Development of special tests for bolted connections for offshore wind turbine jacket foundations

Scope

- Motivation for developing test
- Challenges using bolting subsea and in splash zone
- Development of tests

Successful use of bolting of onshore towers

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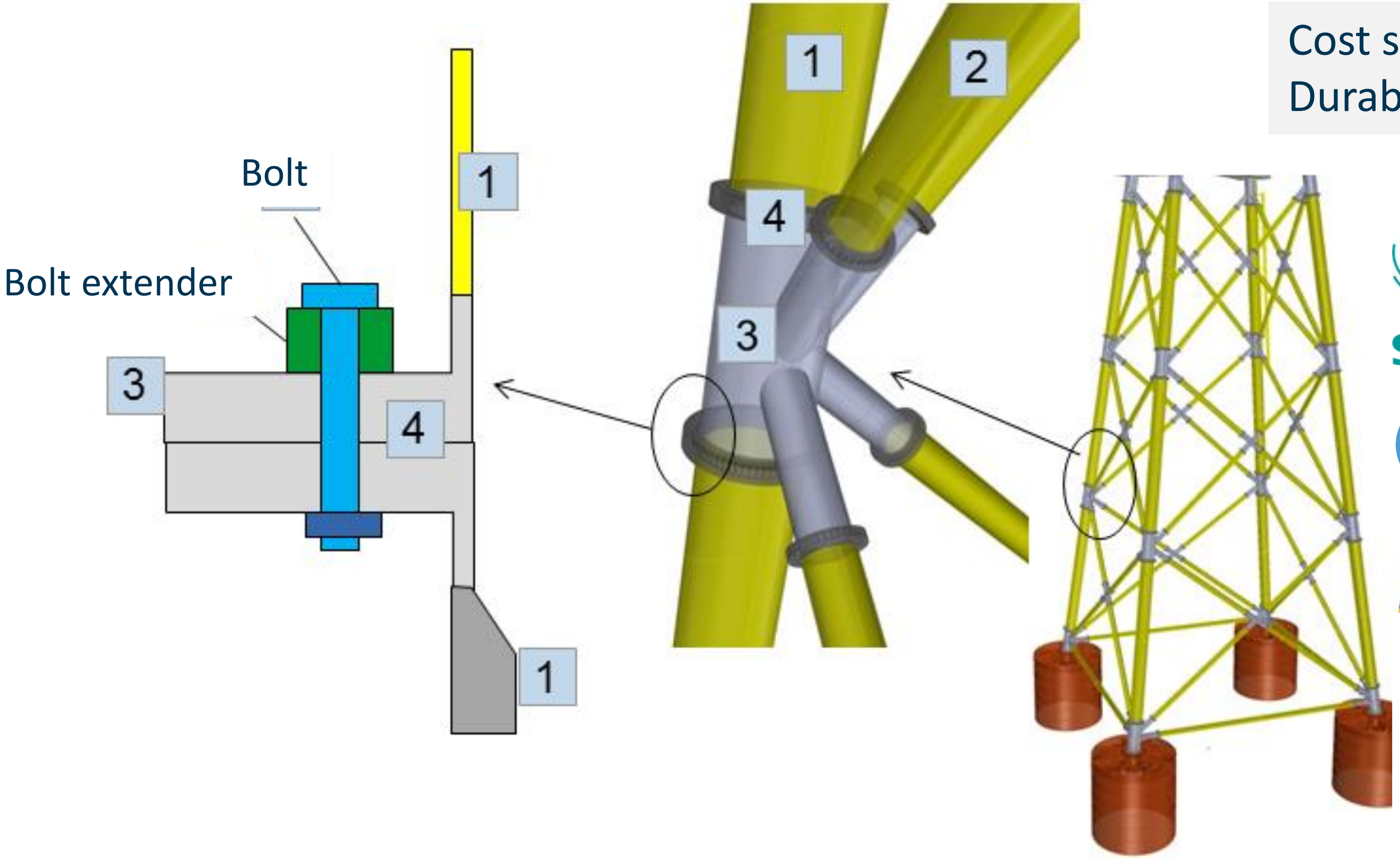
Motivation – R&D project on bolted jackets

CeJacket project – Jackets made from pre-coated line pipe

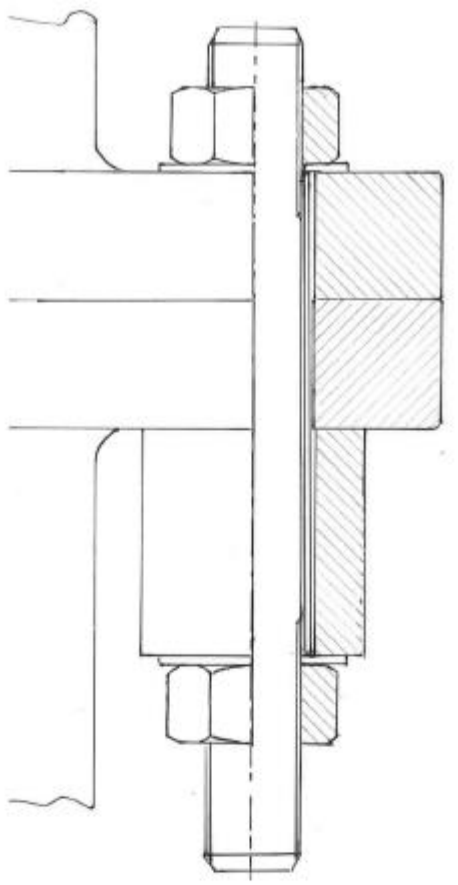
Nodes and tube elements of bracings and legs will ideally be assembled with bolted joints as flange connections



Cost savings
Durable FBE coating

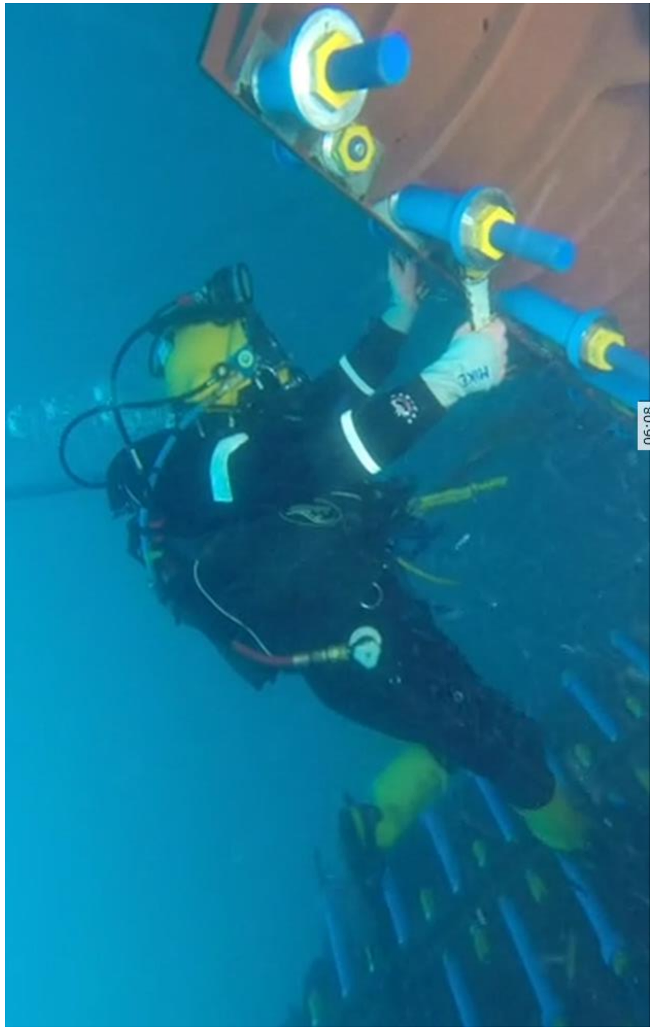
Subsea – Different concepts for bolted connections

1. Carbon steel 8.8 bolts with CP and temporary corrosion protection
2. Stainless steel 8.8 bolts
3. Encapsulated steel bolts
4. Coated parts (organic, TSM and combinations)



Challenges in using bolting subsea

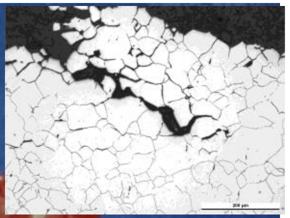
- Must last entire lifetime
- Strict QA/QC requirements to bolts
- Limited possibility for retightening
- Consider risk of HISC with CP
- Special fatigue considerations



Clamp installation on oil rig. Source: ing.dk

Learn from failures

Stainless steel bolt for lifeboat on ship

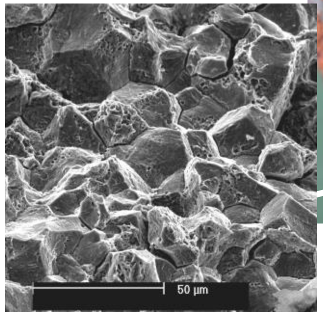


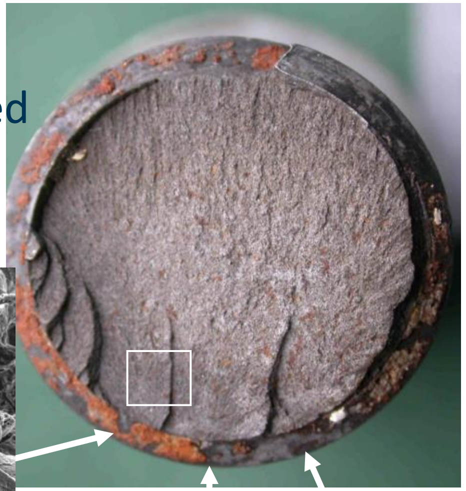
Insufficient alloy grade and poor heat treatment

intergranular corrosion and fracture

Stainless bolt suffering corrosion fatigue due to poor tightening

High-strength bolt suffering hydrogen induced cracking (HISC)



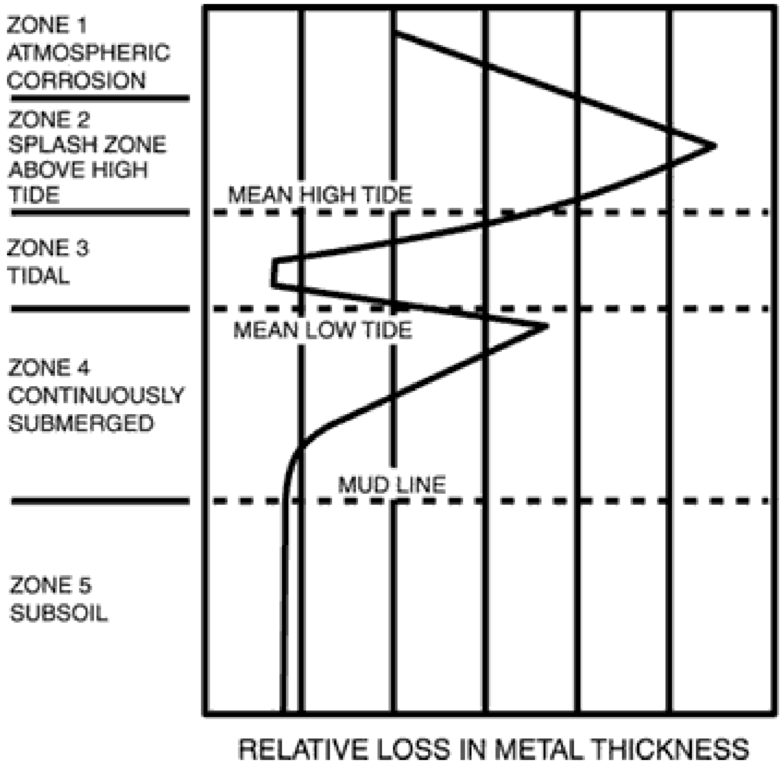


Splash & tidal zone - the biggest challenge

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

- Resistance to change – Welded joints is the first 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

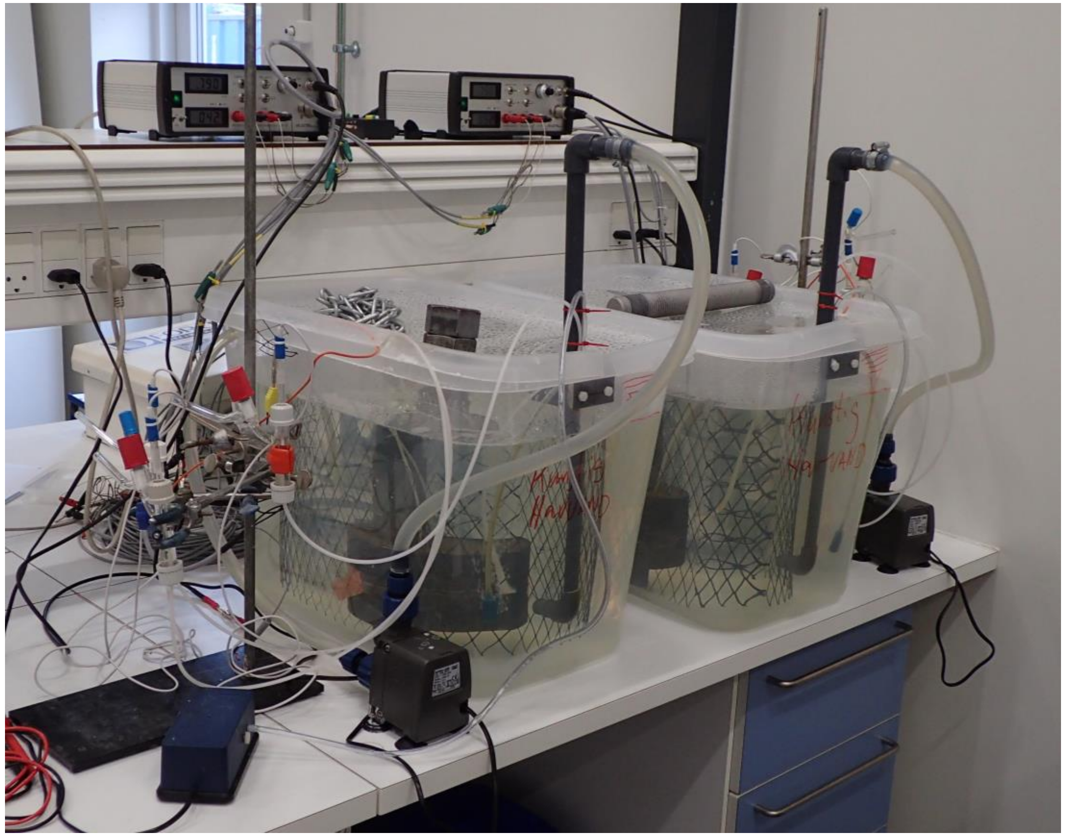
- 1.4401 (AISI 316) or better
- If sheltered, 25Cr duplex or similar

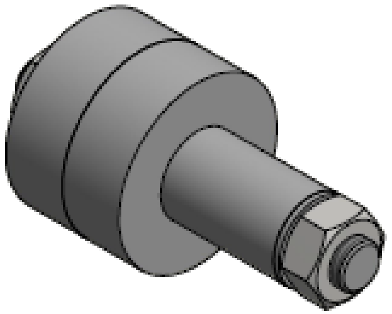
Guidelines are not consistent. Should include closer description of region, temperature, salinity etc.

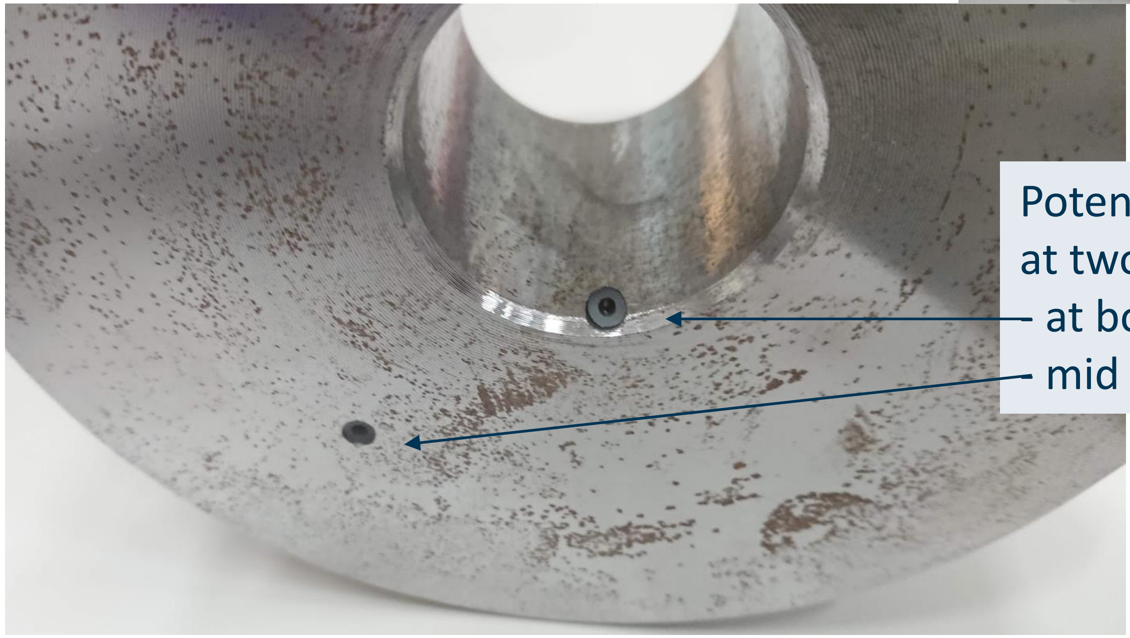
1.4401 is already used for smaller parts on foundations, boat-landings etc. in North Sea

Objective: qualify intermediate and feasible alloy alternatives

Gap test







Potential measured at two depths in gap
- at bolt
- mid of gap

Exposure at room temperature
Artificial seawater ASTM D1141, circulated
Potentiostatic control of specimen
Datalogging of current and potential

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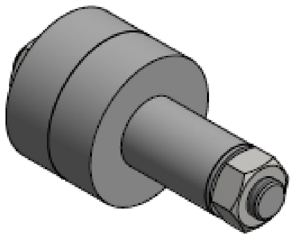
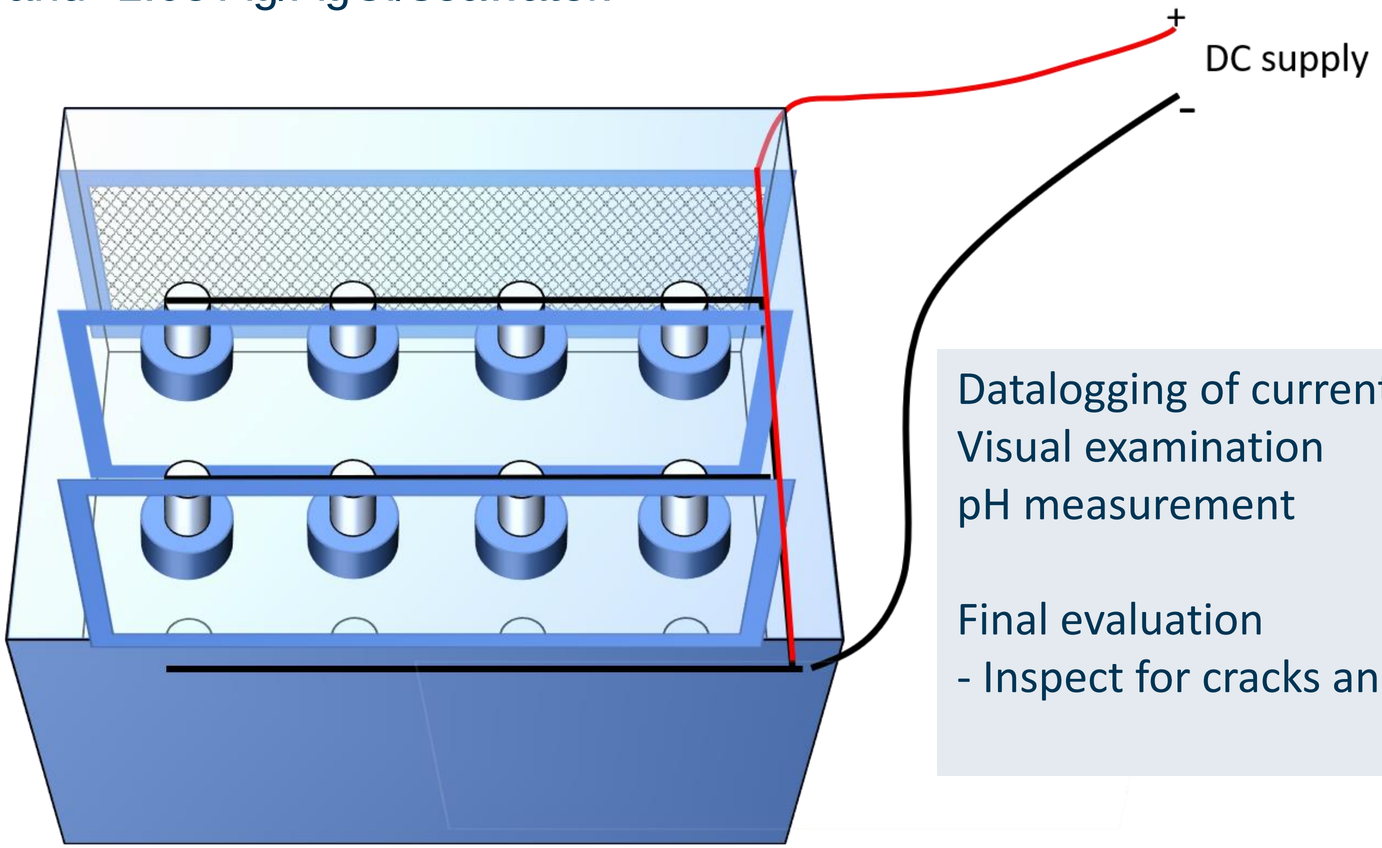
Submerged test of bolted flange

- The bolts are exposed in artificial seawater while having CP applied. Three different potentials are applied, i.e. -0.8 V, -0.9 and -1.05 Ag/AgCl/seawater.

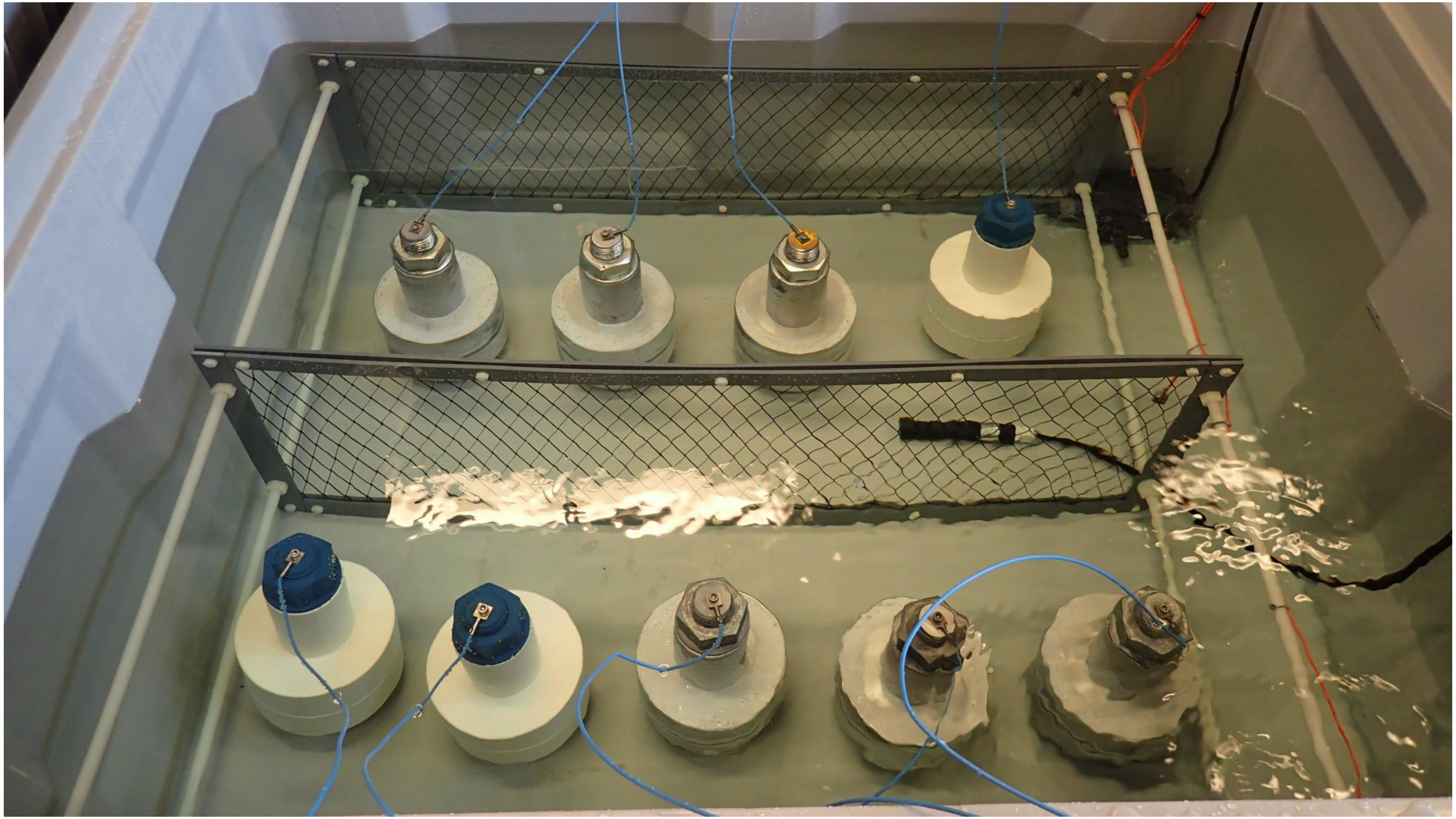




Datalogging of current and potential
Visual examination
pH measurement

Final evaluation
- Inspect for cracks and corrosion

Submerged test of bolted flange



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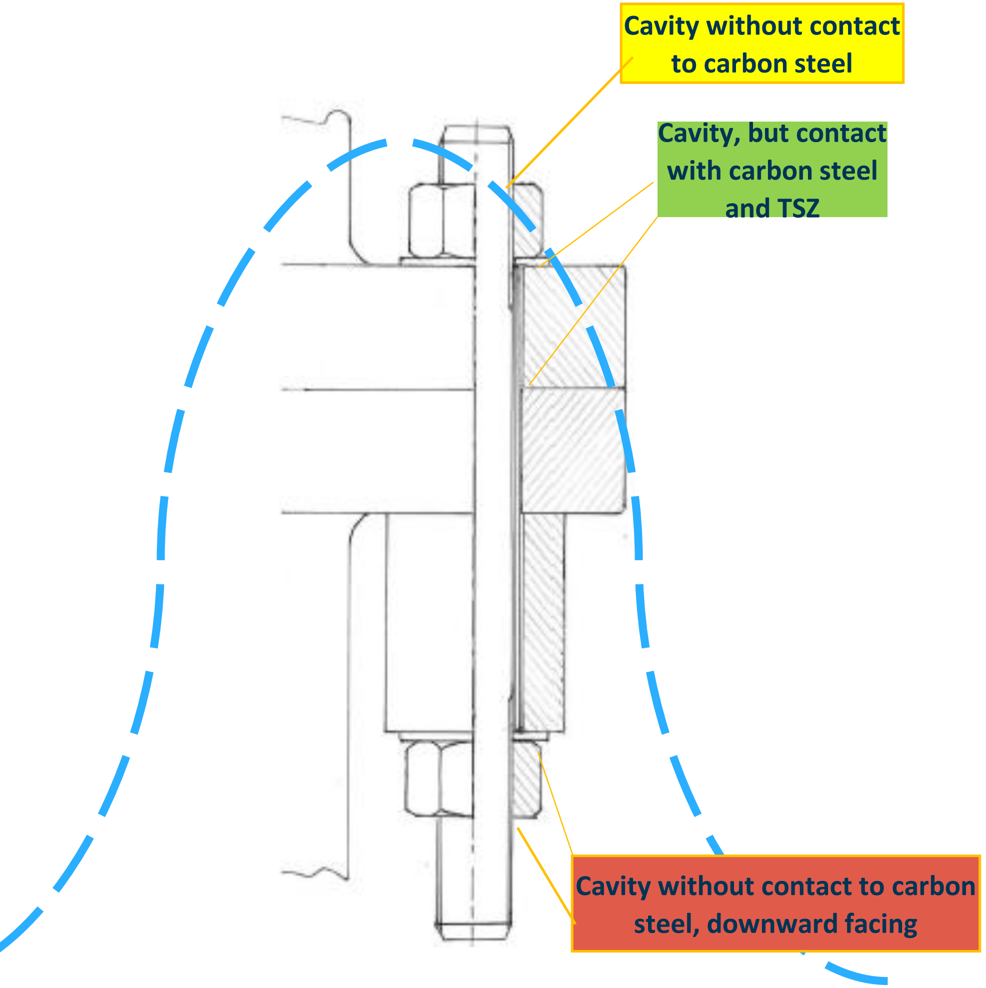
Splash zone test



Factors influencing corrosion of stainless steel in splash zone

Factor	Expected effect on stainless
Cavities	Aggravating – build up local environment
Temperature	Aggravating - facilitates evaporation
Salinity	Aggravating - known [Cl] vs T dependence
pH	Aggravating – if low pH develops in cavity
Wind	Mitigating – decreases time of wetness
Wave action	Mitigating – flushes off micro cells**
Occasional CP	Mitigating – resets localized corrosion, builds up calcareous products
Biology	Both ways
Orientation	Downward is worst
Dissolved oxygen	None
UV	None **

**Strong effect on coated steel flange

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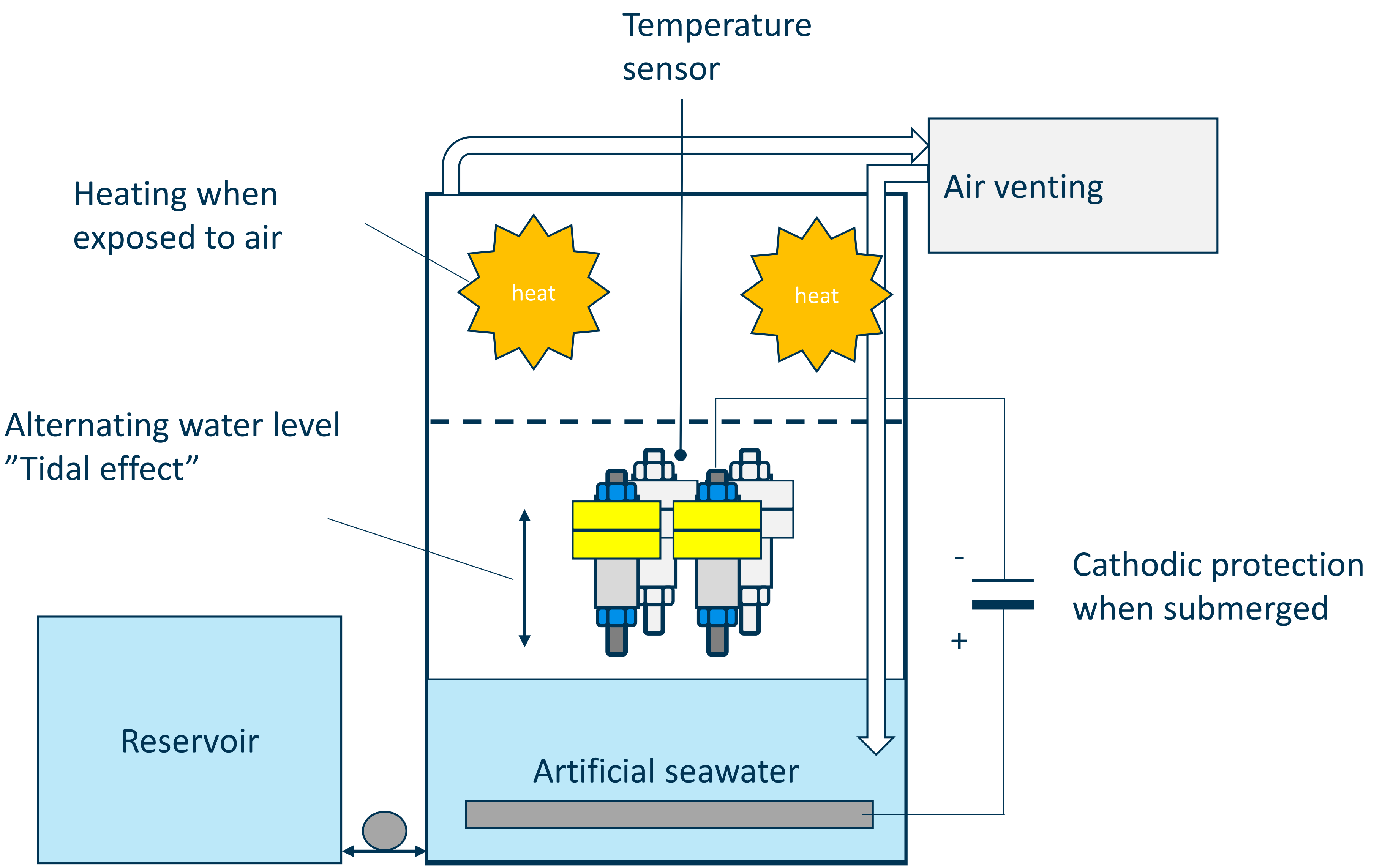
Worst case exposure conditions in splash/tidal zone

North Sea conditions, 3.5% NaCl, tidal period ~12 hrs, max. period with direct sunlight 3 hours

	Exposure scenario	Test (splash + CP)
Atm1	Atmospheric - 1 - calm - sunny and dry	3 hrs Heating to 25°C on surface Venting, low RH
Splz	-frequent splashes (5-10s. period)	0,5 hrs
Subm	Submerged -wave action under submersion	0.5 hrs Submerged Polarised to -900 mV

Splash-zone testing of CRA bolting alloys



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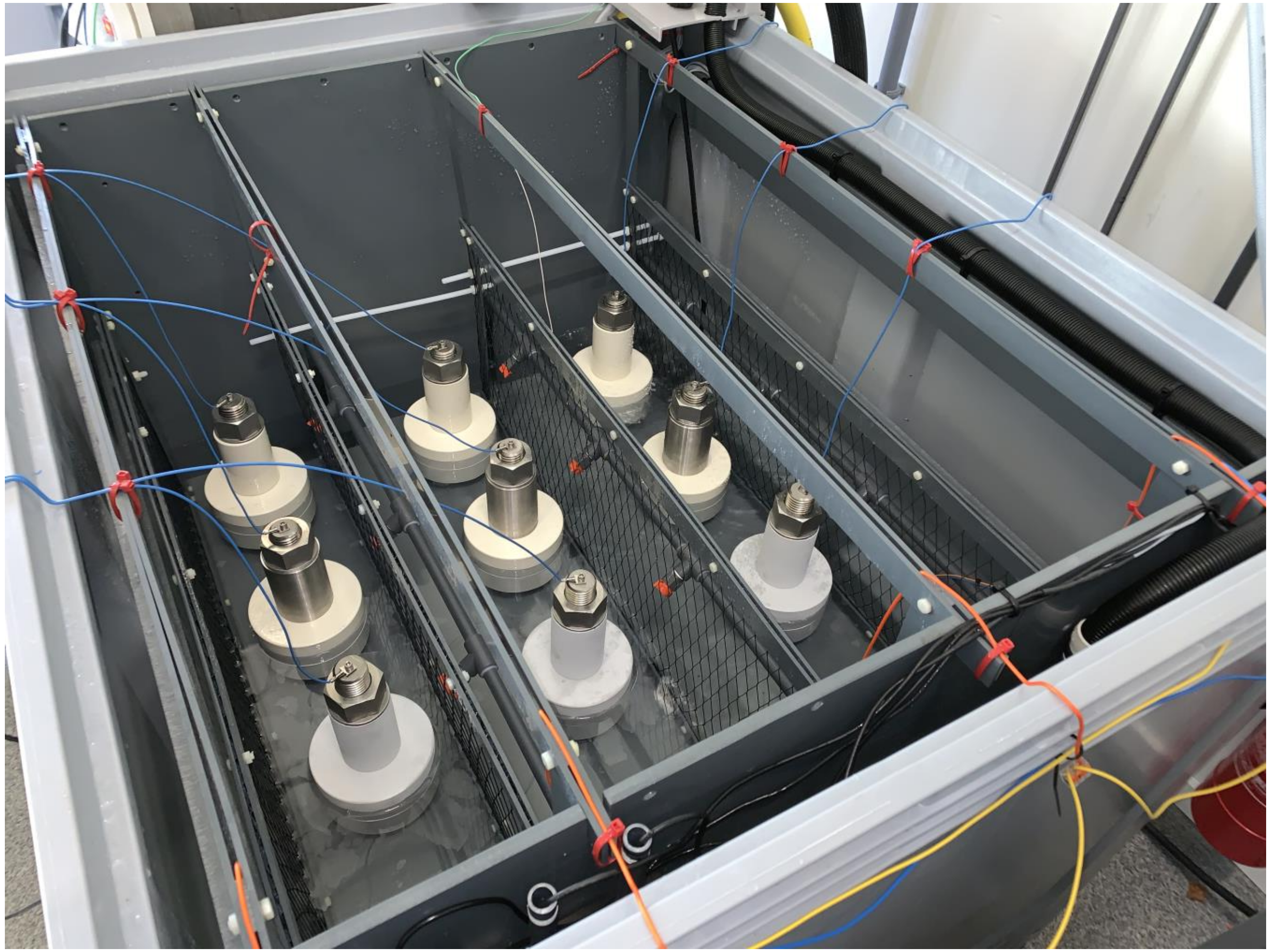
Developed test-concept



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Conclusions

- Submerged bolt connections for jacket structures potentially offer great cost savings
- Development of new design requires thorough evaluation of standards and customized testing
- Development of a specialized tests for bolted connections in splash zone and fully submerged has been developed
- Testing have been conducted successfully producing relevant data