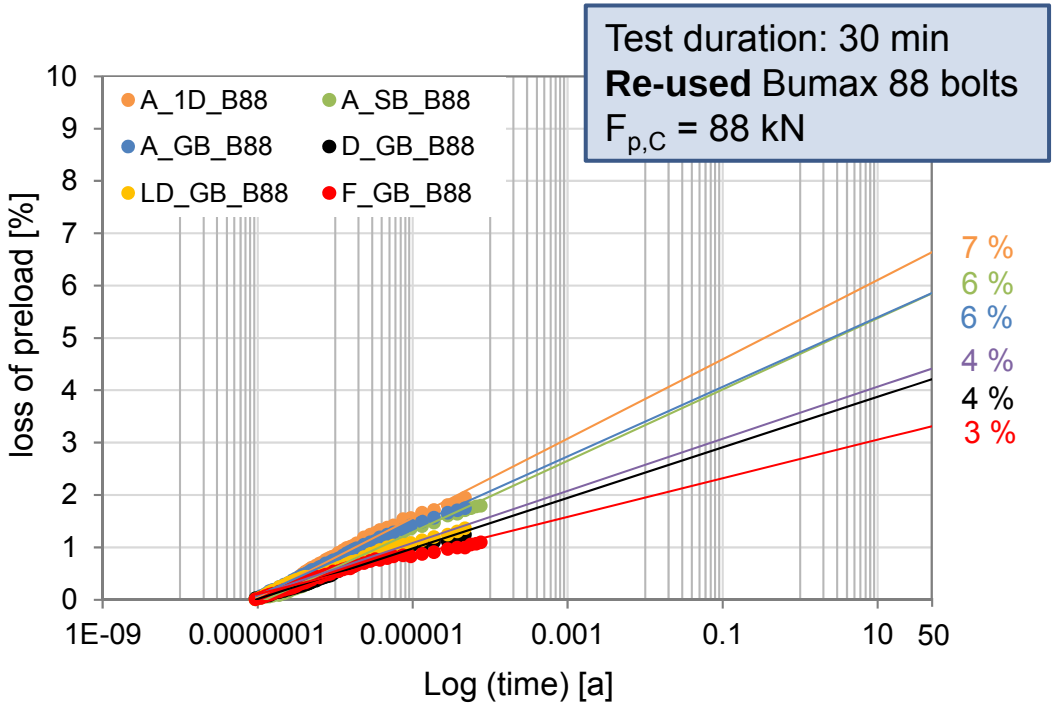
# Loss of Preload

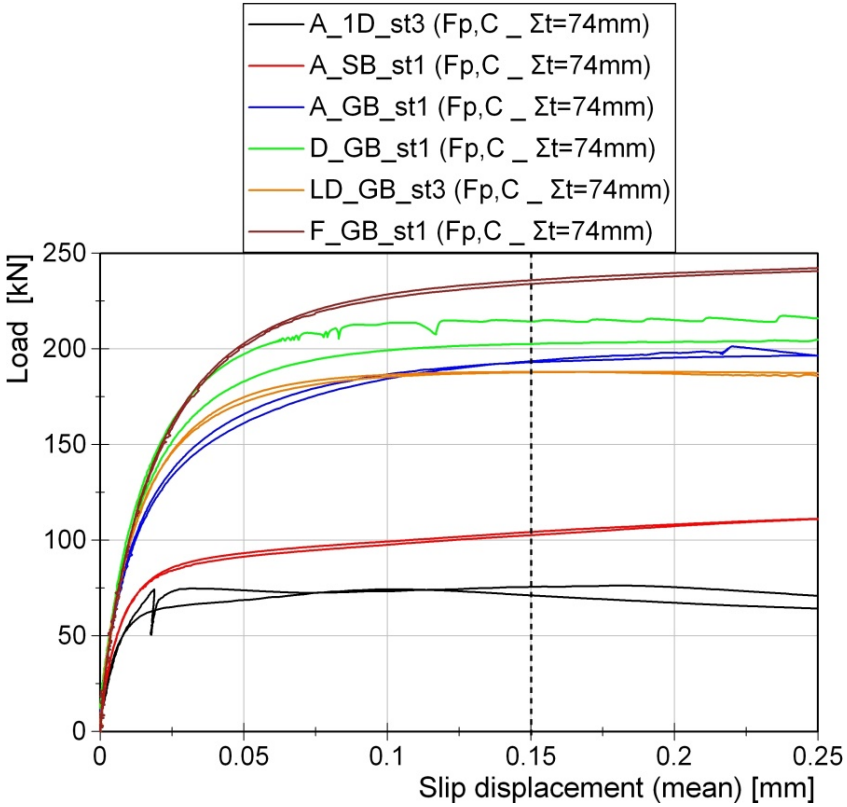


Using re-used bolt sets ⇒ preload losses are mainly caused by the plate material.

When the bolt is re-used ⇒ the additional creep/relaxation in the bolt set is negligible

Preload losses in 50 years ⇒ for new bolts ⇒ about **10 %**

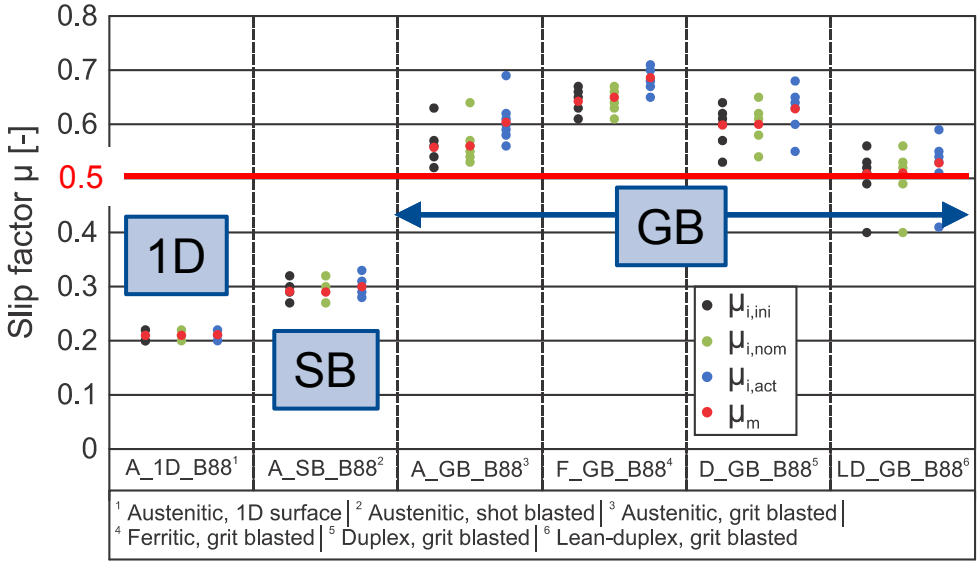
# Static Slip Factor Tests – Bumax 88




Austenitic bolts M16, class 8.8 (Bumax 88)

Stainless steel grades

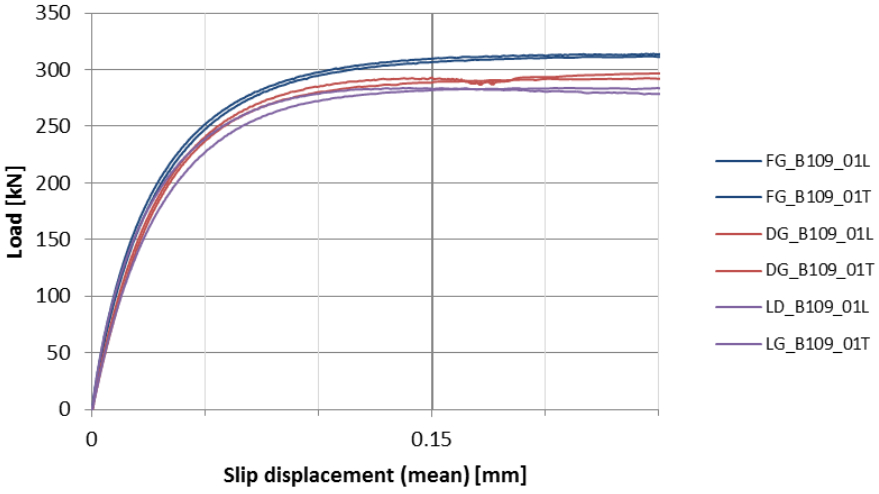
- austenitic (1.4404) - A
- duplex (1.4462) - D
- lean-duplex (1.4162) - LD
- ferritic (1.4003) - F

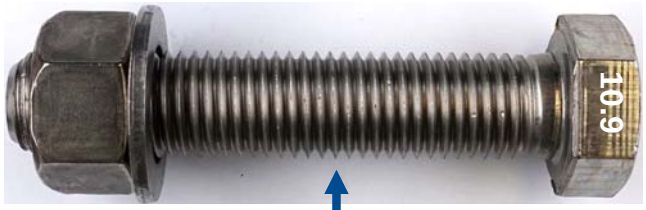



Typical surface finishes

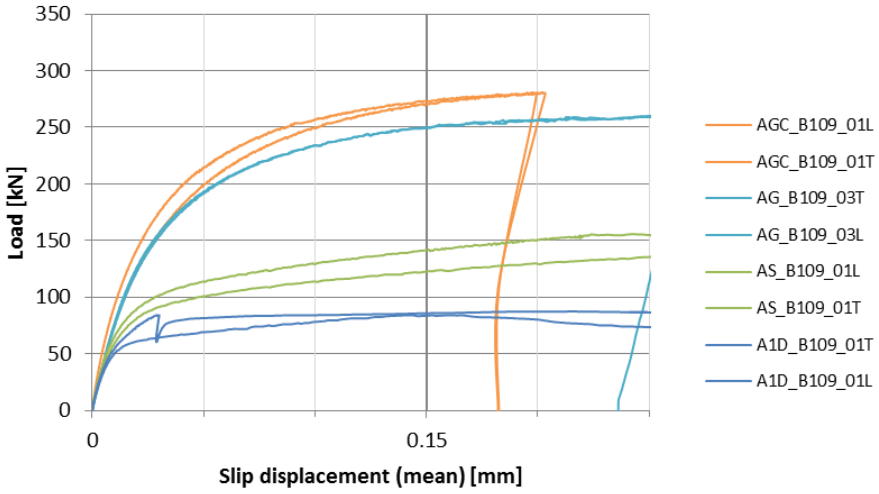
- 1D
- shot blasted (SB)
- grit blasted (GB)

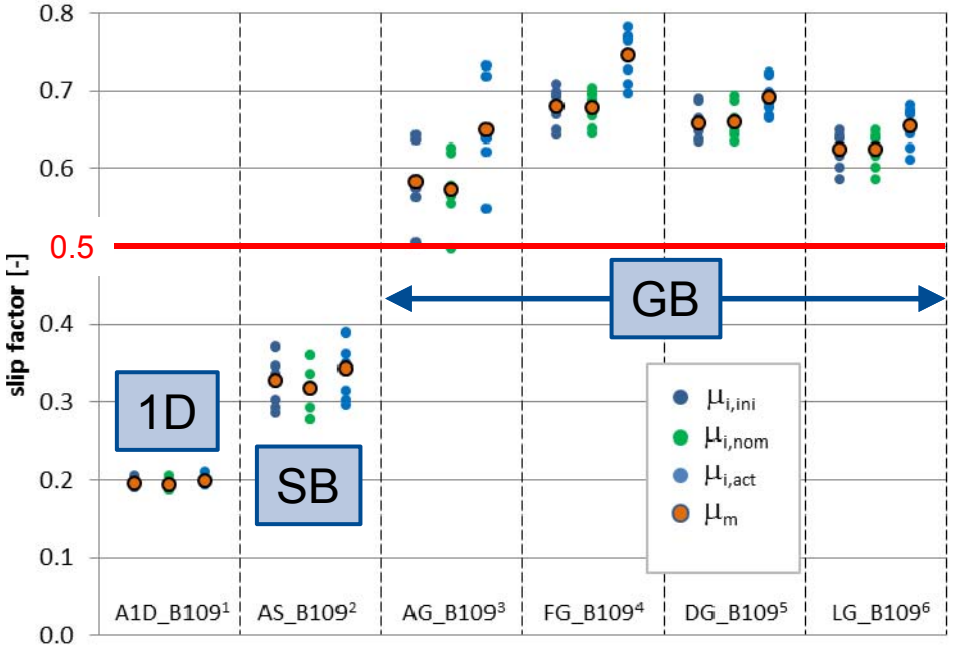
# Static Slip Factor Tests – Bumax 109




Austenitic Bolts M16, Class 10.9 (Bumax 109)



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# Topography Between Contact Surfaces

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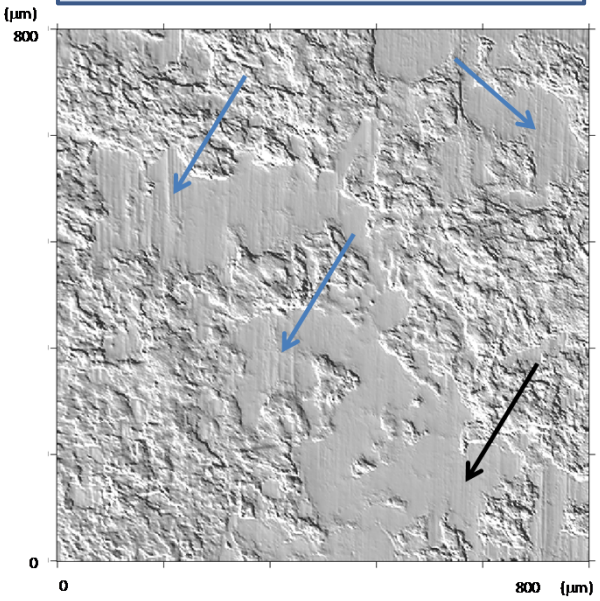
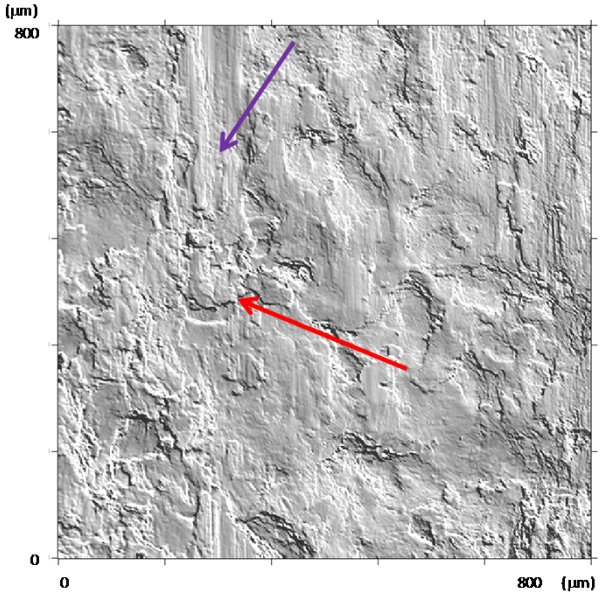
## Austenitic 1.4404 specimens after slip factor test

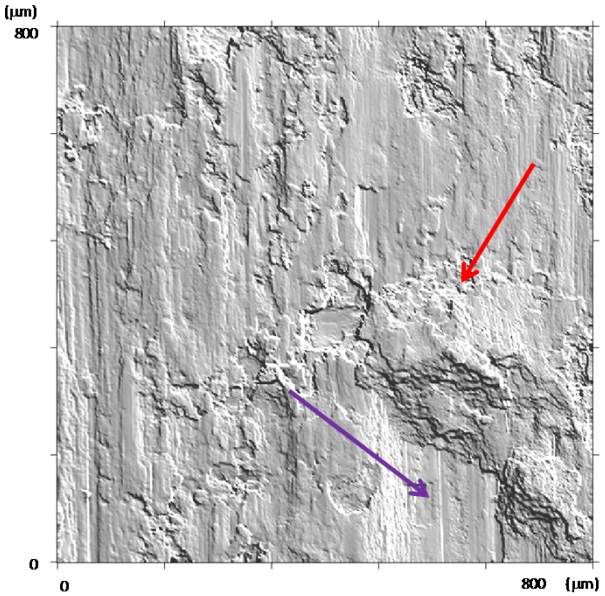
**1D surface**




**Shot blasted surface**




**Grit blasted surface**




Flat and uniform contact spots ⇒ black arrow
Sliding can be demonstrated by the scratches ⇒ blue arrows
Cold welding ⇒ red arrows
Deep scratches made by the cold welds ⇒ magenta arrow



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# Creep Tests

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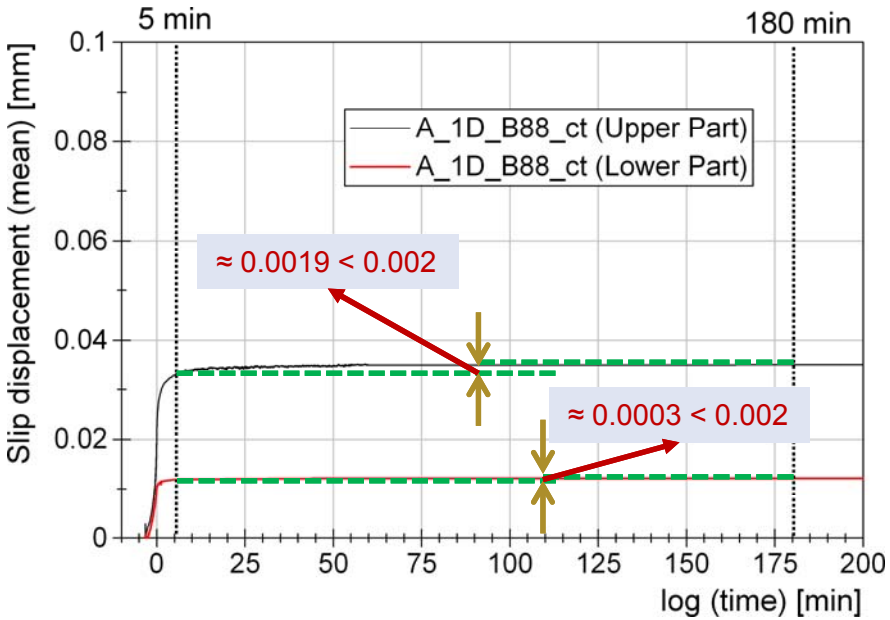
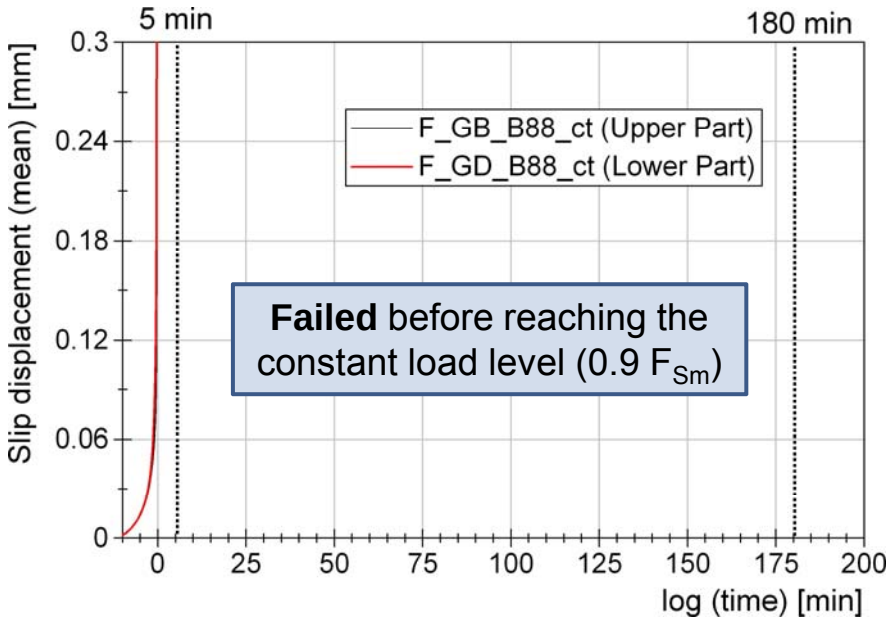
**Austenitic 1.4404 – 1D**




**Ferritic 1.4003 – Grit blasted**




The creep test was passed for:

- Bumax 88 all series except the Ferritic/GB specimen
- Bumax 109 all series except the Austenitic/1D specimen.

⇒ Almost all creep tests were passed, however, extended creep tests were additionally conducted.

# Extended Creep Tests

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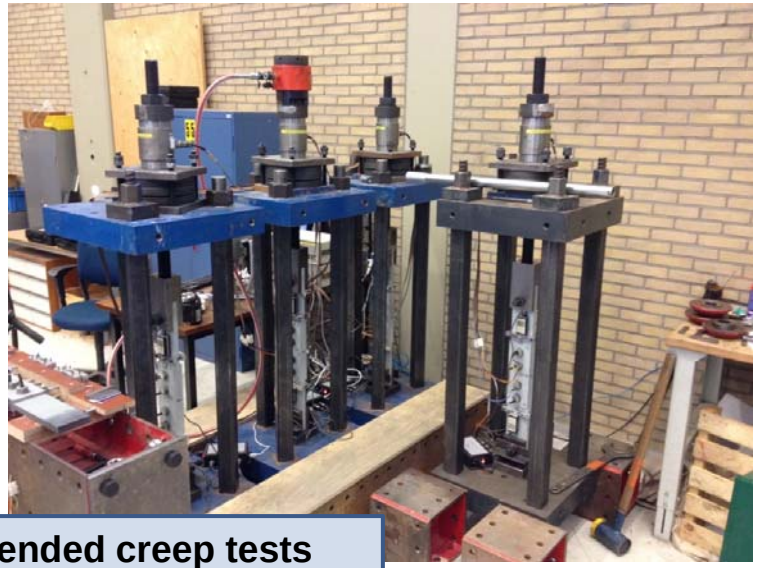
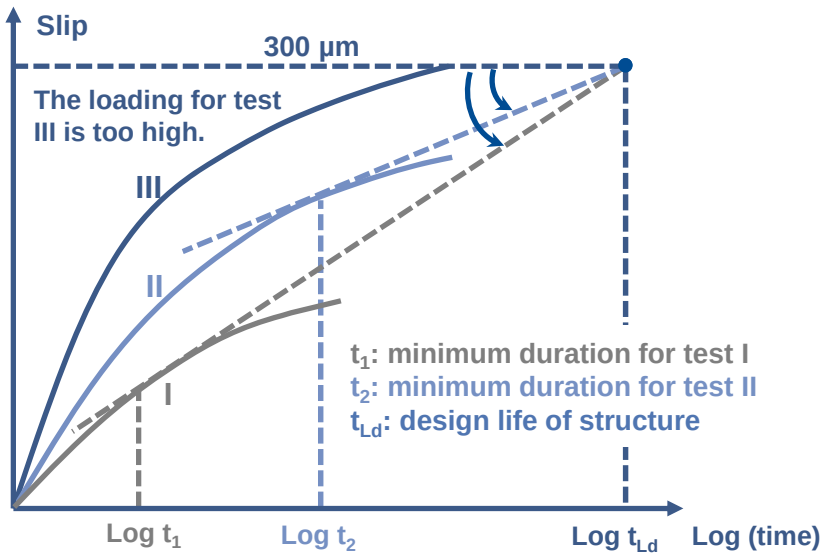
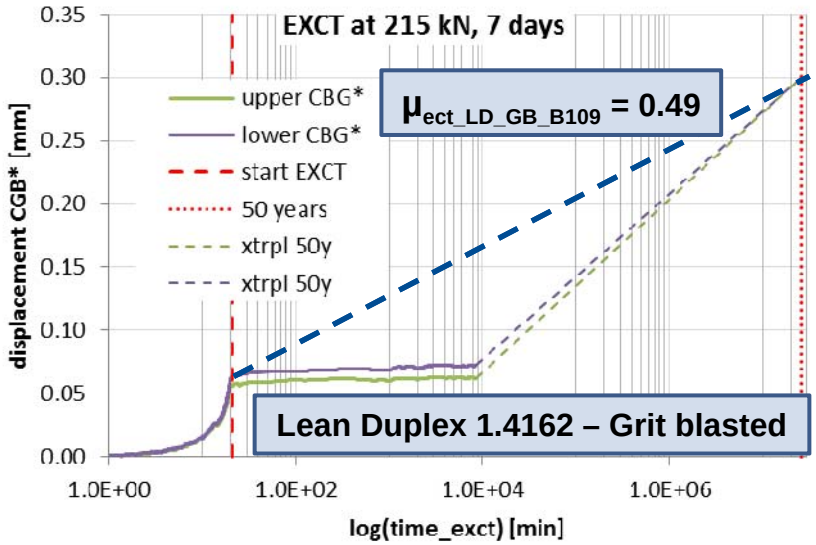


**Test rigs for extended creep tests**



# Extended Creep Tests

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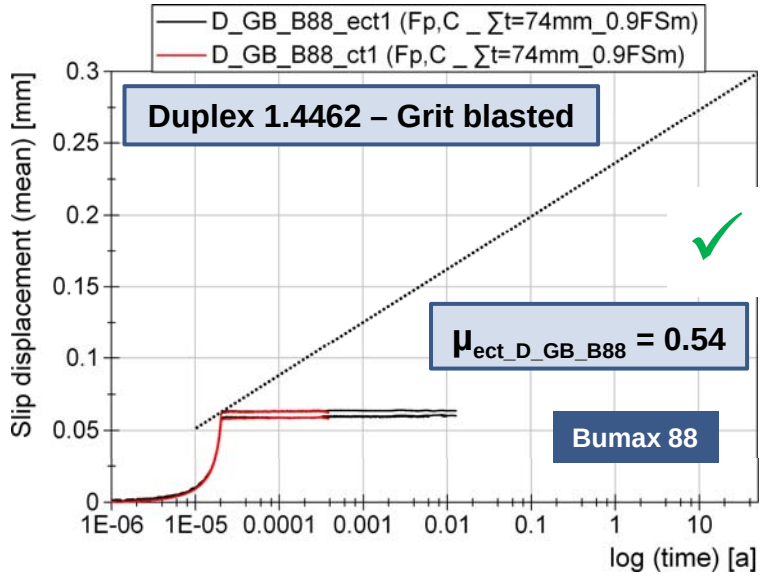


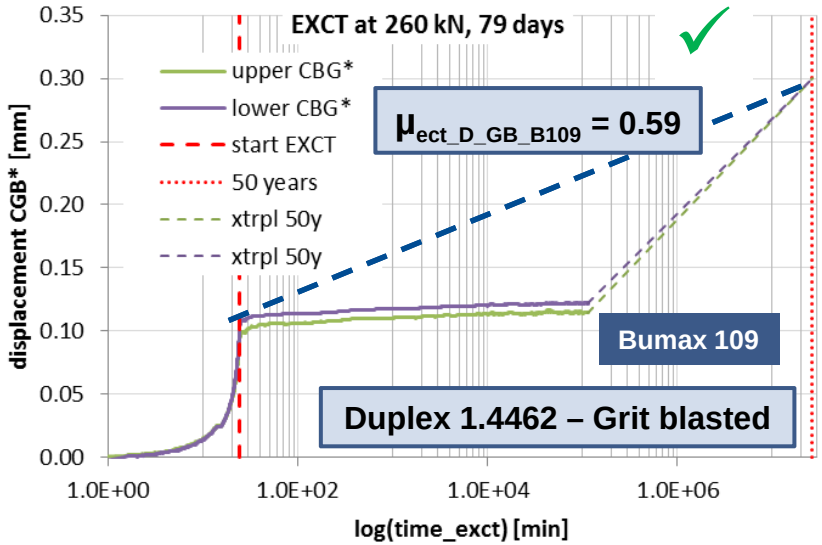


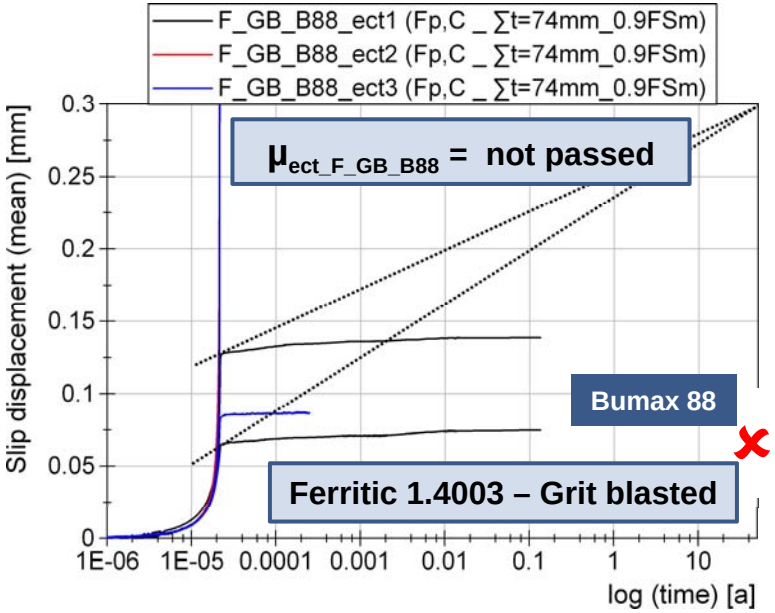


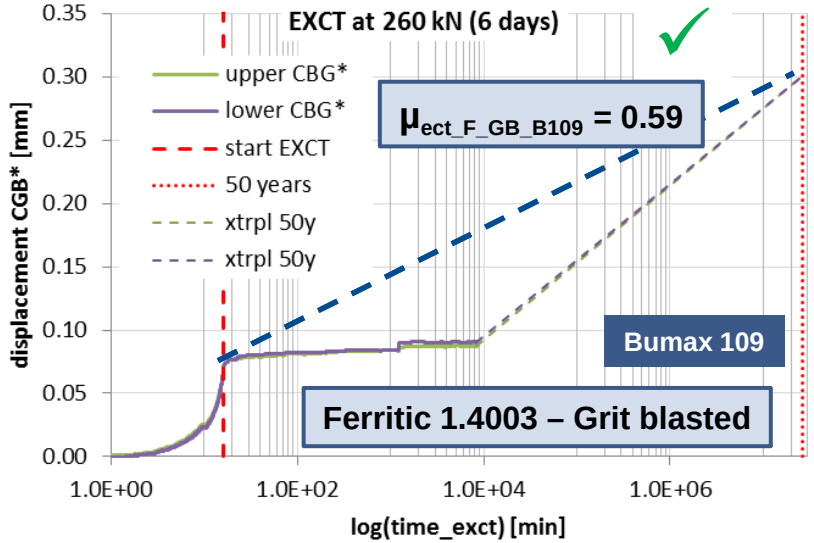

# Extended Creep Tests

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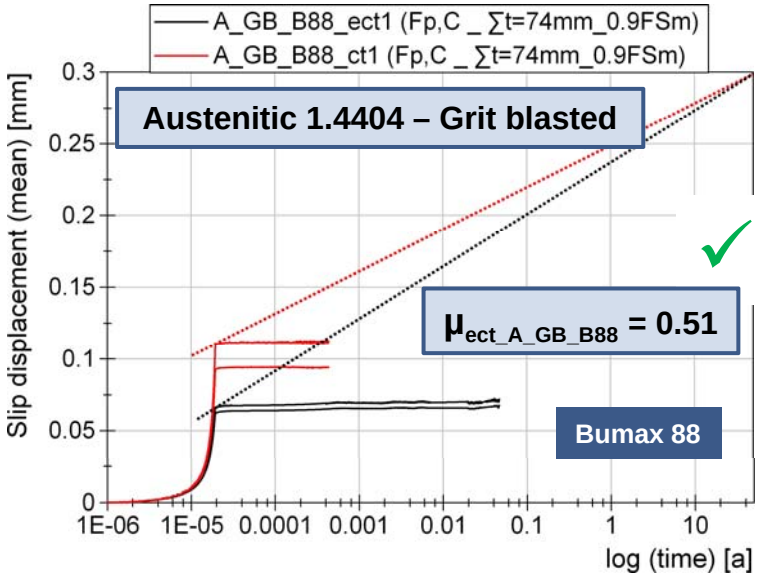


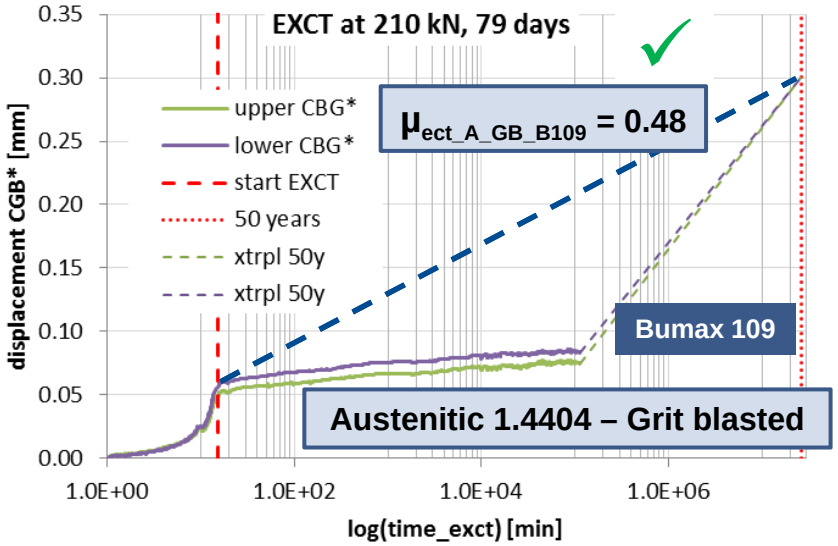


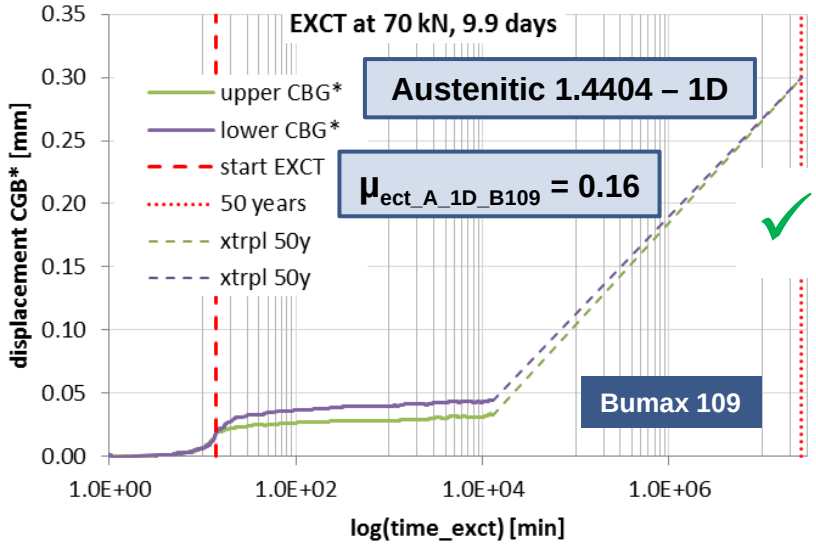


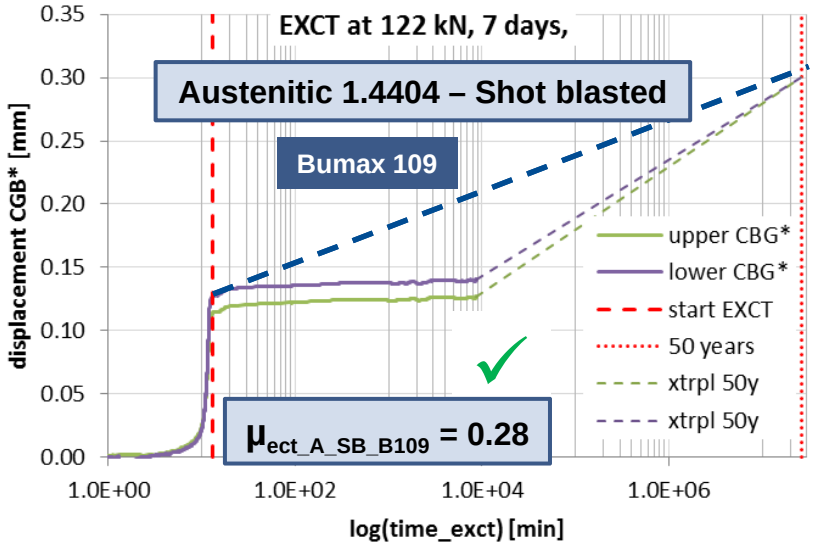

# Slip Factors for Stainless Steel

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| Steel grade | | Surface finish | Bolt grade<br>Preload level: Fp,C | Final slip factor $\mu_{5\%}$ / $\mu_{ect}$ |
|---|---|---|---|---|
| Austenitic | 1.4404 | 1D | Bumax 88 | 0.2/- |
| | | Grit blasted | | 0.49/0.51 |
| Duplex | 1.4462 | | | 0.54/0.54 |
| Austenitic | 1.4404 | 1D | Bumax 109 | -/0.16 |
| | | Shot blasted | | -/0.28 |
| | | Grit blasted | | -/0.48 |
| Duplex | 1.4462 | | | 0.62/0.59 |
| Lean Duplex | 1.4162 | | | 0.56/0.49 |
| Ferritic | 1.4003 | | | 0.64/0.59 |

⇒

| Steel grade | Surface finish | Slip factor μ |
|---|---|---|
| Austenitic | 1D | < 0.2 |
| | Shot blasted | 0.25 |
| | Grit blasted | 0.5 |
| Duplex | Grit blasted | 0.6 |
| Lean Duplex | | 0.5 |
| Ferritic | | 0.6 |

**EN 1090-2**

⇒ ~ Class D

⇒ Class A



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# Summary

⇒ Preload losses in preloaded stainless steel bolted connections ⇒ **not significantly higher** than for bolted connections made of carbon steel.

⇒ **Highest** slip factors ⇒ **grit blasted** surfaces ⇒ $\mu_{ect} \geq$ **0.5**

⇒ **Lowest** slip factor ⇒ **1D** surfaces ⇒ $\mu_{ect_A_1D_B109} = 0.16$

⇒ Higher slip factor for grit blasted faying surfaces can be explained by the topography of the surfaces.

⇒ **Slip factors μ > 0.5 can be achieved**

RFCS-Project SIROCO
Execution and reliability of slip-resistant connections for steel structures using CS and SS



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# Thank you very much for your attention!

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