Experience of Degradation of Mooring Systems used in the

WELAPTEGA

DESIGN ABS ASSESSED

CERTIFIED BY DNV·GL APPROVED SERVICE SUPPLIER

Lloyd's Register TYPE APPROVAL

Certified System SAI GLOBAL ISO 9001 Quality

Mooring Inspections - Worldwide

20 Years experience in the United Kingdom, Norway, Canada, Gulf of Mexico, West Africa, Australia, South East Asia, and India.

● Welaptega Global Projects

Agents:

- IEV Group
- Accpron
- Beijing Safetech
- GCA Energy

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Our Valued Clients

Welaptega operates globally with clients and projects in just about every region of the offshore oil and gas industry.

MAERSK FPSOs | Chevron | woodside | Statoil | MARATHON | PRIDE | bp

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Problems:

- Mooring components:
  - Equipment failing prematurely
  - Galvanized shackles corroded/worn within weeks vs months/years in other environments
- Power Cables:
  - Armour wires worn away and eventually break
  - Characterized by armour wires forming sharp points; always shiny/bright

Mooring Component Failure

- Galvanized shackles corroded/worn prematurely.
- Obviously a combination corrosion and wear. But which is dominant?

American Bureau of Shipping

Det Norske Veritas

Wear

Wear between components expressed by Archard Equation:

- Wear (Volume) = K x Work Done
- Work Done = Frictional Force x Distance Travelled

- K is a function of:

Contact Pressure	**Surface Hardness**
Lubrication	**Ambient Temperature**
Surface Roughness	**Rate of Dissipation of Frictional Heat**
Sliding Velocity	**Elastic and Shear Moduli**

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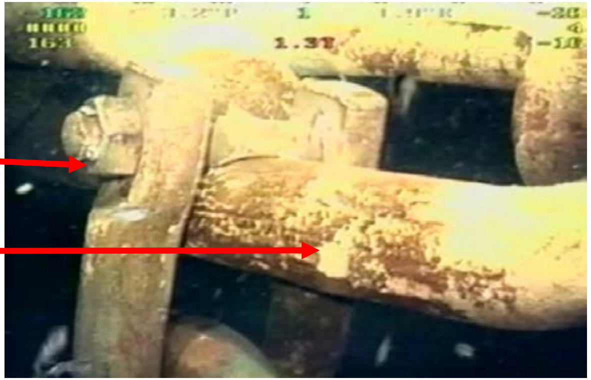
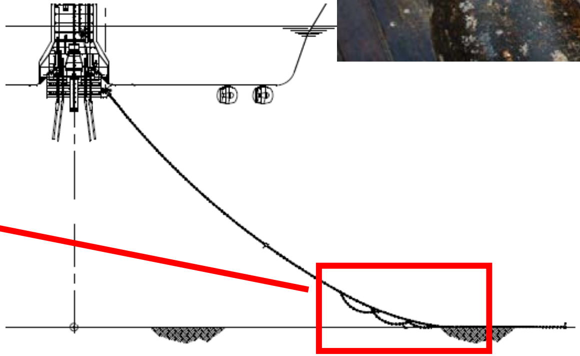
Wear

- Wear rate highest where there high tension and relative motion; relative motion dominates
- Reduce relative motion → reduce the wear
- However, it’s unlikely that any of these factors are unique to the Minas Passage

Drape Chain
Hanger Shackle
(low tension)

Load Carrying Chain
(high tension)

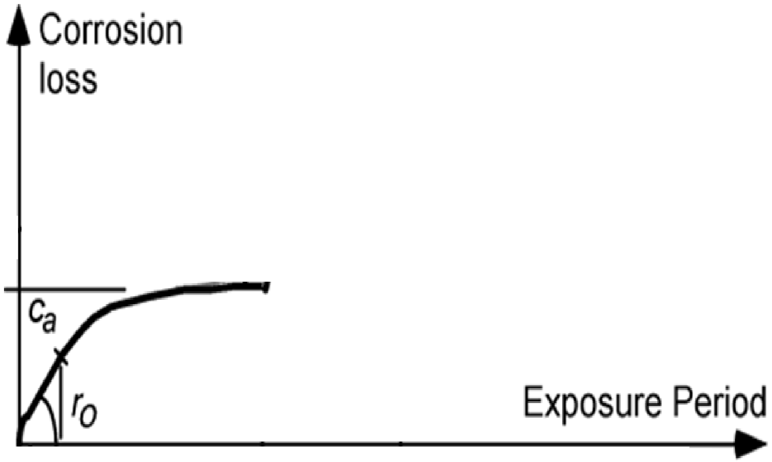




Corrosion

- High initial rate of corrosion (ro), slowing to a lower steady-state rate as oxide layers accumulate to reduce oxygen diffusion to steel surface

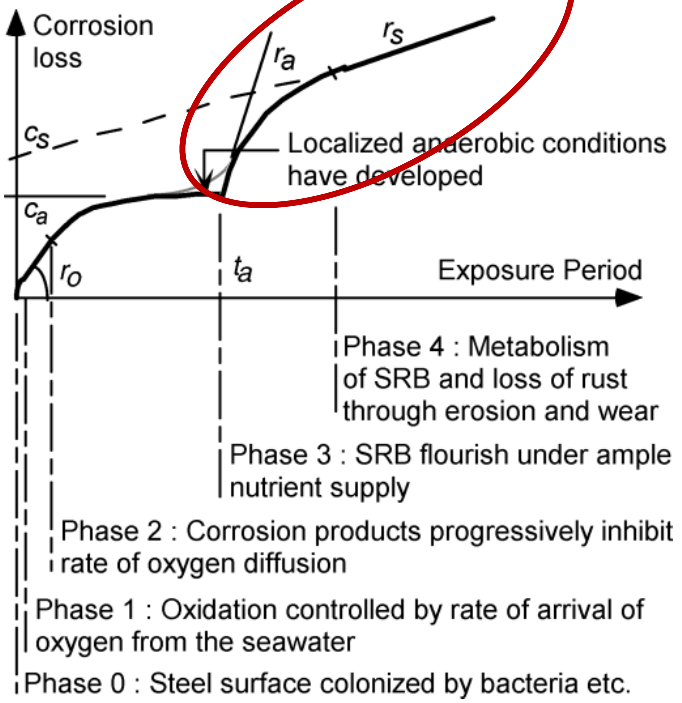
- Major contributors to corrosion rate:
  - Dissolved oxygen content
  - Water temperature
  - Flow rate, water velocity
    - Significant impact on corrosion rate in early stage of exposure to sea water (r_o)
    - Once oxide layers formed, flow rate is insignificant on steady state corrosion rate



Robert E. Melchers
Development of new applied models for steel corrosion in marine applications including shipping

Multiphase Aerobic-Anaerobic (Biological) Corrosion

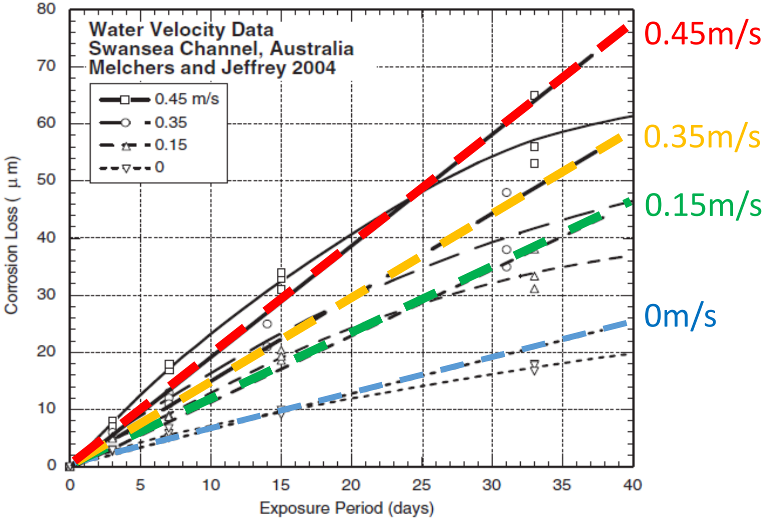
- Microbes (especially Sulfate Reducing Bacteria) do not attack the steel – metabolic by-products create a corrosive environment
- Oxide layers and biofilm must eliminate oxygen diffusion (anaerobic condition)
- Very aggressive corrosion rates in warm water especially under ample supply of nutrients – nitrogen



Robert E. Melchers
Development of new applied models for steel corrosion in marine applications including shipping

What's unique about the Bay Of Fundy wrt Corrosion Rates?

- Water Temperature?
  - Pretty typical of other environments without low corrosion rates
- Dissolved Oxygen?
  - Any evidence of this being higher than typical levels at similar water depths?
- Microbiological Corrosion?
  - High nutrient levels from agricultural run-off could be a factor
  - More typical of warm water environments; Aerobic corrosion layer must build up to create anaerobic environment
- Water Flow Rate
  - Phase 1 corrosion rate increases dramatically with flow rate
  - Note: test shown only goes up to 0.45m/s
    - Peak Tidal current at Cape Sharp is 5.5m/s

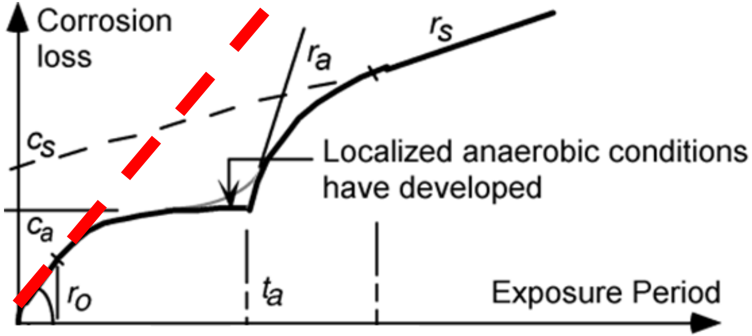


Average water temperature of 20-deg C; higher than Bay of Fundy, but relationship between flow rate and corrosion rate remains the same.

Robert E. Melchers
Corrosion of working chains continuously immersed in seawater

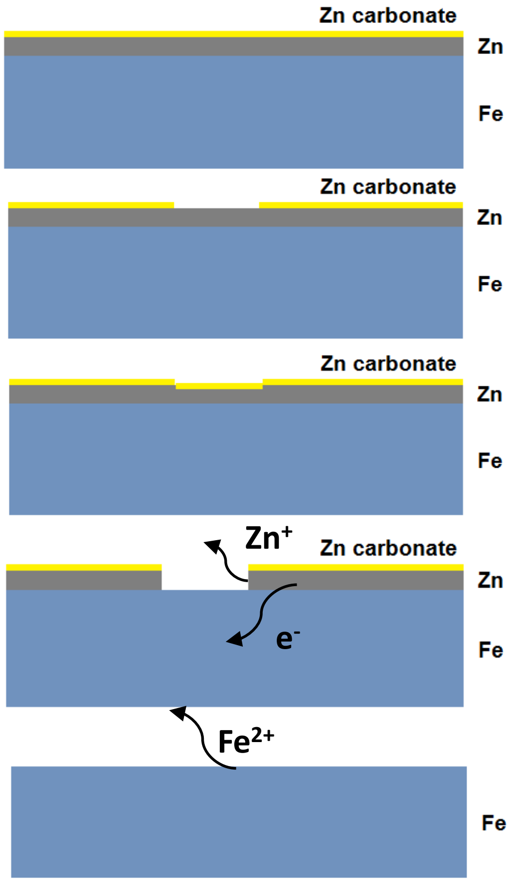
Possible Cause

- High flow rate is leads to high initial corrosion rate, and
- Oxide layer needed to slow the corrosion rate does not establish due to abrasion:
  - Between mooring components,
  - Between components and seabed,
  - Abrasion due to entrained sand in flow?
- Components continually remaining in the Phase 1 high aerobic corrosion phase



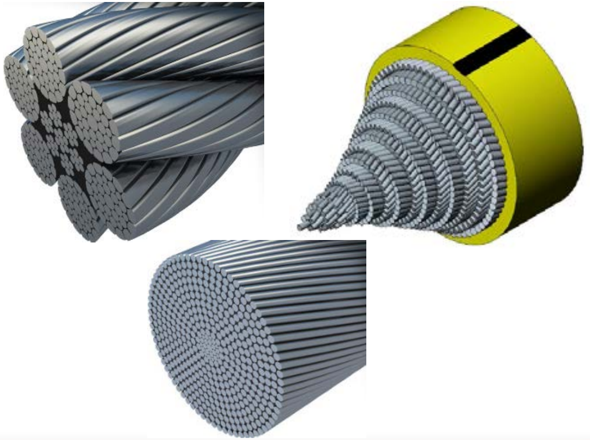
What about Galvanizing?

- In sea water, galvanized surfaces form zinc carbonate and calcareous deposits to form a barrier to corrosion
- The zinc carbonate barrier is self repairing; if damaged, new zinc will be consumed to repair the barrier
- However, if the barrier is continually damaged, zinc will be consumed quickly
- If all zinc steel surface is exposed, zinc is further consumed due to creating of a galvanic corrosion cell
- Contributing factors lowering performance of galvanizing:
  - Mechanical damage to barrier – wear between components
  - Water temperature
  - Flow rate/abrasion
    - Removes passive scales and causes further zinc consumption



Galvanizing

- In oil and gas industry:
  - MOORING CHAINS and SHACKLES are never galvanized
    - Steel grades used for O&G platforms are higher strength than typical marine grade; require heat treatment
    - Galvanizing process requires high heat; would reduce material properties
    - Chains designed with corrosion allowances instead
  - WIRE ROPE MOORINGS are always galvanized
    - 6-strand wire or
    - Torque-balanced spiral strand (sheathed or unsheathed)
    - Not typically used in areas of high wear for long periods of time



Power Cable Failure

- Outer armour wires formed into sharp points and lead to failure
  - Cables are not buried (sediment has been washed away in high flow)
  - Cable laid on hard rock seabed, but failure mode is unrelated to the cable wearing from movement on the seabed itself
  - Armour wires are always shiny/bright

  - Cables exhibiting this deterioration were move to areas of lesser current

Wire Rope Corrosion

- Drilling rig wire rope after 7 years in the North Sea
- Aside from corrosion, strands appear in otherwise good condition
  - Zinc is fully consumed; steel stands freely corroding
- Wire wet sand-blasted to inspect further

Degradation of wire rope mooring lines in SE Asian waters; Chaplin, Potts, Curtis

Wire Rope Corrosion

- Once the zinc is consumed, the bare wires freely corrode where zinc carbonate layer is damaged
- Corrosion is accelerated on the side of the wires in close proximity to adjacent strands
- Small movements between strands will disturb and wear away at the corrosion layer, causing further corrosion to the side of strands
- Crown of wires are not abraded and still protected by zinc-carbonate deposits
- The strands eventually appear rectangular or fin-like, forming sharp points

Power Cable – Moving to area of lesser current solved problem

- Lower current area will improve performance of galvanizing layer and decrease the steel corrosion rate if zinc is eventually fully consumed
- Note - Armour wires in failed power cables said to have looked bright/shiny
  - Photo of wire rope (right) has been wet sand-blasted
  - Possible the entrained sand in high flow environment removes corrosion products, contributing to high corrosion rate

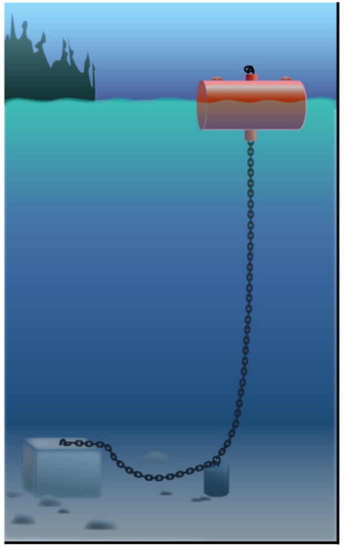
Possible Solutions

Assuming moorings and power cables cannot be moved to lower-flow areas, consider:

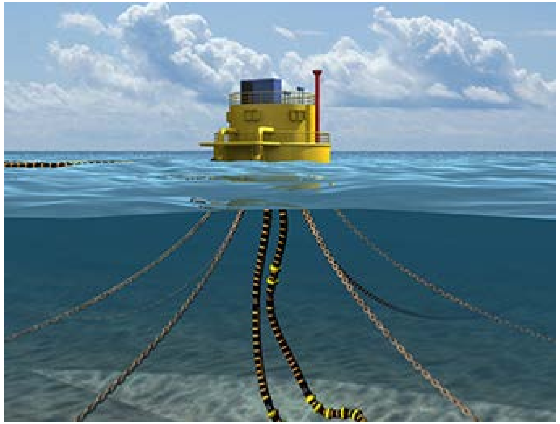
- Reducing motion between mooring components
- Better coatings or design with high corrosion/wear allowance
- Corrosion resistant or non-corroding materials

Possible Solutions to mooring failure

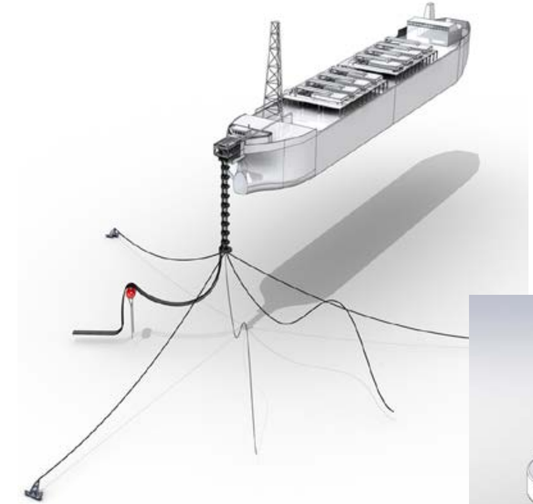
- Reduce motion between mooring components to reduce wear

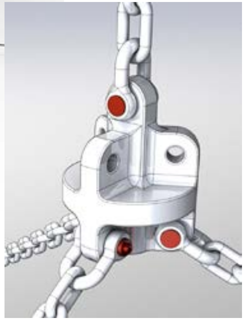


Single line
Low pretension
High relative motion



Typical Single Point Mooring for O&G industry
6 Lines; each line pretensioned to limit lines slackening and relative motion





Tri-Catenary Mooring System
Single line connection to buoy
Split to 3 lines in mid-water
Maintains minimum tension on all lines

Possible Solutions to mooring failure

Coatings or high corrosion/wear allowances

- Coatings for Chain, Steel Connectors
  - TSA – Thermal Sprayed Aluminum
    - Similar to galvanizing, but provides better protection in marine environments
    - Aluminum provides anodic protection if surface coating is damaged
    - Low heat process – suitable for high strength steels
  - TSC – Thermal Sprayed Carbide
    - Resistant to wear, even at the contact zone between chain links
  - More details needed of how these coatings perform, especially in high-flow environments
- Add a corrosion/wear allowance to the required chain size
  - Use recovered components to estimate corrosion/wear rate
  - Increased weight of chain may be problematic
  - If wear flats reduce rolling between links, bending loads increase

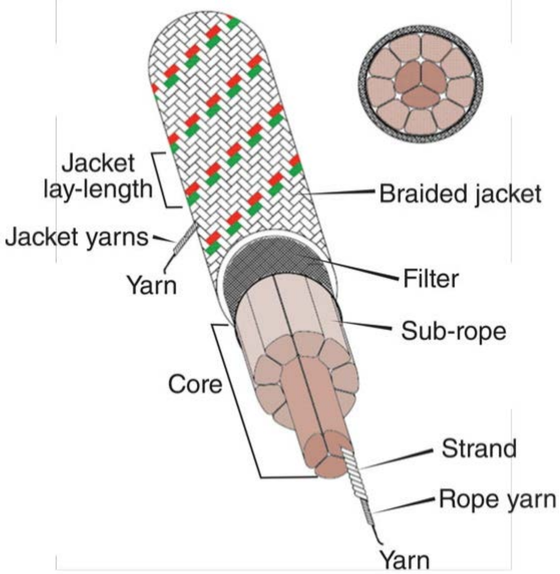
Vicinay Cadenas

Det Norske Veritas

Possible Solutions to mooring failure

Use corrosion resistant or non-corroding materials

- Stainless steel commonly used in fish farms with high-flow
- Fibre ropes have very good track record in O&G industry
  - Polyester, Aramid, High-modulus Polyethylene (HMPE)
    - (near) Neutral weight in water
    - Low abrasion resistance – for use in water column only
    - Fibre rope can becomes damaged if sand gets into rope fibres
    - Unknown how sand filters will perform in high flow like Minas Basin, but commonly used in Gulf of Mexico where loop currents can reach 1.8-2m/s



Possible Solutions to cable failure

External coatings – eliminate water getting to armour strands

- Plastic sheathing
    - May get damaged from abrasion on hard seabed
- Grease or blocking compound on armour wires, with or without additional plastic sheathing
    - Most effective in cold water (warm water lowers the viscosity)

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