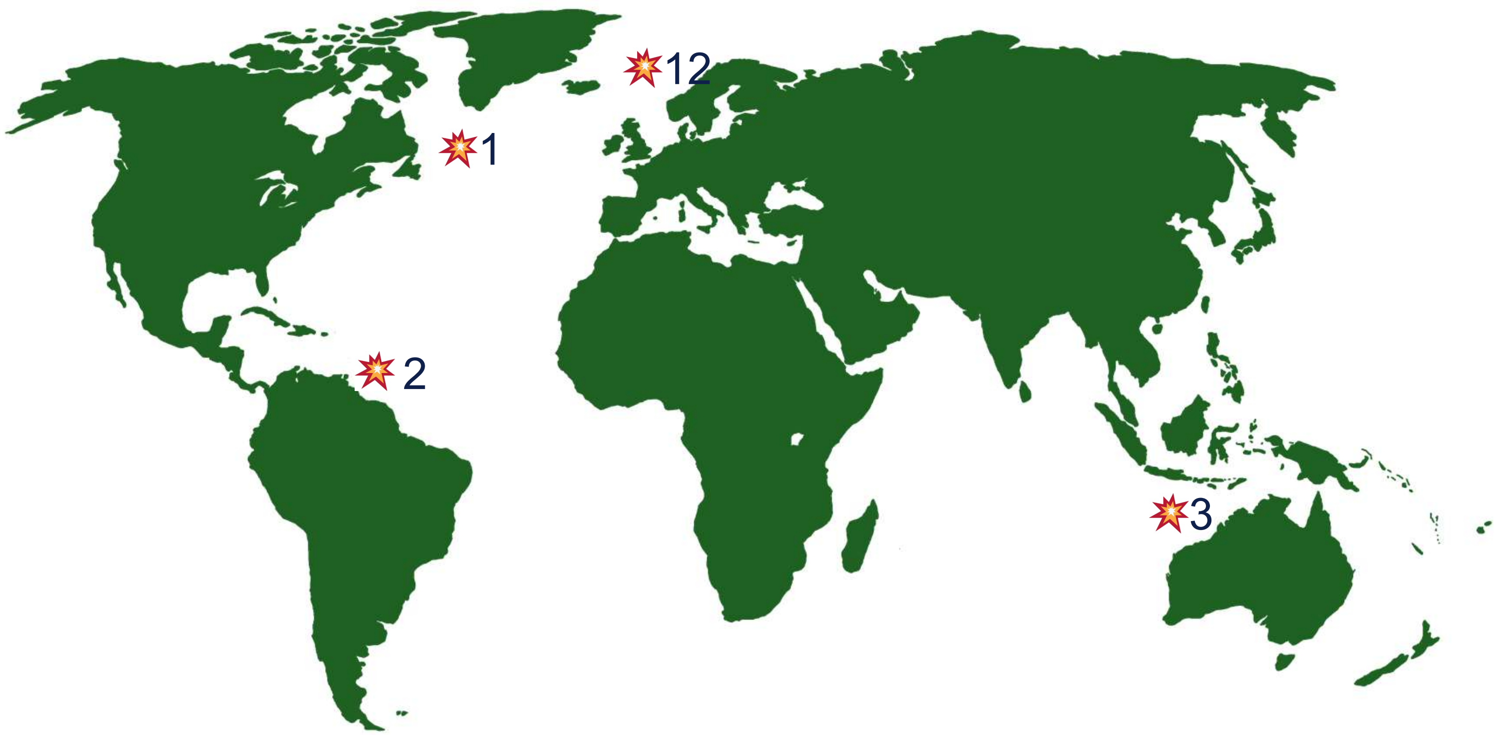
WHEN TRUST MATTERS

High strength mooring chains - status & actions

Mooring Integrity Forum, Rotterdam, June 2022

Dag-Børre Lillestøl
16 June 2022

Overview of failures - geography (documented cases)



Background – Recent DNV involvement with "R5"

Initiated an internal task force in 2020

- Inspectors
- Laboratory testing Bergen and Høvik
- Material experts
- Mooring experts
- Interaction with industry stakeholders

Mandate

- Obtain overview and investigate previous failures
- Understand the entire lifecycle/"value chain"
- Identify need for corrective actions
- Inform the industry

- Renewal inspections
- Failure investigations
- Fatigue testing
  - Full scale fatigue test (slow strain)
- SSRT studies
  - Susceptibility to Hydrogen
- DNV work summarized in
  - Report – (internal report due to client data)
  - High-level status review presented at Ankerhåndteringskonferansen, Nov. 2021, Stavanger, by Erik Carlberg
  - More detailed presentation held at TEKNA Conference in Trondheim May 2022

Current activities on “R5” w/DNV involvement

- Proposal for new chain handling requirements in DNV-RU-OU-0300 App. D - on hearing for July 2022 Edition. (entering into force January 2023)
  - Onshore handling (including loading/unloading)
  - Offshore handling/AHV operations (to be aligned with revised GOMO Ch.11)
  - New condition/usage based inspection regime for mooring chain
- Initiative to look at anchor test loads – requirements and current practise (w/DNV Geo. Dept)
  - Update of DNV-RP-E301
- DNV contract-study for PTIL on high strength chain – to be concluded October 2022
- Revision of DNV-OS-E302, Offshore mooring chain, July 2022 + 2023 Edition
- GOMO industry workgroup – revise chapter 11 – anchor-handling in “Guidance for Offshore Marine Operations” – target completion Q3 2022

DNV-OS-E302- Mooring chain material

Steel grade	Yield stress	Tensile strength	Elongation	Reduction of area	Charpy V-notch		
	R_e	R_m	A_5	Z	Temperature [1]	Average energy	Single energy
	N/mm^2	N/mm^2	%	%	°C	J	J
R3	410	690	17	50 [2]	0	60	45
					-20	40	30
R3S	490	770	15	50 [2]	0	65	49
					-20	45	34
R4	580	860	12	50 [3]	-20	50	38
R4S	700	960	12	50 [3]	-20	56	42
R5	760	1000	12	50 [3]	-20	58	44
R6	900	1100	12	50 [3]	-20	60	46

[1] For grade R3 and R3S, testing may be carried out at either 0°C or -20°C.
[2] For cast accessories, the minimum value shall be 40%.
[3] For cast accessories, the minimum value shall be 35%.

HISC susceptibility scope limit

RP-B101, 550MPa of extra high strength steels

RP-B401, 700MPa for Martensitic steels

Metallurgy - mechanical properties

- Relation between yield and tensile
- Maximum tensile within grade
- DNV-OS-E302:

Table 3 Minimum mechanical properties for chain cables

Grade	Yield stress 4)	Tensile strength 4)	Elongation	Reduction of area	Charpy V-notch				
						Base		Weld	
	R_e	R_m	A_5	Z	Temperature 1)	Average energy	Single energy	Average energy	Single energy
	N/mm^2	N/mm^2	%	%	°C	J	J	J	J
R3	410	690	17	50 2)	0	60	45	50	38
					-20	40	30	30	23
R3S	490	770	15	50 2)	0	65	49	53	40
					-20	45	34	33	25
R4	580	860	12	50 3)	-20	50	38	36	27
R4S	700	960	12	50 3)	-20	56	42	40	30
R5	760	1000	12	50 3)	-20	58	44	42	32
R6	900	1100	12	50 3)	-20	60	46	44	34

1) For grade R3 and R3S, testing may be carried out at either 0°C or -20°C.
2) For cast accessories, the minimum value shall be 40%.
3) For cast accessories, the minimum value shall be 35%.
4) ~~For guidance only: Typical yield to tensile strength ration is in the range of 0.85 to 0.95.~~ Tensile strength is ~~normally not to exceed the minimum tensile strength with more than 150 MPa.~~

- Test of one fractured link R5 grade:

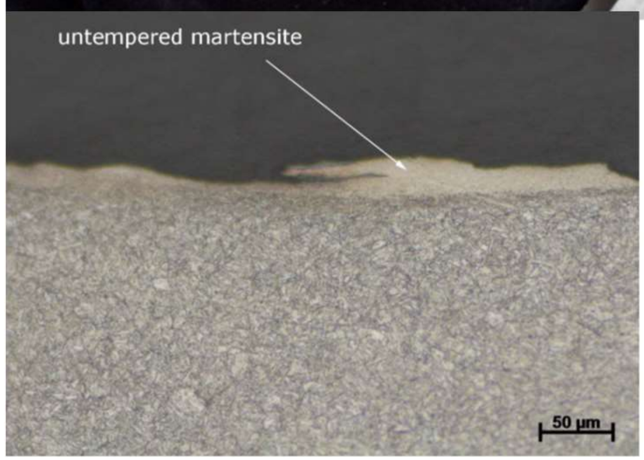
Yield strength [Mpa]	Tensile strength [Mpa]	Elongation [%]
~ 1200	~ 1210	~12

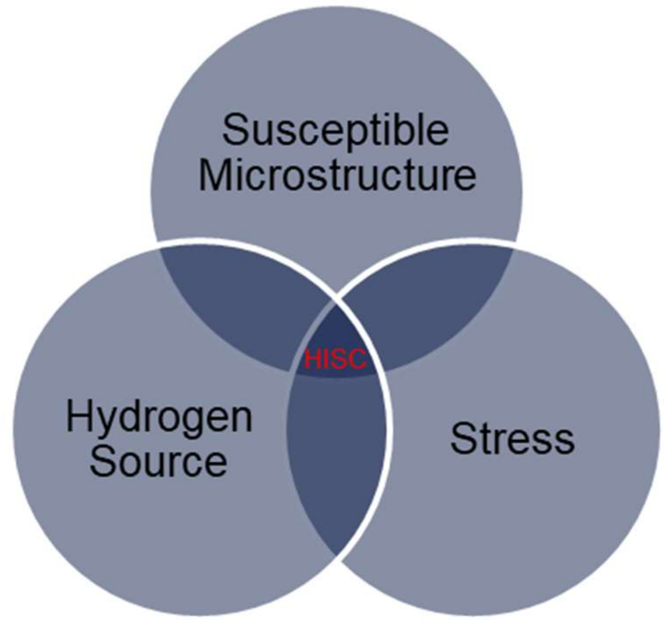
- Production tests showed acceptable results during certification

Proposed modified in the July 2022 Edition – currently on hearing

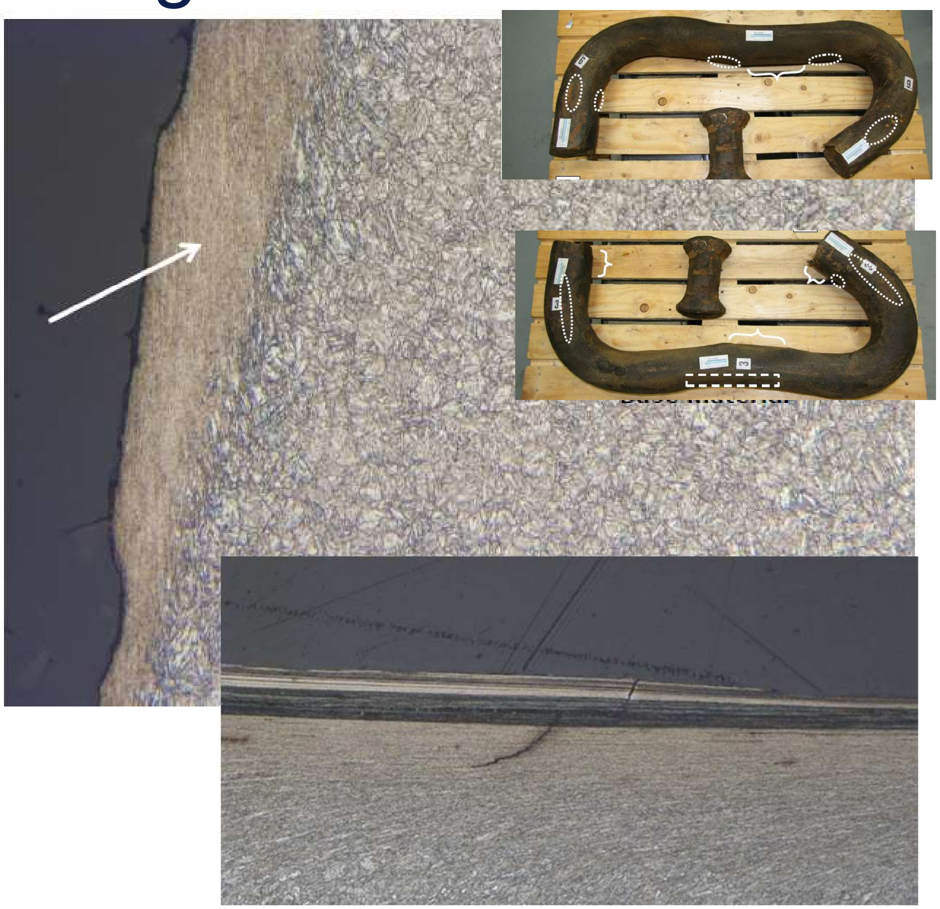
4) The ratio between yield strength to tensile strength shall not exceed 0.95. Tensile strength shall not exceed the minimum tensile strength with more than 150 MPa.

The challenge





Straight area fracture- Crack initiation



- In general the microstructure is of quenched and tempered. As normal.
- In 3 cases surface layer of newly formed martensite was identified connected with the wear dents. Corrosion may have removed such feature on other cases.
- Cracks initiate in wear and dent marks (5), Weld lack of fusion (1)
- Crack initiate in low load stress areas- tensile residual stress (extrados)
- Slanted micro cracks visible near fracture start
- Local hardness measured up to 600 HV locally (330 HV in base material)

Indicates:

1. Wear events create hardened material surface layer with high risk of crack initiation.

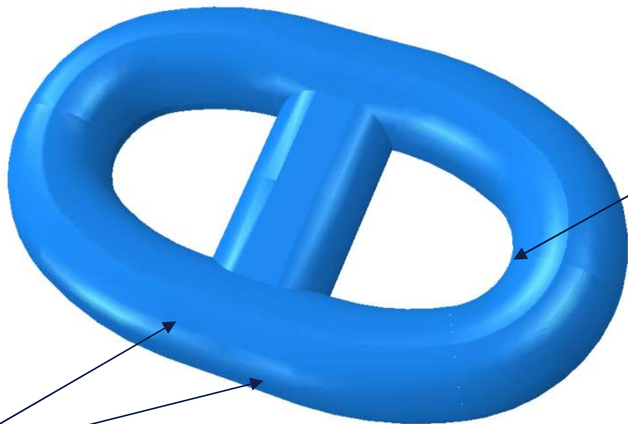
Crown area fracture- Specific crack initiation

- General microstructure of quenched and tempered martensite.
- Most cracks initiate in high interlink contact and wear marks
- Cracks initiate in low load stress areas but high residual stress (intrados)
- Some failures identified at very low load when retrieving from chain locker
- Corrosion and final failure “destroyed” initiation areas.
- Local hardness measured up to 400 HV locally (330 HV in base material)

Indicates:

1. High interlink contact events create hardened material or deformed surface layer with high risk of crack initiation

Data summary- factors influencing the failure mechanism



Interlink dents and wear

Deformation hardening
(minor changes in microstructure)
with slanted crack initiation

CP

Local increase in hardness (400 HV)

Drag marks and dents

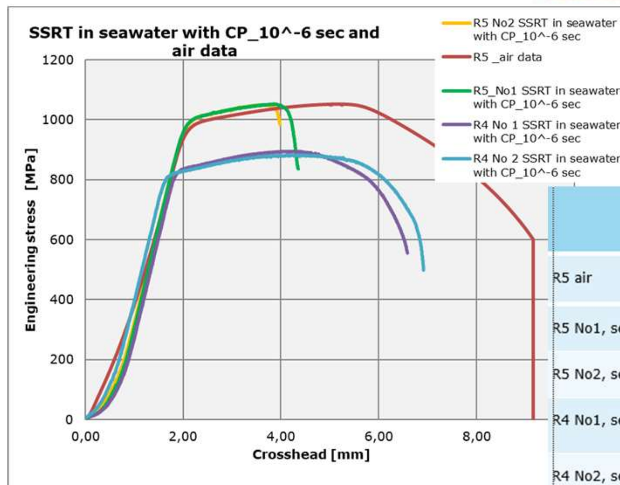
Newly formed martensite

CP

High local hardened material layer (600 HV)

Susceptibility to hydrogen (DNV tests in laboratory)

- Investigations on hydrogen susceptibility
  - Slow Strain Rate Testing (SSRT)
- Stress concentrations from the weld indications in combination with CP
  - Mixed fatigue/brittle process
- Operational measures to prevent hydrogen from CP should be considered
  - Chains not used, stored in the chain locker-SACP/ICCP…?
  - CP during high load operations
- Combination with hardened material



	YS (MPa)	TS (MPa)	Test length	strain at max load [1)]
R5 air	967	1051	67 mm	~7.4%
R5 No1, seawater with CP	~995	~1050	50 mm	~4%
R5 No2, seawater with CP	~980	~1048	50 mm	~4%
R4 No1, seawater with CP	~835	~889	50 mm	~5.5%
R4 No2, seawater with CP	~795	863	50 mm	~6.5%

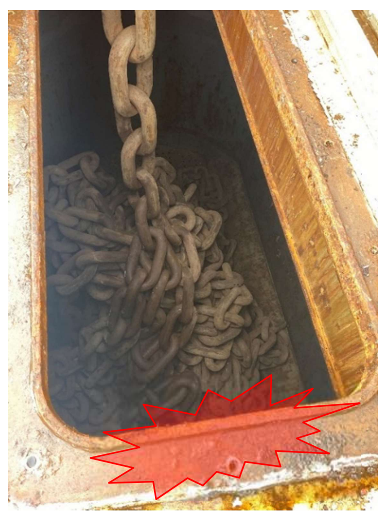
DNV

Onshore handling
keep friction and impact loads below critical level

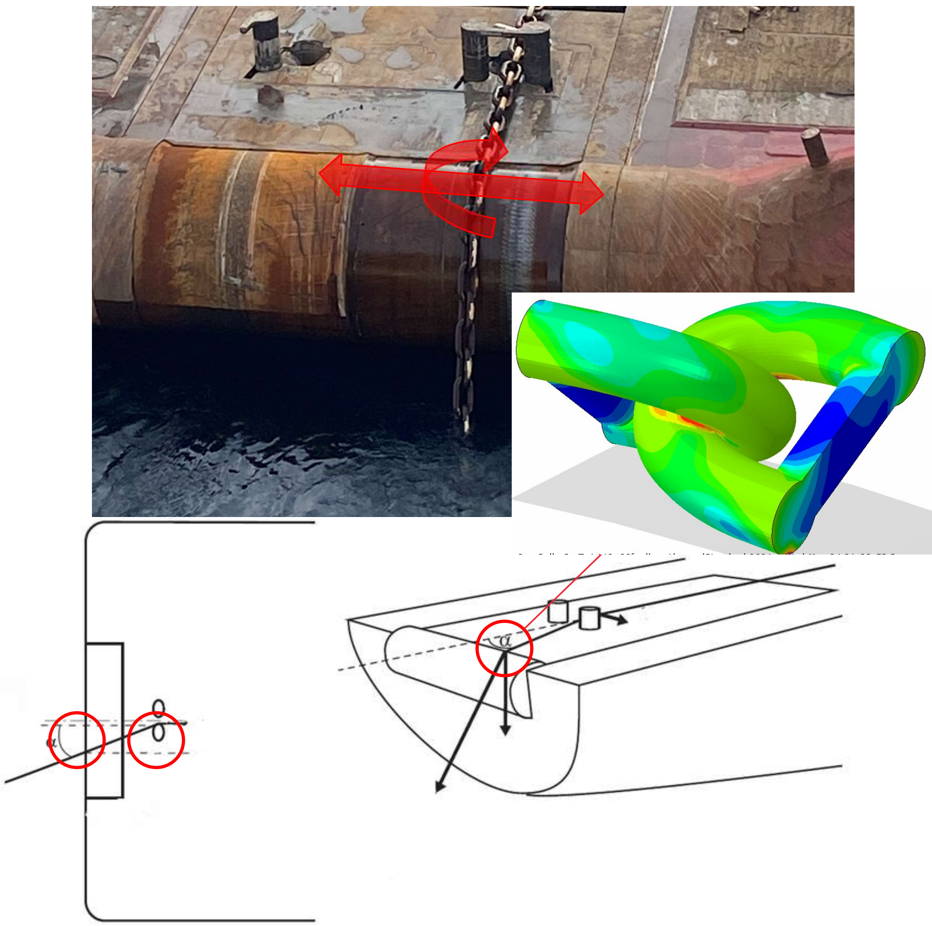
- Several industry players have introduced company specific requirements to onshore handling
- DNV-RU-OU-0300 introduces requirements for onshore handling in July 2022 Edition – covering also loading and unloading of chain from AHV to shore base

Offshore handling -
“high strength chain” requires a new approach

- High loads over time
  - Installation 300-400 tons 15-30 minutes
  - Recovery ??? Tons
  - Are we also overdoing the already high ULS loads…. ..bollard pull vs. line load?
- No chain over stern roller – while under high tension
  - Hydrogen
  - Damages
- Fibre rope insert (if use of ICCP)
- Load control – utilize AHV loads cells
  - Improve sampling rate and usage
- Fatigue assessment
  - AHV winch log…
  - Single events – “how much is “breakouts” eating up the fatigue life…



Chain handling offshore – vessel-chain interaction



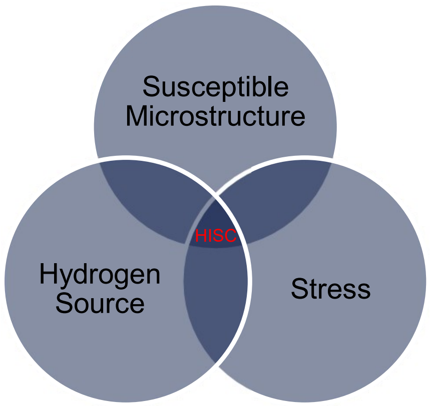
- Increased stresses in a few concentrated links
- Chain may rotate/twist under load while on roller
- Chafing with vessel roll/angle of tension
- Impact and high friction loads -> susceptible microstructure

- Chain MBL rated for tension-tension load - assuming no mechanical contact and combined torsion
- All other “external” forces reduces the strength capacity – but with how much?
- Safety margin required…
- Fixed reduction factor to be used in AHV operations?

- The risk of HISC further justifies removing/isolating R5 chain from the stern-roller in “tension-operations” above a given tension level

Sources of hydrogen

- Hydrogen contributes to many failures
  - Mechanical damage
  - Corrosion protection
  - High loads
- Possible sources
  - AHV ICCP
  - Chasing/anodes
  - ICCP on the rig
  - CP in chain locker



- Mitigating actions
  - Ensure no contact with electric current
  - Fibre rope insert during anchor handling
  - Martensite – remove drag marks

  - Rig chain - use and storage
  - Reduce friction/impact in all handling operations

Inspections – traditional approach to be modified

- DNV-RU-OU-0300, every 5 years:

2.3.3 Chain

For chain which is less than 20 years old with proper documentation and service history, and no previous failures the extent of examination shall be:

— 100% visual examination
— 5% NDT on general chain
— 20% NDT on chain which has been in way of fairleads over last five (5) years
— 20% NDT on chain which will be in way of fairleads over next five (5) years.

- Increase Probability of detection
  - Grinding prior to MT
- Visual inspection after each use
  - Drag marks (hardness tests to be introduced…)
  - More focus on “minor” damages and exposure
  - Load history/exposure

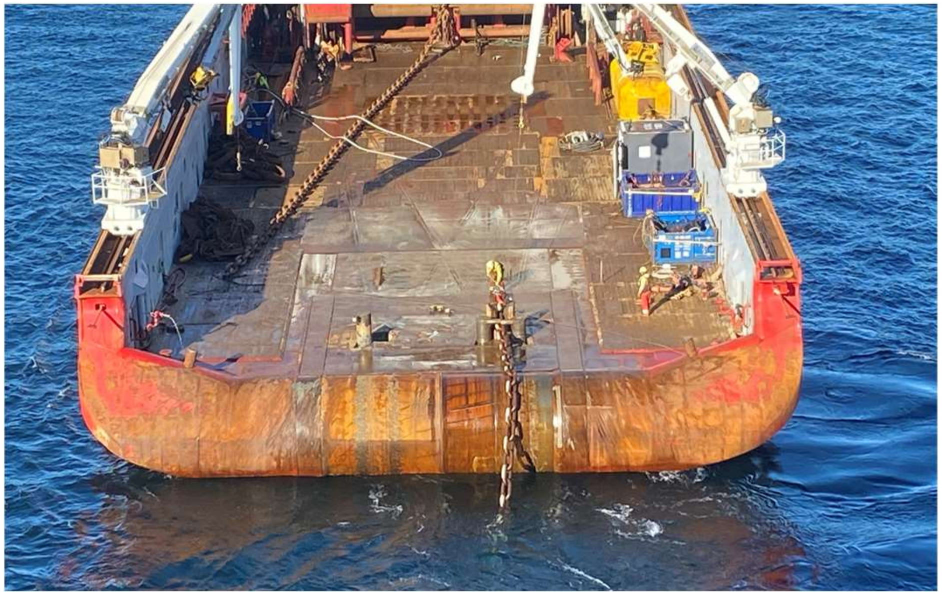
More guidance and new/updated in-service requirements for inspection/NDT required

Actions from the “R5 case” - DNV-RU-OU-0300, App. D update

First update in July 2022 Edition – next step planned for 2023 Edition

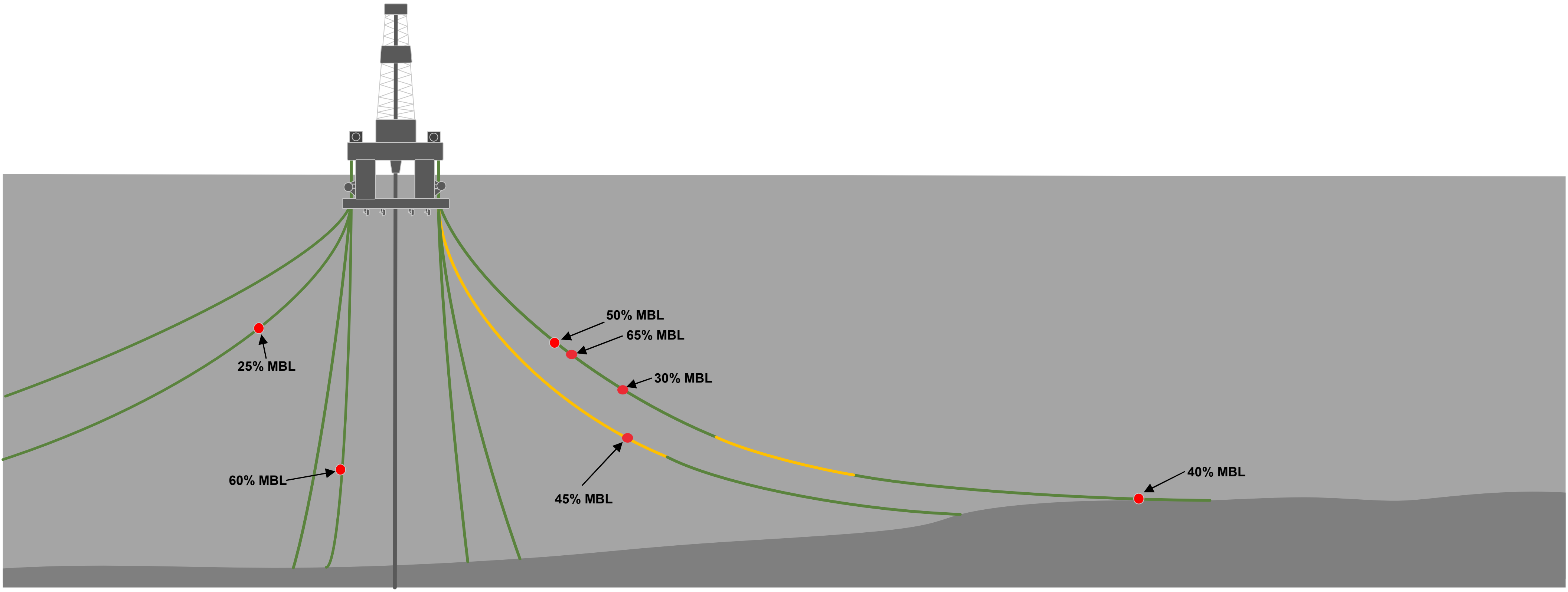
- New requirements to handling:
  - Onshore handling
    - New general requirements
    - Specific add. requirements for R5 (high strength)
    - Focus on loading/offloading of chain
- Offshore handling:
  - Installation/pre-tensioning
  - Recovery/breakout
  - Logging of tension data
  - Reduction of impact & overloads
  - Specific requirements for R5
    - measures to prevent hydrogen from CP
    - reduce risk of HISC

- New condition and usage-based survey scheme
  - Risk-based inspection interval vs. accumulated service life/loads



Mooring system integrity

The situation to be avoided: - multiple weakened chain links/components present in the system



DNV conclusive remarks

- Complex with many failure mechanisms
  - Hydrogen
  - Handling of the chain (offshore and onshore)
  - Fabrication
- Many stakeholders
  - The industry need to (and is) joining forces
- Way forward:
  - Best practice inspections (increase POD)
  - Best practise chain handling onshore/offshore
  - Best practice anchor handling
  - Manufacturing improvements
  - Increase knowledge of high strength chains
  - Quantify and understand risk and mitigation options

- Focus points & thoughts…
  - **Shift focus from "bollard pull" to "actual line load" – during AHV operations**
  - Need to better understand (or take into account) vessel dynamics and the effect of the chain imposed loads
  - **Utilize the loads cells already in-place on AHV winches and further develop the use and application of the data provided ->**
  - **Optimize use of tension control and load cell data to control loads...developments needed**
  - Focus on planning for both installation and recovery phase – how to get the anchors out safely - at planning stage
  - When designing the mooring system –> avoid high strength chain where the risk of damage is high or high impact loads can't be avoided
  - Larger lower grade chain to be utilized for the part of line subject to recovery operations…or other retract solutions used?
  - Until ICCP is clearly understood and quantified wrt. effect on chain – isolate the part of line which shall be part of the mooring spread
  - Components to be used in the mooring system spread to be aft of roller/"in the sea" during pre-tension and recovery
  - Investigate and quantify "rig chain" conditions – SW in locker w/CP and ICCP…how to protect the rig chain from HISC…what are the parameters to monitor and control?

WHEN TRUST MATTERS

Thank you

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