THE MORTAVIKA BREAKWATER – 12 YEARS AFTER

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1. SUMMARY

The state of a dynamically stable berm breakwater built in 1992/1993 near Stavanger, Norway is examined. The breakwater underwent extensive reshaping during and immediately after its construction in the winter of 1992/1993, and has remained fairly stable until January 2005. Two consecutive heavy storms inflicted damage so heavy that repairs are deemed to be necessary. The wave exposure during the lifetime is examined, and theoretical models for the recession are compared with the recorded data. A repair strategy is proposed.

2. BACKGROUND AND HISTORY

The breakwater was built i 1992 to serve as protection for a ferry terminal. The salient points in its history are as follows.

- Jan –Dec 1992: under construction. The breakwater is subjected to some moderate storms in its partially finished phase.
- August 1993: 3500 m3 of rocks with W_{50} = 8.0 tons are added to fill in anomalies detected during the completion survey.
- January 2000: heaviest storm on record since 1993. The breakwater is inspected, and found to be reshaped, but not damaged
- January 2005: Heaviest storm in the lifetime of the breakwater occurs. The berm is reshaped and at places entirely lost, and the crest is breached at one location in the middle of the breakwater
- March 2005: New survey of breakwater status. Survey shows that the remaining primary berm thicknessis down to 0.0 m at places, typically 1.0 – 2.0 m.
- May 2005: proposed strategy for repairs is presented. A total of 10,000 m3 of rocks with W_{50} = 8.0 tons is needed.

3. ORIGINAL DESIGN

The original design was presented at the ICS in Hornafjørdur in 1994 (1). The essential data for the breakwater are shown in Table 1.

Table 1 Essential data for the Mortavika breakwater

Parameter	Unit	Value
Design significant wave height $H_{s,100}$	m	6.8
Design peak spectral period $T_{p,100}$	s	15.6
Design water level relative to MWL	m	+1.0
Breakwater volume	m^3	380,000
Max water depth at toe	m	21
Berm elevation	m	+2
Berm width	m	16.0
Crest height	m	+8.0
Mean weight of rock units in berm	ton	5.5 – 8.0
$H_0 = H_{s,100} / \left(\Delta D_{50} \right)$	-	2.77 – 3.14
$T_0 = T_z \sqrt{g / D_{50}}$	-	30.4 – 32.3
H_0T_0	-	84 - 101

The design was based on measurements on site, numerical modeling and laboratory model tests.

4. WAVE LOADING 1992 – 2005

The wave loading in the years 1992 – 2005 has been established on the basis on hindcast wave data provided by the Norwegian Meteorological Institute. Applying the same wave reduction factor as applied for the design in 1991, it is found the highest significant wave height to appear in front of the breakwater is
H_s = 4.8 m/ Tp =13 – 14 s, which occurred in January 2005.

An examination of the annual maxima for significant wave heights shows that in the 12 years of service, 2005 was the worst year yet for the breakwater.

Figure 1 shows the variation of annual maxima for significant wave heights, and Table 2 shows a breakdown of all wave hindcast wave data into wave height and wave period classes.

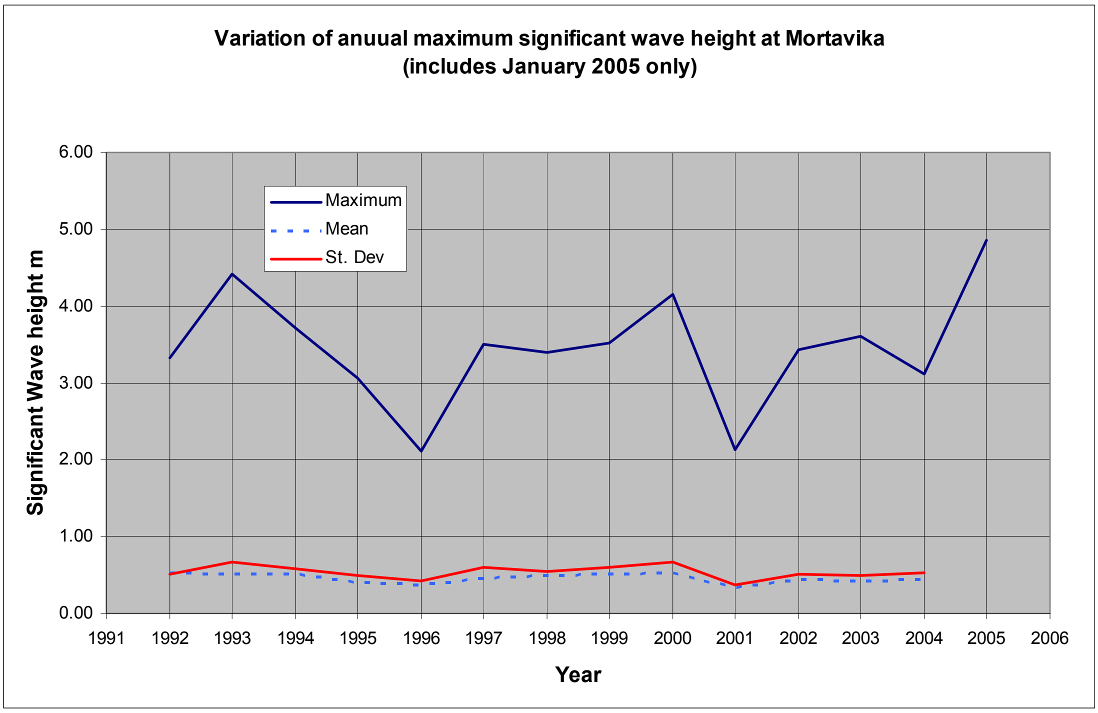

Figure 1 Variation of annual maximum significant wave height at Mortavika. The graph shows clear local maxima in 1993 (opening year), 2000 and 2005. Notice that 2005 includes only January.

Table 2 Scatter diagram for significant wave height at Mortavika vs. peak spectral period, from 1992 through January 2005.

FREQUENCY TABLE of Hm0 vs. Tp **Total sea** data at **LP 1262** from **Jan 90** to **38443**

Hm0 \ **Tp**	**<2**	**2-3**	**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**	**Sum**	**Marg. distr.**	**Cum. distr.**	**Tp Average**
< **0.2**	12	145	728	1905	1417	1207	944	864	745	611	586	443	300	172	49	25	4	4	1		10162	0.531	0.531	8.1
0.4			209	400	412	426	343	291	183	175	148	147	106	38	28	15	5	2	2		2930	0.153	0.685	7.8
0.6				162	269	352	235	178	111	101	96	123	159	43	15	9	1	3			1857	0.097	0.782	8.0
0.8				40	96	284	233	159	66	41	31	48	97	41	12	3	1	1			1153	0.060	0.842	8.3
1.0				4	31	127	259	148	68	22	21	22	66	29	13	1	2				813	0.043	0.885	8.4
1.2				1	19	69	211	152	61	29	15	12	22	29	15	6					641	0.034	0.918	8.6
1.4					2	31	107	156	65	20	14	6	6	12	8	1	1				429	0.022	0.941	8.6
1.6						10	49	136	73	23	7	6	8	5	3	2					322	0.017	0.957	8.9
1.8						1	31	77	83	22	9	6	4	5	1						239	0.013	0.970	9.0
2.0							11	39	67	32	4	2	3	2					1		161	0.008	0.978	9.4
2.2							4	28	57	29	7	4	3			1					133	0.007	0.985	9.6
2.4								6	29	34	8	4	3								84	0.004	0.990	9.7
2.6								2	19	27	17	3	2	2							72	0.004	0.994	10.2
2.8								2	12	9	13	3		1							40	0.002	0.996	10.4
3.0								1	1	7	10	3	1								23	0.001	0.997	10.6
3.2										15	6	3									24	0.001	0.998	11.2
3.4									1	5	5	3	2	1							17	0.001	0.999	10.9
3.6										2	5	4									11	0.001	1.000	11.4
3.8																					0	0.000	1.000	11.3
4.0											2	1	1	1							5	0.000	1.000	12.0
4.2												1									1	0.000	1.000	12.1
4.4												1	1								2	0.000	1.000	12.3
4.6																					0	0.000	1.000	12.5
4.8													1								1	0.000	1.000	14.8
5.0																					0	0.000	1.000	12.9
5.2																					0	0.000	1.000	12.4
5.4																					0	0.000	1.000	0.0
5.6																					0	0.000	1.000	13.5
5.8																					0	0.000	1.000	0.0
6.0																					0	0.000	1.000	0.0
6.2																					0	0.000	1.000	0.0
6.4																					0	0.000	1.000	0.0
6.6																					0	0.000	1.000	0.0
6.8																					0	0.000	1.000	0.0
7.0																					0	0.000	1.000	0.0
7.2																					0	0.000	1.000	0.0
7.4																					0	0.000	1.000	0.0
7.6																					0	0.000	1.000	0.0
7.8																					0	0.000	1.000	0.0
8.0																					0	0.000	1.000	0.0
Sum	12	145	937	2512	2246	2507	2427	2239	1641	1204	1004	845	784	381	144	63	14	10	4	0	19120			
Marg. distr.	0.001	0.008	0.049	0.131	0.117	0.131	0.127	0.117	0.086	0.063	0.053	0.044	0.041	0.020	0.008	0.003	0.001	0.001	0.000	0.000				
Cum. distr.	0.001	0.008	0.057	0.189	0.306	0.437	0.564	0.681	0.767	0.830	0.883	0.927	0.968	0.988	0.995	0.998	0.999	1.000	1.000	1.000				
Average	0.0	0.1	0.1	0.1	0.2	0.3	0.5	0.6	0.6	0.6	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.3	0.6					

	mean	**max.**
Hm0	0.5	4.79
Tp	7.9	19.73

5. RESHAPING AND DAMAGES 2005

5.1 Survey

The reshaping and the damages to the breakwater as accumulated up to and including the January 2005 storm have been recorded in a survey conducted in March 2005. The survey was conducted along section lines taken at 10 m intervals, see Figure 2.

The post-storm inspection showed no visible damage on the head, and this part has not been surveyed.

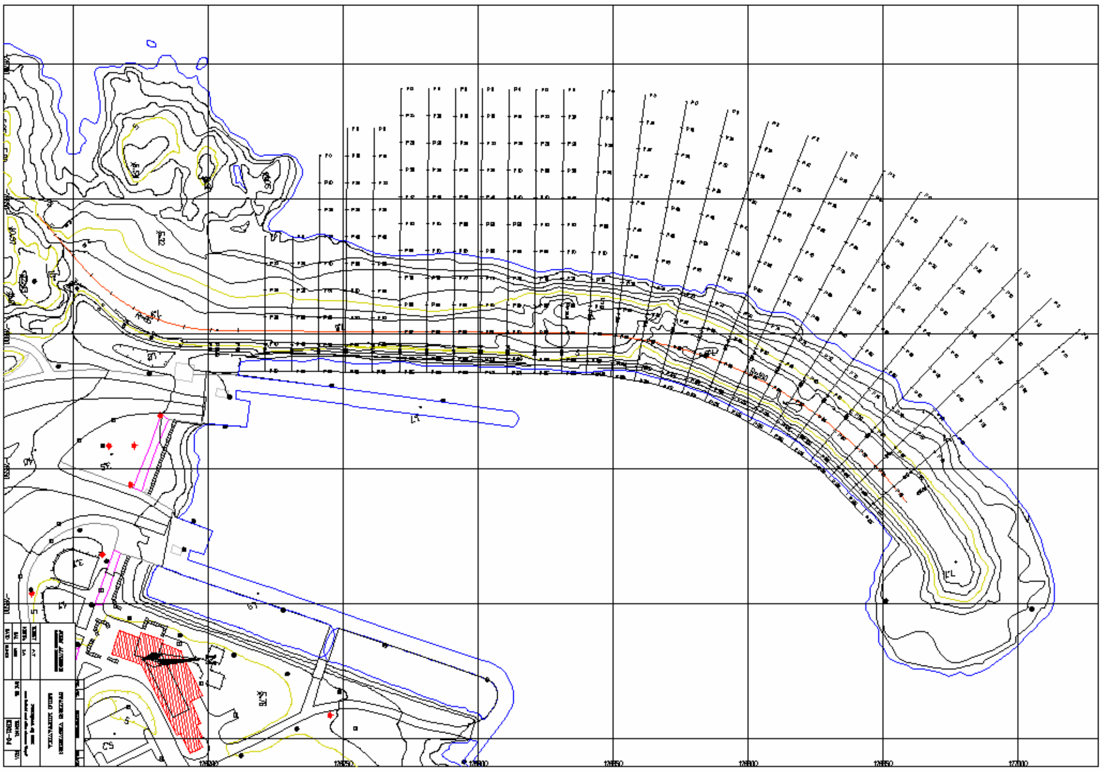

Figure 2 Plan of survey lines and elevation isolines in the 2005 survey.

The breakwater was built with a primary berm layer of rocks with W_{50} = 8.0 and 5.5 tons. Below this first layer is an inner berm consisting of smaller rocks with W_{50} = 4.0 tons. The interface between these two layers is shown with a blue line (in the berm section) in Figure 3.

The 2005 survey shows that the outer surface of the berm is presently only 0 – 2.0 m away from the blue line and the inner berm at its minimum point.

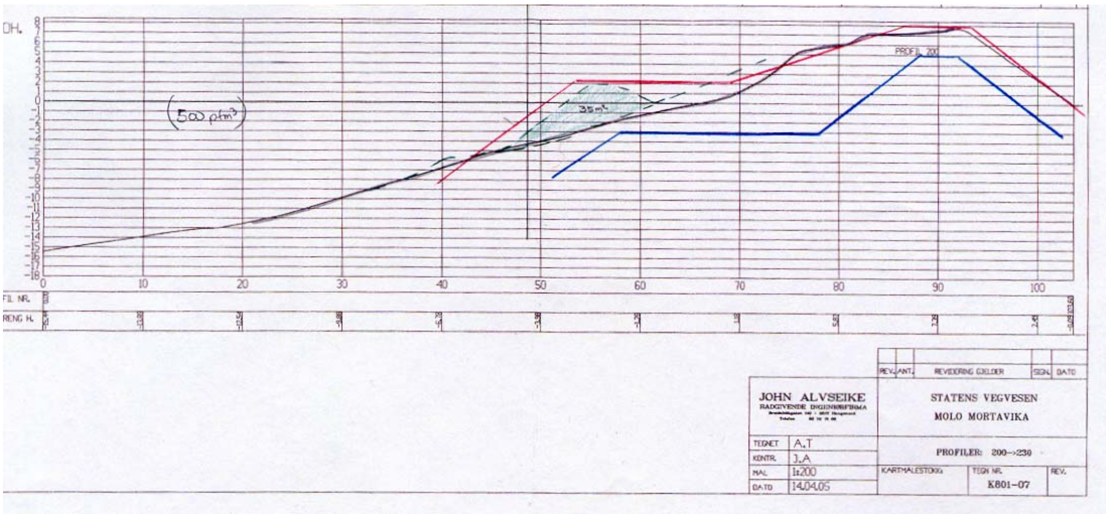

Figure 3 Result from the 2005 survey (sample). Intended profile (shown in red line), limit of primary berm layer (blue), 2005 survey (solid grey), August 2003 survey (dotted green), and volume added in 1993 (green shaded).

5.2 Comparison with theoretical data

A comparison between the 1993 and the 2005 surveys shows that the largest part of the reshaping has occurred before August 1993, i. e. during construction and sometime during the first 8 months of service after completion. Reshaping as a result of the waves during the lifetime of the breakwater will therefore in this analysis be taken as the reshaping from August 1993 through January 2005.

A theoretical expression for the retraction of the forward edge of the breakwater berm has been presented by Tørum (2). This expression gives the recession R as a function of the H_0T_0-parameter, the water depth d at the structure toe and the graduation factor $f_g=d_{85}/d_{15}$. It is known, however, that in its first form, Tørum's expression included only the H_0T_0 terms and a constant term.

The first version of the expression is:

$$R/D_{50} = 0.0000027\,(H_0T_0)^3 + 0.000009\,(H_0T_0)^2 + 0.11\,(H_0T_0) - K,$$

where the recommended value of K = 0.8 from experimental data

Menze (see also 2) expanded this expression to include the effects of water depth and graduation, and gave the following value of the term K.

$$K = K' = (-9.9f_g^2 + 23.9f_g - 10.5) - f_d$$

where

$$f_g = d_{85}/d_{15}$$
$$f_d = -0.16(d/D_{50}) + 4$$

The expression is based on experimental data from the laboratory. It does however, not include parameters to account for the cumulative effect of storms in succession. Oblique wave attack could theoretically be accounted for by applying a cosine-factor, but volumes removed at one location would necessarily have to deposit somewhere else, so that a more advanced model seems to be required.

To make a comparison, we have however computed the theoretical recession applying the highest sea state to have appeared at Mortavika since August 1993, i. e. in January 2005. The computations have been carried out with a variable K-value and a fixed K=0.8.

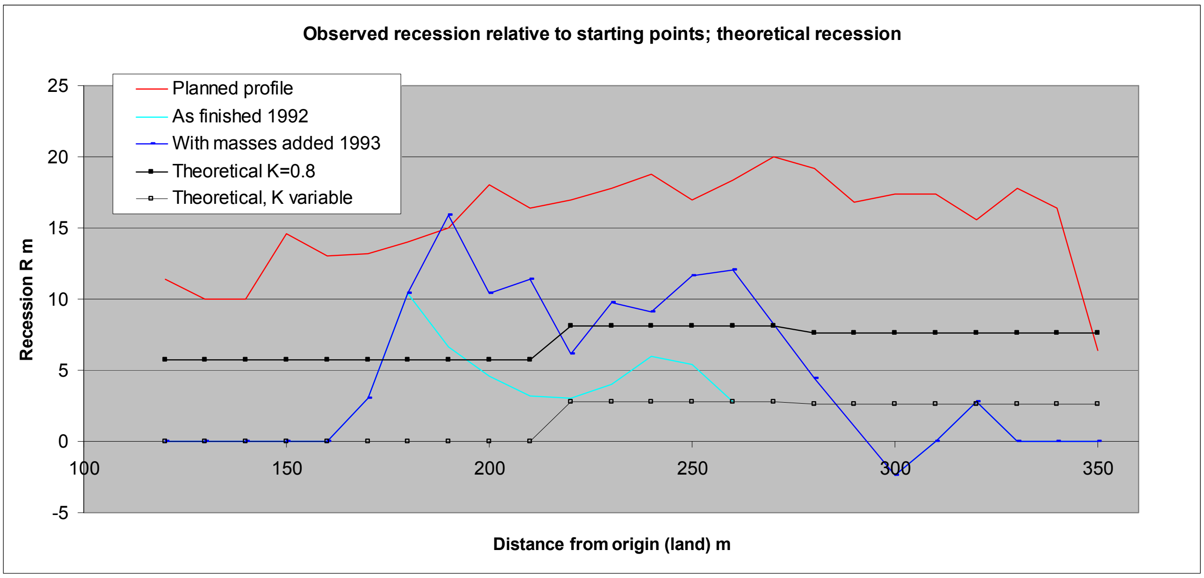

Figure 4 Observed and theoretically calculated recession. The observed recession is shown relative to different starting points, as planned (red), final profile in January 1992 (blue), and final as-built profile in August 1993 (turquoise).

It appears that the model does not reflect well the variations in recession depths along the breakwater. It is believed that this is because the model tool was developed for a berm breakwater which was closer to the statically stable type (and therefore had a berm which is higher and narrower), and because in the Mortavika case, the wave height variation along the breakwater is not very well modeled due to lack of data.

It is interesting to note that the model appears to predict recession values closer to the observed ones with a constant K-value = 0.8 than it does with the more advanced depth- and graduation-dependent term.

6. REPAIR STRATEGY

The repair strategy has not been decided at the time of writing. The proposal, however, is to repair the breakwater by filling Class I-rock (W_{50} = 8.0 tons) on the breakwater berm. For practical reasons, this must be performed by barge. By requiring a certain minimum of cover over the inner berm limit, it is proposed to place a predetermined volume of rock in a pattern which may resemble a new berm, but which will deviate from the berm shape because of the limitations of the berm and the placing equipment.

It has been calculated that a total volume of 10,000 m^3 is needed to provide sufficient protection for the breakwater to retain the strength it had before the 2005 storm season. The breakwater will continue to be a dynamically stable breakwater, and it is not deemed feasible to convert it into a dynamically stable breakwater.

In addition, it is deemed necessary to restore the breakwater crest to its former elevation of 8.0 m, and to secure loose blocks on the breakwater top and rear side.

7. REFERENCES

1. Lothe A E and Espedal T G: Design and Construction of Berm Breakwaters – The Norwegian Experience, Hornafjørdur International Coastal Symposium, Proceedings, 1994
2. ISO: Actions from Waves and Currents on Coastal Structures, ISO/TC 98/SC 3/WG 8, (Draft report, but sections cited are also published elsewhere)