IQPC – 14.03.2018 - Bremen

Challenges in using bolted connections for large subsea wind structures

Jens Schiersing Thomsen - Siemens Gamesa

Troels Mathiesen, Ditte Bilgrav Bangsgaard

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	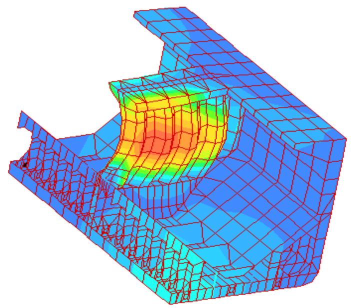		
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	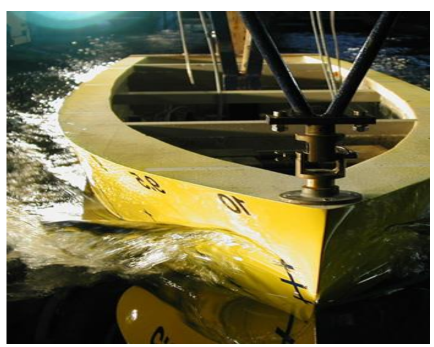		

Successful use of bolting of onshore towers

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Bolts M24 – now standard ISO 4014.

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Successful use of bolting onshore towers

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3 – legged flanged wind turbine > 30 years of operation

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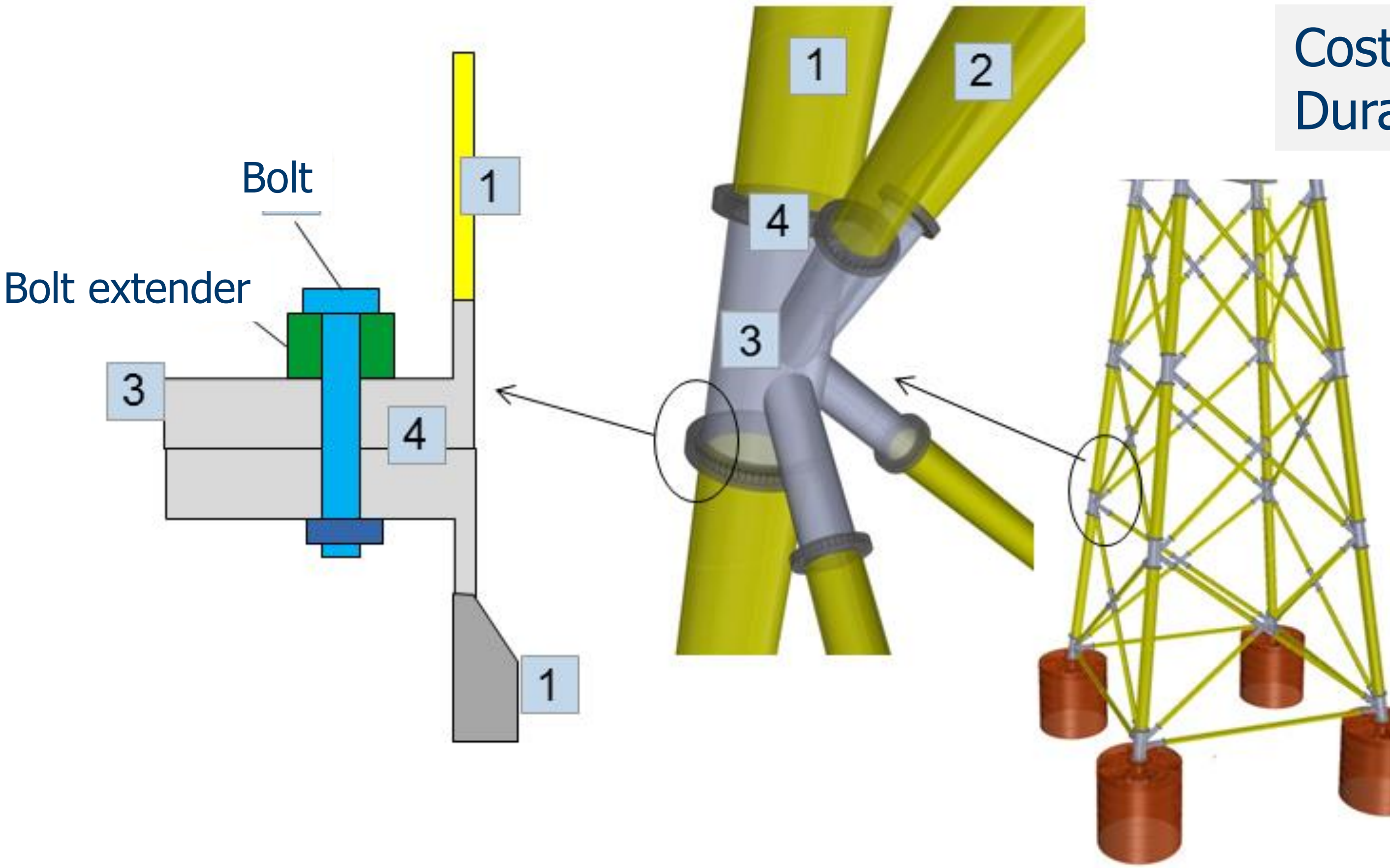
Motivation – R&D project on bolted jackets

CeJacket project – Jackets made from pre-coated line pipe

Nodes and tube elements of bracings and legs will ideally be assembled with bolted joints as flange connections

Cost savings
Durable FBE coating

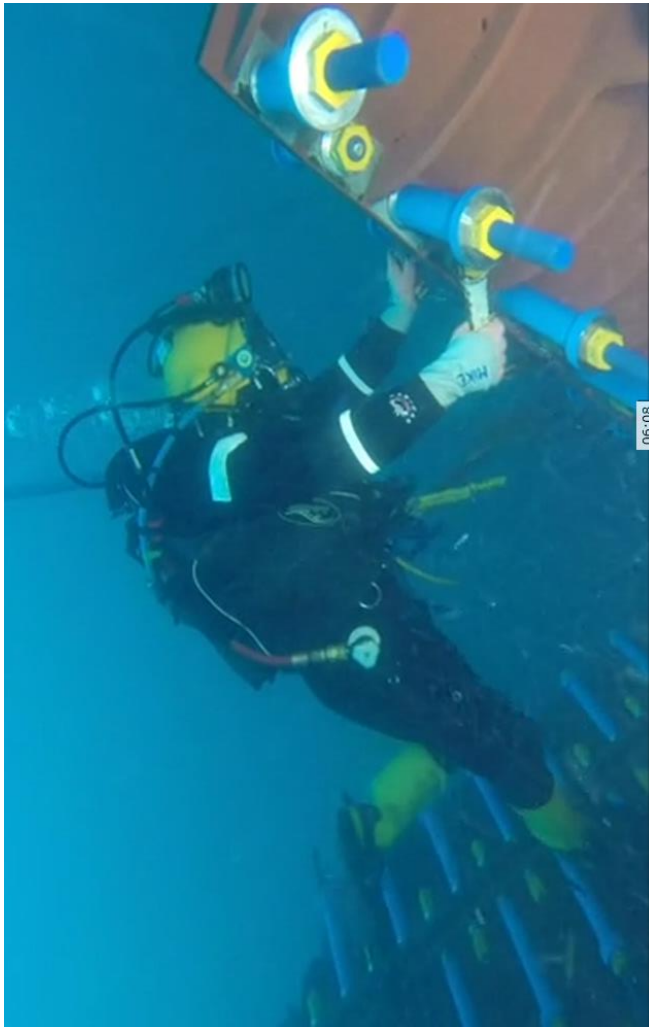


Challenges in using bolting subsea

- Must last entire lifetime
- Strict QA/QC requirements to bolts
- Limited possibility for retightening
- Consider risk of HISC with CP
- Special fatigue considerations

The CeJacket project addresses all items

- Learn from failures !
- Comply with limits in guidelines
- Customized testing



Clamp installation on oil rig. Source: ing.dk

Personal experience - drilling risers for deep water oil production

NACE Corrosion - Paper C2015-6164

- Large scale corrosion investigation
- 150 riser joints from 9 different projects in 4 oceans
- Galvanic corrosion due to stainless steel

Learn from failures

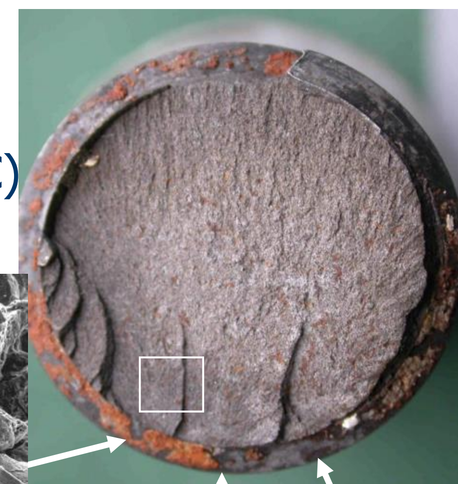
Stainless steel bolt for lifeboat on ship

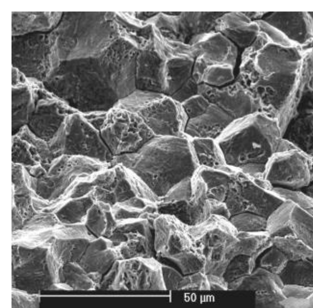
Insufficient alloy grade and poor heat treatment

intergranular corrosion and fracture

Stainless bolt suffering corrosion fatigue due to poor tightening

High-strength bolt suffering hydrogen induced cracking (HISC)





Known incidents from oil and gas

Bolting for BOPs in Gulf of Mexico.

Hydrogen related fractures

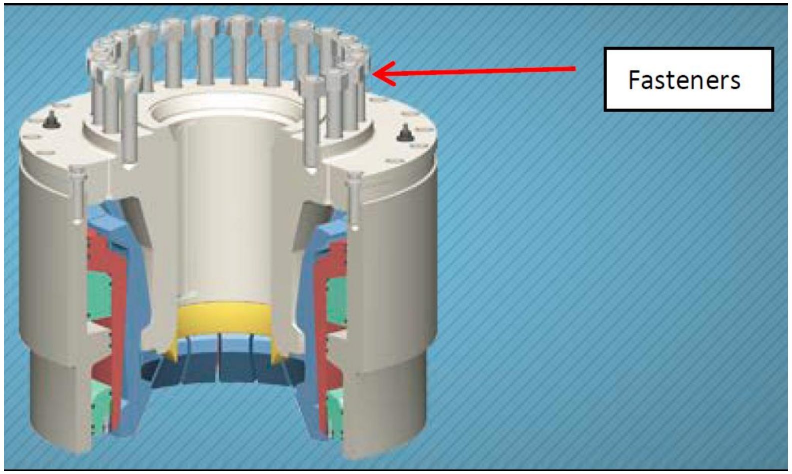
2003: HRC >34, ICCP potential too low, TSA coating

2012: HRC >34, issue with heat treatment

2014: HRC >34, issues with casting and heat treatment

Incidents has raised alertness, e.g.

- BSEE investigations (QC-FIT)



2014 incident. Source: bsee.org

Strength class of bolts

- In corrosive environments the following applies, according to our extensive experience:
  - 12.9 will fail
  - 10.9 may fail
  - 8.8 is safe to use

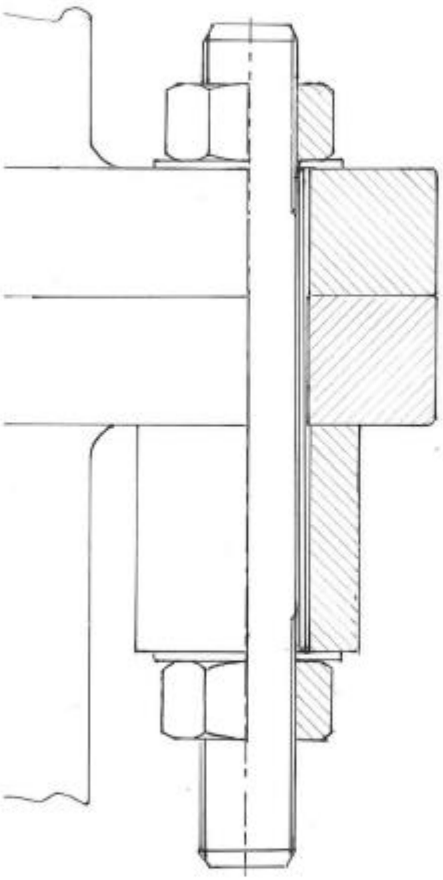
ISO 898-1	**8.8**	**10.9**	**12.9**
Hardness [HV]	255-335	320-380	385-435
Tensile strength, nom. [MPa]	800	1000	1200
Chemical composition ≤0.025 P, ≤0.025 S	0.15-0.55 C	0.2-0.55 C	0.3-0.5 C

CP and bolts – how to avoid HISC

- HV requirements – maximum of 350 HV *(DNVGL-RP-B401)*. Only 8.8 bolts meet this
- Potential requirements *(DNVGL-RP-B401)*
  - Design protection potential below - 0.80 V relative to the Ag/AgCl/seawater reference electrode
  - Over-protection below -1.15 V
- Galvanic anodes preferred over ICCP

Subsea – 3 concepts pursued for CeJacket

1. Carbon steel 8.8 bolts with CP and temporary corrosion protection
2. Stainless steel 8.8 bolts
3. Encapsulated steel bolts

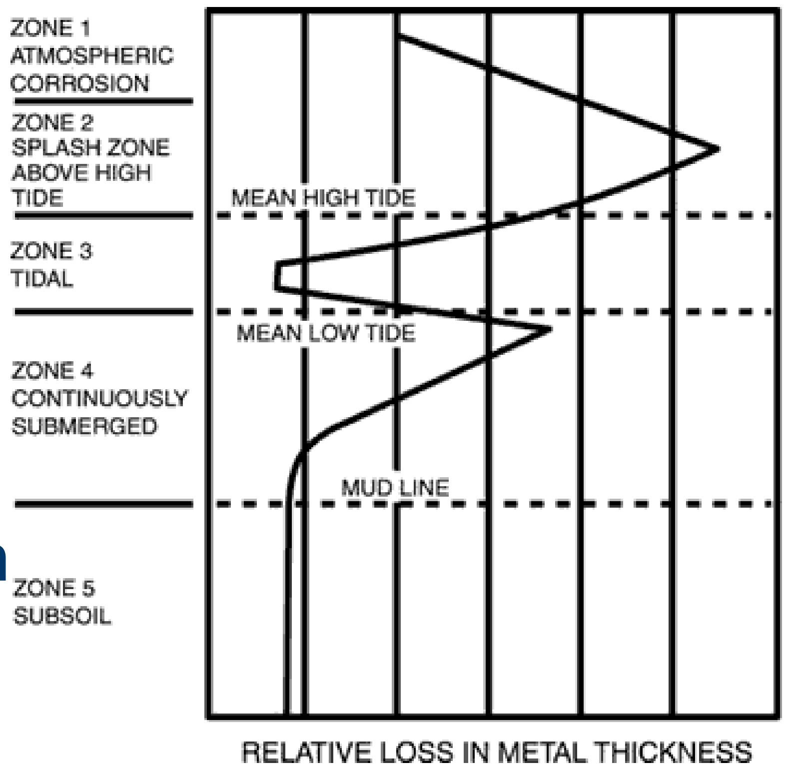


Splash & tidal zone - the biggest challenge

- Bare CS has highest corrosion rate in this zone
- CP is only working while immersed
- Sun & evaporation
- Marine fouling

- Welded joints is the first option
- CRA or encapsulated bolts are evaluated as second option

Corrosion of steel in marine environment



(LaQue: Marine corrosion, 1975)

Guidelines for CRA bolting in splash zone

ISO 21457. Oil and gas standard.

- Seawater resistant material, e.g. nickel alloys 625/725
- Costly

DNVGL-RP-0476

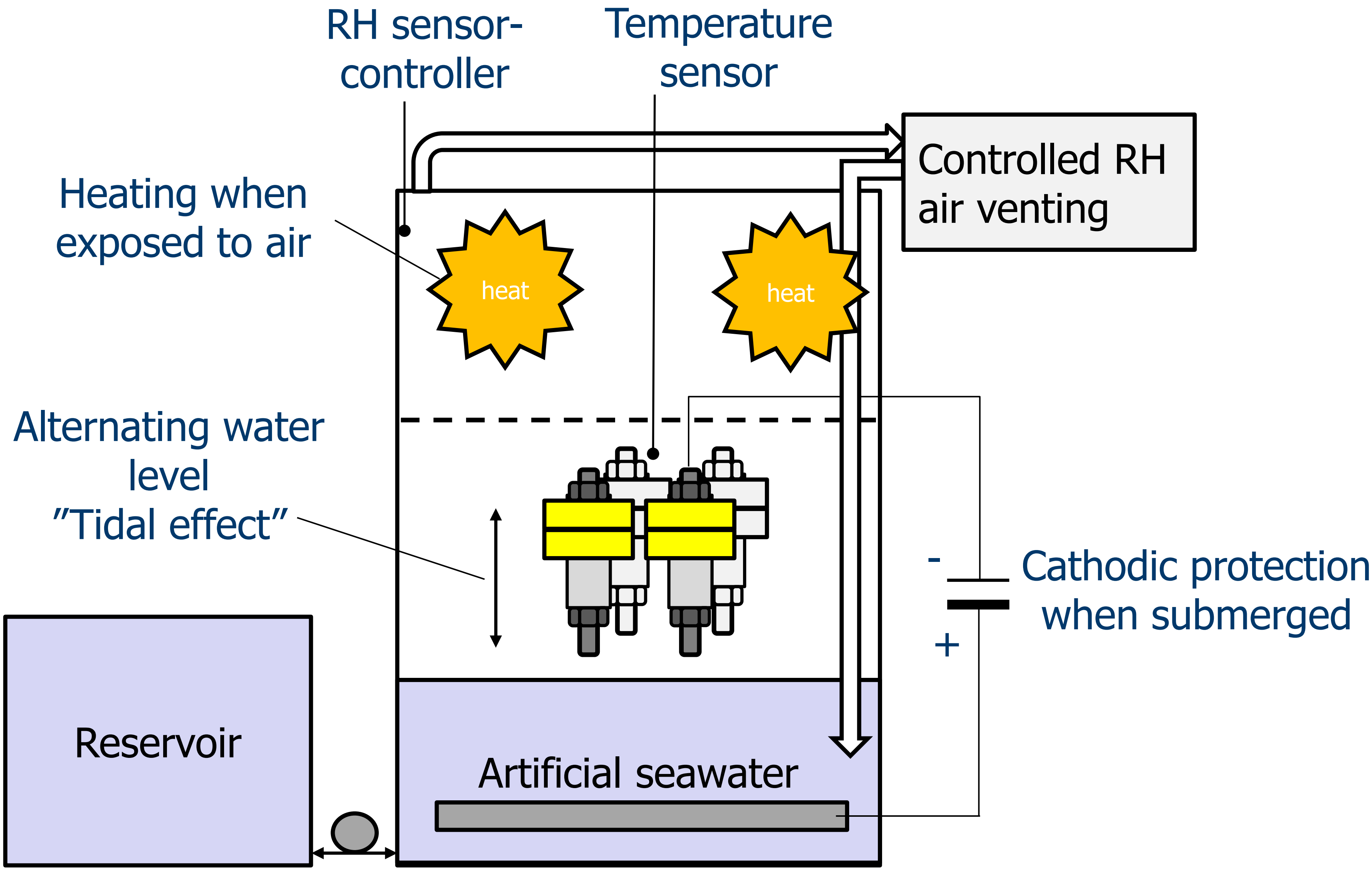
- 1.4401 (AISI 316) or better
- If sheltered, 25Cr duplex or similar

Guidelines are not consistent. Should include closer description of region, temperature, salinity etc.

1.4401 is already used for smaller parts on foundations, boat-landings etc. in North Sea

Objective: qualify intermediate and feasible alloy alternatives

Splash-zone testing of CRA bolting alloys



Full-scale test bench at Lindøe - DK

9 x 20 m strong floor with strong wall
Load capacity: bending up to 60 MN-m
Static, dynamic and fatigue testing

Strain-gauge in M42 bolt

Conclusions

- Submerged bolt connections for jacket structures offer large cost savings
- Development of new design requires thorough evaluation of standards and customized testing
- Known failures are closely reviewed to ensure safe design
- 3 concepts are pursued
  - Steel + CP
  - Corrosion resistant alloys (CRAs)
  - Encapsulated bolts
- Qualification includes
  - customized splash zone testing of CRAs
  - full-scale mechanical testing of flange design

Thank you for your attention

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