Bølgekamhøyder beregnet i henhold til gjeldende NORSOK

23-08-2023 Gunnar Lian

Estimation of characteristic actions (N-003, section 6.1.1.3)

- For fixed structures behaving quasi-statically, q-probability hydrodynamic actions can be estimated using the design wave method.
- For other structures, q-probability actions and action effects should if possible be based on long-term action or action effect analyses.
- Two essentially different approaches for the long-term analyses are recommended:
  - all short-term conditions approach (all important sea states)
  - storm event approach
- In addition, the metocean contour method (an approximate method using only short-term analysis) is recommended for nonlinear problems

Long-term modelling of wave conditions (N-003 section 6.2.1.6).

- The following distribution functions are recommended:

- H_S: A 3-parameter Weibull distribution. The parameters should be estimated using method of moments.

- T_P given H_S: log-normal distribution

- Omni-directional modelling is done in a similar way by pooling data from the various direction sectors.

11.6.3.2 Airgap and wave in deck analysis for fixed structures

- It is recommended to design bottom fixed structures with a still water airgap at least 1.1 times the 2nd order crest height plus the combined tide and storm surge as given in Table 7

- Alternatively, the higher order wave effects and spatial statistics will have to be evaluated in detail

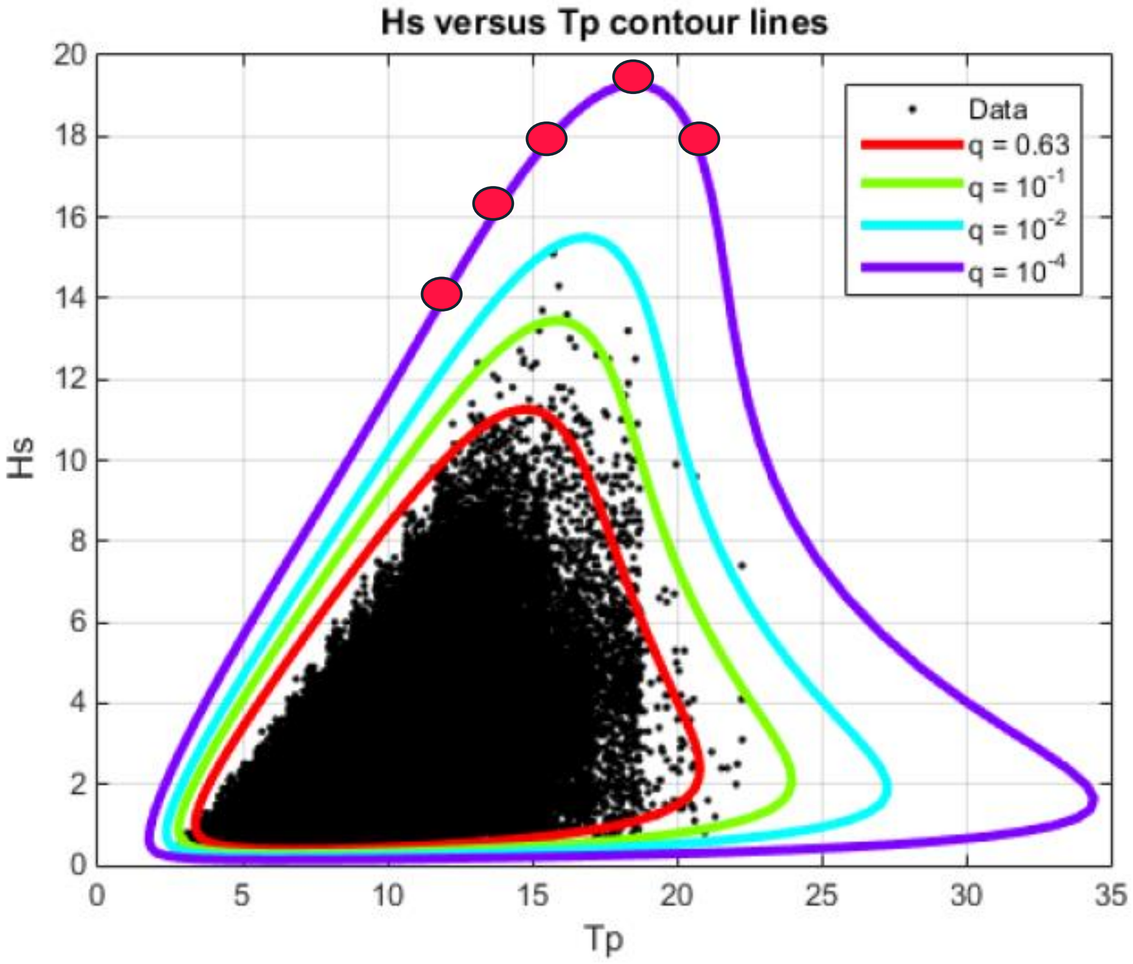
NORSOK N-003
Combination of metocean conditions

Table 7 – Combination of water levels, metocean and earthquake conditions with expected mean values and annual probability of exceedance 10^{-2} and 10^{-4}

Limit states		Wind	Waves (e	Current (f	Sea spray icing	Sea ice	Ice-bergs	Snow	Earth-quake	Sea level (a
Ultimate limit states	1	10^{-2}	10^{-2}	10^{-1}	-	-	-	-	-	$HAT + S_{10^{-2}}$
	2	10^{-1}	10^{-1}	10^{-2}	-	-	-	-	-	$HAT + S_{10^{-2}}$
	3	10^{-1}	10^{-1}	10^{-1}	10^{-2}	-	-	10^{-1}	-	MWL
	4	10^{-1}	0,63 (c	10^{-1}	-	10^{-2}	-	-	-	MWL
	5	10^{-1}	10^{-1}	10^{-1}	-	-	10^{-2}	-	-	MWL
	6	10^{-1}	10^{-1}	10^{-1}	10^{-1}	-	-	10^{-2}	-	MWL
	7	-	-	-	-	-	-	-	10^{-2}	MWL (b
Accidental limit states	1	10^{-4}	10^{-2}	10^{-1}	-	-	-	-	-	$MWL + S_{10^{-4}}$
	2	10^{-2}	10^{-4}	10^{-1}	-	-	-	-	-	$MWL + S_{10^{-4}}$
	3	10^{-1}	10^{-1}	10^{-4}	-	-	-	-	-	$MWL + S_{10^{-4}}$
	4	10^{-2}	10^{-1}	-	10^{-4}	-	-	-	-	MWL
	5	-	-	-	-	10^{-4} (d	-	-	-	MWL
	6	0,63	0,63	0,63	-	-	10^{-4} (d	-	-	MWL
	7	0,63 (g	0,63 (g	-	-	-	-	10^{-4}	-	MWL
	8		-		-	-	-	-	10^{-4}	MWL (b

Metocean contour method

- The metocean contour method is a simplified approach to estimate the *q*-probability response.
- Main steps:
    1. Determine *q*-probability contour of H_s and T_p.
    2. Identify the worst combination along the contour.
    3. Establish the 3-hour extreme value distribution for the worst sea state.
    4. *q*-probability response can then be estimated by a proper percentile of the 3-hour extreme value distribution. NORSOK N-003 specify that 0.9 can be used for ULS and 0.95 for ALS. (If COV is larger than 0.2, a full LTA should be performed)



Open

"All" Sea-States approach

equinor

100 000 year scatter-diagram

Hs (m)	Tp (s)																									
	<3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15 - 16	16 – 17	17 – 18	18 – 19	19 – 20	20 – 21	21 – 22	22 – 23	23 – 24	24 – 25	25 – 26	> 26	SUM
0-1	168252	1353876	3742132	5692847	6093794	5247179	3927769	2680111	1718342	1056162	630893	369769	214093	123056	70467	40310	23079	13245	7627	4411	2563	1498	880	520	779	33183654
1-2	17616	600404	4193784	11829755	19103886	21544411	19121250	14398145	9661402	5972155	3480114	1943350	1052380	557535	290873	150185	77036	39371	20093	10259	5247	2691	1386	716	785	114074830
2-3	86	20008	471721	3009769	8435177	13711816	15353445	13231621	9450716	5886263	3313540	1729919	853623	403788	185070	82867	36479	15867	6846	2939	1258	539	231	99	75	76203761
3-4	0	115	14365	279696	1690412	4649260	7377138	7894062	6335525	4107532	2268445	1109191	494151	204958	80460	30279	11033	3923	1370	472	161	55	19	6	3	36552631
4-5	0	0	115	10194	175952	1010108	2662908	3983870	3914633	2802909	1576720	736623	297955	107697	35643	11008	3220	903	245	65	17	4	1	0	0	17330789
5-6	0	0	0	114	7972	123026	654590	1593365	2154146	1858990	1134393	528401	199096	63442	17697	4440	1024	221	45	9	2	0	0	0	0	8340973
6-7	0	0	0	0	120	6634	88558	417080	892608	1039077	751622	373668	137942	40149	9656	1992	363	60	9	1	0	0	0	0	0	3759539
7-8	0	0	0	0	1	142	5966	64927	255152	454753	434327	252364	98439	27846	6072	1072	159	21	2	0	0	0	0	0	0	1601244
8-9	0	0	0	0	0	1	191	5640	46697	144136	203464	153181	69332	20743	4425	716	92	10	1	0	0	0	0	0	0	648629
9-10	0	0	0	0	0	0	3	270	5266	31194	71973	77578	44944	15647	3581	580	70	7	1	0	0	0	0	0	0	251114
10-11	0	0	0	0	0	0	0	7	369	4501	18311	30668	24821	11018	2972	530	67	6	0	0	0	0	0	0	0	93270
11-12	0	0	0	0	0	0	0	0	17	438	3294	9070	10957	6684	2306	494	71	7	1	0	0	0	0	0	0	33339
12-13	0	0	0	0	0	0	0	0	1	30	424	1979	3722	3289	1543	425	75	9	1	0	0	0	0	0	0	11498
13-14	0	0	0	0	0	0	0	0	0	2	40	322	961	1269	844	314	72	11	1	0	0	0	0	0	0	3834
14-15	0	0	0	0	0	0	0	0	0	0	3	40	190	380	366	189	58	11	2	0	0	0	0	0	0	1239
15-16	0	0	0	0	0	0	0	0	0	0	0	4	29	89	125	91	38	10	2	0	0	0	0	0	0	388
16-17	0	0	0	0	0	0	0	0	0	0	0	0	4	16	34	35	20	7	2	0	0	0	0	0	0	118
17-18	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	11	9	4	1	0	0	0	0	0	0	35
18-19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	2	1	0	0	0	0	0	0	10
19 - 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	3
20 - 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Sum	185954	1974403	8422117	20822376	35507314	46292579	49191819	44269101	34434872	23358142	13887563	7316126	3502639	1587609	712144	325539	152968	73694	36249	18158	9249	4787	2516	1342	1642	292090901

$$F_{X_{3h}}(x) = \int_{h_s} \int_{t_p} \underbrace{F_{X3h_{max}|H_s,T_p}(x|h_s,t_p)}_{\text{Short-term}} \underbrace{f_{H_s,T_p}(h_s,t_p)}_{\text{Long-term}} \, dh_s dt_p$$

$$F_{X_{3h}}(x) \approx \sum_{i=1}^{m} \sum_{j=1}^{n} F_{X3h_{max}|H_i,T_j}(x|h_i,t_j) \frac{N_{ij}}{N}$$

All sea states approach

In general, the long-term probability distribution should be performed, conditional on the wave sectors:

$$F_{X_{3h}}(x|\theta_i) = \int_{h_s}\int_{t_p} F_{X_{3h}|H_s,T_p,\theta}\left(x|h_s, t_p, \theta_i\right) f_{H_s,T_p|\theta}(h_s, t_p|\theta_i)\, dh_s\, dt_p$$

The long-term probability distribution is then:

$$F_{X_{3h}}(x) = \sum_{all\ i} F_{X_{3h}}(x|\theta_i) p_i$$

All sea states approach

- For the second order wave crest height, the short-term response is only weakly dependent on the directional sector (by the conditional wave period) and the problem is often simplified by using the omni-directional distribution of H_s estimated from:

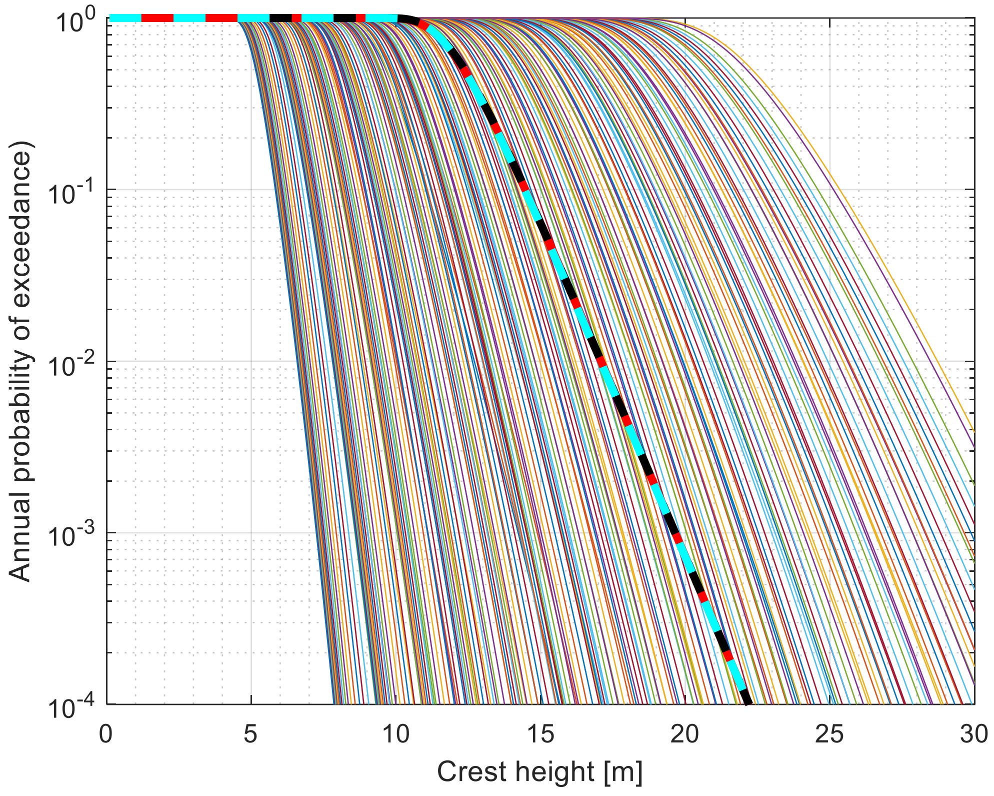
$$F_{H_s}(h_s) = \sum_{all\ i} F_{H_s|\theta}(h_s|\theta_i)p_i$$

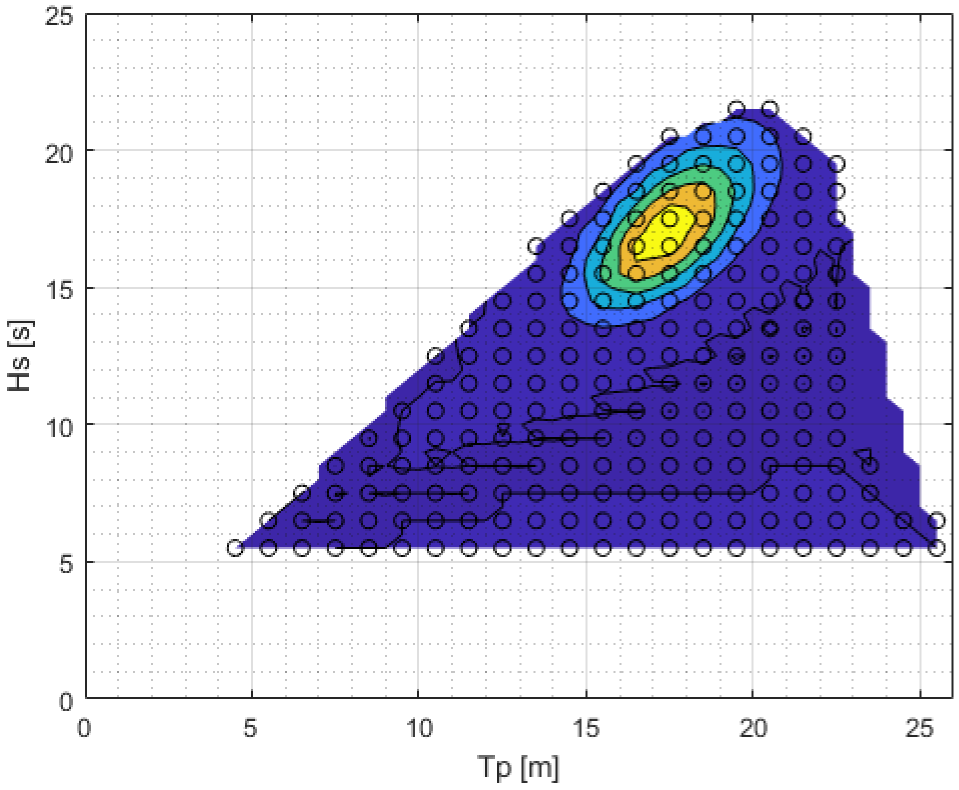
The target q-probability response is estimated from:

$$1 - F_{X_{3h}}(x_q) = q/m_{3h}$$

m_{3h} is the annual number of 3-hours events in the target population.

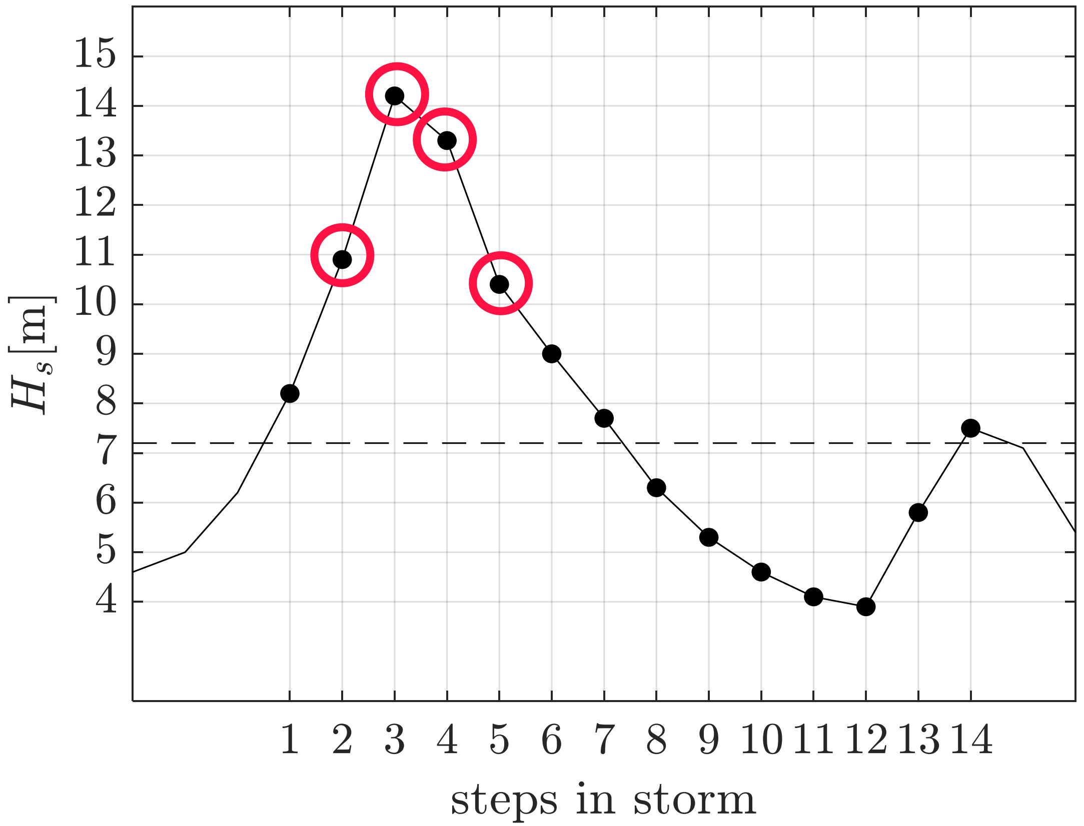
All sea states approach





Open

Storm event approach



$$F_{Y|k}(y|\mathrm{k})$$
$$= P\left[\left(Y_{1_k} \leq y\right) \cap \left(Y_{2_k} \leq y\right) \cap \cdots \left(Y_{m_k} \leq y\right) | k\right]$$

$$= \prod_{m=1}^{m_k} F_{Y_{3h}m|k}(y|m,\mathrm{k})$$

Open

Storm event approach

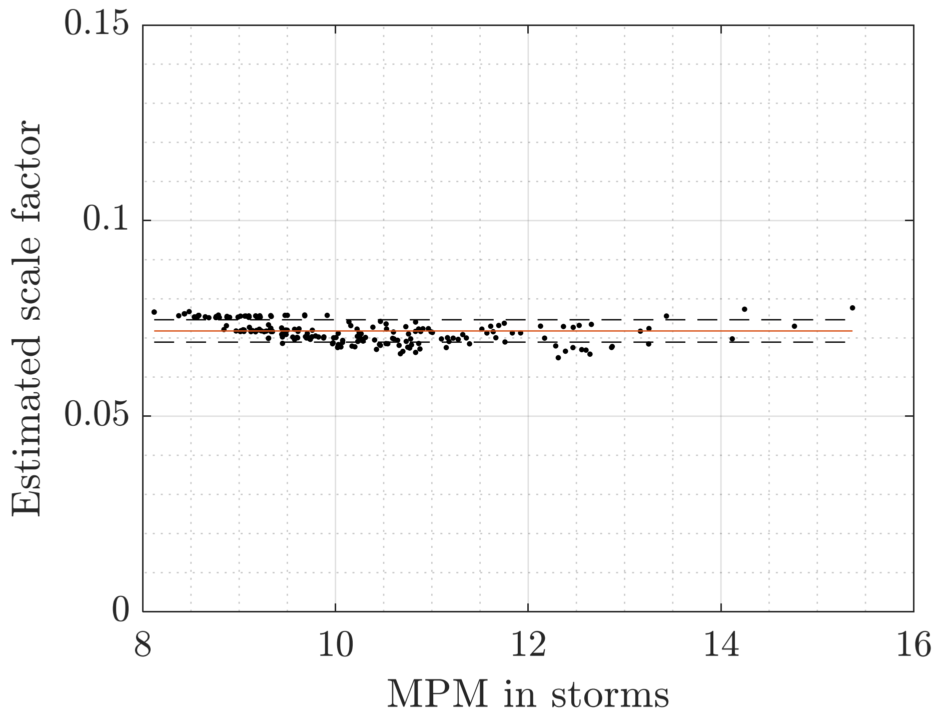
$$F_Y(y) = \int_{\tilde{y}} F_{Y|\tilde{Y}}(y|\tilde{y}) f_{\tilde{Y}}(\tilde{y}) d\tilde{y}$$

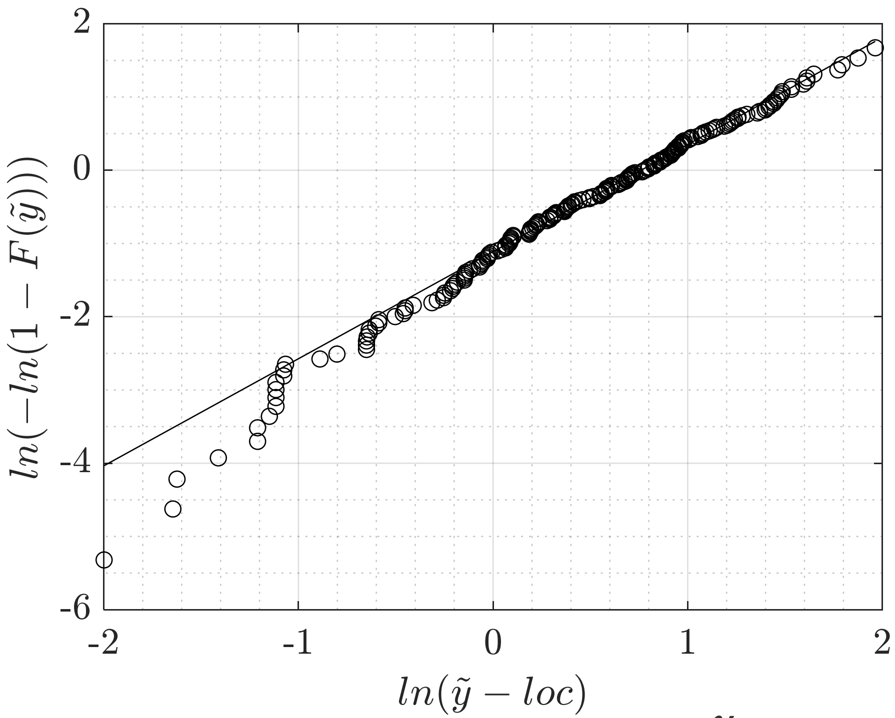
$$F_{Y|\tilde{y}}(y|\tilde{y}) = \exp\left\{-\exp\left[-\ln N\left(\left(\frac{y}{\tilde{y}}\right)^2 - 1\right)\right]\right\}$$

Tromans, P. S. and L. Vanderschuren (1995).

$$F_{Y|\tilde{y}}(y|\tilde{y}) = \exp\left\{-\exp\left[-\left(\frac{y-\tilde{y}}{\psi\tilde{y}}\right)\right]\right\}$$

Storm event approach

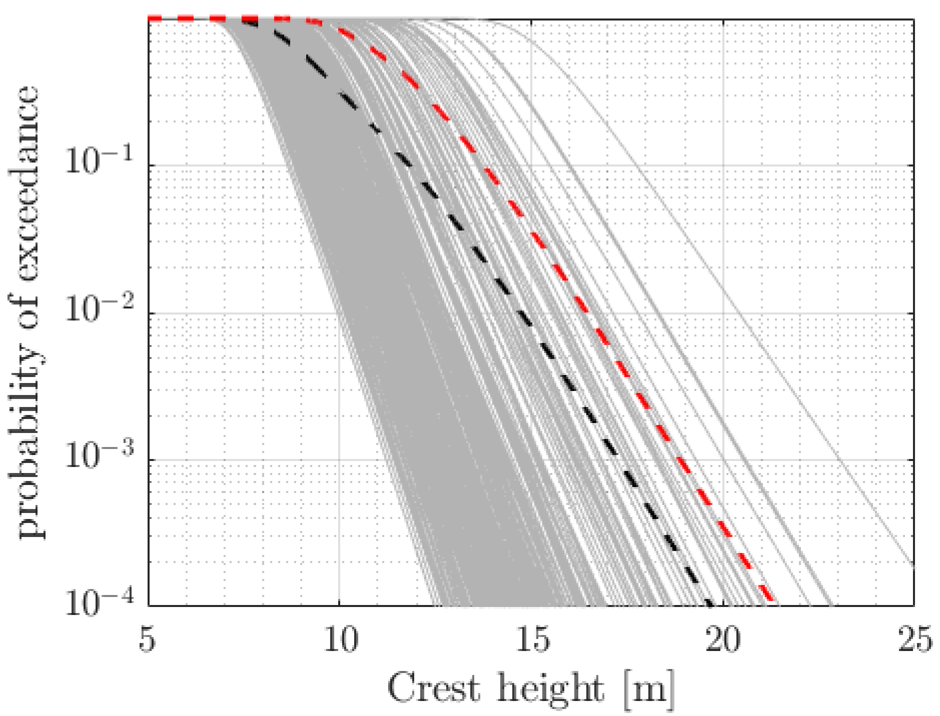


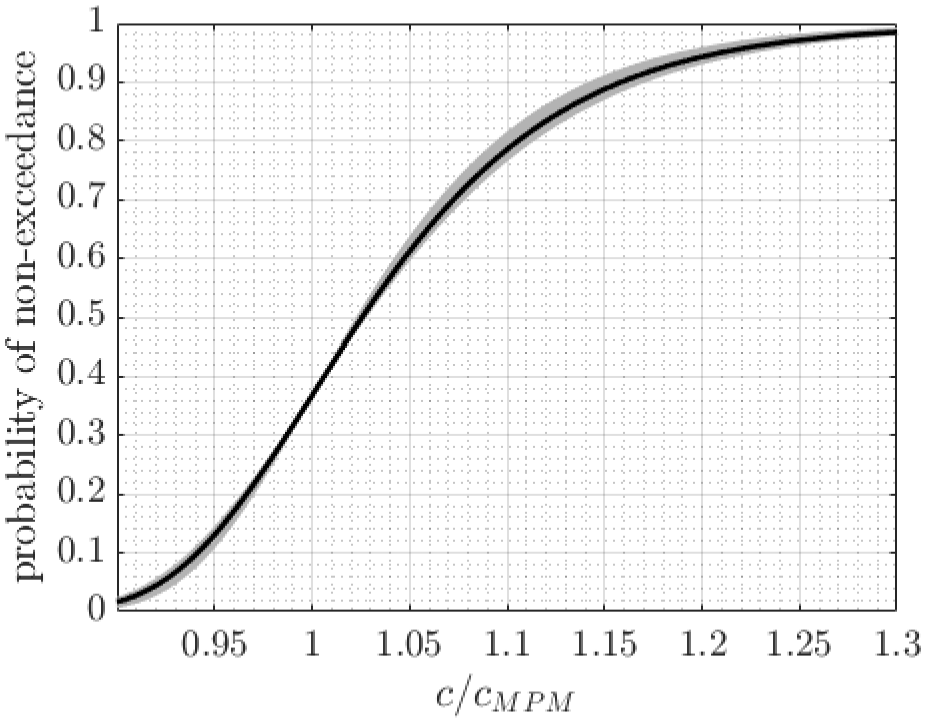


$$\sigma^2_{\text{exact}} = \frac{\pi^2}{6}(\psi\tilde{y})^2 \Rightarrow \psi = \frac{\sqrt{6}}{\pi\tilde{y}}\sigma_{exact}$$

$$F_{\tilde{Y}}(\tilde{y}) = 1 - exp\left\{-\left(\frac{\tilde{y}-\alpha_W}{\beta_W}\right)^{\gamma}\right\}$$

Storm event approach

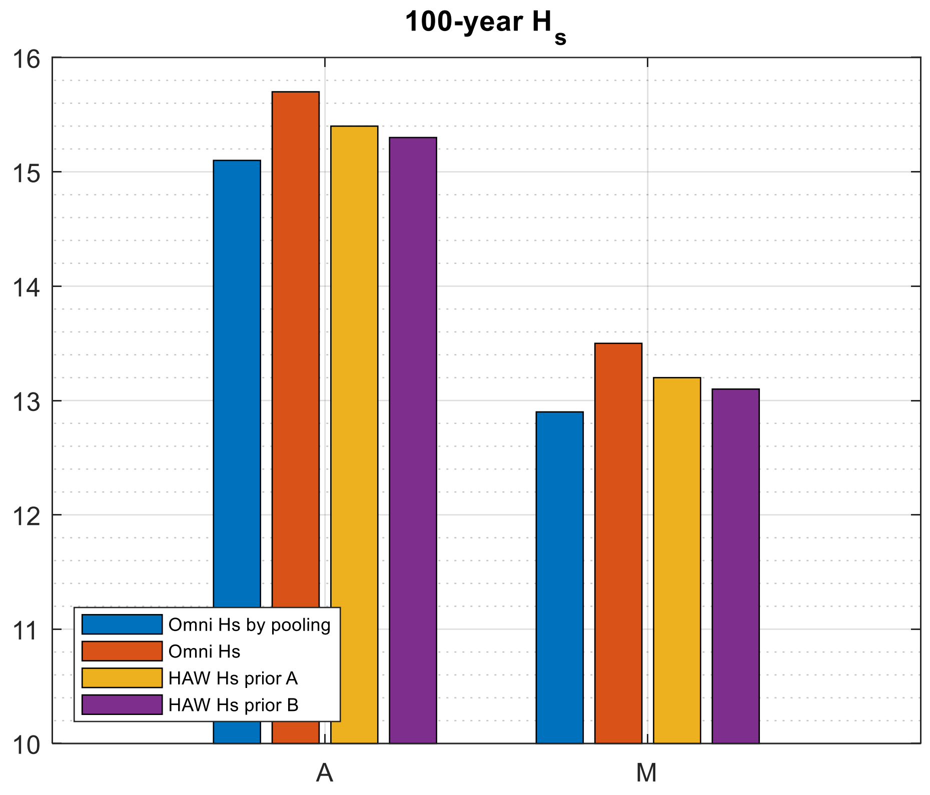


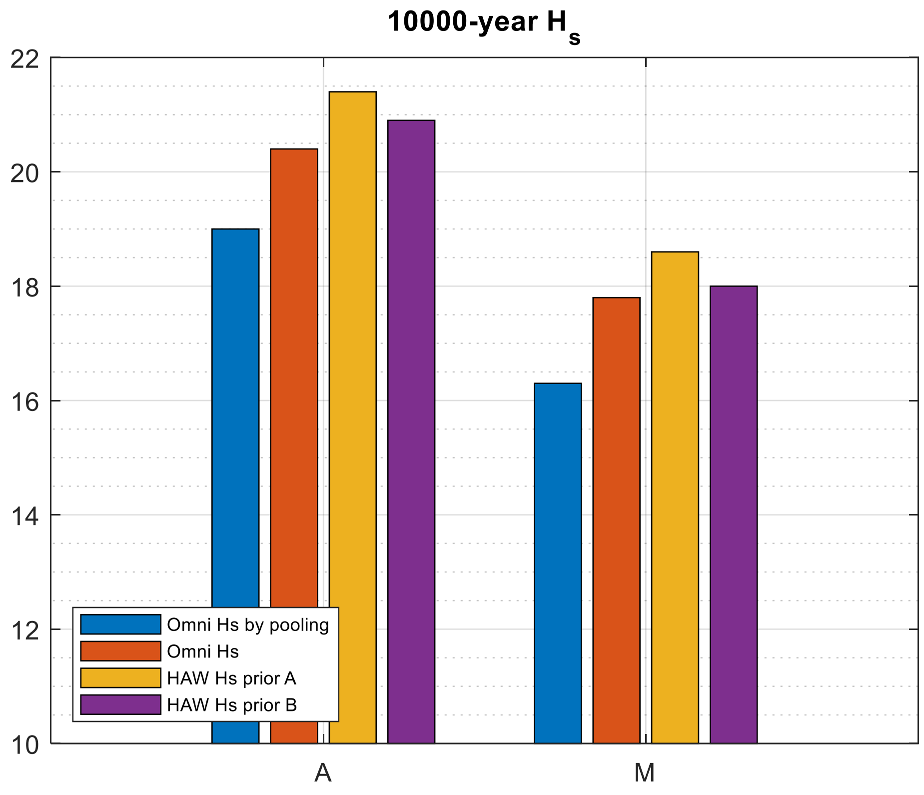


$$F_Y(y) = \frac{1}{k_0} \sum_k F_{Y|k}(y|\mathrm{k}) \qquad F_{Y_{1y}}(y) = F_Y^{\lambda}(y)$$

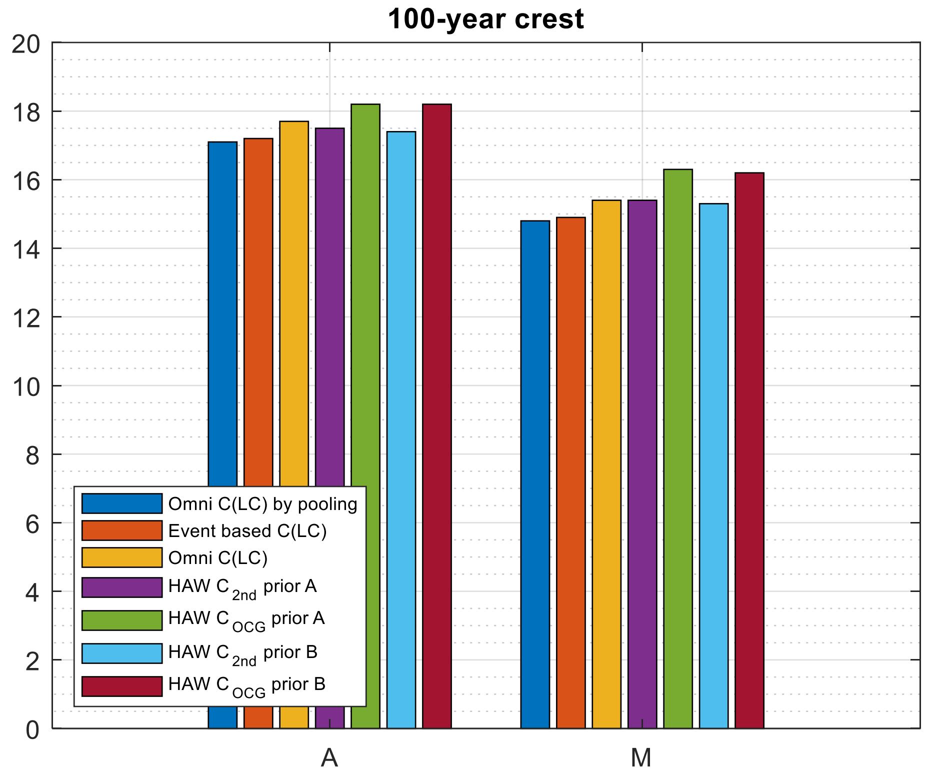
$$F_{Y|\tilde{y}}(y|\tilde{y}) = \exp\left\{-\exp\left[-\left(\frac{y-\tilde{y}}{\psi\tilde{y}}\right)\right]\right\}$$

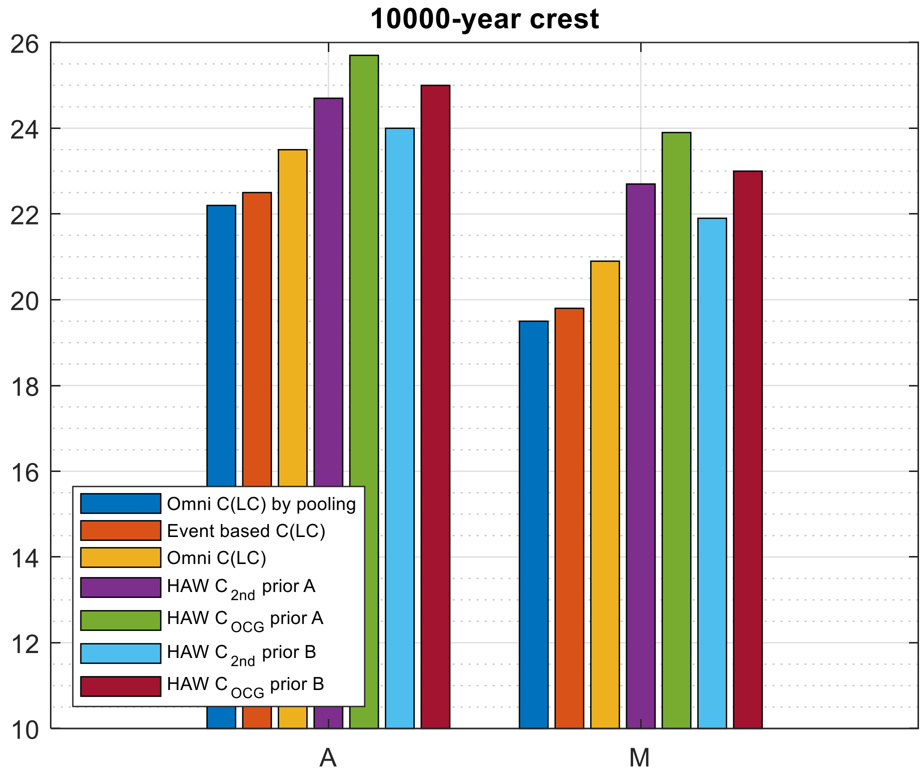
Comparison of Hs according to NORSOK vs HAW at location A and M





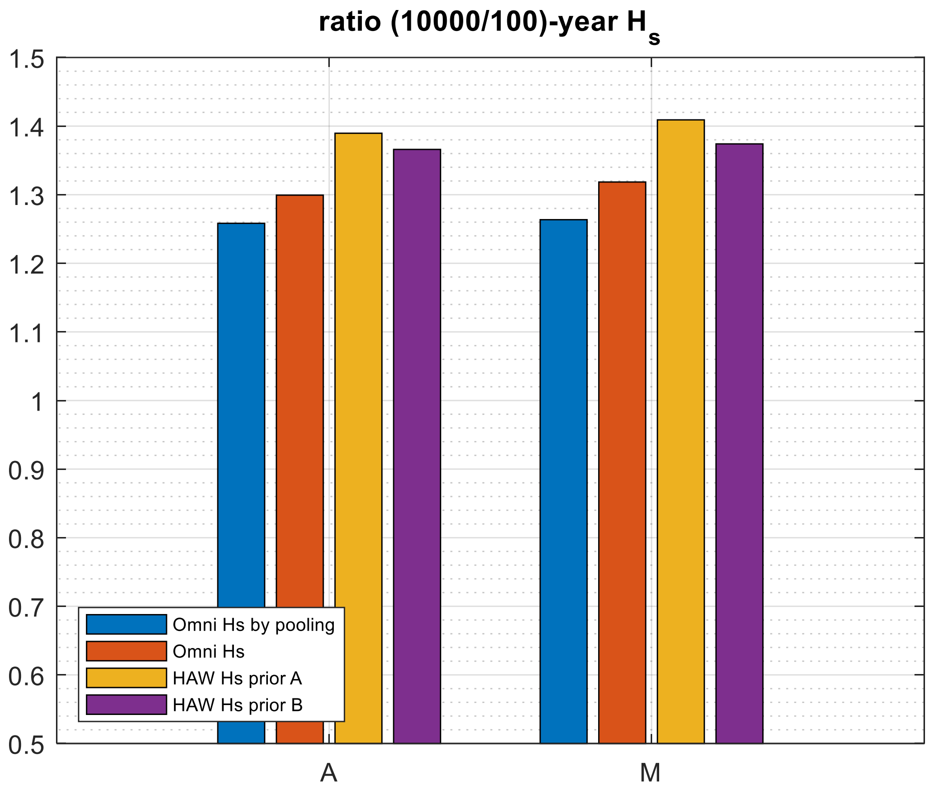
Comparison of Crest height according to NORSOK vs HAW at location A and M

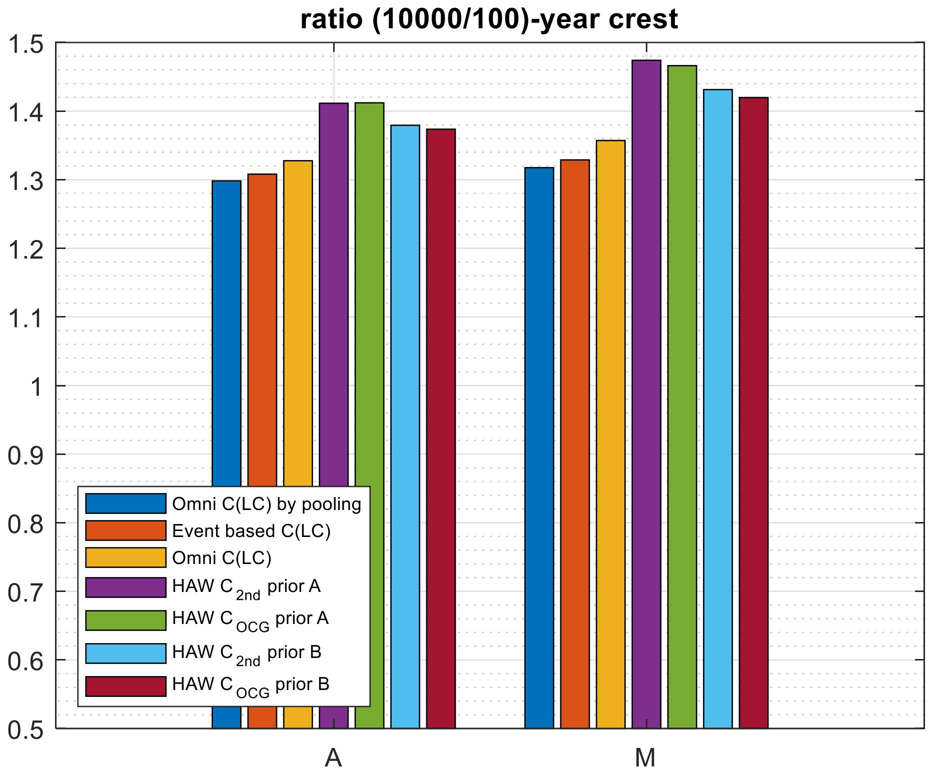




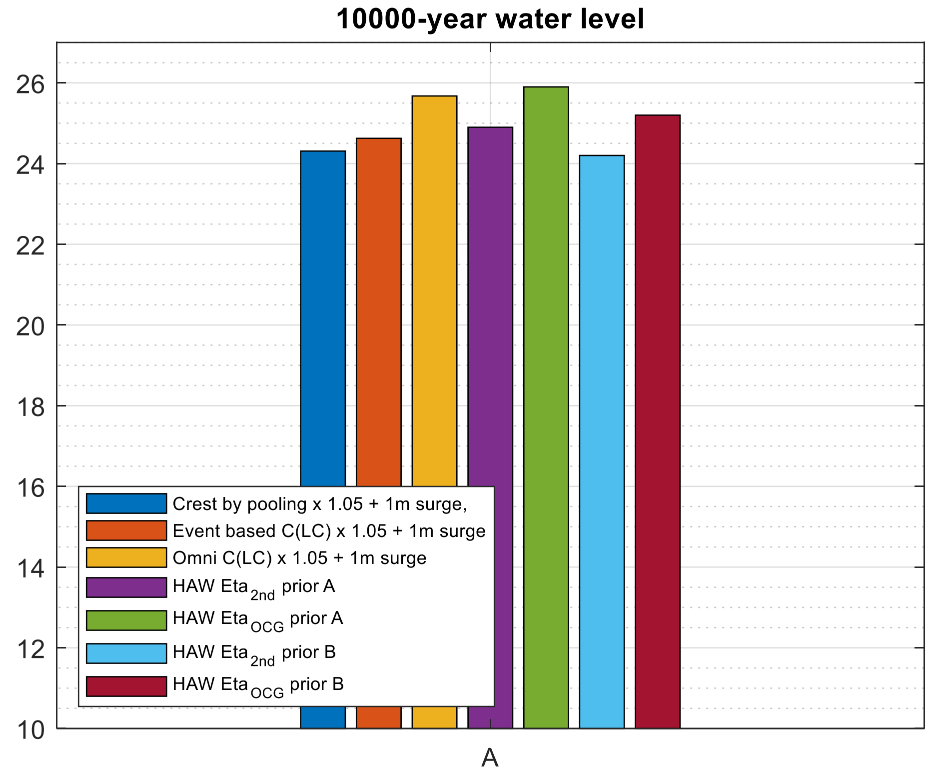
Note: It is recommended to design bottom fixed structures with a still water airgap at least 1.1 times the 2nd order crest height plus the combined tide and storm surge as given in Table 7

Ratio 10000/100





Total water level, (incl 5% for higher than second order, but without area effect)



	Storm surge [cm]				HAW
Location	1-year	10-year	100-year	10000-year	"associated" Storm surge
A	53	68	81	105	20
B	55	72	87	115	30
C	58	75	91	119	20
D	57	75	92	124	5
E	55	72	89	120	25
F	54	73	92	128	20
G	57	79	100	144	35
H	55	74	93	130	20
I	66	93	119	172	35
J	65	92	119	175	35
K	66	93	121	178	30
L	73	103	131	186	60
M	80	117	154	226	80
N	84	124	164	246	90

Sea level according to Table 7 can be used as a conservative approach in lack of more detailed and verified joint models.