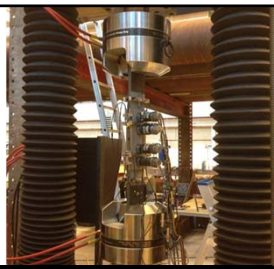
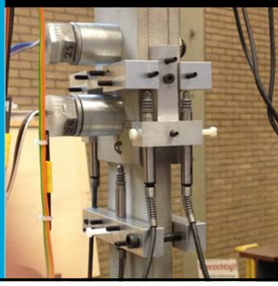
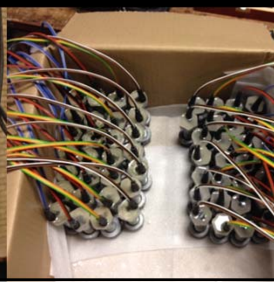


Slip-Resistant Connections
Preload in bolts

Peter de Vries





TU Delft

EU RFCS-Research Project

SIROCO

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

European Commission
RESEARCH AND INNOVATION
Industrial Technologies
Research Fund for Coal and Steel

RFSR-CT-2014-00024

Partners

Universität Duisburg Essen, EGGA, ISK, outokumpu Sweden, BUFAB, TU Delft, Fraunhofer IPA, VTT, outokumpu Finland, SCI Steel Knowledge, ARUP

Research Objectives

General

- improved test procedure for testing the slip factor,

Carbon Steel & Stainless Steel

- Influence of preload level on slip factor,
- innovative coating systems,
- Influence of the surface roughness,

Stainless Steel

- development of design rules for preloading of SS bolts and
- development of design rules for slip-resistant connections made of SS.

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Overview of the Research Topics

SIROCO

Test Procedures

- 1090-2 annex G: execution specs and criteria for:
  - short term tests
  - creep sensitivity test
  - extended creep test
- Method to determine preload in bolts in existing structures

Carbon Steel (CS)

- Influence of preload level on slip factor
  - $F_{p,C} = 0.7\ f_{ub}\ A_s$ vs. $F_{p,C}^* = 0.7\ f_{yb}\ A_s$
  - HR-bolts 8.8 vs 10.9
- Use of alternative bolting techniques
  - Injection Bolts
  - Combination of injection and friction grip bolts
  - Alternative resins
- influence of surface roughness R_z on slip factor

Stainless Steel (SS)

Plates

- Creep behaviour
  - Austenitic
  - Ferritic
  - Duplex
- Influence of surface treatment (roughness, coatings) on slip factor

Bolts

- Relaxation behaviour
  - Austenitic
  - Duplex
- Pretensioning methods

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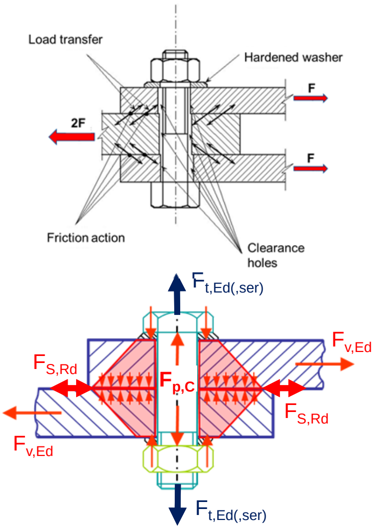
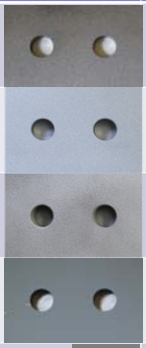
Friction grip connections

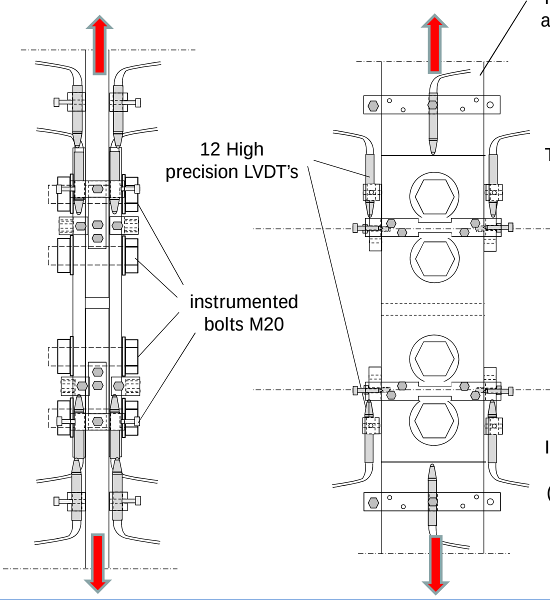


Condition of the faying surfaces		Slip Factor $\mu_{EN\ 1090\text{-}2}$
Grit blasted R_z = 80 μm **GB**		0.5
Zinc spray-metallized 140 μm DFT **Zn-SM**		0.4
Aluminium spray-metallized 250 μm DFT **Al-SM**		0.4
Alkali zinc silicate coated 60 μm DFT **ASI-Zn**		0.4
Hot dip galvanized, 100 μm DFT **HDG**		-



$$F_{S,Rd} = f\,(F_{P,C}, F_{t,Ed}, \mu)$$

Test pieces, measuring devices

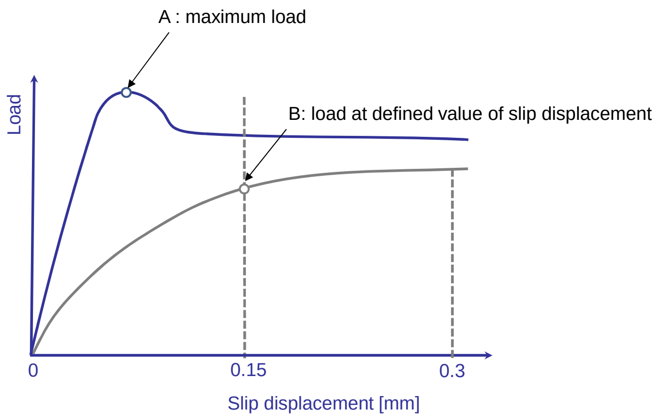


Testpiece dimensions acc. to EN1090 specs for M20

Steel: S355
Width: 100 mm
Thickness: 10-20-10

Inner plates coupled during production (identical thickness)

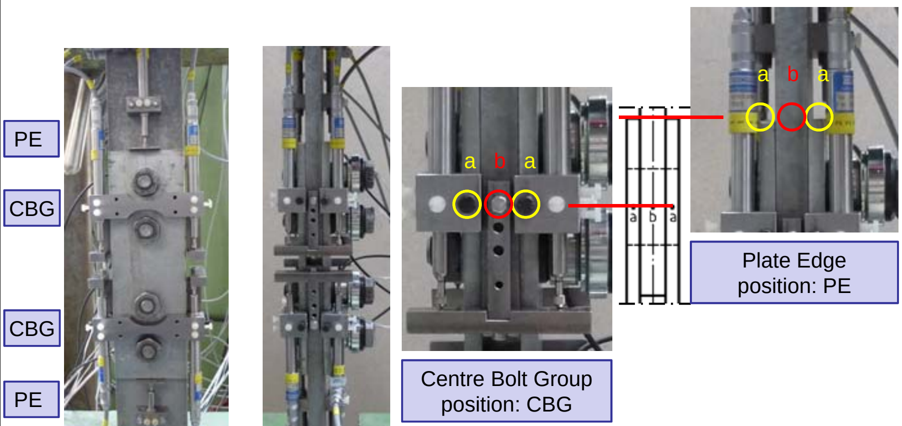
Evaluation of load-displacement curves - Slip criterion



- The **slip load** for a connection, F_{si}, is defined as the load at which a **slip** of **0.15 mm** occurs or the maximum load, if reached before 0.15 mm slip

How much slip can be allowed in a “stiff” connection?
What is the deformation limit?

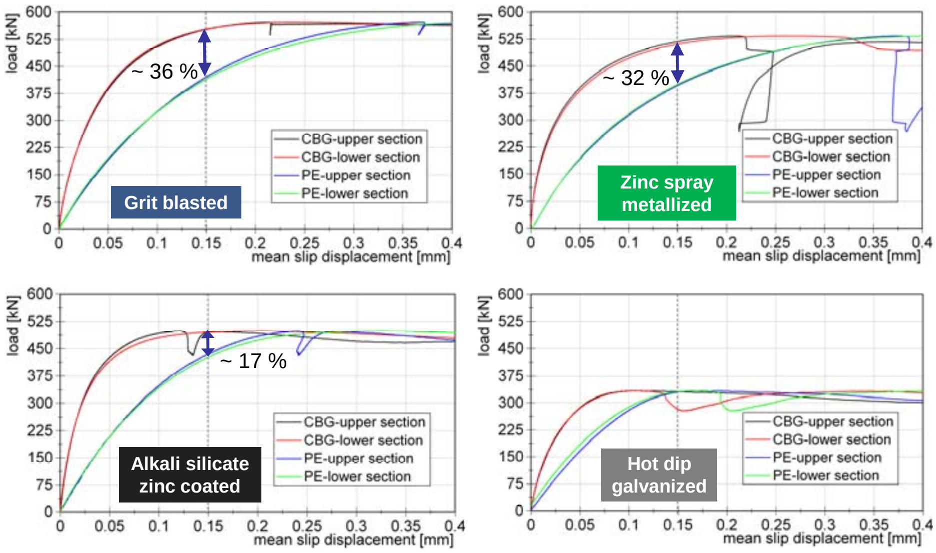
Positioning of the displacement transducers (LVDTs)



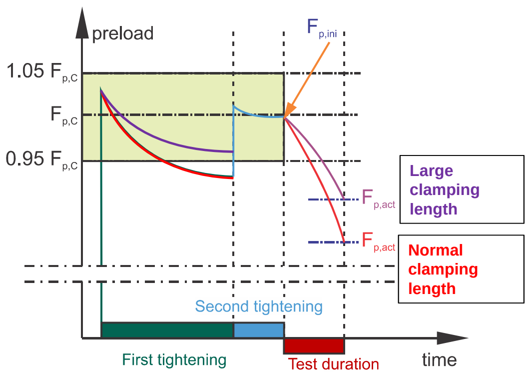
EN 1090-2:2008+A1:2011

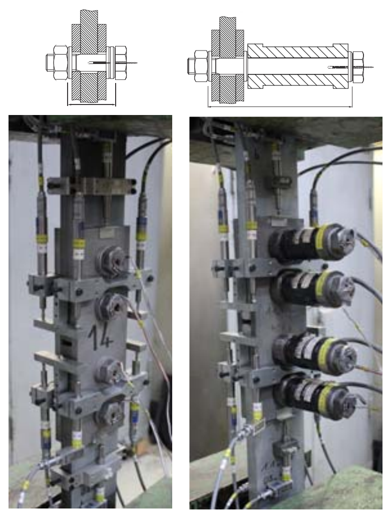
*„The slip shall be taken as the relative displacement between **adjacent points** on an inner plate and a cover plate, in the direction of the applied load“*

Influence of position of displacement measuring



Preload losses during slip factor test





- slip factor definitions

$$\mu = \frac{F_{slip}}{4 \cdot F_{p,C}} \qquad \mu_{ini} = \frac{F_{slip}}{4 \cdot F_{p,ini}} \qquad \mu_{act} = \frac{F_{slip}}{4 \cdot F_{p,act}}$$

Friction coeff.

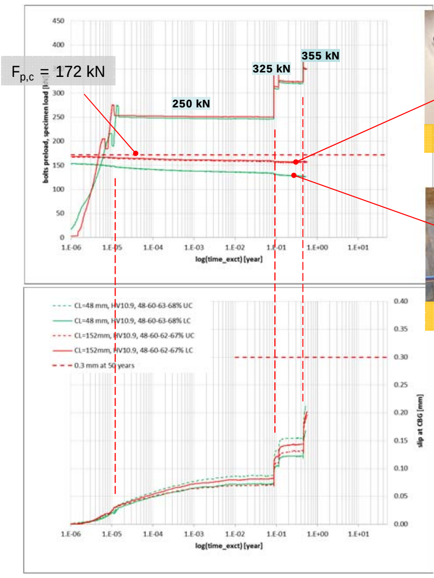
Creep sensitive coatings

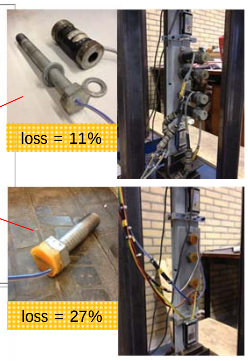
If coating appears to be sensitive to creep then extended creep tests must be performed.

Load level ?
Duration ?

Extended creep test rigs
- Capacity 415 kN
- Continuous simultaneous measurement of
  - Specimen loading
  - Preload forces in bolts
  - Slips at PE

Influence preload level on the slip factor





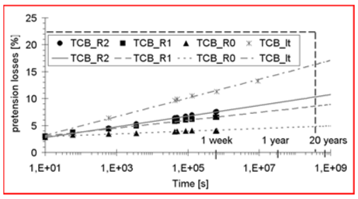
Result:

$$\mu_{ini} \approx \frac{355}{4.172} = 0.5$$

For both clamping lengths ! ?

Preload of bolts in existing structures

Bolt preload is function of time
Losses depend on
- surface coating (type, thickness)
- influence of temperature variations
- loading (history) of the connection



$$F_{p,C,lt,d} = F_{p,C}\cdot\left(1-\frac{0,92\cdot\ln(t)+1,96}{100}\right)$$

Preload losses can have an effect on:
- safety of structures
- maintenance costs: Fatigue life plates (detail cat. 112 -> 50)
- What level of losses is still acceptable?

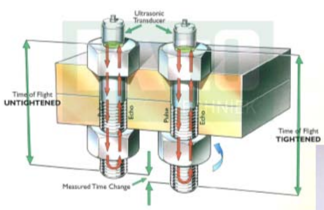
Knowledge of preload in existing structures can lead to
- Improvement of structural safety assessments of connections for extended life time predictions / renovations of structures
- Reduction of maintenance costs

Method to determine preload of bolts in existing structures

Approach 1:

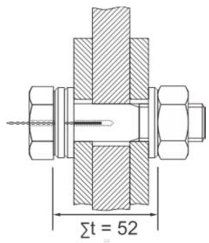
Ultra Sonic measuring of bolt length variation caused by untightening.

- Typical bolt length very short
- Irregularities bolt head, type of sensor (hand-held / glued on)
- Variability material properties



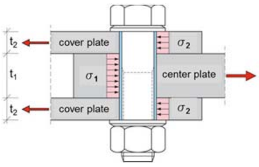

Approach 2:

Instrumented bolts (in situ glued in strain gauge)
Possible through newly developed type of strain gauge.

Finally: tests on bolts in existing structures (bridges)

Injection bolts



- Resin: Araldit SW 404 with hardener HY 2404.
- experiments show that the long duration bearing stress of the tested resin can be taken as 200 N/mm^2.
- The short duration bearing stress can be taken considerably higher than the long duration bearing stress, e.g. as 280 N/mm^2.
- Aim is to modify Eurocode 3 part 1-8 and EN 1090-2 accordingly and make a distinction between long duration and short duration load combinations.
- Alternative resins available. How to test suitability ?
- Models to describe behaviour of long bolts
- Improve models for large slotted holes

Follow up projects

- Loss of preload
  - new structures: monitoring techniques
  - existing structures:
    - remaining slip resistance of connections
    - Influence of cyclic loads on preload losses
  - Better models to describe the losses in time
- FE Modelling of friction grip connections
- Partners ?

Thank you for your attention