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Fatigue assessment of mobile offshore chain Anchorhandling operations

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Marine Operasjoner i Praksis

Background of study

- Multiple mooring line breakage incidents in mobile offshore mooring systems used for Equinor over the past years.
  - R5 grade 84 mm stud chain
  - Incidents have occurred during anchor prelay, recovery and MOU in operation
  - All incidents are related to the **bottom chain segments**

- Bottom chain segments are subject to rough handling and high loads during lifetime:
  - Onshore handling – Mobilization / Demobilization
  - Anchor prelay (up to 100-year ULS load)
  - Hook-up → in operation → disconnection
  - Anchor recovery (high loads and duration in challenging soil conditions)

  } Cycle repeated typ. 2-3 times a year

- **No class requirements** for fatigue analysis of mobile mooring chain → chain subject to onshore inspection and renewal surveys
- **Prelay:** chain being pulled up to 45%-50% of MBL where the dynamic loads range above
- **Recovery:** loads up to or above 65% of MBL due to short chain segments and high sea states

Description of study – Fatigue assessment – Anchor handling operations

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Scope Of Work

Investigate the impact of anchor handling operations to the overall fatigue life of bottom chain segments for mobile offshore units.

- Hydrodynamic modelling of anchor handling vessel
- Coupled time domain analysis
    - Anchor prelay
    - Anchor recovery
- Fatigue damage calculation for 84 mm stud chain

Verification of study

- Two independent studies
- Different vessels / modelling assumptions
- Similar env. parameters and location details
- Equinor (Orcaflex)
- Delmar (SIMA)

The two reports are openly available

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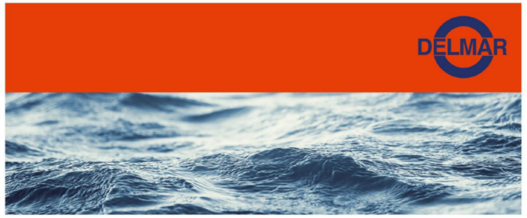

EQUINOR
FATIGUE ASSESSMENT OF MOBILE OFFSHORE MOORING CHAIN

STUD-CHAIN FATIGUE ANALYSES
FOR AHV PRELAY- AND RECOVERY
OPERATIONS

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Status / Comments: Issued for Comments

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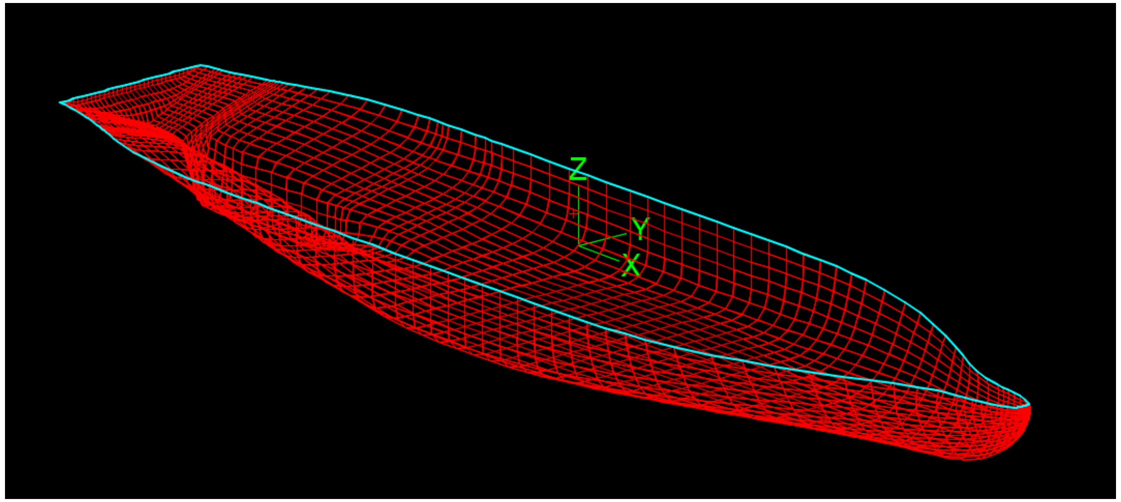
delmarsystems.com TOTAL MOORING SOLUTIONS

Description of study – Fatigue assessment – Vessels

Vessel (Equinor)	Value
Length in waterline	107 m
Breadth	24 m
Draught	6.6 m
Displacement	10700 Te

- Model made in Multisurf
- Diffraction analysis in Orcawave
- Coupled time domain analysis in Orcaflex
- Wind / Current excluded in analysis model.
- **Delmar vessel model**
  - Inhouse developed
  - displacement ~12500 Te otherwise similar characteristics



Description of study – Fatigue assessment – S-N curves

Recent low frequency high tension amplitude fatigue testing of 84 mm R5 stud chain indicates that (more extensive testing required to conclude):

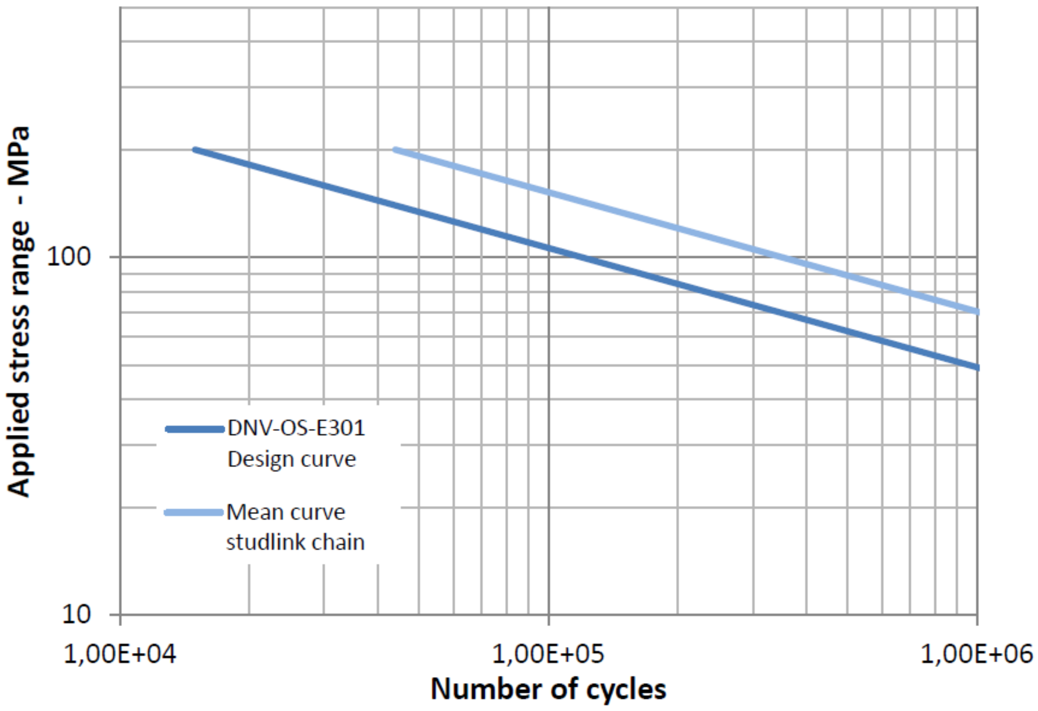
- Mean load >30% MBL (257 Te) expected cycles to failure follows the DNV design curve
- Mean load <30% MBL (257 Te) expected cycles to failure is above the DNV design curve

The fatigue capacity presented in the reports are based on

- **DNV-OS-E301 design curve**
- **No design fatigue factor**

Miner's sum of 1.0 equals expected fatigue capacity of chain.

Safety factors considers uncertainties in loads, material variability, environmental variability, fatigue behavior, aging and wear.



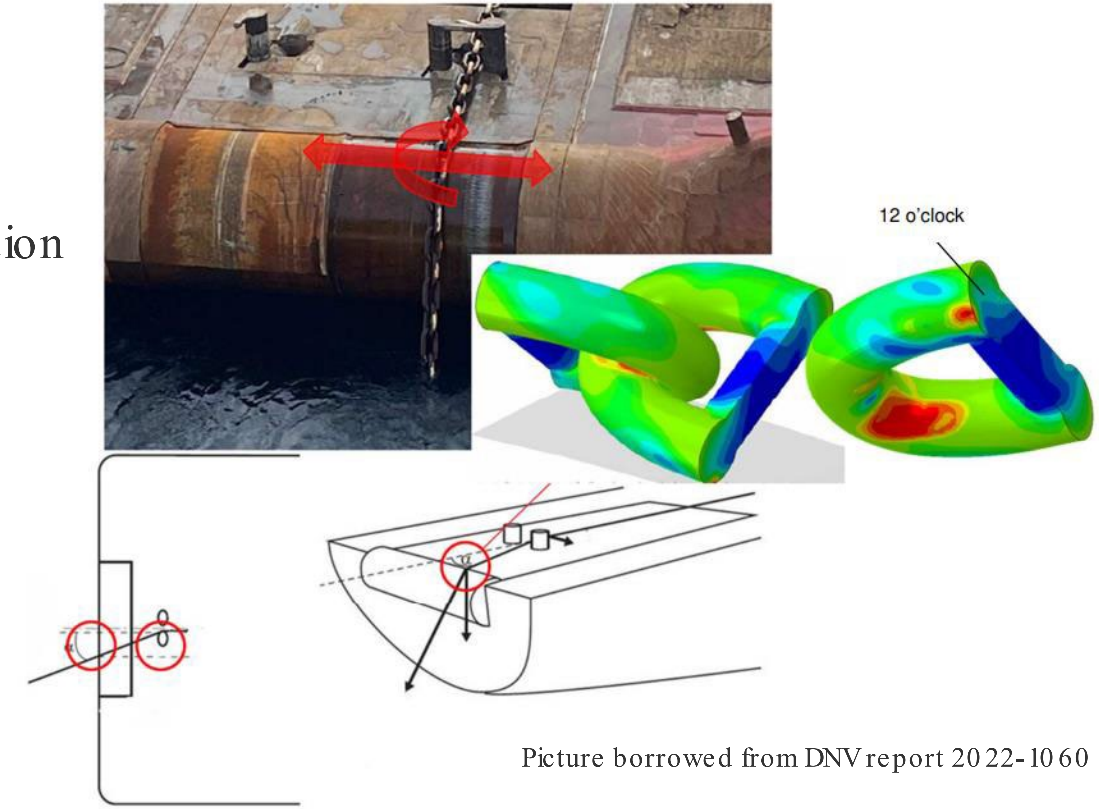
Effects of anchor chain on stern roller and wear & corrosion

Chain on stern roller $\propto \frac{1}{SCF^3}$ SCF = 1.15 → 66% of fatigue capacity

Wear $\propto (100\% - A_{red})^3$ Area reduction of 10 % (approx. 5% nom. diameter → 73% of fatigue capacity

Fatigue capacity may be significantly reduced due to:

- Chain on stern roller / anchor handling winch in combination with high loads
- Area reduction due to wear marks / corrosion



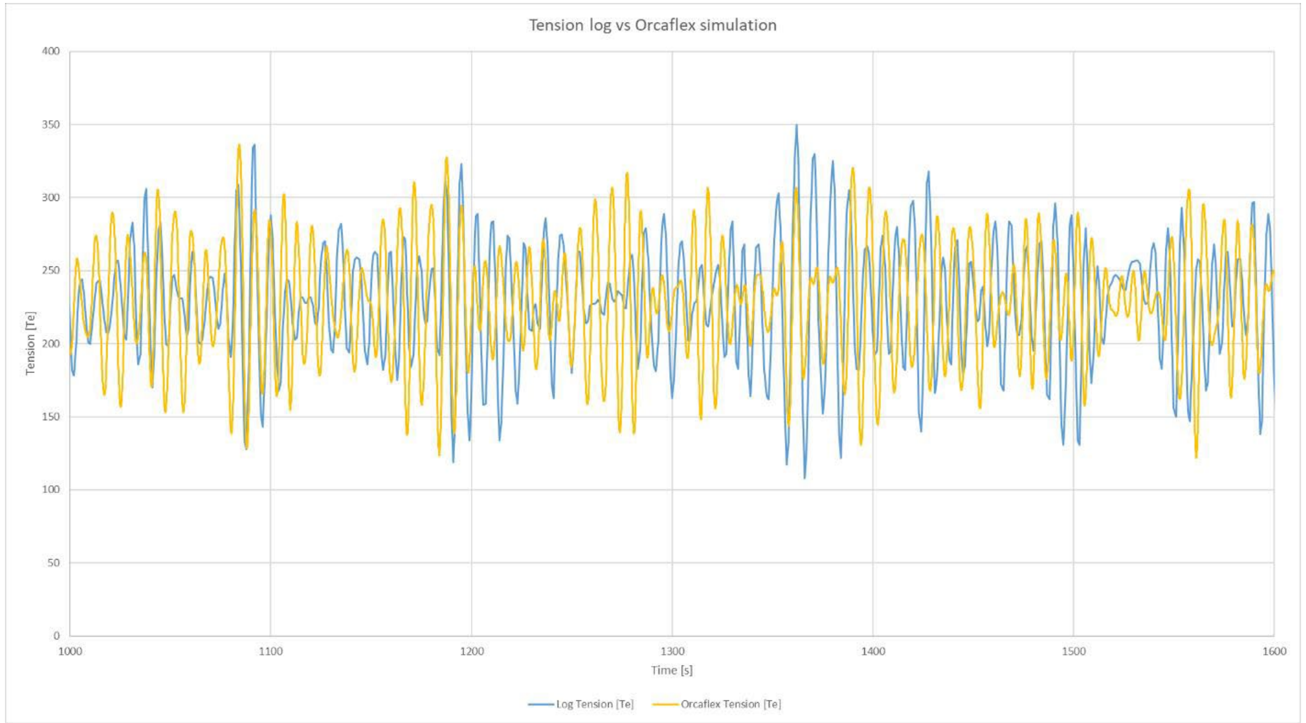
Picture borrowed from DNV report 2022-1060

Description of study – Fatigue assessment – Analysis

Environmental data	
Water depth	315 m
Hs range	1.5 m to 4.0 m
Tp range	6 s to 13 s
Wave headings	0 deg to 180 deg
Wave Spectrum	JONSWAP, short crested
Prelay	
Length of wire from stern roller	390 m
Bollard pull	307 Te – 350 Te
Simulation length	15 min build-up + 15 min tension test
Recovery	
Chain from stern roller	1.3 to 1.5 x Water depth
Bollard pull	150 Te to 200 Te
Simulation length	1 hr

Pre- and post-processing of results

- Total load cases: 336
- Use of Rainflow counting and DNV S-N design curves
- Calculation of cumulative fatigue damage and damage pr.hr
- Quite good agreement between analysis results and actual tension logs!

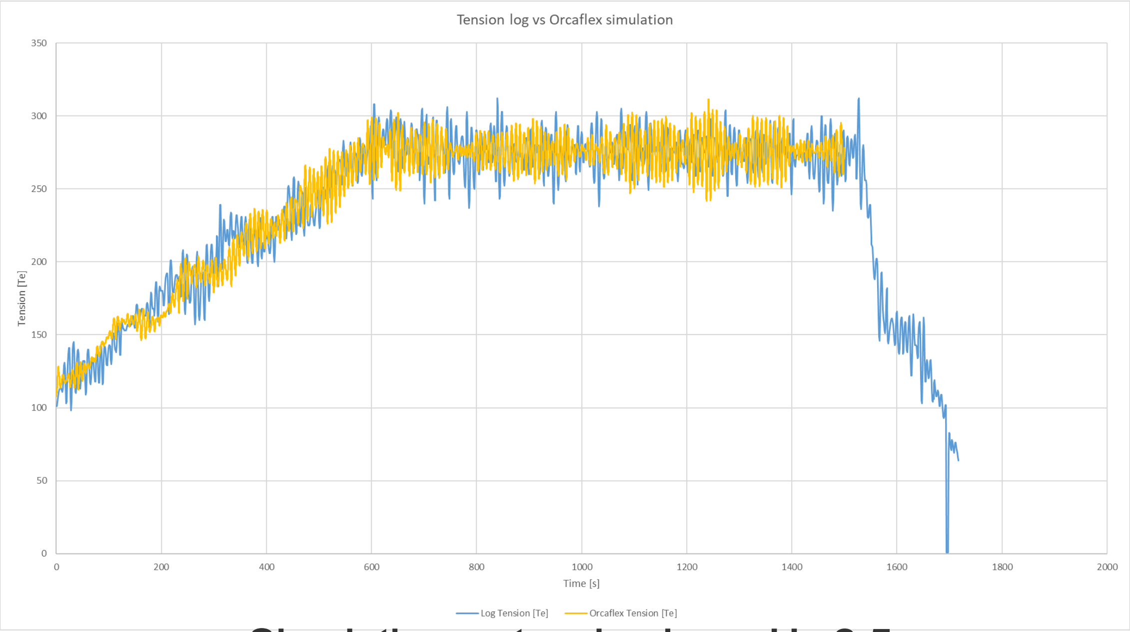


Prelay operations

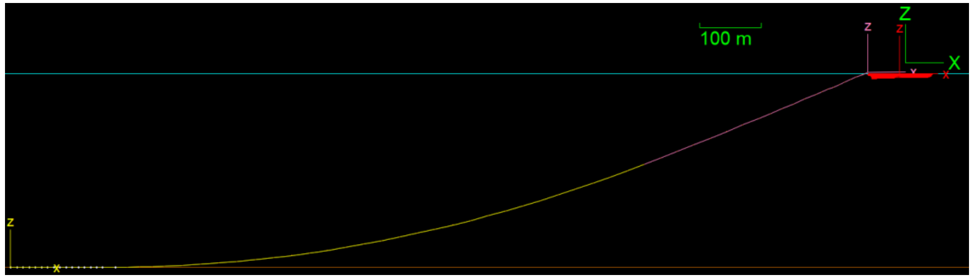
Observations

- High mean load
- Low fatigue damage accumulation from anchor prelay
    - Short duration of tension test (Typ. 15 min + 15 min)
    - Low load variations due to geometric stiffness of catenary
    - In Hs = 4 m, >2700 prelays before fatigue capacity is reached

Hs [m]	Mean [kN]	Std. [kN]	1hr MPM [kN]
1.5	3225	86	3524
2.0	3226	107	3594
2.5	3227	131	3674
3.0	3228	151	3752
3.5	3229	172	3822
4.0	3231	191	3883



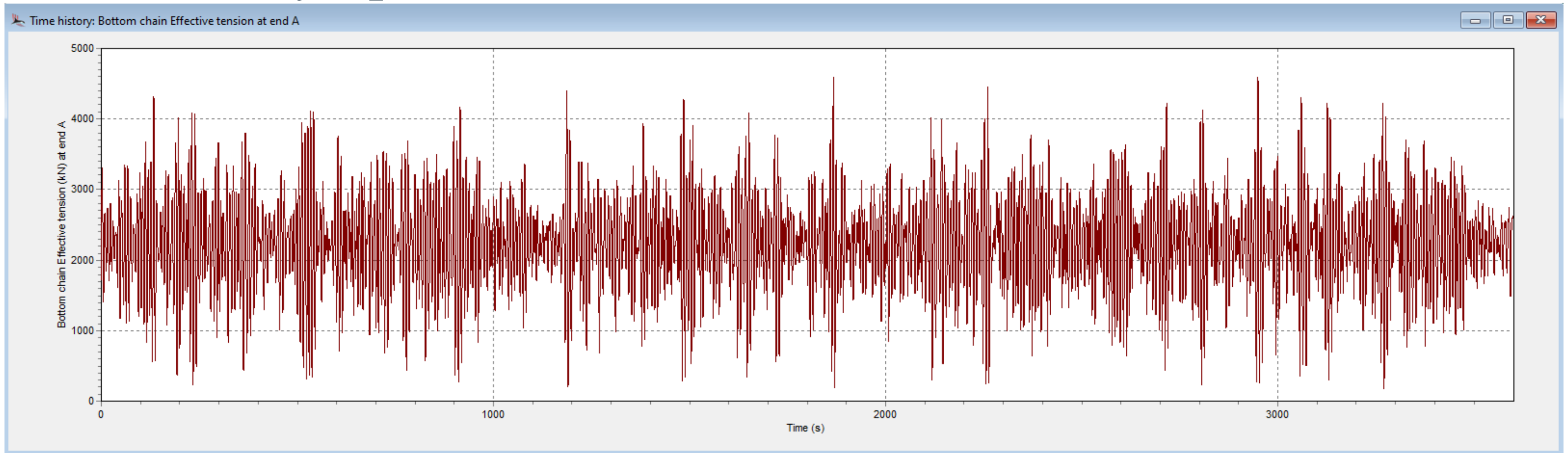
Simulation vs tension log ~ Hs 2.5 m

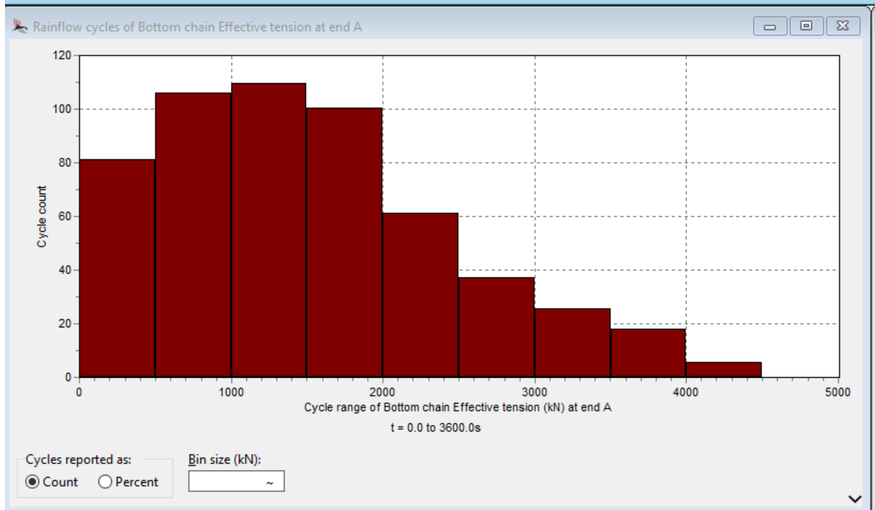


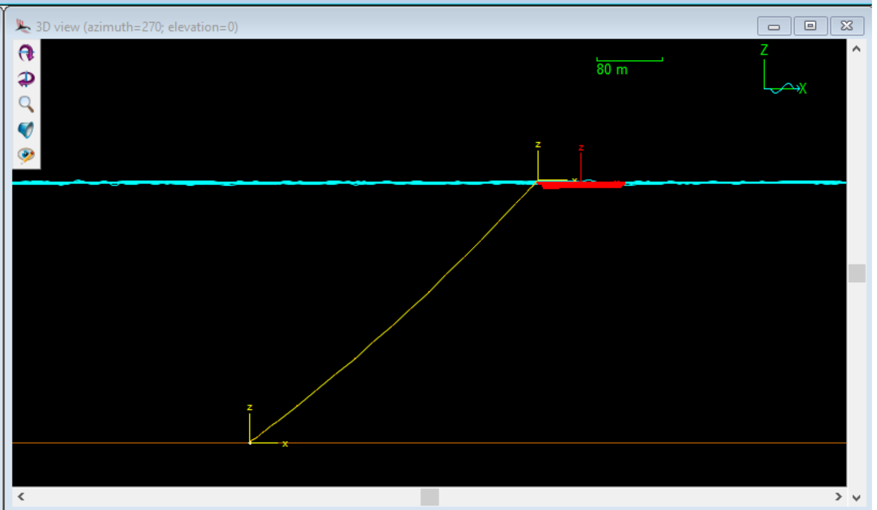
Conclusion: Prelay operations have negligible impact on fatigue capacity of chain

Note: Anchor prelay is still an important contributor to mooring line failure due to high mean tension which may lead to propagation of an existing crack, especially in combination with HISC

Recovery operations







1 hr simulations

Actual duration of anchor recovery is varying. Typ. <<1hr up to several hrs in challenging soil conditions.

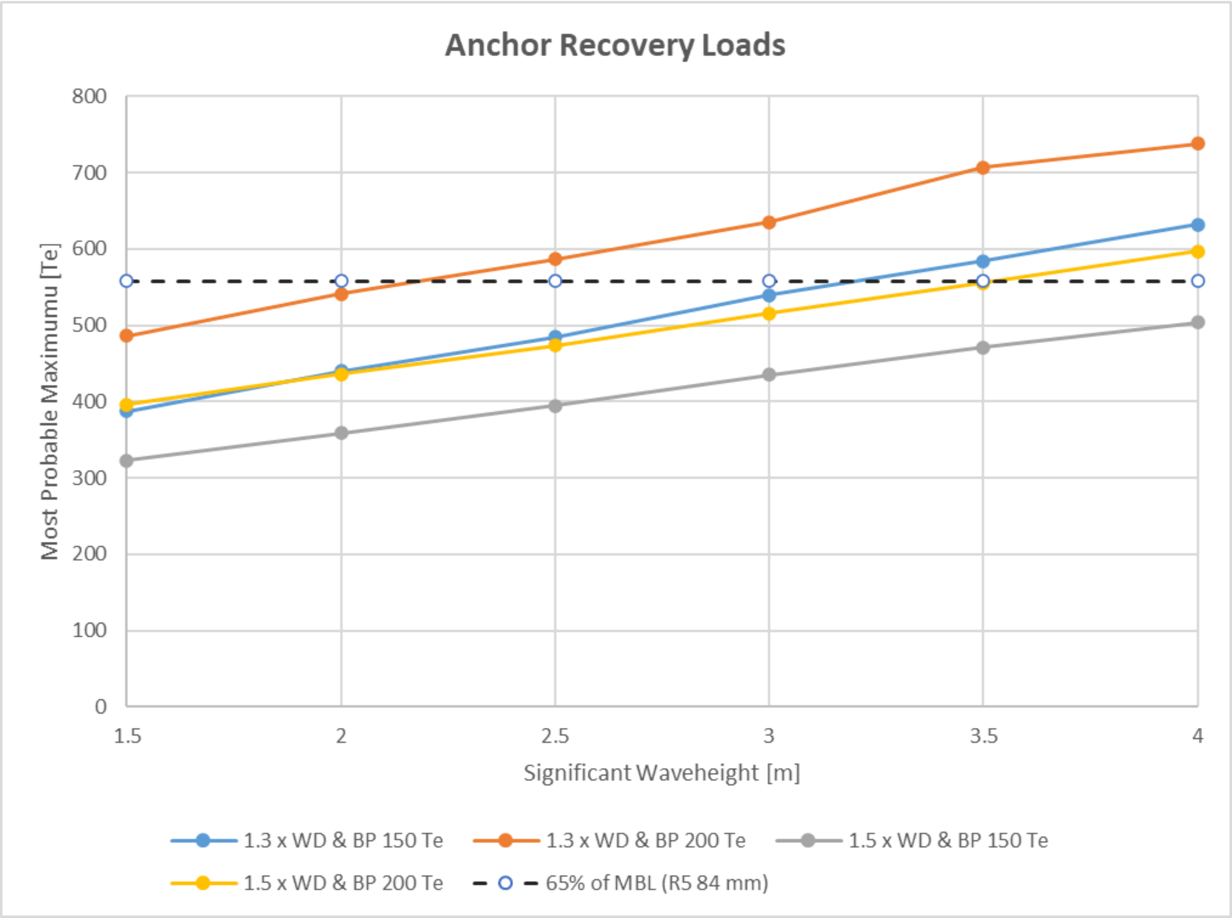
Note:

It is reasonable to assume that the AHV master adapts to the environmental loads by reducing Bollard Pull or increasing the length of chain/wire from stern roller to reduce the peak loads.

Example: 1.5x WD, BP 150Te, Hs 3.5 m Tp 8 s, Wave Direction 60 deg off stern

Mean load: 2240 kN STD: 675 kN → Sign load approx. 230 Te ± 140 Te → MPM ~471Te → 37 hrs fatigue capacity

Recovery operations - Loads



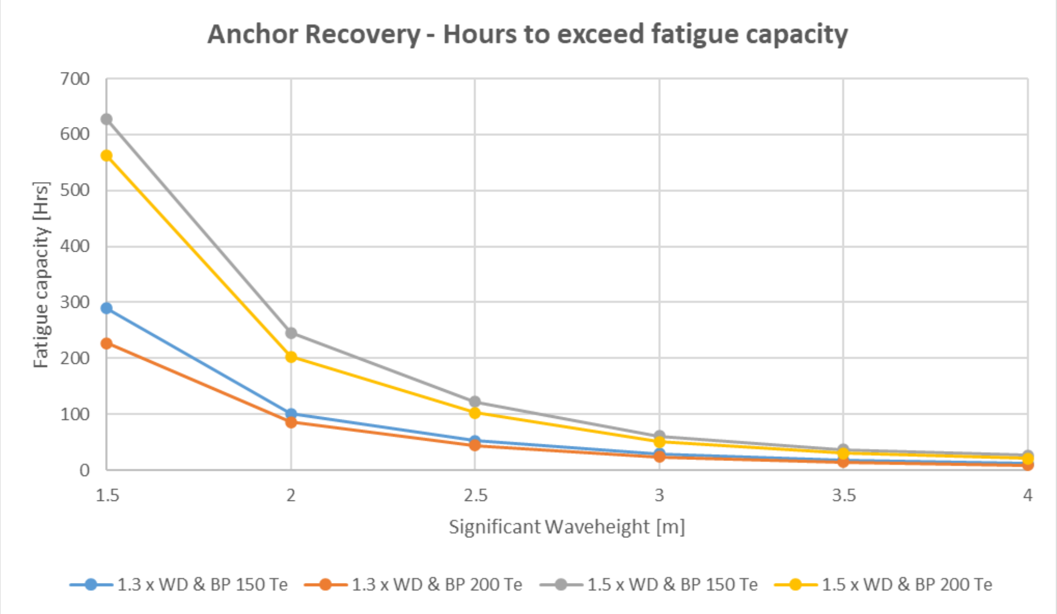
	MOST PROBABLE MAXIMUM				STANDARD DEVIATION			
Length	**1.3 x WD**		**1.5 x WD**		**1.3 x WD**		**1.5 x WD**	
BP	**150**	**BP200**	**BP150**	**BP200**	**BP150**	**BP200**	**BP150**	**BP200**
Mean	**264 Te**	**343 Te**	**230 Te**	**297 Te**	**264 Te**	**343 Te**	**230 Te**	**297 Te**
Hs [m]	**[Te]**	**[Te]**	**[Te]**	**[Te]**	**[Te]**	**[Te]**	**[Te]**	**[Te]**
1.5	388	486	323	396	36	42	26	28
2.0	440	541	359	436	51	59	37	40
2.5	485	586	394	473	65	72	47	50
3.0	540	636	435	515	82	86	59	62
3.5	585	707	471	556	93	108	69	74
4.0	632	738	504	597	106	116	79	86

Significant load ~ Mean ± 2 x STD

- High mean load and peak loads above 65% of MBL
- High load variations → significant fatigue damage
- Significant load reduction going from 1.3xWD to 1.5xWD

Recovery operations – Fatigue damage (hrs to failure)

Note: DNV design curve, Miner's sum = 1.0, WD 315 m



	SCF = 1.00				SCF = 1.15			
	1.3 x WD		1.5 x WD		1.3 x WD		1.5 x WD	
Hs	BP150	BP200	BP150	BP200	BP150	BP200	BP150	BP200
[m]	[hr]	[hr]	[hr]	[hr]	[hr]	[hr]	[hr]	[hr]
1.5	289	227	627	562	190	149	412	370
2.0	101	86	246	203	66	57	162	133
2.5	53	44	122	103	35	29	80	68
3.0	29	24	61	51	19	16	40	34
3.5	18	15	37	30	12	10	24	20
4.0	12	9	27	21	8	6	18	14

Observations:

Significant fatigue damage from anchor recovery!

Example:

- 3 hr duration
- Chain length 1.3 x WD @ BP 150 Te
- Hs ~ 3.0 m = 29 hrs fatigue capacity

~10% of fatigue capacity used for one recovery operation!

Recovery operations – Delmar study

Table 6-1: Fatigue service life [hours] for 315m water depth; 0, 30 and 60 deg wave directions.

Wave dir	0 deg						30 deg						60 deg					
Line length	1.3 x WD			1.5 x WD			1.3 x WD			1.5 x WD			1.3 x WD			1.5 x WD		
BP [Te] / Hs [m]	150	175	200	150	175	200	150	175	200	150	175	200	150	175	200	150	175	200
1	7161	5015	3864	24495	22913	21536	4613	3845	3007	8169	7925	8303	1961	1957	1867	3120	3005	3162
1.5	1704	1309	1063	6028	5231	4806	1099	986	829	2395	2201	2188	526	513	493	977	912	917
2	595	468	380	2081	1776	1393	399	369	327	943	846	821	205	198	191	411	378	374
2.5	273	228	193	910	777	688	184	172	157	448	400	384	97	95	92	190	174	171
3	144	127	112	468	398	364	99	92	86	226	201	193	50	48	47	101	91	88
3.5	85	74	66	266	229	201	58	54	51	128	112	106	30	28	27	61	54	52
4	55	49	42	152	129	119	36	32	30	80	68	63	20	18	17	41	36	34

Table 6-2: Fatigue service life [hours] for 315m water depth; 90, 120 and 150 deg wave directions.

Wave dir	90 deg						120 deg						150 deg					
Line length	1.3 x WD			1.5 x WD			1.3 x WD			1.5 x WD			1.3 x WD			1.5 x WD		
BP [Te] / Hs [m]	150	175	200	150	175	200	150	175	200	150	175	200	150	175	200	150	175	200
1	1213	1256	1278	1950	1903	2000	1239	1275	1293	2031	1967	2058	1966	1973	1877	3133	3067	3254
1.5	345	345	346	630	598	607	347	347	347	644	615	625	522	510	492	983	939	957
2	139	138	137	260	248	250	140	139	137	276	261	260	202	196	191	392	376	380
2.5	60	60	60	117	110	109	65	65	66	124	119	119	91	91	92	171	163	163
3	33	32	32	64	60	59	35	35	35	68	65	65	48	48	48	93	88	88
3.5	20	19	19	40	37	36	21	21	21	42	40	40	29	28	28	56	54	53
4	14	13	13	28	25	24	14	14	14	28	27	27	18	18	17	38	35	35

Table 6-3: Fatigue service life [hours] for 315m water depth; 180 deg wave direction.

Wave dir	180 deg					
Line length	1.3 x WD			1.5 x WD		
BP [Te] / Hs [m]	150	175	200	150	175	200
1	2876	2737	2490	4693	4588	4869
1.5	728	695	651	1431	1352	1373
2	275	263	251	582	547	546
2.5	130	125	120	277	261	258
3	69	67	66	142	133	131
3.5	38	37	37	79	74	73
4	23	22	22	48	45	44

Wave dir	150 deg (30 deg off bow)			
Line length	1.3 x WD		1.5 x WD	
BP [Te]	150	200	150	200
1.5	1221	722	5321	3244
2	471	287	1829	1209
2.5	212	154	756	544
3	116	83	404	267
3.5	63	49	229	157
4	42	30	144	90

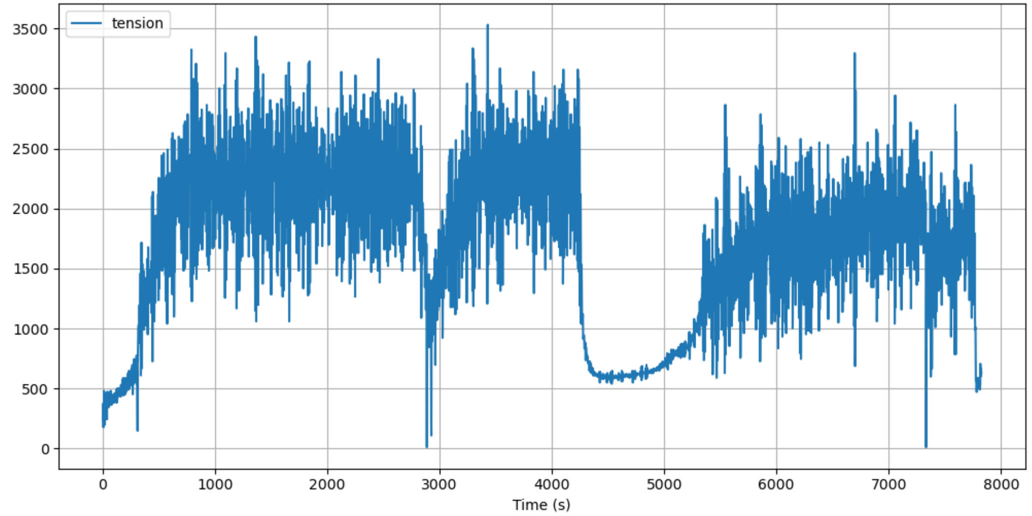
Wave dir	60 deg (60 deg off stern)			
Line length	1.3 x WD		1.5 x WD	
BP [Te]	150	200	150	200
1.5	289	227	660	562
2	101	86	246	203
2.5	53	44	122	103
3	29	24	61	51
3.5	18	15	37	30
4	12	9	27	21

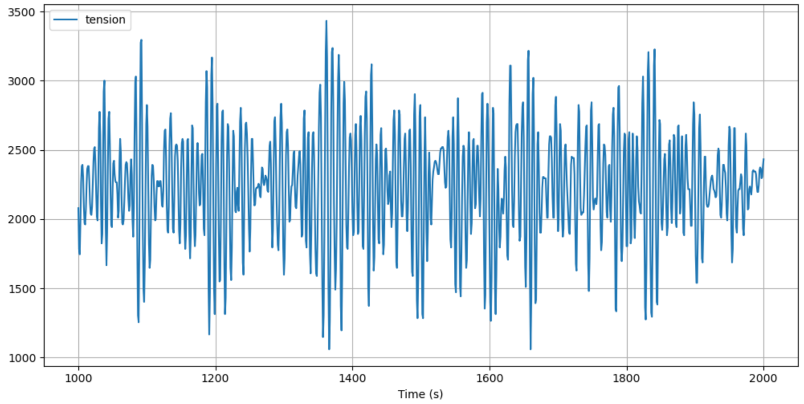
Wave dir	0 deg (Following sea)			
Line length	1.3 x WD		1.5 x WD	
BP [Te]	150	200	150	200
1.5	510	324	1562	1323
2	186	135	576	459
2.5	90	62	232	191
3	47	37	135	108
3.5	30	23	74	60
4	18	15	48	37

- Despite of different:
  - Vessel models
  - Wave spreading
  - Analysis software
  - Analysis assumptions
  - ++
- Comparable results!

Example - Postprocessing of Anchorhandling tension logs

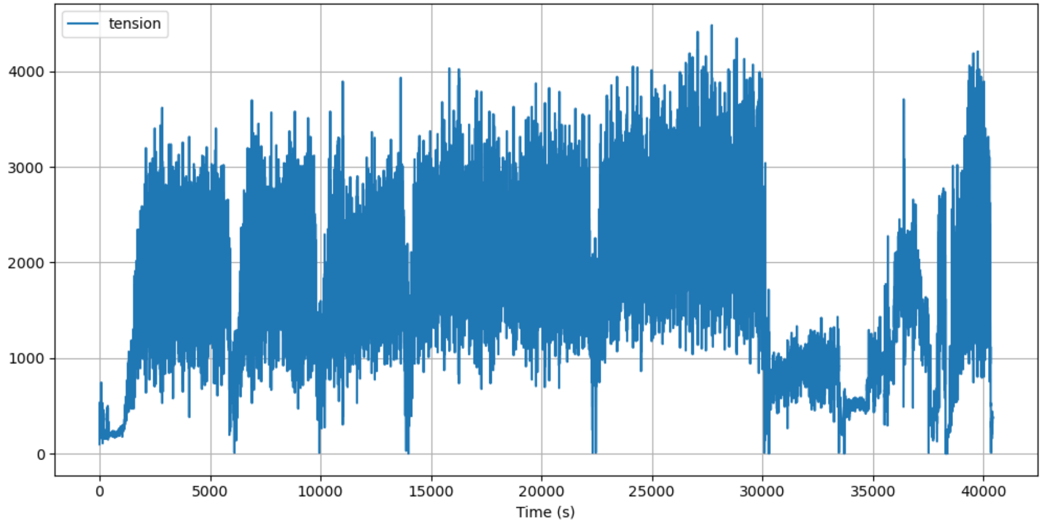
Postprocess AHV tension logs to determine the fatigue damage. Examples assuming 84 mm stud chain and DNV S-N curves:

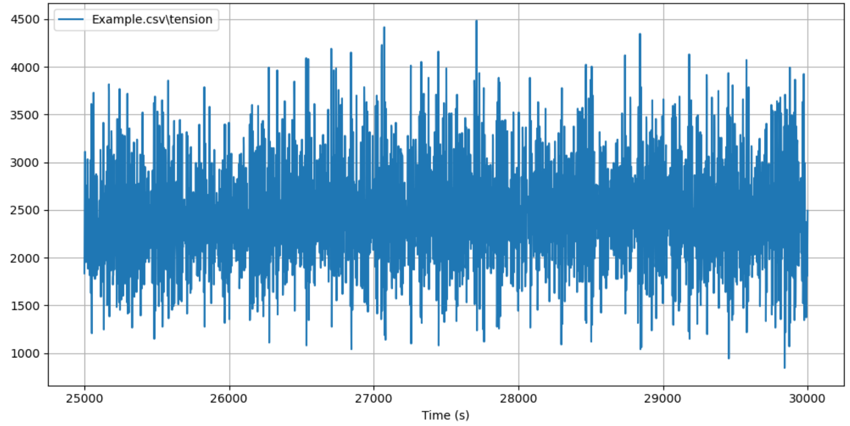




1000 s:
STD: 391 kN
Mean: 2240 kN

~2.0 hr operation → 0.6% of fatigue capacity





5000 s Statistics:
STD: 515 kN
Mean: 2445 kN

~10 hr operation → 7.4% of fatigue capacity

Conclusion and recommendations for further work

1. Fatigue damage contribution from anchor prelay operations is negligible
2. Anchor recovery may be one of the underlying causes for line breakage incidents considering
   - Number of operations (historical)
   - Harsh conditions
   - Duration of recovery in challenging soil conditions
   - Fatigue capacity reduction due to chain on stern roller / wear / corrosion

Recommendations for further work

1. Increase number of wave seeds / simulations to validate statistics and increase confidence in results. Parametrical study of water depth, length of chain and environmental loads.
2. Evaluate the application of DNV design S-N curve vs results from fatigue testing.
3. Post-processing of AHV tension logs to determine the accumulated fatigue damage for each operation.
4. FLS analysis of a MOU in operation for assessment of overall fatigue life of mobile offshore chain.
5. Evaluate operational measures to minimize fatigue damage / peak loads.
   - I.e change of methodology for recovery of anchors (where applicable)
   - anchor type

Fatigue assessment of mobile offshore chain Anchorhandling operations

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