IACS

Safer and Cleaner Shipping

CSR Harmonisation

Loads

Industry Presentation

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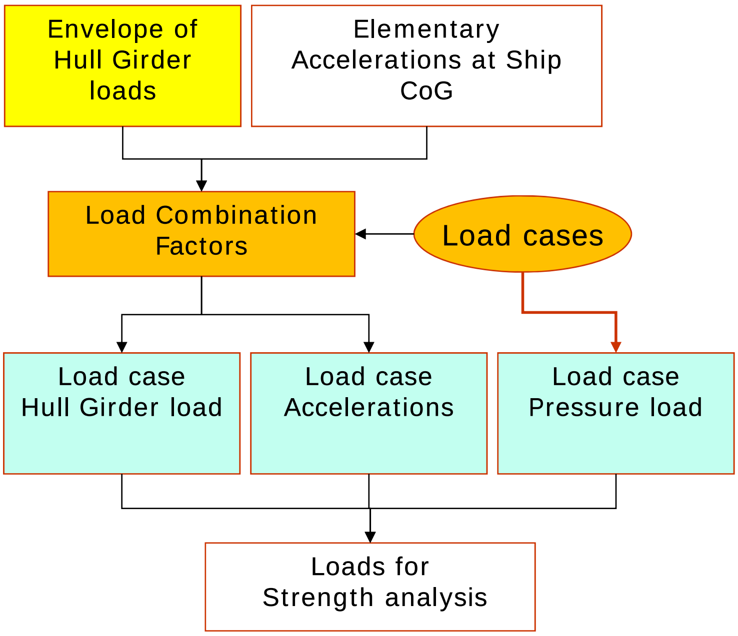
Safer and Cleaner Shipping

CSR-H loads: content

- Scheme of CSR-H loads
- Generation of loads
- Rule loads
    - Extreme
    - Fatigue

Scheme of CSR-H loads

- **Principles**
  - Scatter diagram North Atlantic
  - Envelope of hull girder loads
  - Principle of Equivalent Design Wave (EDW)

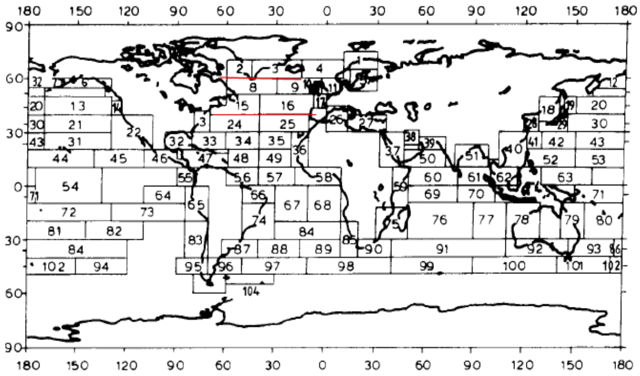


Generation of loads

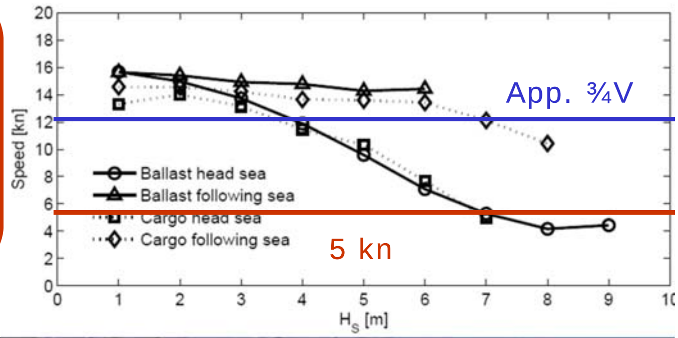
- Wave data and ship speed in direct computations
- Equivalent design wave approach
- Definition of equivalent design wave (EDW)
  - Hull girder & acceleration
  - Pressure
  - Selection & validation

Wave data and ship speed

- Wave data : Re-examination of wave data:
  - Recommend not to revise the IACS Rec. 34 scatter diagram
    - Uncertainties which influence accuracy of climate model's simulations and projections.
    - Predictions given by new metocean databases need further investigations.
    - Consensus not reached about the probability of occurrence of rogue waves
  - IACS Rec.34 has been used in direct computations



- Ship speed
  - 5 knots for extreme conditions = minimum speed to maintain manoeuvring and other operations
  - ¾ V_{design} for fatigue load computations = average speed in 25 years

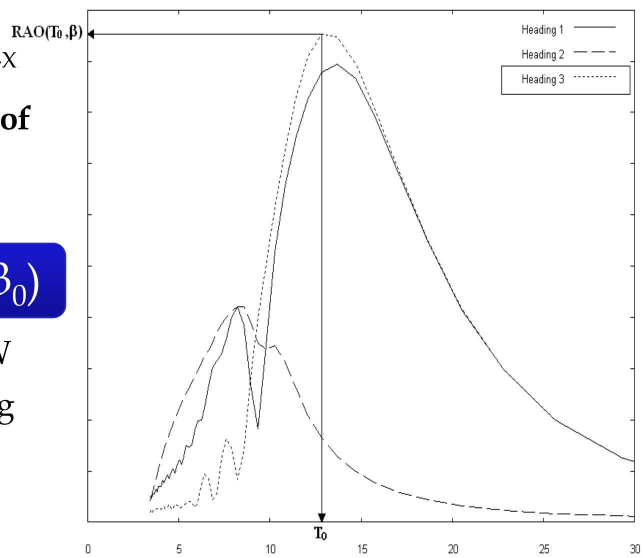


Definition of an Equivalent Design Wave (EDW)

- EDW approach – HOW
  - **Hydrodynamic analysis** -> load RAO (Response Amplitude Operator)
  - **Spectral analysis** -> Long Term value of each load at 10^{-X}
  - Determine (T_0, β_0) from the **maximum of load RAO**
  - **Determine A_0** by the ratio

$$A_0 = \text{LT value at } 10^{-X} / \text{RAO}(T_0, \beta_0)$$

  - Regular wave (A_0, T_0, β_0) is called EDW
  - Which produces the same load of Long Term value
  - At 10^{-X}
  - Each load component has an EDW
- Commonly accepted method for calculating the loads



Hull girder loads and accelerations of EDW

- **Hull girder loads** = Load Combination Factor × Load envelope value
  - Load envelope given by Rule formulae : M_{wv}, M_{wh}, Q_{wv}, …
  - LCFs are defined for each EDW

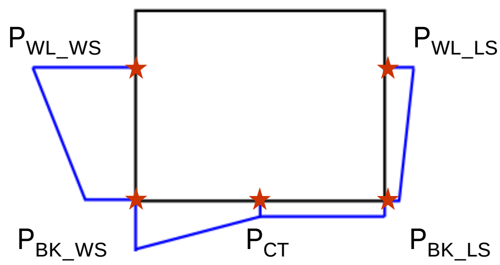
Load component		LCF	OST-1P	OST-2P	OST-1S	OST-2S	OSA-1P	OSA-2P	OSA-1S	OSA-2S
Hull girder loads	M_{WV}	C_{WV}	$-0.3 - 0.2f_T$	$0.3 + 0.2f_T$	$-0.3 - 0.2f_T$	$0.3 + 0.2f_T$	$0.75 - 0.5f_T$	$-0.75 + 0.5f_T$	$0.75 - 0.5f_T$	$-0.75 + 0.5f_T$
	Q_{WV}	C_{QW}	$(-0.35-0.2f_T)\ f_{lp}$	$(0.35+0.2f_T)\ f_{lp}$	$(-0.35-0.2f_T)\ f_{lp}$	$(0.35+0.2f_T)\ f_{lp}$	$(0.6-0.4f_T)\ f_{lp}$	$(-0.6+0.4f_T)\ f_{lp}$	$(0.6-0.4f_T)\ f_{lp}$	$(-0.6+0.4f_T)\ f_{lp}$
	M_{WH}	C_{WH}	-0.9	0.9	0.9	-0.9	$0.55 + 0.2f_T$	$-0.55 - 0.2f_T$	$-0.55 - 0.2f_T$	$0.55 + 0.2f_T$
	M_{WT}	C_{WT}	$-f_{lp\text{-}OST}$	$f_{lp\text{-}OST}$	$f_{lp\text{-}OST}$	$-f_{lp\text{-}OST}$	$-f_{lp\text{-}OSA}$	$f_{lp\text{-}OSA}$	$f_{lp\text{-}OSA}$	$-f_{lp\text{-}OSA}$

- **Accelerations** = Load Combination Factor × Ship elementary acceleration
  - Acceleration at ship CoG given by rule formulae: a_{surge}, a_{sway}, a_{heave}, a_{roll}, …
  - LCFs are defined for each EDW
  - Accelerations at any position (a_X, a_Y, a_Z) are defined by the position coordinates and global accelerations at ship CoG. For example:

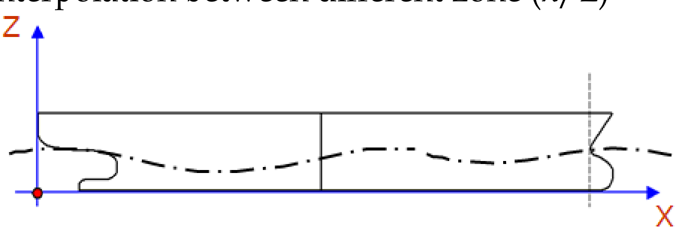
$$a_z = C_{ZH}\ a_{heave} + C_{ZR}\ a_{roll}\ y - C_{ZP}\ a_{pitch}\ (x - 0.45L)$$

Sea pressure of EDW

- Pressure distribution given explicitly for each EDW
  - Transverse distribution
    - Pressure points : waterline, bilge, centreline, weather and lee sides
    - Linear interpolation in (y,z)



  - Longitudinal distribution
    - Amplitude and phase distribution along the ship
    - Pressure points: 12 points at waterline, bilge, centreline, weather and lee sides
    - Linear interpolation between different zone (x/L)

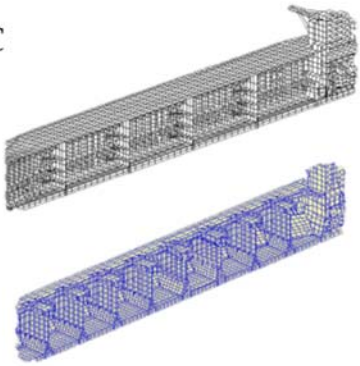


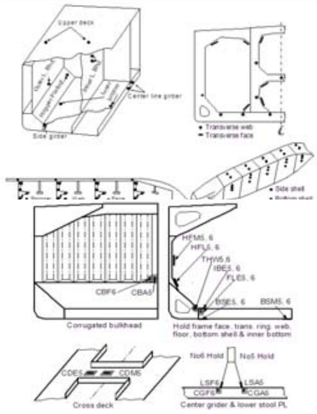
Selection of EDW and validation

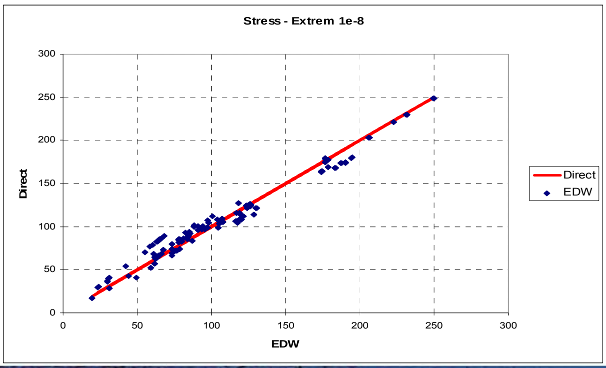
- EDW approach – SELECTION
  - Two FE model used: OT and BC
  - 38 EDWs have been examined
  - Critical EDW selected by the relevance ratio

$$C = \frac{\sigma_{EDW}}{\sigma_{LT\ value}}$$

  - Selection of EDWs which produce maximum stress
- EDW approach – VALIDATION
  - Only 5+2 winners
  - Comparison results using selected EDWs and Direct computations



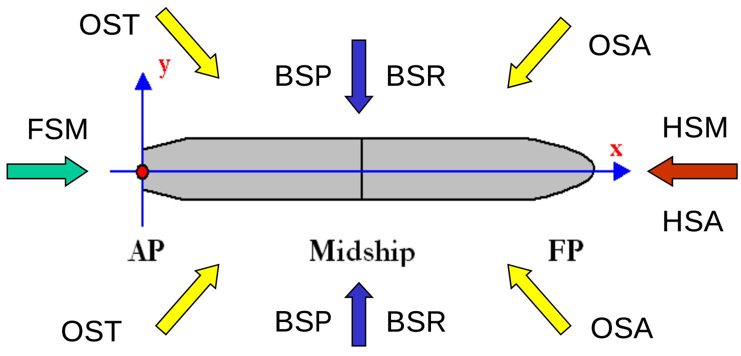




Rule loads

- **Extreme loads**
  - **Rule dynamic load cases**
  - **Improvements**
- **Fatigue loads**
  - **Way to develop fatigue loads**
  - **Validation of EDW approach**
  - **Rule dynamic load cases**
  - **Improvements**

Rule dynamic load cases for extreme loads



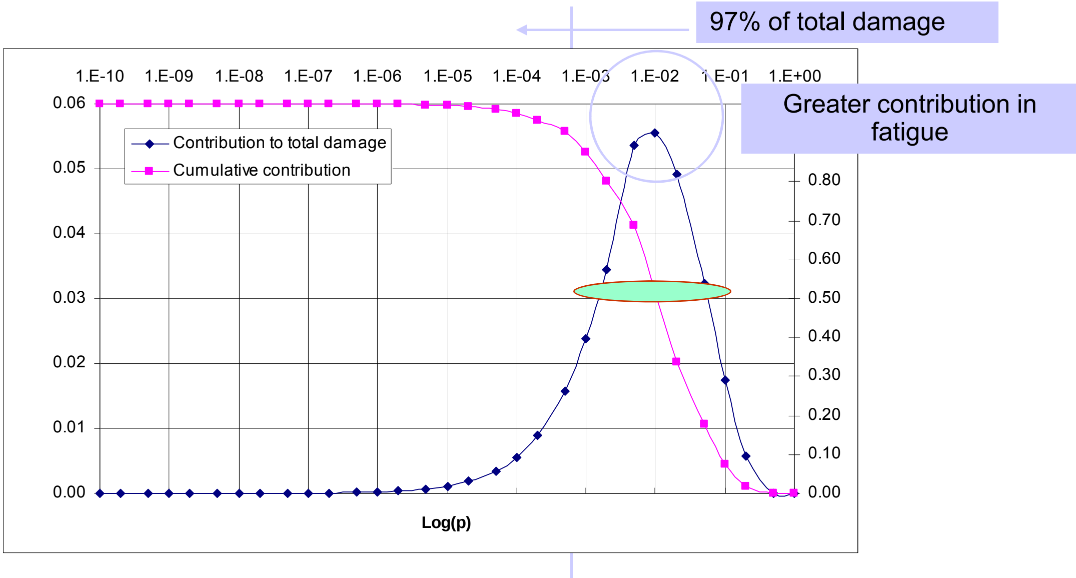
- 7 selected EDWs for extreme loads at 10^{-8} level as dynamic load cases
  - **HSM**: head sea EDW maximizing VBM amidships
  - **FSM**: following sea EDW maximizing VBM amidships (occurring with zero vertical acceleration at midship)
  - **BSR**: beam sea EDW maximizing roll motion
  - **BSP**: beam sea EDW maximizing waterline pressure at amidships
  - **OST**: oblique sea EDW maximizing torsional moment at ¼L
  - **HSA**: head sea EDW maximizing A_Z at FP
  - **OSA**: oblique sea EDW maximizing pitch acceleration (to cover some particular cases and open to ships other than OT/BC)

Improvements for extreme loads

- Load case accelerations
  - Accelerations (a_X, a_Y, a_Z) are defined by the position coordinates and global accelerations at ship CoG, with LCF associated with each load case;
  - Consistent variations along the ship and across the section.
- Load case external pressures
  - External pressure distributions are derived from direct computations for each load case.
  - Continuous variations along the ship and around ship section.
- Envelope values of accelerations and external pressures
  - As a reference, the envelope value of accelerations is defined as in CSR-OT.

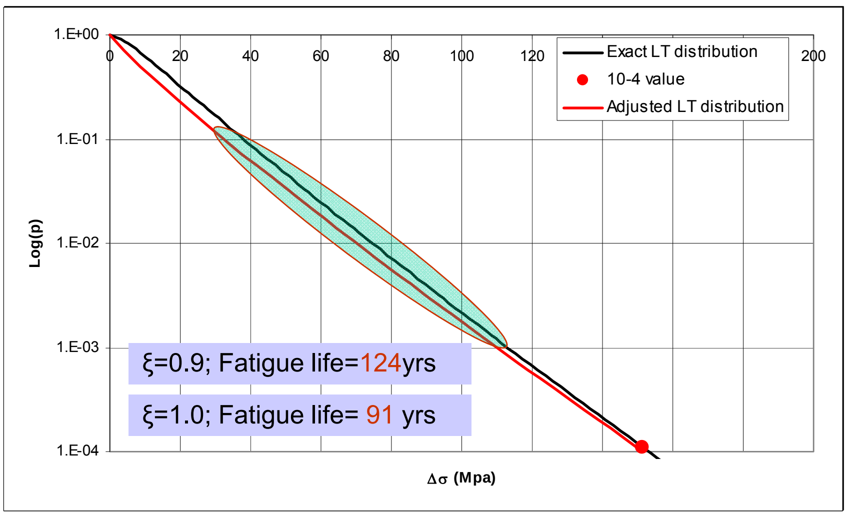
Way to develop fatigue load in CSR-H

- Consider a SN curve with a typical change of slope at 10^7 cycles, we obtain the (density and accumulated) contribution of stress range in function of different probability levels



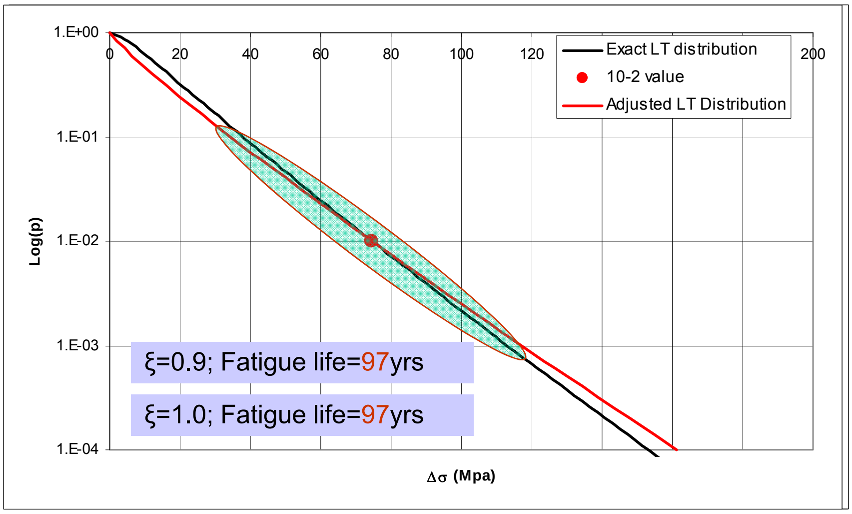
Selection of probability level - 1

- CSR-OT/CSR-BC approach:
  - Define the loads at 10^{-4}
  - Associate with Weibull shape parameter to generate a long term distribution



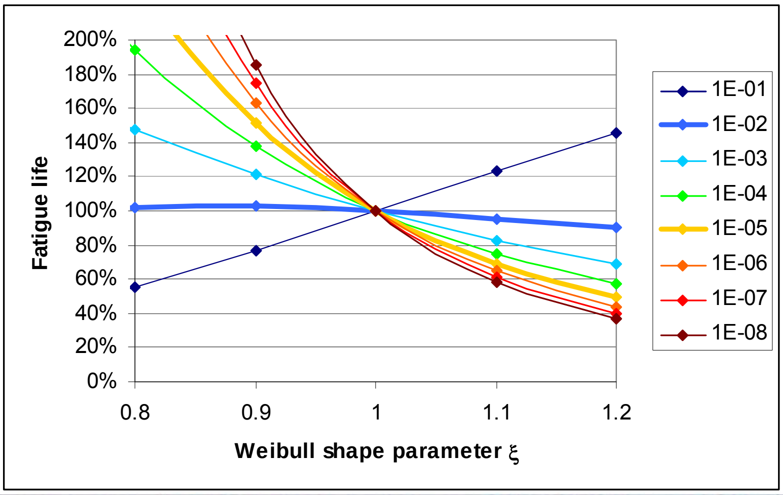
Selection of probability level - 2

- Alternative approach:
  - Define the loads at 10^{-2} : seems to be much less sensitive to the Weibull shape parameter.



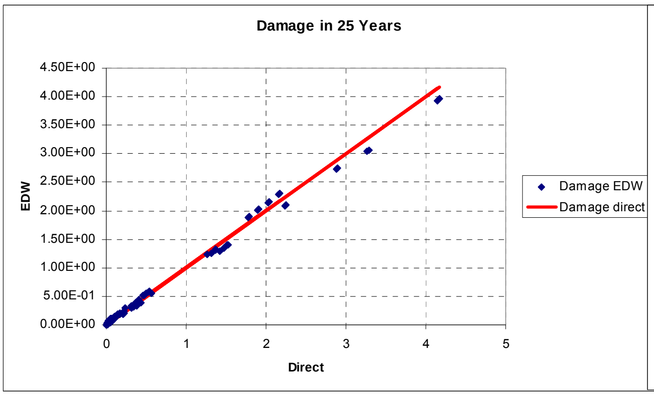
Shape parameter sensitivity

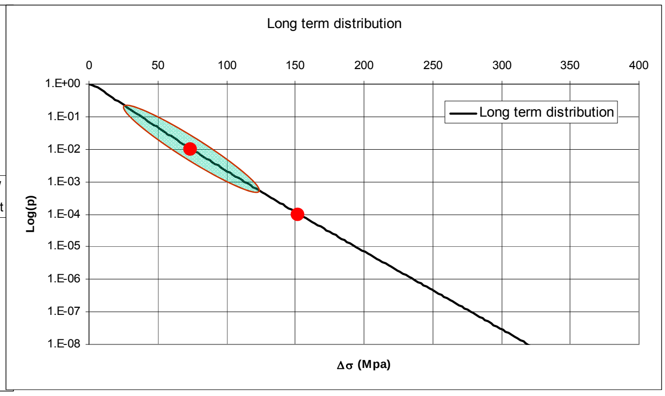
- There are two possibilities regarding the choice of the probability level of the EDWs:
  - 10^{-2} : with a constant ξ value (ξ = 1)
  - 10^{-4} : with a variable ξ value as in CSR-OT



Validation of EDW approach for fatigue loads

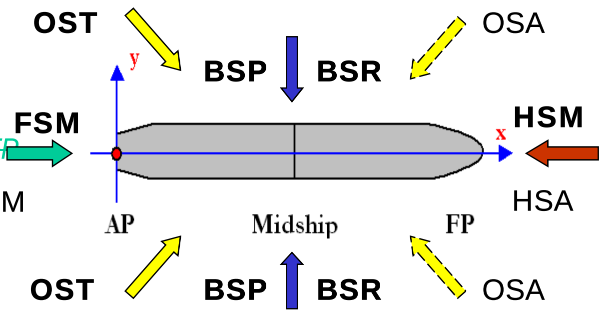
- Damage evaluated based the EDW value at 10^{-2}, the number of cycle of the EDW in 25 years and shape factor = 1.0
  - Reference loads different but the most contributive range of probability remain the same
- Comparison with direct computations

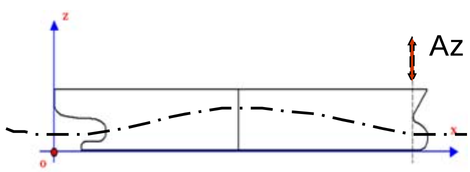




Rule dynamic load cases for fatigue

- 5 selected EDWs at 10^{-2} level as dynamic load cases for fatigue:
  - **HSM**: head sea EDW maximizing VBM amidships
  - ~~HSA: head sea EDW maximizing A_z at FP~~
  - **FSM**: following sea EDW maximizing VBM amidships
  - **BSR**: beam sea EDW maximizing roll motion
  - **BSP**: beam sea EDW maximizing waterline pressure at amidships
  - **OST**: oblique sea EDW maximizing torsional moment at ¼L
  - ~~OSA: oblique sea EDW maximizing pitch acceleration~~





HSA and OSA are covered by HSM

Improvements for fatigue loads

- Improvement
  - Probability level at 10^{-2}
  - Shape parameter independent (taken as 1.0)
- Gaps filled
  - Reduction factor evaluated for each load components of EDW in which speed effect is considered
  - External pressure loads
  - Extrapolation height over the waterline

$$f_p = \frac{\text{LT value at } 10^{-2} \text{ with } 3/4\, V_{design}}{\text{LT value at } 10^{-8} \text{ with V} = 5}$$

- Damage
  - Stress range computed for each dynamic load case
  - Damage corresponds to the highest damage evaluated from dynamic load cases

Conclusions on CSR-H load

- Consistent approach and strong technical background
  - EDW re-analysed,
  - Acceleration defined by the combination from 6 acceleration components at ship CoG,
  - Pressure load distribution associated with each EDW,
  - 53 BC and 51 OT used in direct computations
  - Convergent results obtained from different CS and different methods

Exemples of BC

No.	L_{PP}	B	D	V	Full homo. loading cond.				Partial loading cond.				Normal ballast cond.			
					d	C_B	GM/B	KG/D	d	C_B	GM/B	KG/D	d	C_B	GM/B	KG/D
	m	m	m	kont	m	-	-	-	m	-	-	-	m	-	-	-
1	107	20.0	10.4	13.5	8.0	0.75	0.09	0.62	-	-	-	-	4.54	0.69	0.14	0.60
2	127	21.0	10.8	12.0	8.1	0.80	0.10	0.61	-	-	-	-	4.38	0.75	0.23	0.55
3	138	22.0	12.2	14.0	9.4	0.78	0.07	0.61	-	-	-	-	5.15	0.74	0.11	0.60
4	148	22.0	13.1	14.4	9.5	0.78	0.08	0.61	-	-	-	-	5.34	0.72	0.12	0.59
5	150	25.0	13.6	14.0	10.0	0.79	0.08	0.59	-	-	-	-	4.93	0.74	0.17	0.56
6	160	27.0	13.6	14.0	9.8	0.79	0.12	0.59	7.65	0.77	0.15	0.58	5.00	0.73	0.26	0.55
7	172	31.0	15.8	14.0	11.2	0.81	0.11	0.57	-	-			5.07	0.74	0.30	0.52
8	174	31.0	15.8	14.0	11.0	0.82	0.11	0.58	-	-			5.49	0.77	0.27	0.50
9	177	30.0	16.2	14.0	11.0	0.82	0.10	0.59	-	-			6.16	0.79	0.22	0.52
10	181	31.0	16.5	14.5	11.6	0.81	0.10	0.60	-	-			5.45	0.75	0.28	0.52
11	182	31.0	16.5	14.5	10.7	0.81	0.10	0.57	-	-			5.38	0.76	0.27	0.50
12	215	32.0	18.2	13.9	12.4	0.83	0.10	0.56	9.2	0.80	0.14	0.53	6.11	0.76	0.25	0.51
13	217	32.0	19.0	14.8	13.9	0.84	0.09	0.56	-	-			6.05	0.77	0.25	0.48
14	217	32.0	18.3	14.0	12.2	0.83	0.10	0.56	-	-			7.75	0.80	0.16	0.52
15	225	38.0	19.9	14.4	13.9	0.83	0.12	0.58	8.8	0.78	0.19	0.57	5.74	0.74	0.38	0.47
16	230	43.0	20.5	14.0	12.6	0.83	0.17	0.56	10.0	0.81	0.22	0.53	7.82	0.80	0.32	0.44
17	260	43.0	24.0	14.2	17.6	0.84	0.10	0.57	12.8	0.82	0.12	0.55	7.66	0.78	0.27	0.50
18	278	45.0	24.0	14.7	17.7	0.84	0.12	0.55	13.0	0.82	0.16	0.50	7.64	0.79	0.31	0.45
19	278	46.0	23.3	14.7	17.2	0.85	0.13	0.56	13.2	0.83	0.17	0.55	7.30	0.78	0.36	0.48
20	280	46.0	25.0	16.0	18.4	0.85	0.11	0.57	12.8	0.82	0.20	0.47	7.76	0.76	0.32	0.48
21	285	48.0	25.0	12.8	17.9	0.82	0.11	0.56	-	-			7.34	0.77	0.36	0.41
22	285	50.0	26.7	14.6	19.6	0.83	0.12	0.56	16.4	0.81	0.16	0.50	8.13	0.75	0.32	0.50

Exemples of OT

No.	L_{PP}	B	D	V	Full loading cond.				Partial loading cond.				Normal ballast cond.			
					d	C_B	GM/B	KG/D	d	C_B	GM/B	KG/D	d	C_B	GM/B	KG/D
	m	m	m	kont	m	-	-	-	m	-	-	-	m	-	-	-
1	110	20.0	11.2	13.0	8.8	0.75	0.09	0.60	-	-	-	-	4.4	0.68	0.17	0.54
2	130	23.0	12.0	14.0	9.0	0.78	0.11	0.57	-	-	-	-	4.2	0.72	0.24	0.50
3	143	25.0	12.5	15.0	9.5	0.78	0.08	0.64	-	-	-	-	5.2	0.72	0.16	0.54
4	145	25.0	13.0	13.0	8.5	0.77	0.12	0.54	5.5	0.74	0.18	0.56	5.3	0.74	0.18	0.57
5	160	30.0	16.5	14.0	11.0	0.82	0.12	0.53	7.9	0.81	0.18	0.47	5.4	0.79	0.24	0.44
6	165	28.0	16.0	15.0	10.0	0.83	0.08	0.57	7.6	0.81	0.13	0.52	6.2	0.74	0.25	0.44
7	170	28.0	16.5	15.0	11.0	0.80	0.09	0.56	7.3	0.76	0.10	0.58	6.2	0.77	0.12	0.61
8	172	32.0	19.0	15.5	12.5	0.78	0.08	0.57	10.1	0.76	0.10	0.53	6.2	0.78	0.19	0.46
9	180	28.0	15.0	15.0	11.0	0.82	0.11	0.53	-	-			6.3	0.75	0.23	0.42
10	194	38.0	18.5	14.0	11.5	0.80	0.14	0.59	7.6	0.77	0.24	0.53	6.3	0.74	0.30	0.43
11	200	36.0	19.0	15.0	12.0	0.79	0.14	0.52	9.5	0.77	0.17	0.50	6.5	0.78	0.24	0.53
12	210	32.0	20.0	14.0	12.5	0.83	0.12	0.48	9.6	0.80	0.18	0.41	6.7	0.75	0.24	0.45
13	215	32.0	20.5	14.0	12.5	0.82	0.08	0.52	8.8	0.79	0.10	0.52	6.8	0.77	0.15	0.53
14	220	42.0	20.2	14.0	14.0	0.82	0.15	0.58	10.5	0.79	0.21	0.53	6.8	0.77	0.52	0.41
15	220	42.0	20.2	14.0	14.0	0.82	0.15	0.58	11.0	0.80	0.17	0.59	6.8	0.75	0.41	0.43
16	230	42.0	20.5	14.0	13.6	0.81	0.16	0.53	10.3	0.79	0.20	0.52	7.2	0.76	0.28	0.56
17	230	42.0	21.0	15.0	14.8	0.82	0.13	0.58	11.1	0.79	0.18	0.52	7.5	0.76	0.30	0.46
18	235	42.0	19.5	14.0	13.5	0.82	0.17	0.52	9.3	0.79	0.23	0.53	7.6	0.74	0.34	0.51
19	235	42.0	21.0	14.5	14.8	0.83	0.13	0.58	11.2	0.81	0.19	0.50	7.7	0.76	0.31	0.43
20	260	45.0	22.5	15.5	17.2	0.81	0.12	0.57	11.9	0.78	0.18	0.50	8.1	0.78	0.23	0.68
21	305	55.0	29.0	14.0	19.5	0.81	0.14	0.52	14.1	0.79	0.17	0.52	8.5	0.72	0.31	0.53
22	310	58.0	28.5	15.5	19.0	0.78	0.16	0.53	13.7	0.75	0.23	0.48	8.6	0.75	0.36	0.50
23	315	59.0	30.5	14.5	21.0	0.79	0.15	0.53	12.4	0.73	0.24	0.53	8.8	0.69	0.40	0.46
24	318	60.0	28.5	16.5	19.5	0.81	0.15	0.57	14.5	0.78	0.20	0.56	9.0	0.71	0.37	0.42
25	320	60.0	28.5	15.5	19.0	0.79	0.15	0.56	14.9	0.77	0.19	0.56	9.0	0.75	0.43	0.31
26	320	60.0	29.0	16.0	20.5	0.81	0.15	0.56	15.5	0.79	0.19	0.53	9.0	0.73	0.42	0.37
27	322	58.0	29.0	15.5	19.5	0.79	0.16	0.54	13.9	0.76	0.22	0.51	10.1	0.75	0.36	0.49

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Thank you for your attention !