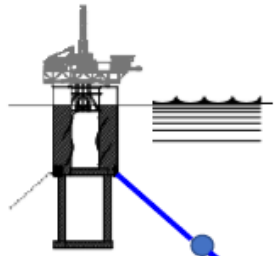


Mooring Challenges 2023



equinor

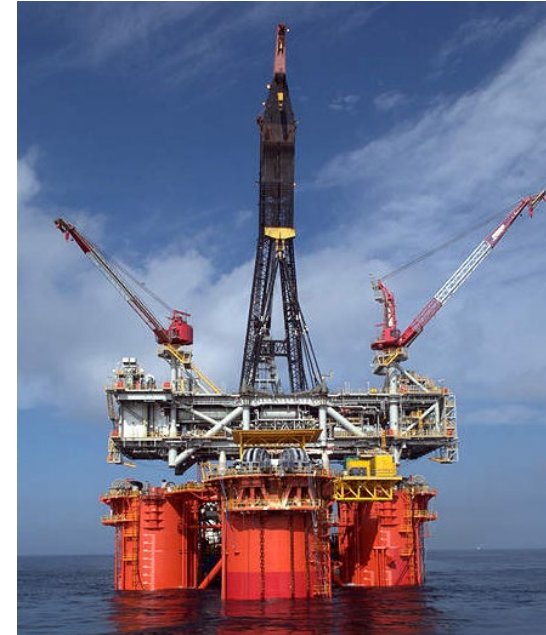
R5 chain challenges



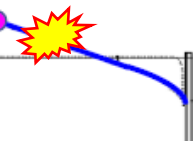
Titan mooring line – and breakage

— Chain
— Polyester Rope

~4.000' / ~1.200 m



5" (127mm) R4?
Ramnäs 2008

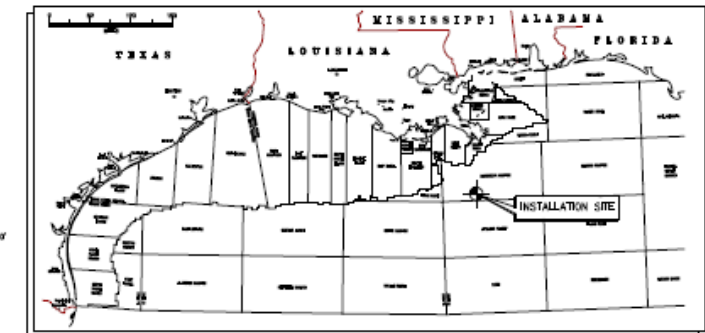


AS-BUILT PRESET

MOORING INSTALLATION SPECIFICATION

| LEG No. | LEG HEADING | FAIRLEAD TO ANCHOR HORIZ. DIST. (FT.) | ANCHOR POSITION (X) FT. (Y) FT. | WATER DEPTH AT ANCHOR (FT.) | PILE TYPE (FT.) |
|---------|-------------|---------------------------------------|---------------------------------|-----------------------------|-----------------|
| 1 | 136° | 6,555 | X= 967,474' Y= 10,174,089' | -4,290 | TYPE 2 (225) |
| 2 | 145° | 6,551 | X= 966,690' Y= 10,173,446' | -4,290 | TYPE 2 (225) |
| 3 | 167° | 6,569 | X= 964,424' Y= 10,172,407' | -4,255 | TYPE 1 (205) |
| 4 | 176° | 6,876 | X= 963,417' Y= 10,171,942' | -4,245 | TYPE 1 (205) |
| 5 | 255° | 6,670 | X= 956,298' Y= 10,177,225' | -3,950 | TYPE 1 (205) |
| 6 | 264° | 6,661 | X= 956,120' Y= 10,178,267' | -3,930 | TYPE 1 (205) |
| 7 | 287° | 6,696 | X= 956,332' Y= 10,180,837' | -3,835 | TYPE 2 (225) |
| 8 | 296° | 6,464 | X= 956,928' Y= 10,181,737' | -3,820 | TYPE 2 (225) |
| 9 | 016° | 6,695 | X= 964,824' Y= 10,185,431' | -3,870 | TYPE 2 (225) |
| 10 | 026° | 6,697 | X= 965,842' Y= 10,185,039' | -3,885 | TYPE 2 (225) |
| 11 | 048° | 6,712 | X= 967,893' Y= 10,183,532' | -3,930 | TYPE 1 (205) |
| 12 | 057° | 6,692 | X= 968,535' Y= 10,182,672' | -3,955 | TYPE 1 (205) |

NOTE: LEG HEADING IS MEASURED CLOCKWISE FROM TRUE NORTH.
NOTE: THE AS-BUILT POSITION ALLOWS WELL SLOT No.5 TO BE POSITIONED OVER SUBSEA WELL SLOT No.1.



REGIONAL MAP

ATP OIL and GAS
PRESET MOORING INSTALLATION AT MC-941

OVERVIEW OF
MOORING PLAN AND BATHYMETRY
(AS-BUILT)

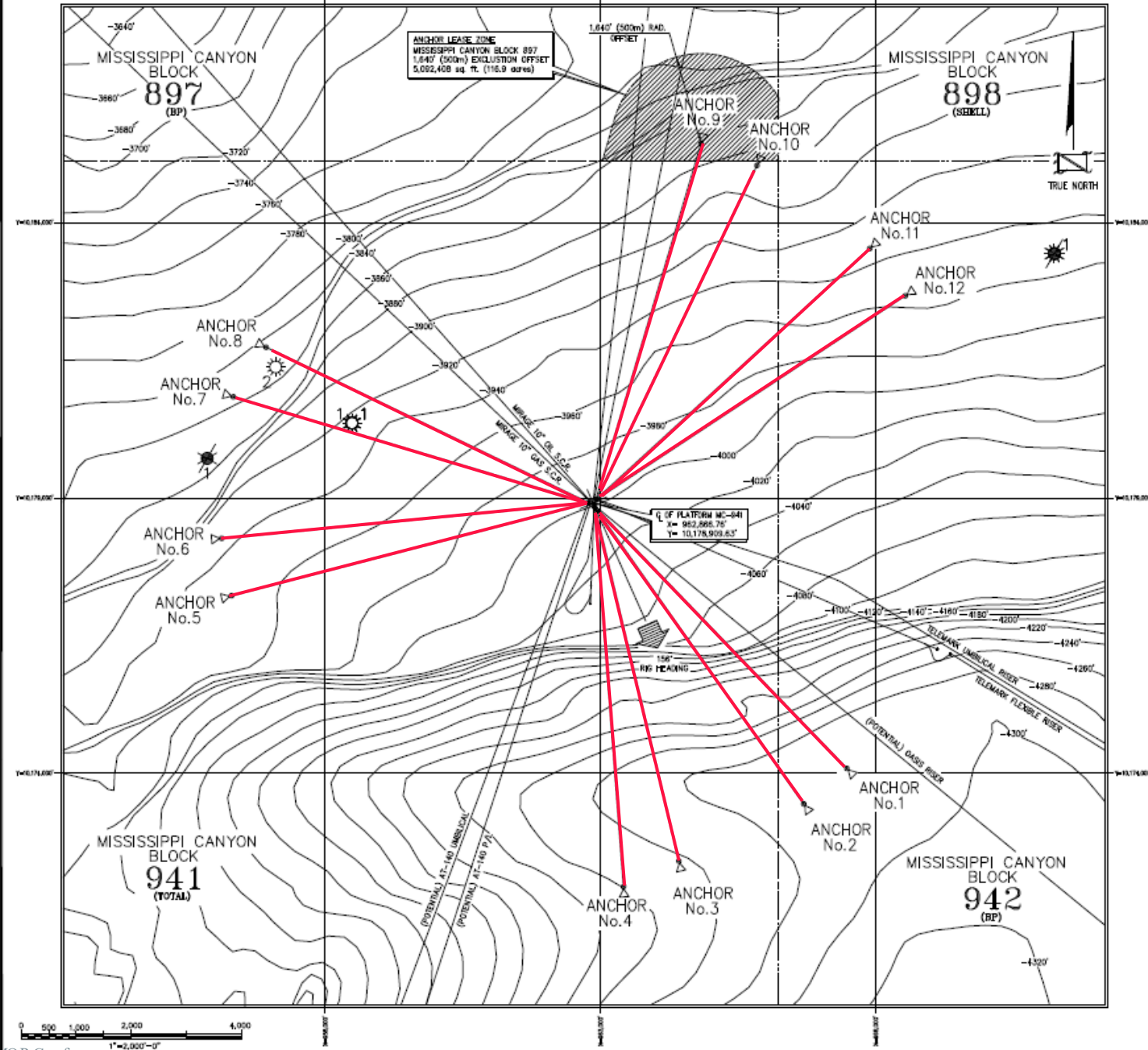


FIGURE 1 rev.1



OPERATOR: deep3D Last Rev. Date: 03/17/10 Time: 16:42:15 File Name: P:\10400\10403\312\PLAN\10403_04_00_PLOT-01.DWG Project Code: 10403-04
 CONFIDENTIAL NOTE: ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED EXCEPT WHERE SHOWN OTHERWISE. THIS INFORMATION SHALL NOT BE RELEASED OR DISCLOSED TO ANY OTHER PARTY OR TO THE PUBLIC FOR ANY PURPOSE OTHER THAN FOR THE BENEFIT OF AND AUTHORIZED BY A MEMORANDUM.

Broken link brought to deck



The broken link



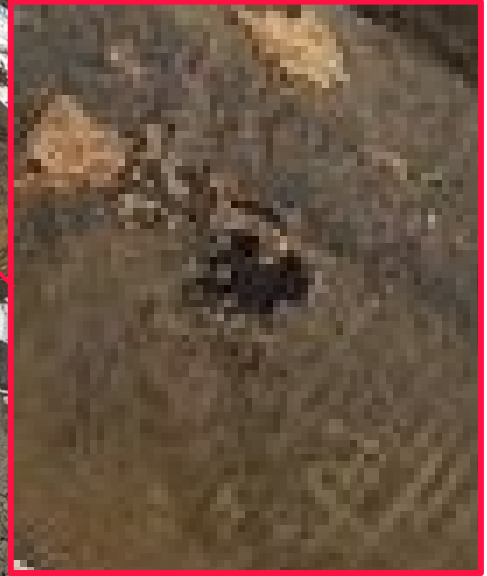
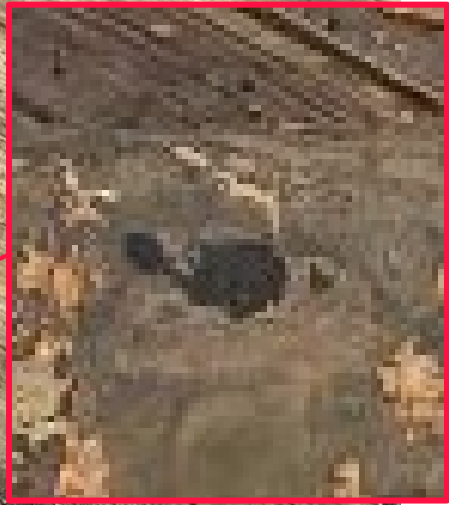
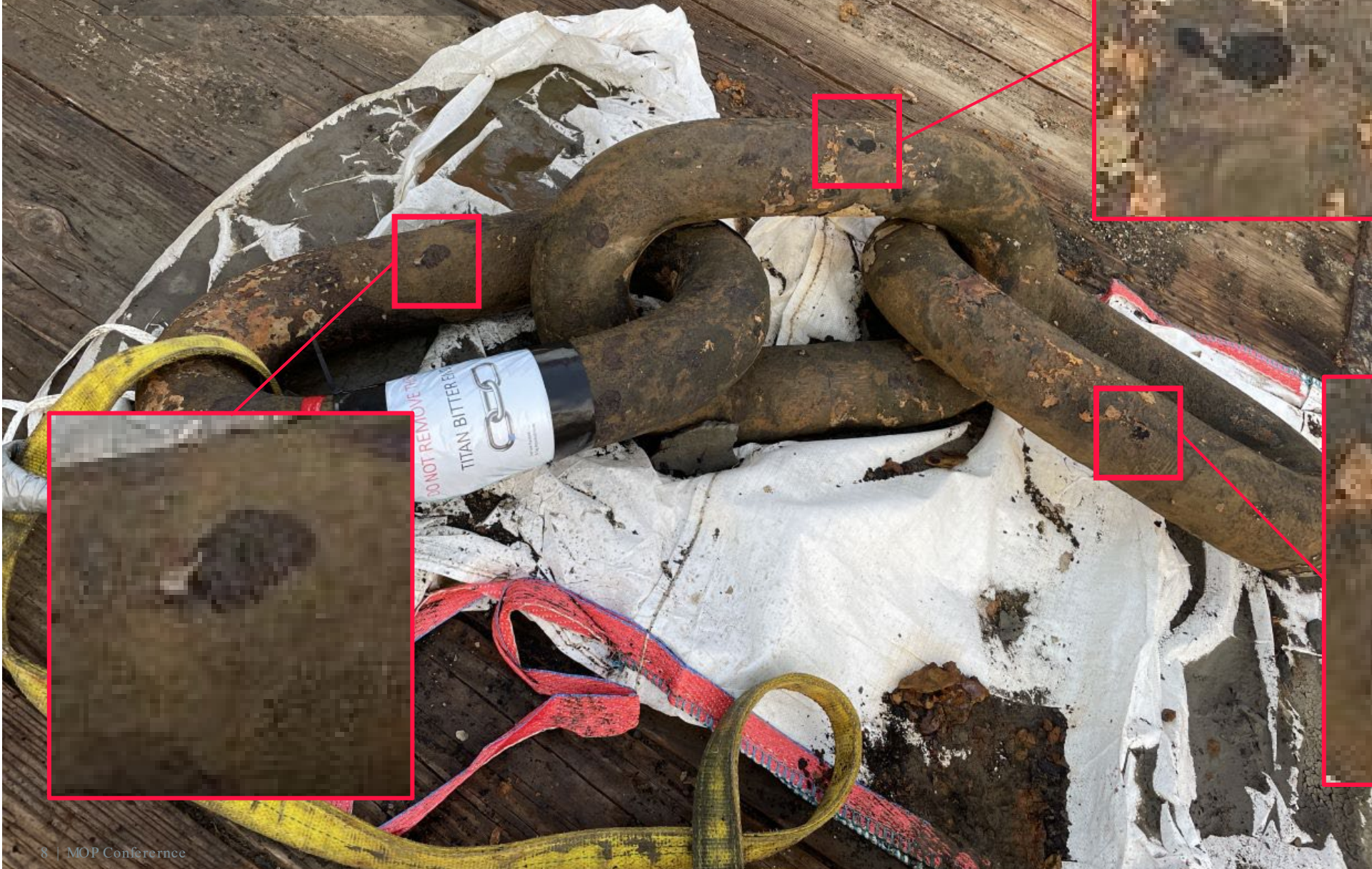
- Crown breakage. Typical for fatigue and hydrogen assisted cracking

Chain surface condition (all 7 links)



- Crack-like surface grooves on crown sides. Also on top of crown on some links.
- Pittings with pattern known from bacterial corrosion (Sulphate Reducing Bacteria - SRB)

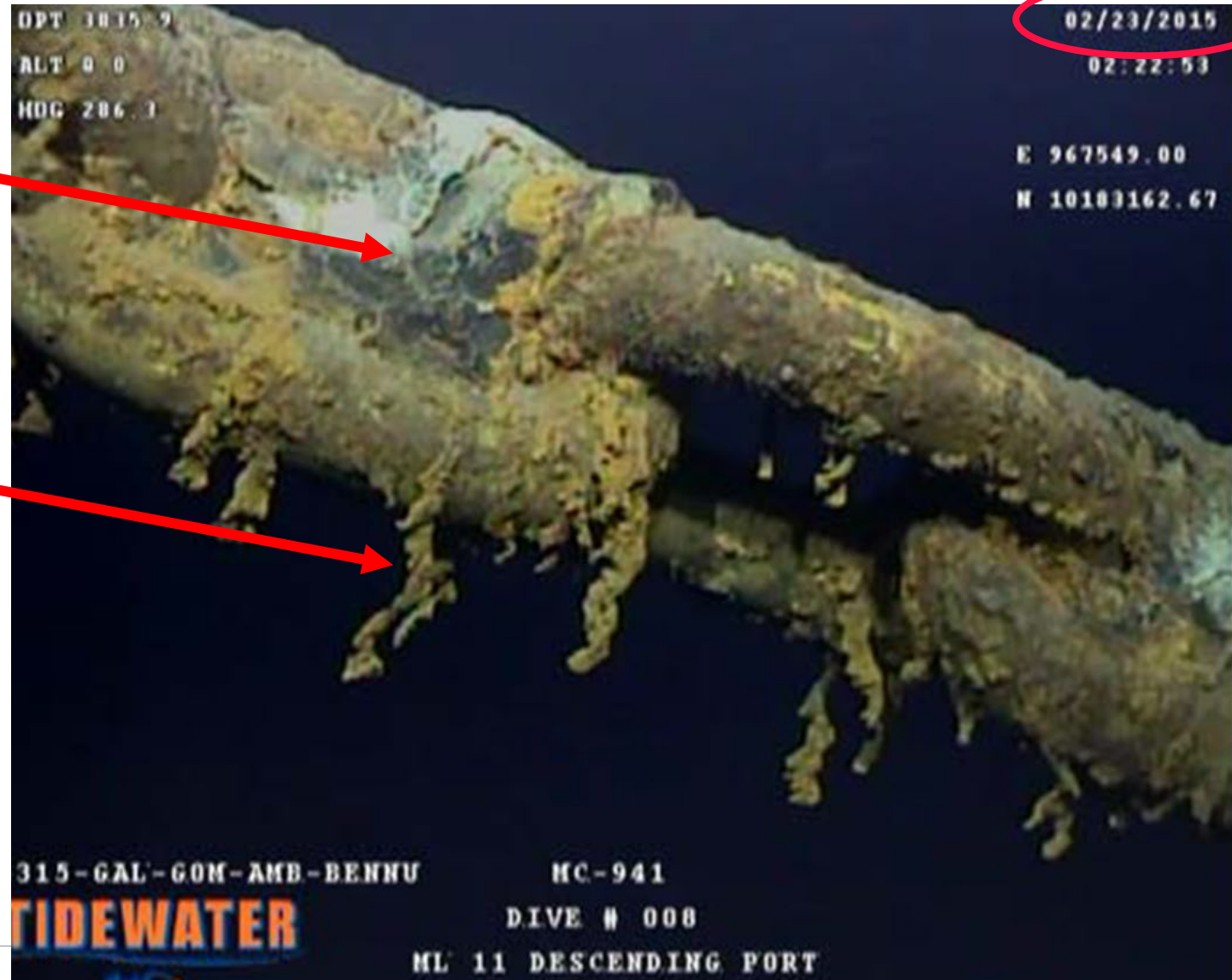
SRB indications



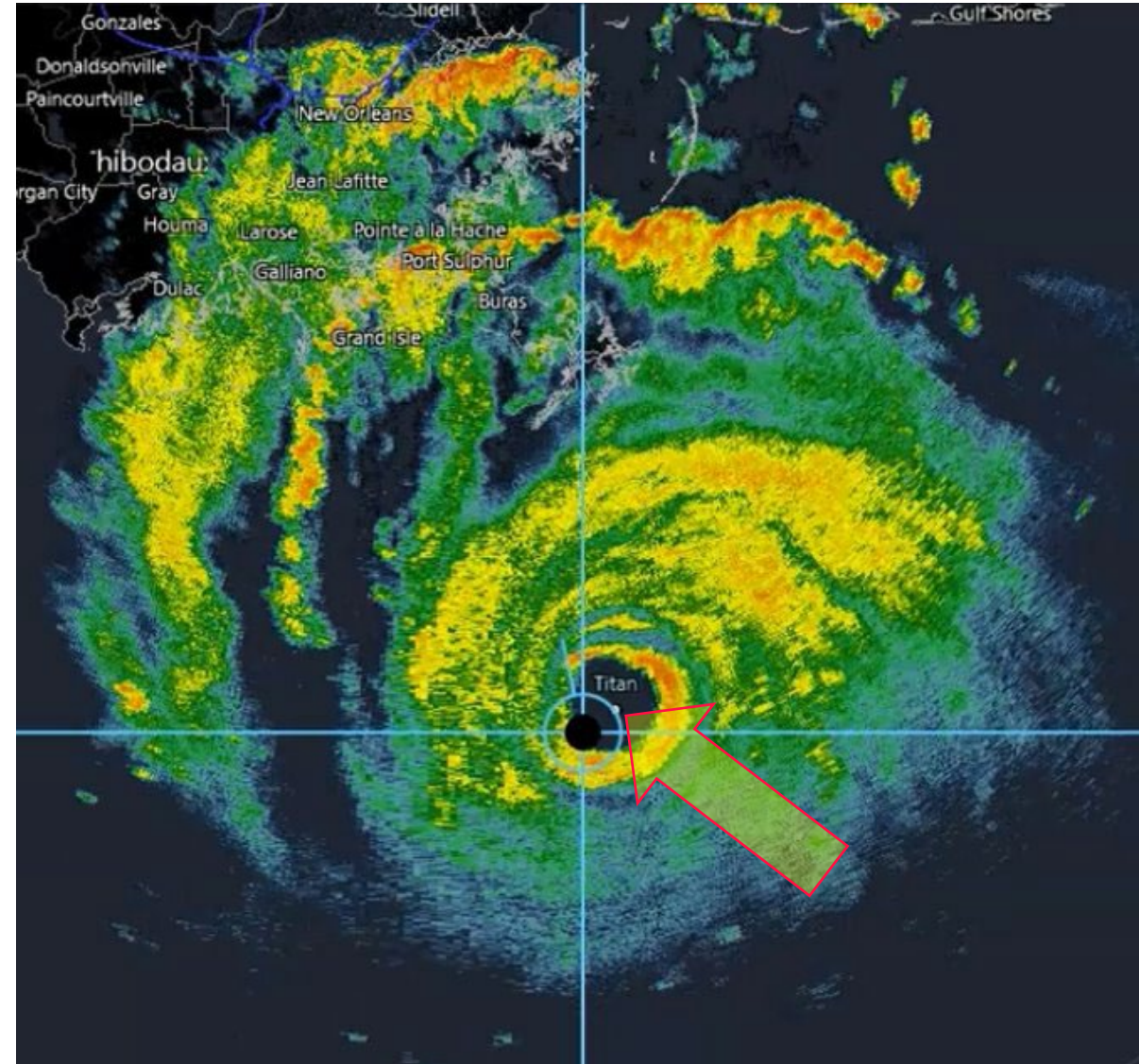
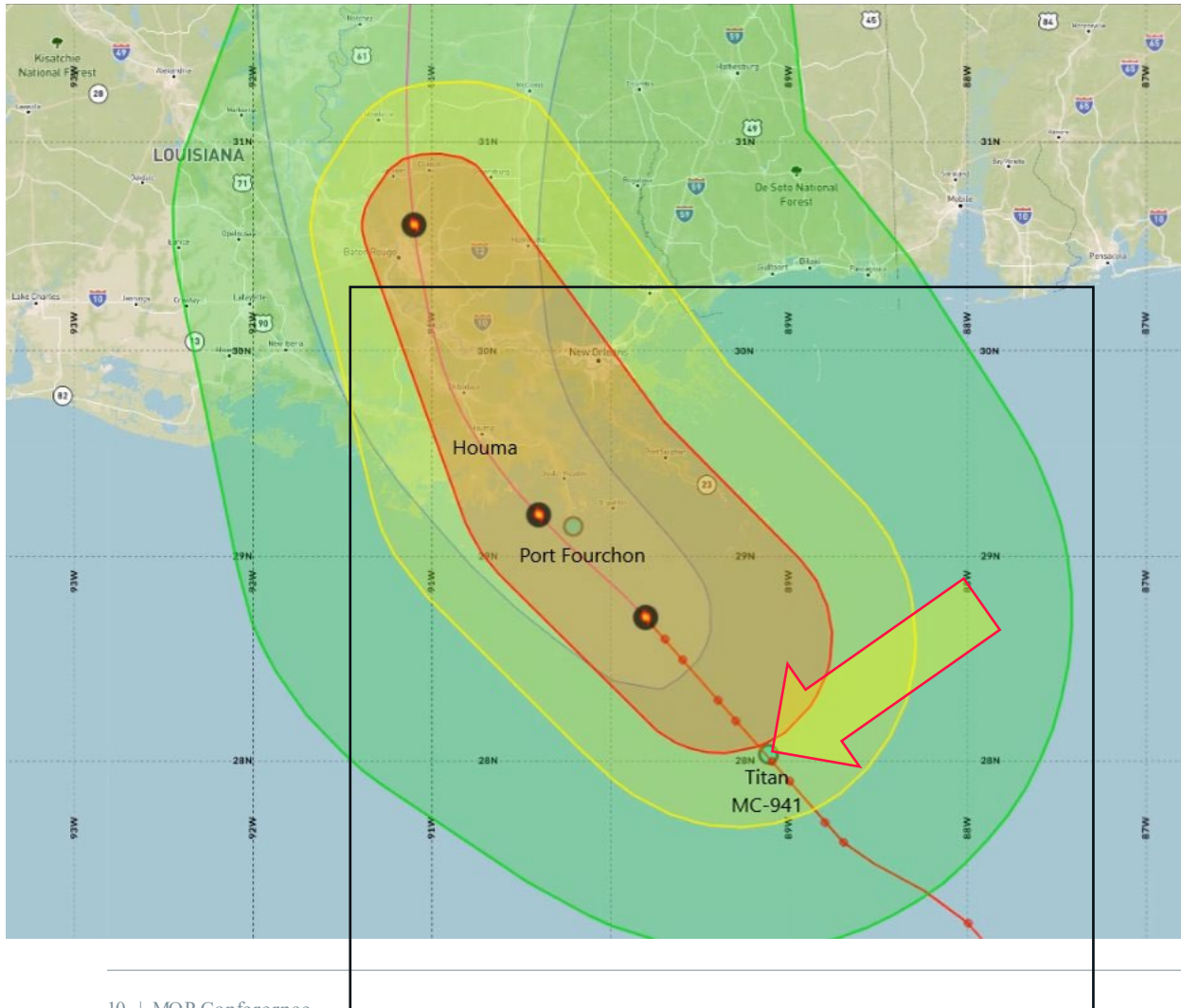
General inspection findings

Grey stuff

Rusticles



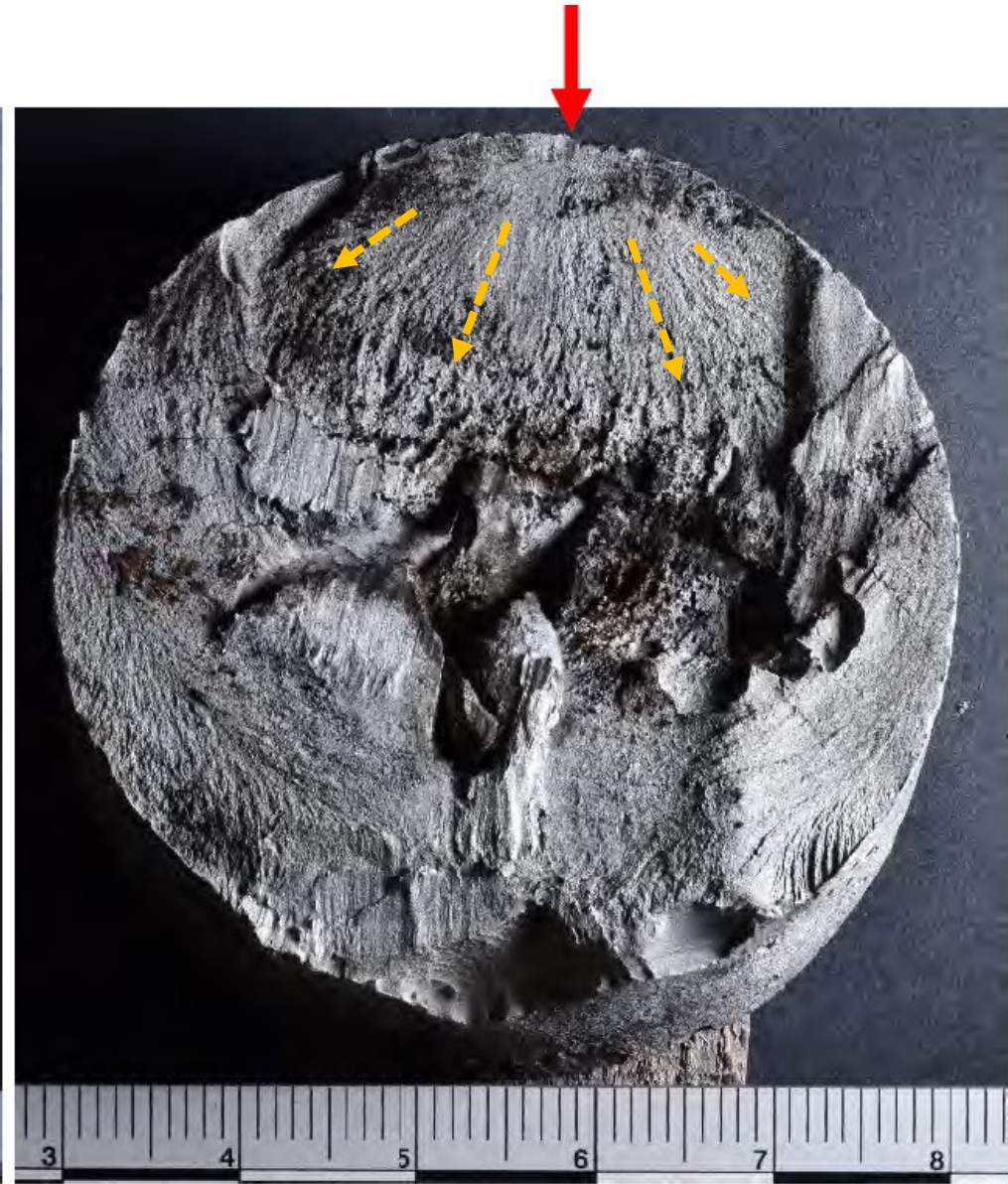
In the Eye of the Storm **Ida**



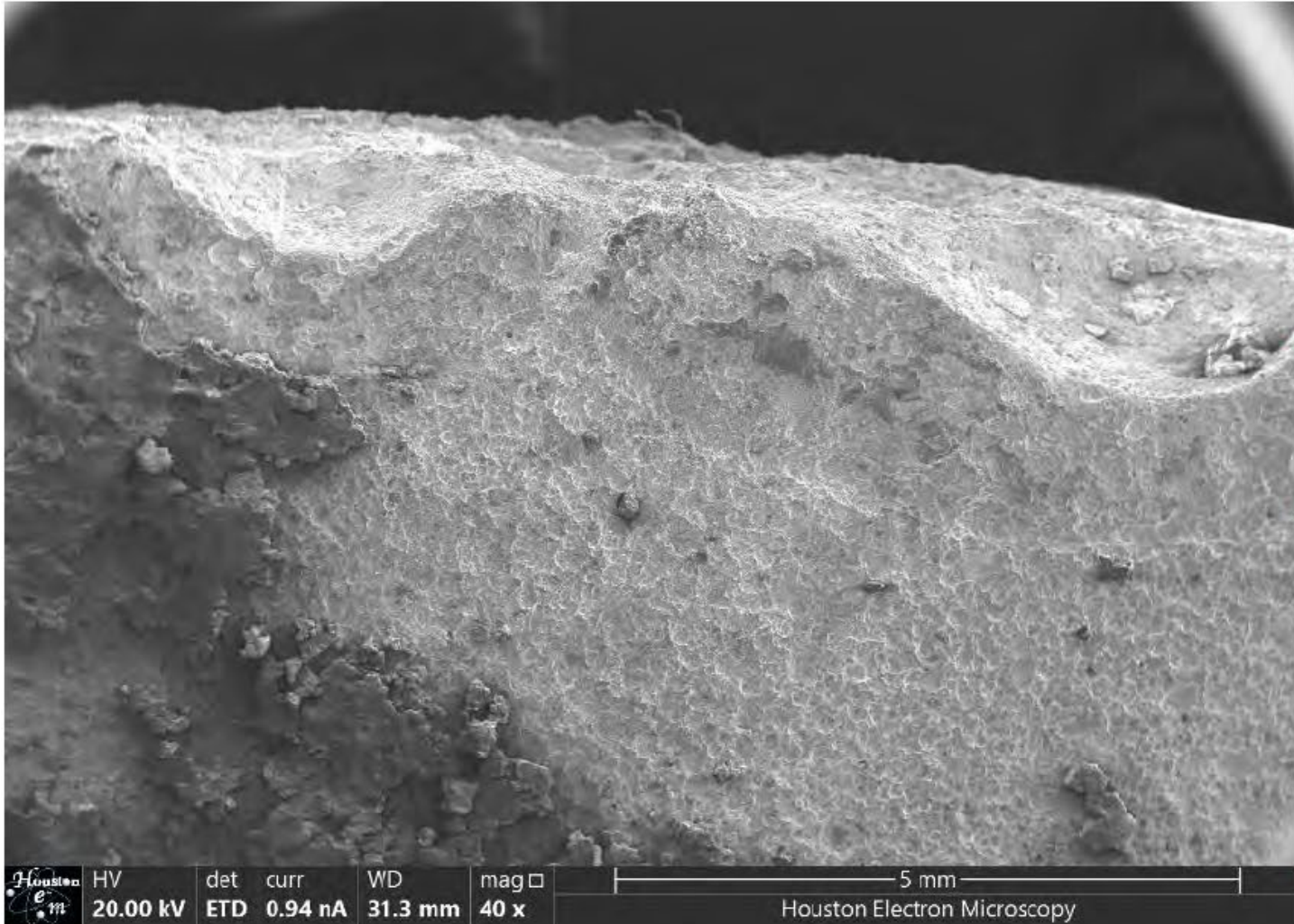
11 years with rusticles...



Fracture surface



Crack initiation



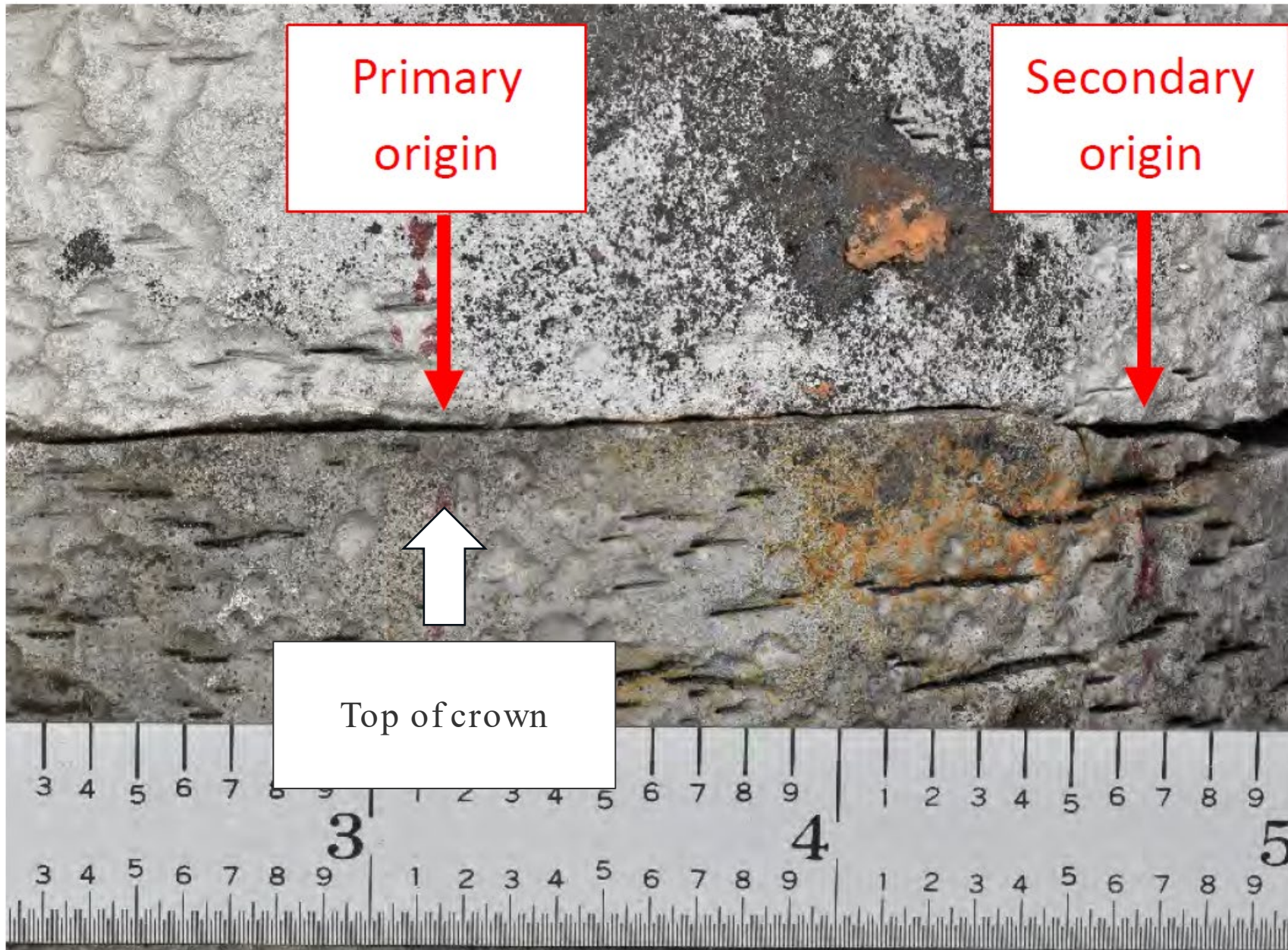
(Crack-like pit)

Surface Pit

Initial Crack Surface

← Transition in Fracture Morphology

Fracture Surface



TENSION TESTS

| | | | | |
|------------------------------|---|----------------------------------|-----------|-----------|
| Specimens | - | 0.505" diameter reduced sections | | |
| Sample | - | <u>NW</u> | <u>FW</u> | <u>CR</u> |
| Yield Strength, psi | | | | |
| At 0.2% offset | - | 140,800 | 119,500 | 131,100 |
| At 0.5% total extension | - | 113,200 | 116,400 | 125,500 |
| Tensile Strength, psi | - | 145,400 | 133,000 | 143,200 |
| Elongation, in 2" % | - | 19.1 | 14.3 | 18.8 |
| Reduction of Area, % | - | 69.1 | 56.3 | 63.1 |

Ratio = 0,92

987 MPa

| 450' | maximum values | | |
|-----------|----------------|---------|-------|
| Length No | yield | tensile | ratio |
| 38 | 904 | 984 | 0,92 |
| 39 | 904 | 984 | 0,92 |
| 40 | 904 | 984 | 0,92 |
| 41 | 904 | 984 | 0,92 |
| 42 | 904 | 984 | 0,92 |
| 43 | 891 | 976 | 0,91 |
| 44 | 878 | 960 | 0,92 |
| 45 | 878 | 960 | 0,92 |
| 46 | 923 | 999 | 0,92 |
| 47 | 923 | 999 | 0,92 |
| 48 | 923 | 999 | 0,92 |
| 49 | 923 | 999 | 0,92 |

Yield **971 MPa**
Tensile **1002 MPa** = **R5**

Ratio = 0,97

Yield value may have been affected by the plastic deformation

Broken line

Hardness and forensics comments

Table 3. Through-wall Hardness

| Location | Hardness (HV 10) | |
|-----------------------|-------------------|-----|
| ↓ ↓ ↓ ↓ ↓ | Near Surface | 349 |
| | | 356 |
| | | 341 |
| | | 341 |
| | Near Mid Diameter | 317 |

- Mechanical testing results [...] satisfy the requirements for ABS Grade R4 links (identical to Grade RQ4). However, it was noted that the **yield strength was on the high end for typical Grade R4 chain**, and the yield to **tensile ratio** in the non-welded side was **0.97** versus a specified aim value of 0.92 maximum.
- The hardness and tensile data demonstrate that insufficient material strength was not a cause for the failure, but **the hardness values are borderline for resistance to hydrogen-assisted cracking if a source of hydrogen is present.**

Take-aways to the industry

R4 chains with high strength can be susceptible to Hydrogen

Rusticles seems to / may cause pitting corrosion

Pitting corrosion (from bacteria) produce Hydrogen

Surface issues can start a Hydrogen assisted crack



Floating Offshore Wind

One FTW park = Many FWTs = Very many mooring lines...



Photo: Equinor.com

Typical (upcoming) park:

- 50 FWTs
- 200 mooring lines
- (+power substation)

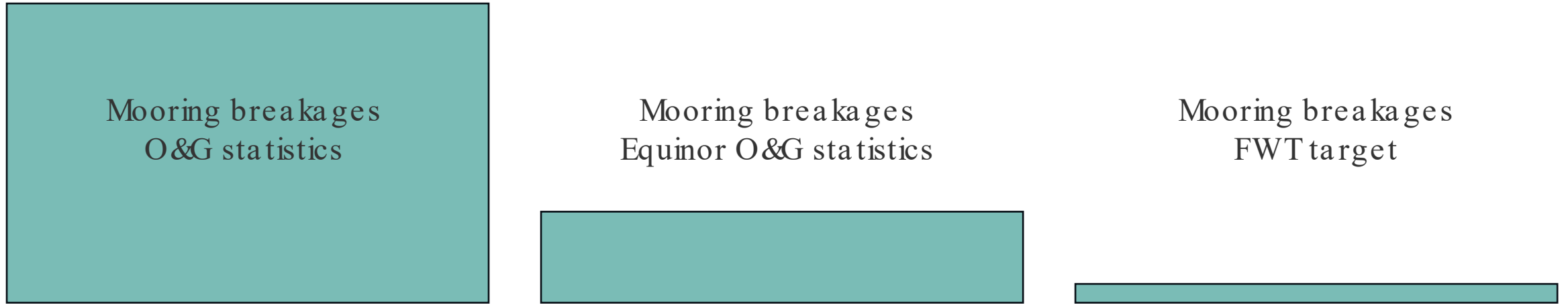
Current Equinor FWT fleet:

- 16 FWTs
- 48 mooring lines

All Equinor O&G assets:

- 20 assets
- 270 mooring lines

Mooring line breakages – acceptance level for FWTs ???



redundant mooring systems – typically 12-16 lines per installation

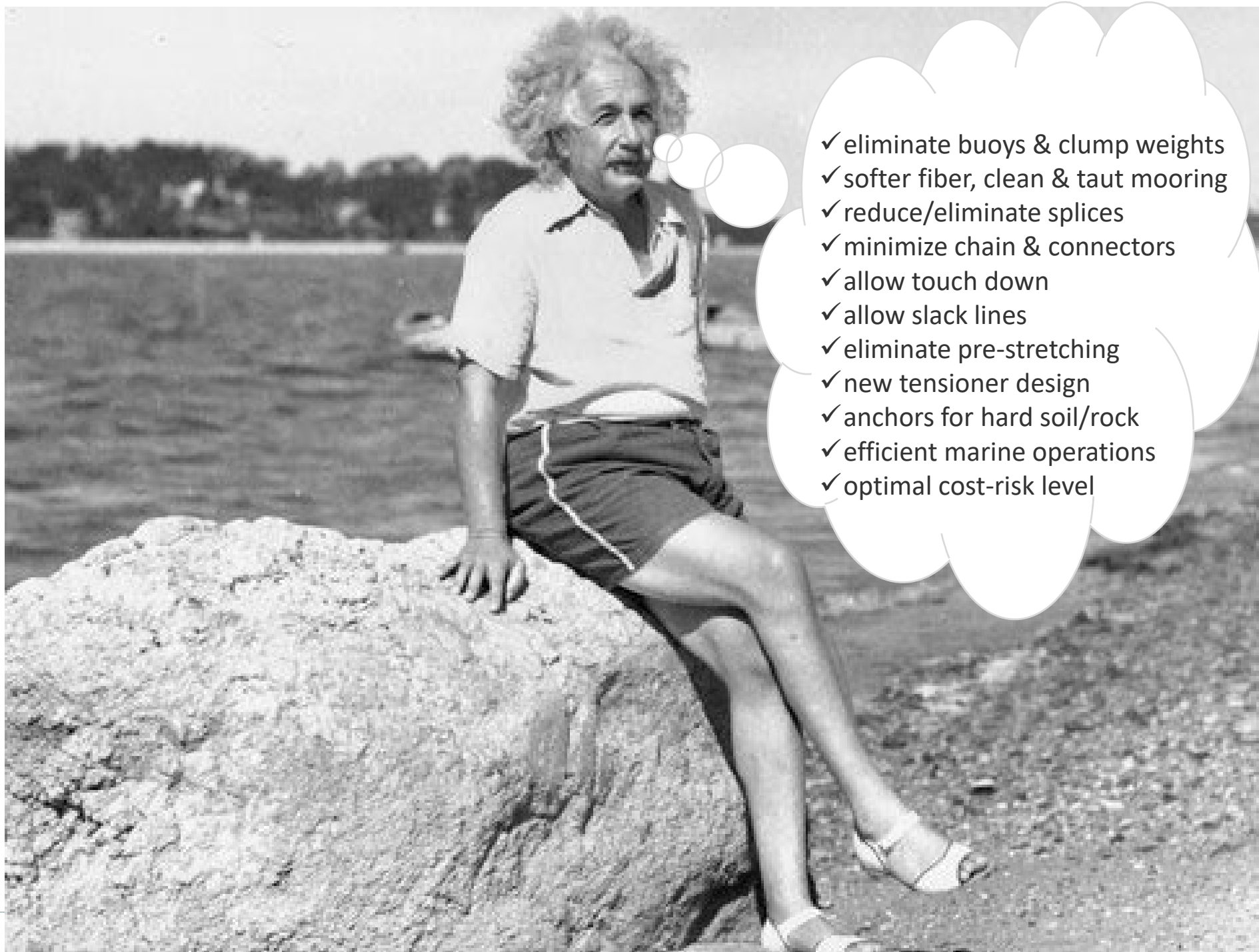
? 2,5 breakages / 1000 line years
Unknown repairs

<1 breakages / 1000 line years
Too many repairs
Life extension replacements

Design errors
Component selection / wear

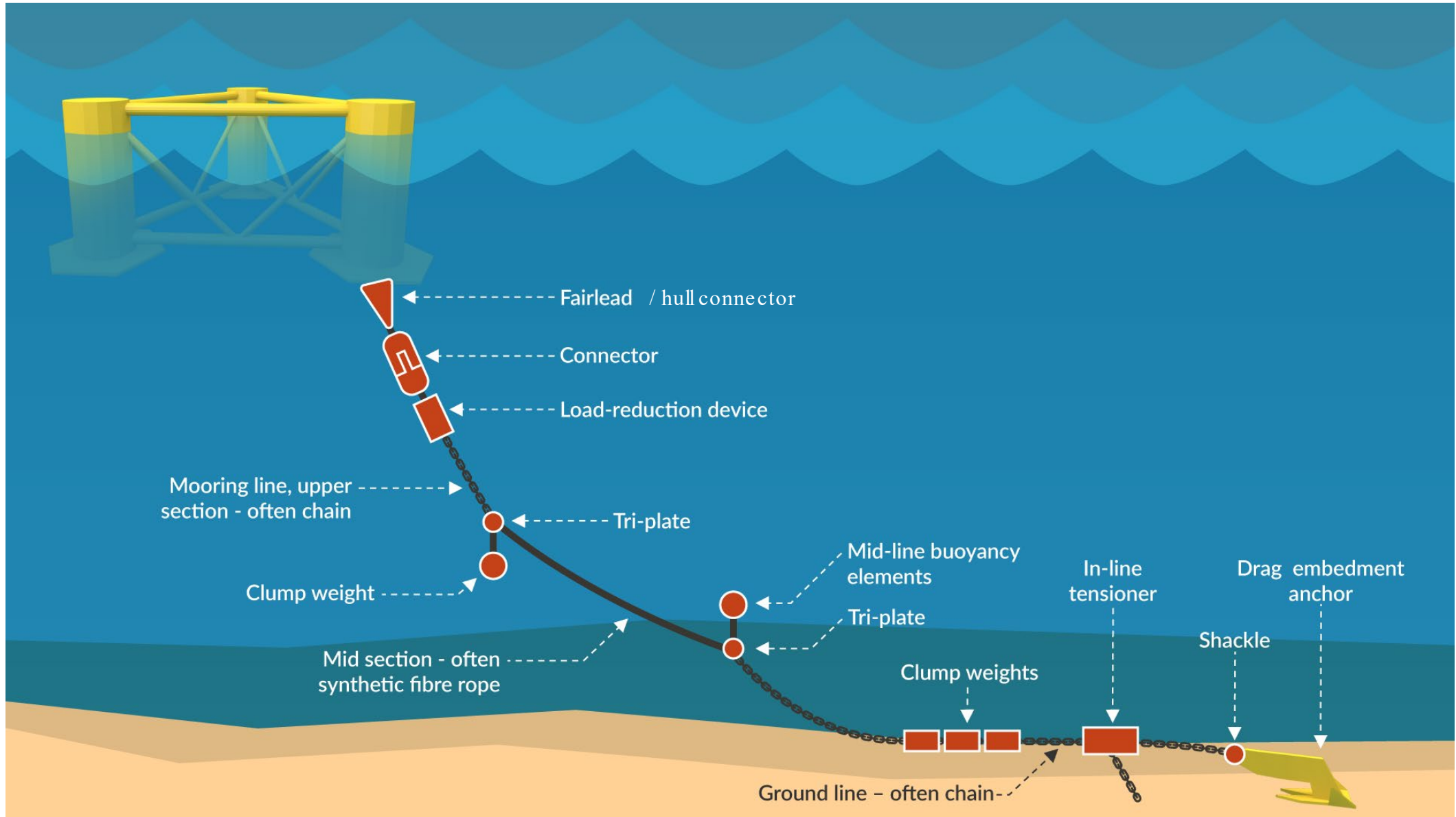
- Accidental failures only!
- No overload failures
 - No design error failures
 - No manufacture caused failures
 - No installation caused failures
 - No wear failures
 - No replacements within design life

Ideal mooring



- ✓ eliminate buoys & clump weights
- ✓ softer fiber, clean & taut mooring
- ✓ reduce/eliminate splices
- ✓ minimize chain & connectors
- ✓ allow touch down
- ✓ allow slack lines
- ✓ eliminate pre-stretching
- ✓ new tensioner design
- ✓ anchors for hard soil/rock
- ✓ efficient marine operations
- ✓ optimal cost-risk level

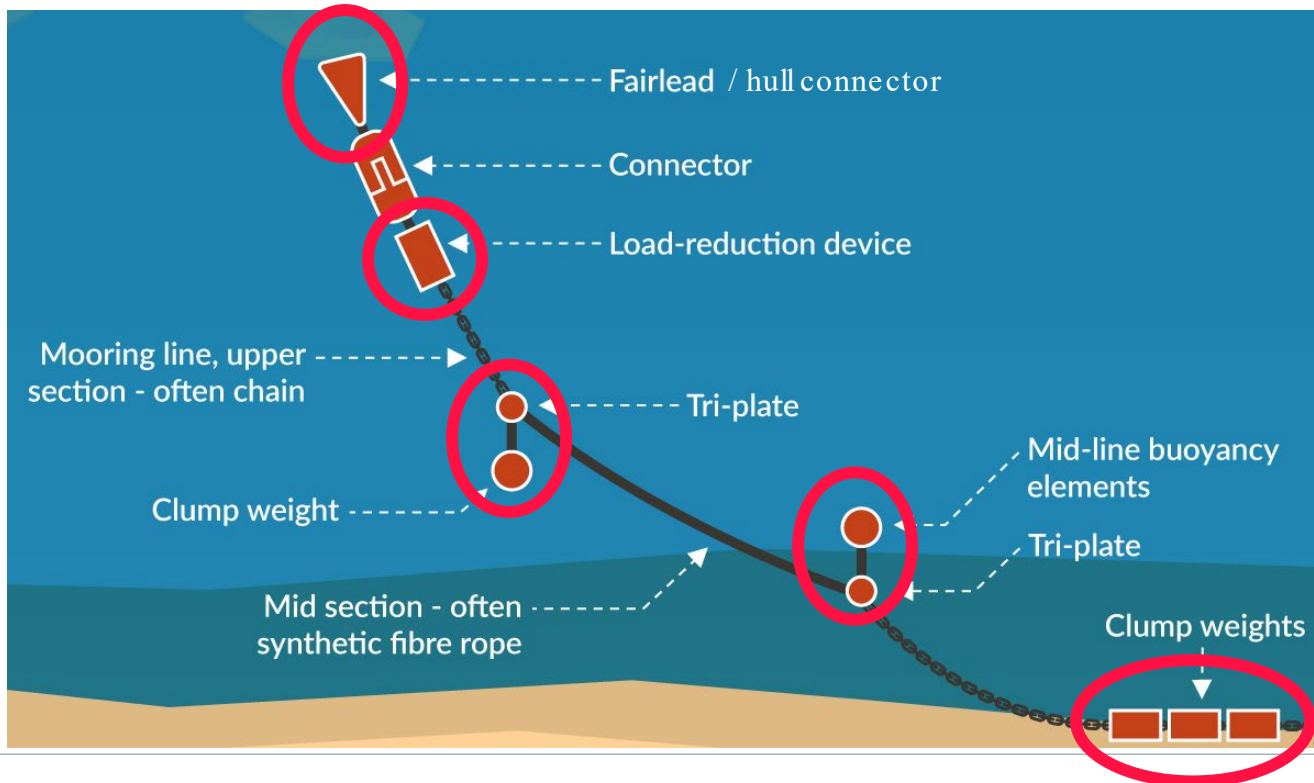
FWT mooring line – possible components



Dynamics, component collapse and wear

- Hull connections
- Heavy weight items
- Buoyancy elements

O&G: Dynamics cause wear and failures!



Difficult to predict dynamics

Snap loads

Difficult to predict wear

Pin design

Non-inspectable wrt wear

complicates installation

Complicates dis/re-connect FWT

A KISS is hard to get!
(keep it simple and smart)

Clump weights
on chain?



Not installation friendly

Falls off

Cause chain wear

Non-inspectable chain

Increase inspection need

Require replacements

NO KISS !!!

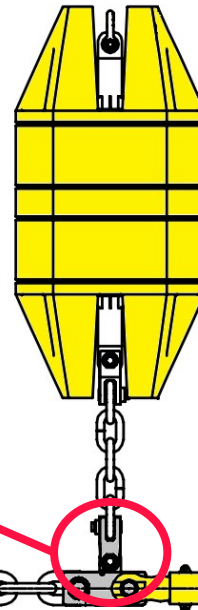
Dynamics: Wear, lost pins and missing buoys



Avoid

Robust

TQ

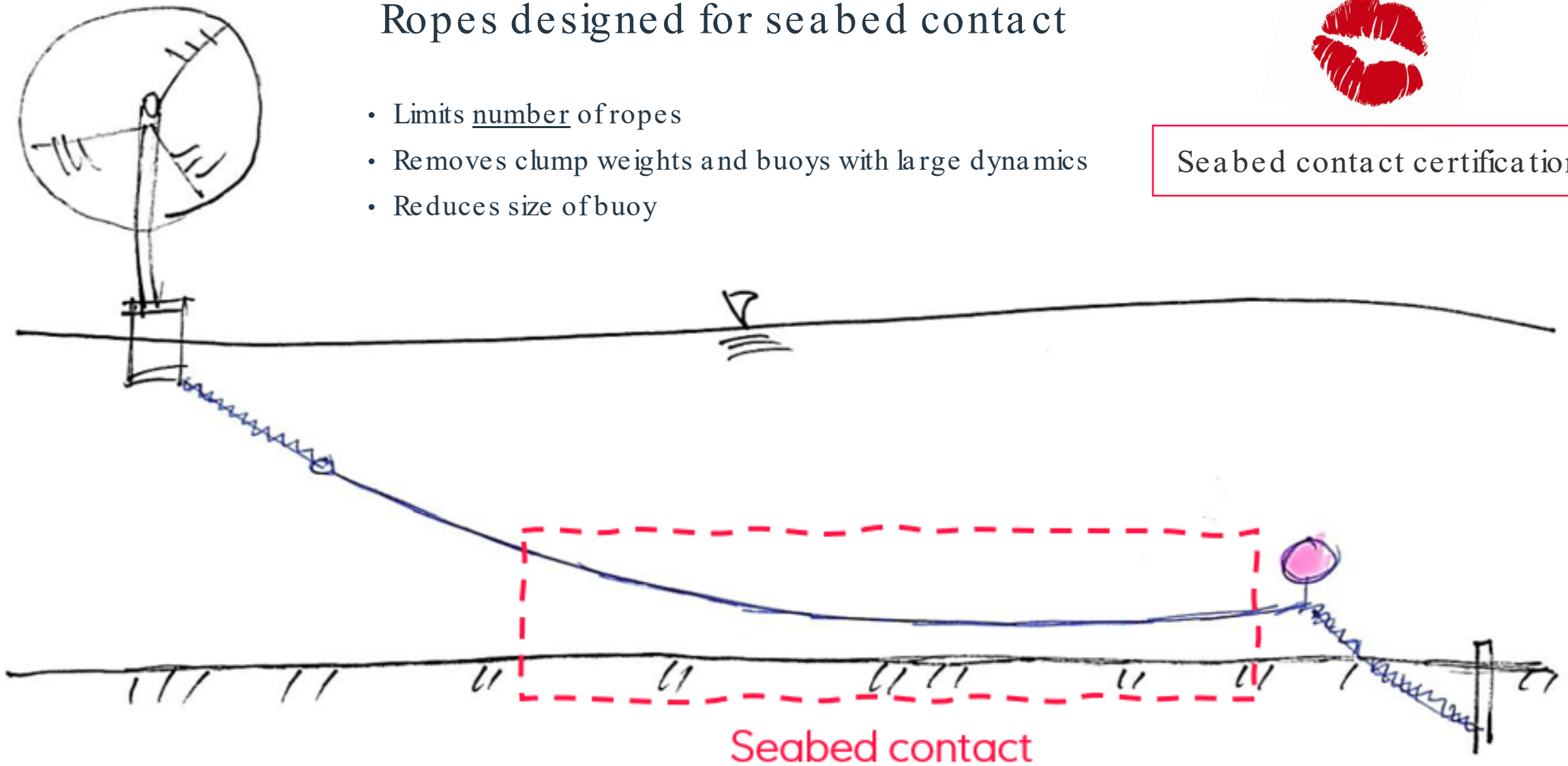


Ropes designed for seabed contact

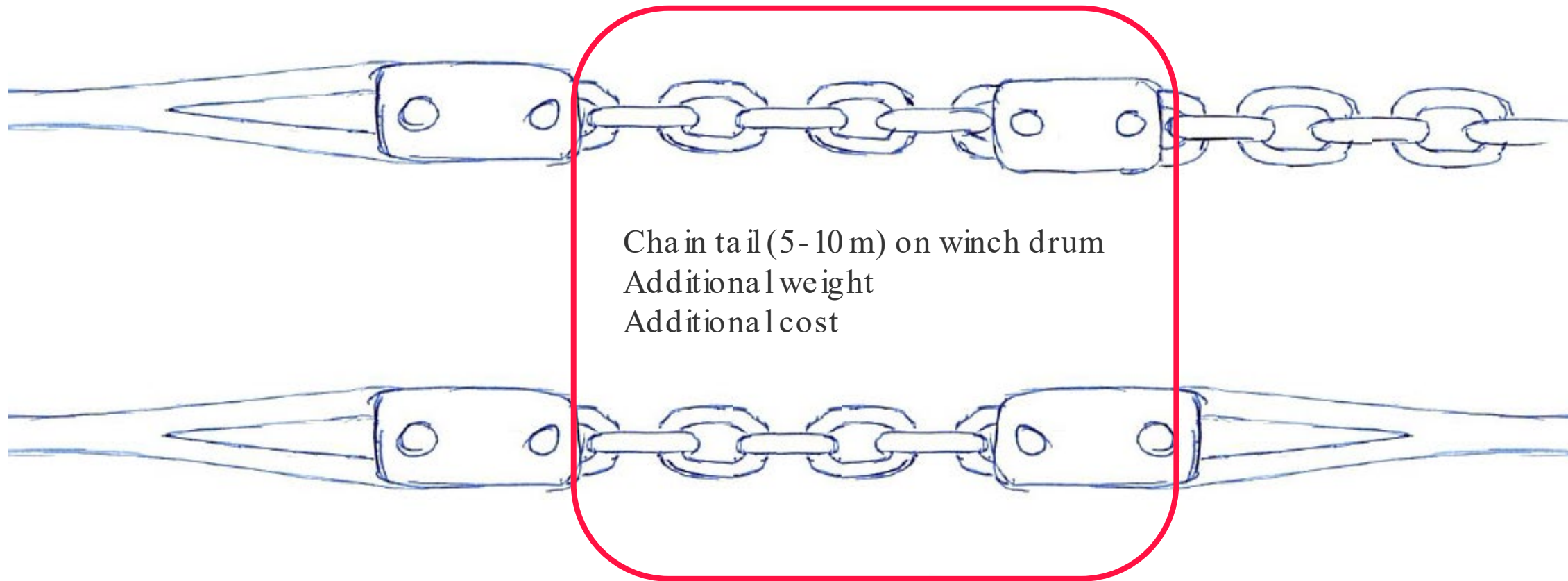
- Limits number of ropes
- Removes clump weights and buoys with large dynamics
- Reduces size of buoy



Seabed contact certification



Rope installation – securing the rope on deck



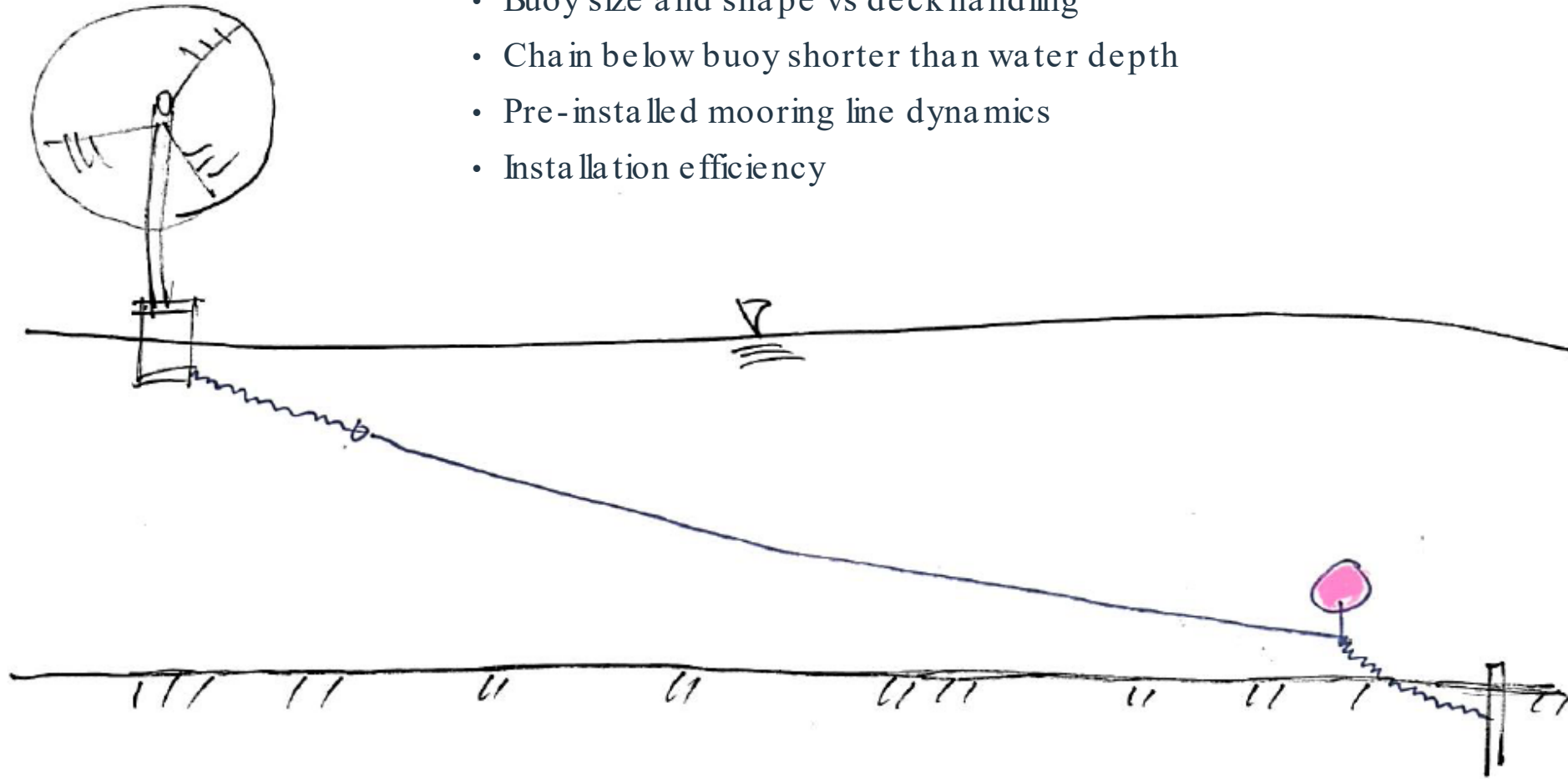
REMOVE 



subsea 7
patented

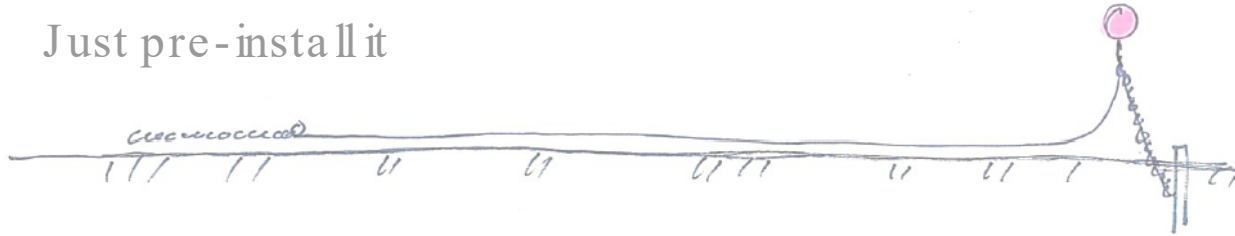
Buoy installation challenges

- Buoy size and shape vs deck handling
- Chain below buoy shorter than water depth
- Pre-installed mooring line dynamics
- Installation efficiency



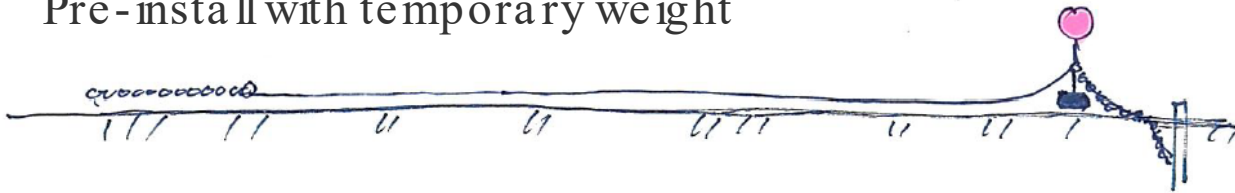
Mooring line with buoy pre-installation options

Just pre-install it



- ! Connect to an anchor
- ! Buoy and rope movements
- ! Rope wear at connection

Pre-install with temporary weight



- ! Load-out with weight
- ! Remove weight after hook-up

Pre-install without buoy



- ! Install buoy after hook-up



New solutions

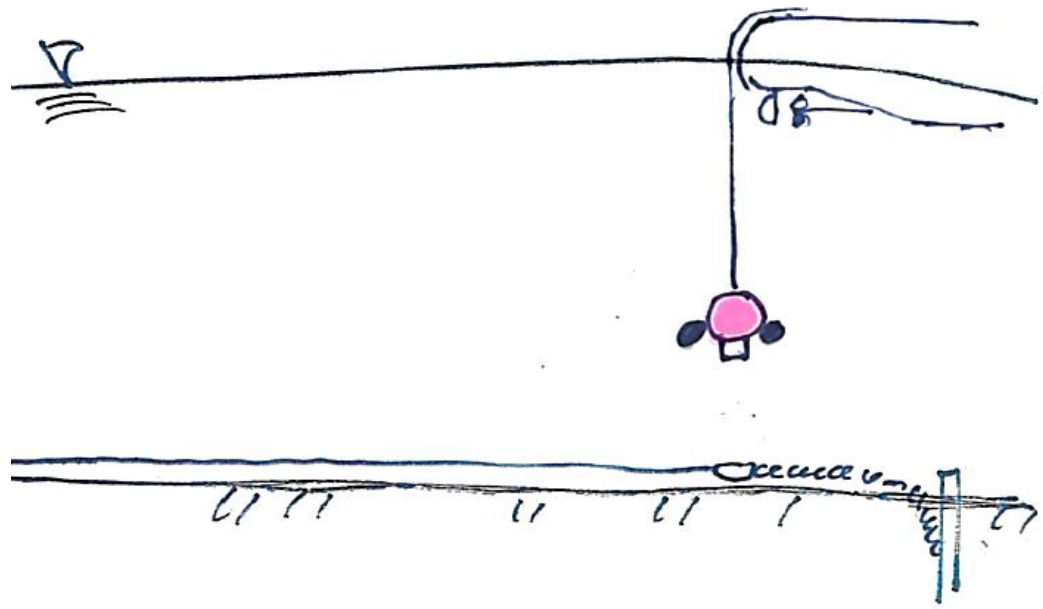
Vessel requirements

Efficiency

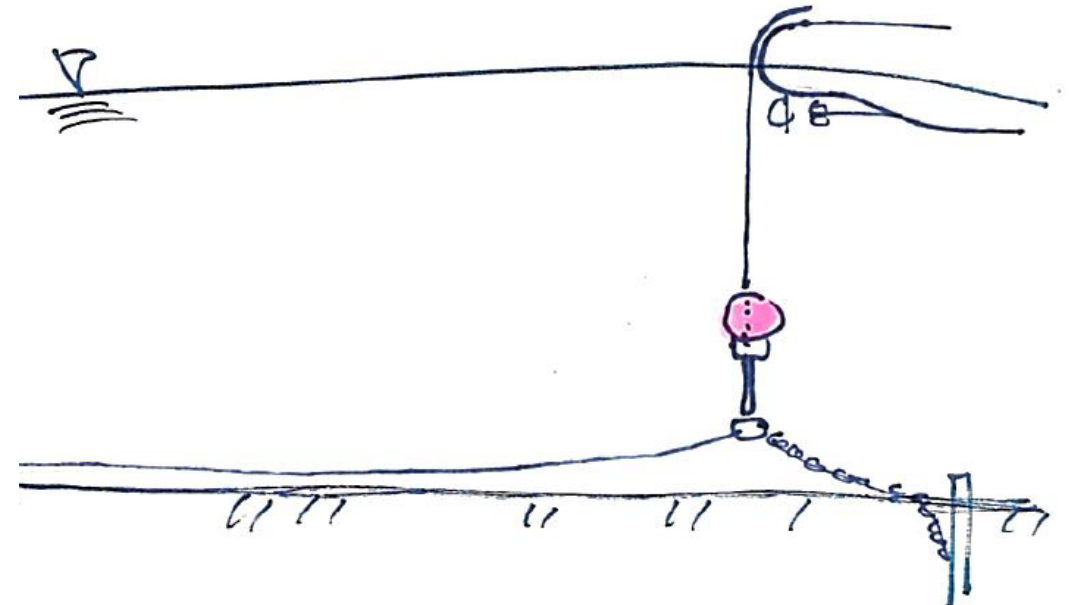
disconnect/reconnect!

Install buoy after hook-up principles

Balance buoy with weights



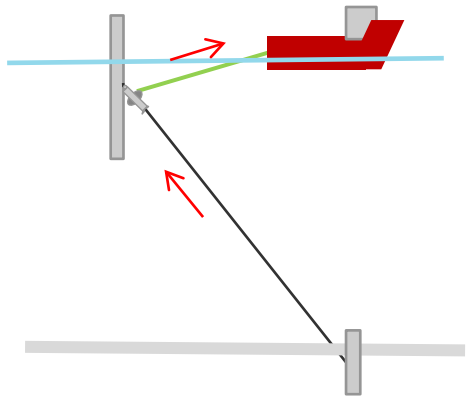
Pull buoy down to connector



New technology is needed!

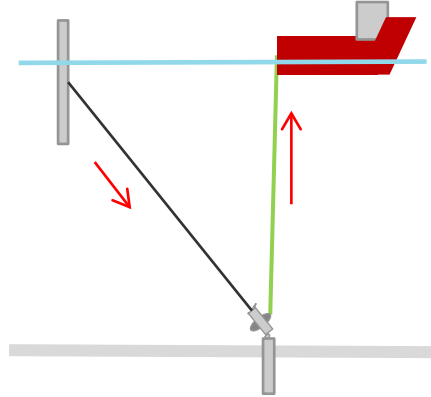
Tensioners

Fairlead chainstopper



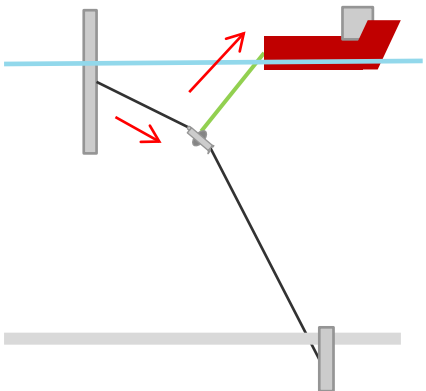
- Propeller thrust towards tensioner
- Chain OPB
- chain tail dynamics
- Complicated hook-up

Anchor tensioner



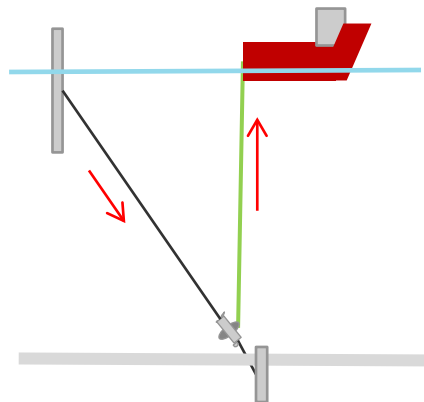
- Increased anchor size
- Shared anchors?

Inline tensioner (ILT)



- Introduce “clump weight” with dynamics
- Chain OPB
- chain tail dynamics

Seabed tensioner



- Limited to Catenary systems only

Chain segments are needed

Wear

Pre-stretch need

Operation complexity

Maintenance

disconnect / reconnect

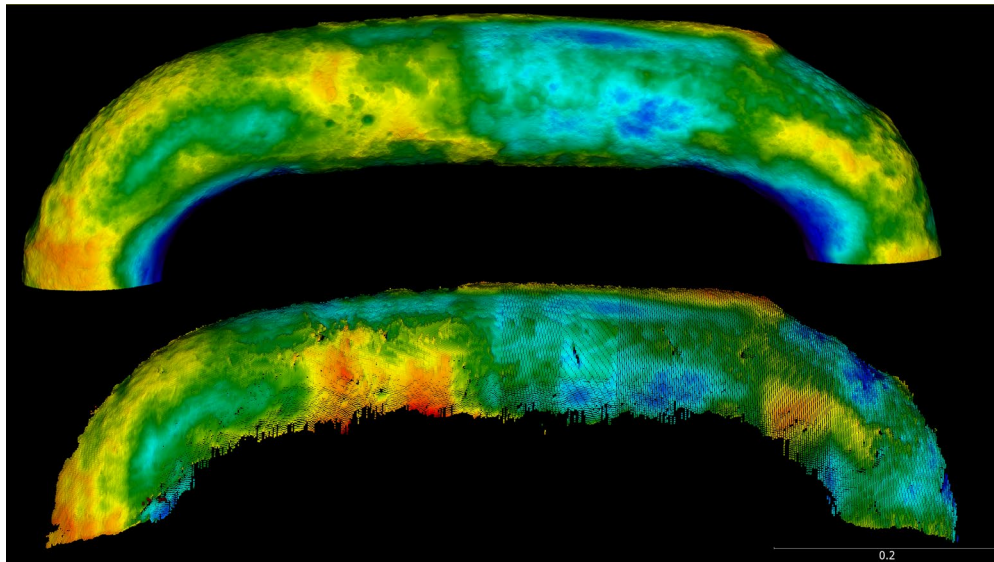
The perfect solution is yet to be designed (?)

Mooring Inspection

Chain detailed inspection – subsea 3D scanning

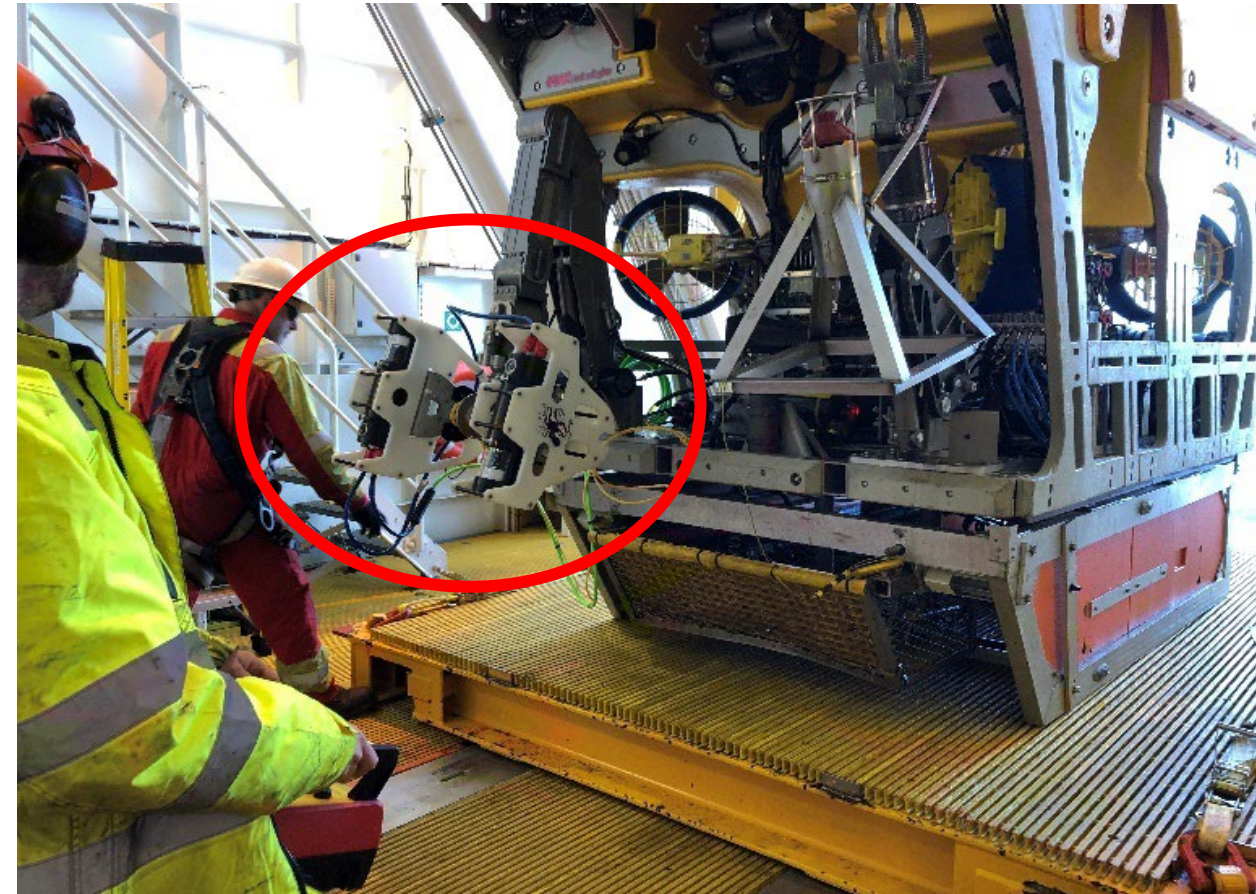
- High requirements to accuracy and resolution
- Subsea laser scanning is available
 - Details OK for 3D scan post processing

Sea Vision by  **KRAKEN**

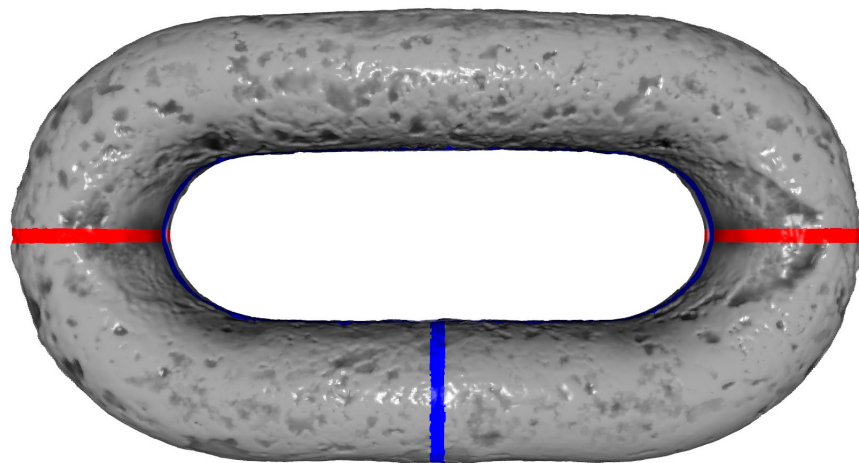
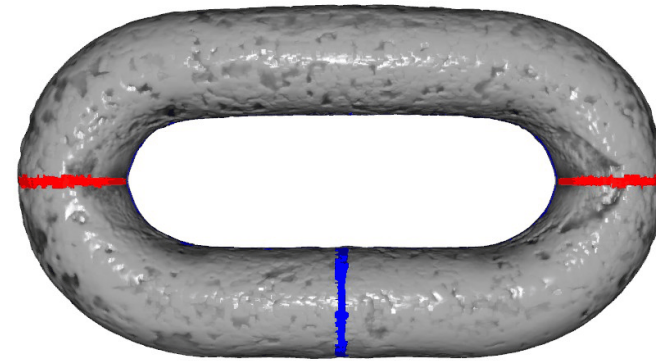
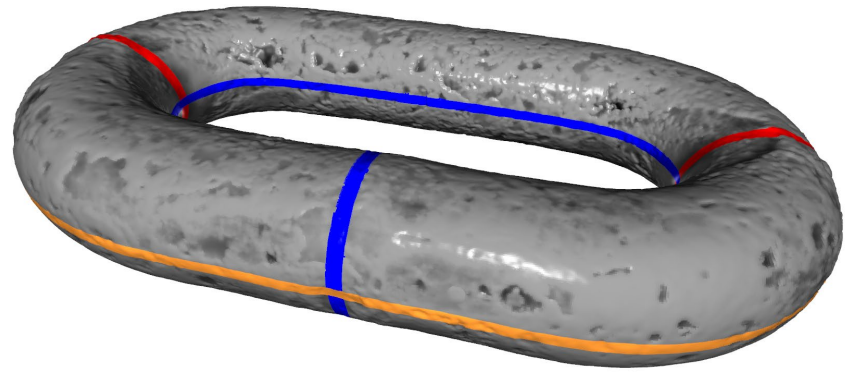


lab
3D scan

Sea Vision
offshore
3D scan



On-shore post processing of 3D scans – roughness maps



On-shore post processing of 3D scans – corrosion loss



Chain cleaning – access for inspection/3D scanning





Mooring Challenges 2023

Elizabeth Hostrup – MOP 17-18 April 2024

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