MODELLING OF WAVE INTERACTION WITH SUBMERGED BREAKWATER USING MIKE 21 BW

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Abstract

Irregular waves transmission over submerged breakwater was analyzed in numerical model, MIKE 21 BW 1D.

Results from this model were compared with laboratory measurements in physical model tests (Johnson, 2005), also with empirical models (D`Argenmond, 1996, Seabrook, 1998, Buccino, 2007).

In model MIKE 21 BW 1D, wave breaking was calculated with default parameters of surface roller concept, and with modified breaker angles (initial-F_i, final-F_0).

Bottom friction (Svendsen & Jonsson, 1980) was included in calculations with bed roughness parameter calculated as $k_N = 2{,}5\ D_{n50}$.

Transmission coefficients obtained from numerical model have shown good agreement with measured data and empirical model data.

1. Introduction

Submerged breakwaters are simple constructions which attenuate wave energy in area beyound breakwaters. Appliance of such constructions can achieve multiple benefits like coast erosion reduction, cheapest coast constructions, overtopping reduction, force reduction etc. Also, the great contribution from cultural point is preservation of old historical town sights and landscapes.

Submerged breakwater design requires determining of transmission energy amount, which defines the protection level of aquatory or constructions behind breakwater. So far, several works were published with recommended empiric equations for calculation of transsmision coefficients for submerged breakwaters. Some prominent works are: Seabrook and Hall, 1998; D’Angremond et al., 1996; Buccino et al., 2007. These equations, for specific wave parameters and breakwater geometric parameters, gives values of the transmission coefficients.

With development of wave numerical models, modelling of wave transmission becomes a challenge and the criterion of the quality of the numerical model. Wave transformation at arival into shallow water has been so far rather well described by various numeric models, while the process of wave deformation from shallow into deep water, so-called ¨deshoaling¨ is still the subject of scientific efforts in numerical modelling. Deshoaling effect includes very complex non-linear interactions, i.e. transition of wave energy into lower and higher harmonics. Numerical model (MIKE21-BW, Madsen et al. 1992) has been verified in the works by Madsen et al. 1997, and by Bredmose et al. 2003. For verification, the results of laboratory tests conducted by Beji and Battjes, 1992, were used. Laboratory tests were carried out on a submerged breakwater with mild slopes (ofshore slope 1:20, shore slope 1:10). Verification was done by comparison of measured and calculated wave profiles, for a narrow band of wave parameters.

2. Objectives

This paper will demonstrate the application of MIKE21-BW-1D for calculation of the transmission coefficient over the submerged breakwater. Possibility of application would be presented by three comparations:

1) Transmission coefficients calculated by MIKE21 model will be compared with the published transmission coefficients from laboratory tests, published in the paper by Johnson et al. 2005 for irregular waves.

2) The same results (MIKE21) will be compared with the said empirical models for determining of transmission coefficients.

3) Also, comparison of transmission coefficients calculated with MIKE21 and with empirical models will be carried out, but for wider range of wave parameters than in previous two comparisons.

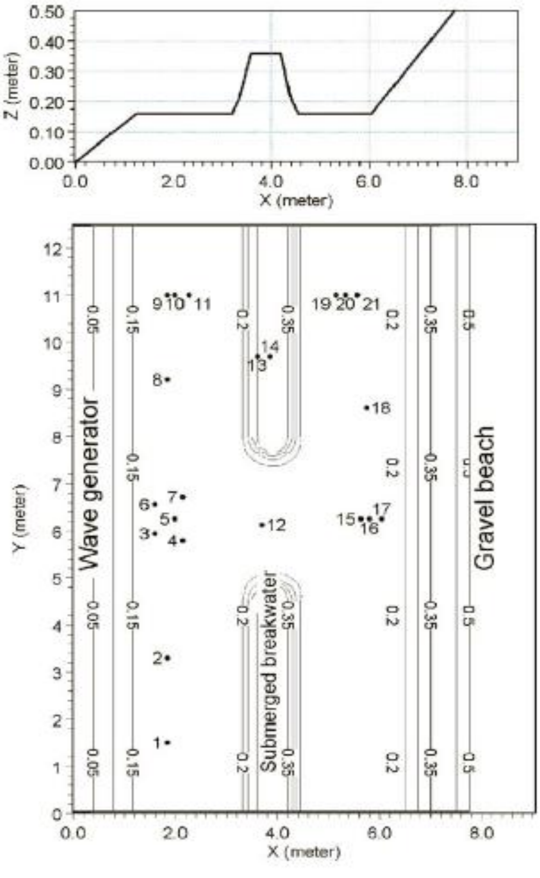

Figure 1. Cross-section and floor plan of basin with wide breakwater crest 0.6 m. Figures from 1 to 21

3. Laboratory experiment

Laboratory experiments were done in the basin 9.7x12 m in the laboratory of Aalborg University, Denmark. The investigation measured the wave setup, transmission coefficients and flow around the breakwater. Out of all investigations, this paper will use the results of measuring of transmission coefficients.

Fig. 1 shows the bathymetry used for laboratory experiments. The breakwater has a 2 m opening in the middle. Two berm widths were used, wide 0.6 m, and narrow 0.2 m

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Breakwaters were made with the core and armour layer of nominal particle size (Dn_{50}=45mm), and side slope 1:2. Behind the breakwater, the beach was made for dissipation of waves, of quarry rock (Dn_{50}=15mm), slope 1:5.

Experiments were carried out for the submerged breakwater, emerged breakwater and zero freeboard breakwater. This paper will deal only with the data referring to the submerged breakwater. Water depth on the breakwater berm is 7 cm, depth at toe is 27 cm, and depth at the wave generator is 43 cm.

Tests were carried out for regular and irregular waves. Irregular waves were generated as the JONSWAP spectrum with direction spreading of 22.7º. This paper uses only the results of transmission coefficients for irregular waves.

Transmission coefficients (Table 1.), are determined as the relation of transmitted significant wave height, H_{0t}, and incident significant wave height, H_{0i}. H_{0t} is determined as the average of measured significant wave heights in gauges 19, 20 and 21, (Figure 1). H_{0i} is determined as the average of measured significant wave heights in gauges 9, 10 and 11.

Test	H_0	T_p	d/L_p	wave type	berm	L_p/H_0	K_t-meas
33	0,12	1,97	0,04	J 3D	wide	50,03	0,52
17	0,12	1,97	0,04	J 3D	narrow	50,03	0,62
34	0,12	1,40	0,09	J 3D	wide	25,17	0,58
18	0,12	1,40	0,09	J 3D	narrow	25,17	0,69
21	0,05	1,32	0,10	J 3D	narrow	50,34	0,81
35	0,05	1,32	0,10	J 3D	wide	50,34	0,73
22	0,05	0,93	0,20	J 3D	narrow	24,99	0,76
36	0,05	0,93	0,20	J 3D	wide	24,99	0,74

Table 1. Program of laboratory experiments and measured coefficients of transmission K_t. H_0-incident significant wave height, T_p-peak period, d-water depth on the toe.

4. Numerical model MIKE21-BW

The numerical model is set up with identical conditions as the longitudinal cross section of laboratory model (Figure 2.). Numerical model was enlarged by 20 times, because calibration of parameters MIKE21-BW was made for realistic wave conditions. In other words, bathymetry, wave heights and wave lengths were enlarged by 20 times. Grid spacing used was Dx=1m, time step Dt=0.02s.The waves were generated as the Jonswap spectrum, and the period of calculation is 10 min, for achieving of stationary conditions.

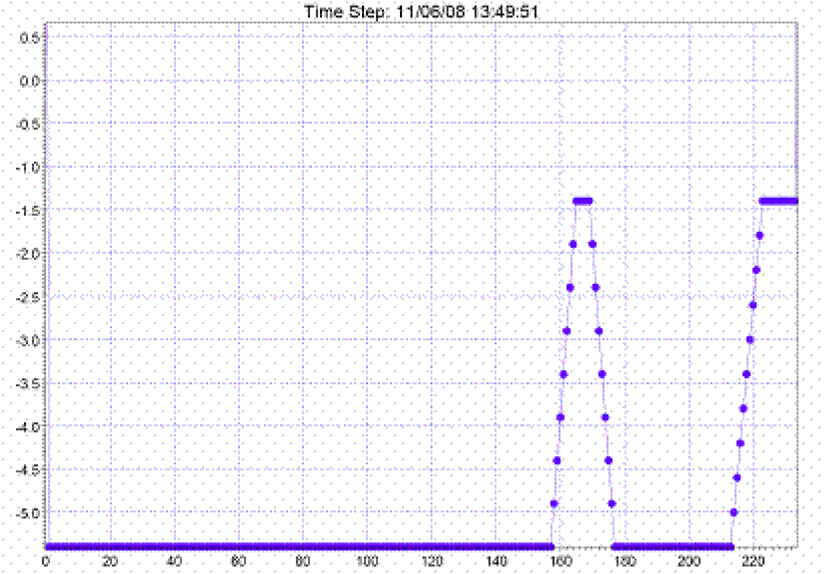

Figure 2. Bathymetry with narrow breakwater berm used for numeric model

Bed friction is defined according to the theory presented in Svendsen et al., 1980. Bed roughness parameter, k_N, for calculation of the wave friction factor is calculated as $k_N=2.5\cdot D_{n50}$. The wave friction factor is limited to the maximum value $f_{wmax}=0.8$, and the mean velocity and the velocity at bottom were calculated according to the linear wave theory. The Manning friction coefficient is determined according to the mentioned theory, and with the given parameters, for water depth equal to mean height of the breakwater, and applied as constant along the entire length of the breakwater.

Wave breaking in the MIKE21-BW model is calculated according to „roller concept“. Standard set parameters of wave breaking were used, initial breaking angle $F_b=20°$; final breaking angle $F_0=10°$, roller form factor, 1.5, roller cellerity factor, 1.3, half time, $T_p/5$). Also for comparison, the calculation was made with recommendations for submerged breakwaters according to Madsen et al., 1997, $F_b=14°$ i $F_0=7°$, others remaining the same.

Test	Hs [m]	Tp [s]	berm [m]
1	3,0	4,9	WIDE
2	3,0	4,9	NARRO
3	2,4	8,8	WIDE
4	2,4	8,8	NARRO
5	2,4	6,3	WIDE
6	2,4	6,3	NARRO
7	2,4	4,8	WIDE
8	2,4	4,8	NARRO
9	2,1	4,5	WIDE
10	2,1	4,5	NARRO
11	2,1	5,8	WIDE
12	2,1	5,8	NARRO
13	2,1	8,1	WIDE
14	2,1	8,1	NARRO
15	1,5	3,8	WIDE
16	1,5	3,8	NARRO
17	1,5	4,9	WIDE
18	1,5	4,9	NARRO
19	1,5	6,9	WIDE
20	1,5	6,9	WIDE
21	1,1	3,2	NARRO
22	1,1	3,2	WIDE
23	1,1	5,9	NARRO
24	1,1	5,9	WIDE
25	1,1	4,2	NARRO
26	1,1	4,2	WIDE
27	0,8	2,8	NARRO
28	0,8	2,8	WIDE
29	0,8	3,6	NARRO
30	0,8	3,6	WIDE
31	0,8	5,1	NARRO
32	0,8	5,1	WIDE

Tablica 2. Program proširenog ispitivanja numeričkim modelom.

The sponge layer was placed o the left side of bathymetry, and on the right end.

For comparison 3), described in Chapter 2., additional calculation was made in MIKE21 according to wide range of wave parameters in Table 2. Wave parameters in Table 2 are limited by stability of the model; i.e. at large wave heights and lengths in relation to depth of water at the breakwater, the model becomes unstable. The results of the numeric model according to Table 2 are compared with empirically obtained transmission coefficients in Chapter 6.

5. Empirical model

The empiric equations were obtained on the basis of laboratory tests of hydraulic behaviour of the breakwater, and are used to calculate average transmission coefficients for given wave parameters and geometric paramaters of the breakwater.

Seabrook and Hall, 1998:

$$K_t = 1 - \exp\left(-0.65\frac{F}{H_{si}} - 1.09\frac{H_{si}}{B}\right) + 0.047\left(\frac{BF}{L_p D_{50a}}\right) - 0.067\left(\frac{H_{si}F}{BD_{50a}}\right), \qquad (1)$$

where: F: freeboard, [m], H_{si} significant wave height, [m], B: berm, [m], L_p peak wave lenght, [m], Dn_{50} nominal diameter of armour layer, [m].

D'Angremond, 1996:

$$K_t = -0.4\frac{F}{H_{si}} + 0.64\left(\frac{B}{H_{si}}\right)^{-0.31} \times \left(1 - e^{-0.5\xi}\right), \quad B/H_i < 8, \tag{2}$$

$$K_t = -0.35\frac{F}{H_{si}} + 0.51\left(\frac{B}{H_{si}}\right)^{-0.65} \times \left(1 - e^{-0.41\xi}\right), \quad B/H_i > 12 \tag{3}$$

where: $\xi = tg\alpha/(\frac{H_{si}}{L_p})^{0.5}$-Irribaren number. For values $8 \le B/H_{si} \le 12$, the values of transmission coefficient are interpolated linearily.

Buccino, 2007:

$$K_t = \frac{1}{1.18\left(\frac{H_{si}}{F}\right)^{0.12} + 0.33\left(\frac{H_{si}}{F}\right)^{1.5}\frac{B}{\sqrt{H_{si}L_p}}} \qquad \textit{for} \qquad 2 \ge \left(\frac{F}{H_{si}}\right) \ge 0.83 \tag{4}$$

$$K_t = \left[\min(0.74;\ 0.62\cdot\xi^{0.17}) - 0.25\cdot\min\left(2.2;\ \frac{B}{\sqrt{H_{si}L_p}}\right)\right]^2 \qquad \textit{for} \qquad \left(\frac{F}{H_{si}}\right) = 0 \tag{5}$$

For values $0.83 \rangle F/H_{si} \rangle 0$, the values of transmission coefficient are linearily interpolated.

6. Results

To enable comparing of results, the following statistic parameter was used:

Mean square error (MSE*)*. It represents dispersion of data around the line of “absolute agreement”.

$$MSE = \sqrt{\frac{\sum(y - \hat{y})^2}{n}}, \tag{6}$$

y	actual value (K_t measured in laboratory),
$\hat{y}$	estimated value of y (K_t calculated by numeric or empirical model)
n	number of comparated transmission coefficients

This paper compares transmission coefficients obtained by laboratory experiments for Jonswap waves with directional dispersion (22.7º), and transmission coefficients obtained by 1D numeric model without directional dispersion. As wave breaking is the dominant process influencing dissipation and transmission of wave energy, and does not depend essentially on the incident wave angle, it is assumed that 1D numeric model will describe the transmission of wave energy well enough. Also, wave diffraction through the opening in the breakwater is neglected, as the gauging probes 19, 20 1nd 21 are deep in the shadow of the breakwater (Fig. 1).

Comparison 1): The comparison will be shown between transmission coefficients obtained by numeric model and by measuring in the laboratory (Fig. 3). Transmission coefficients on the numeric model ($K_{t\ MIKE}$) are calcualted in the identical points as those in laboratory experiment ($K_{t\ measur}$).

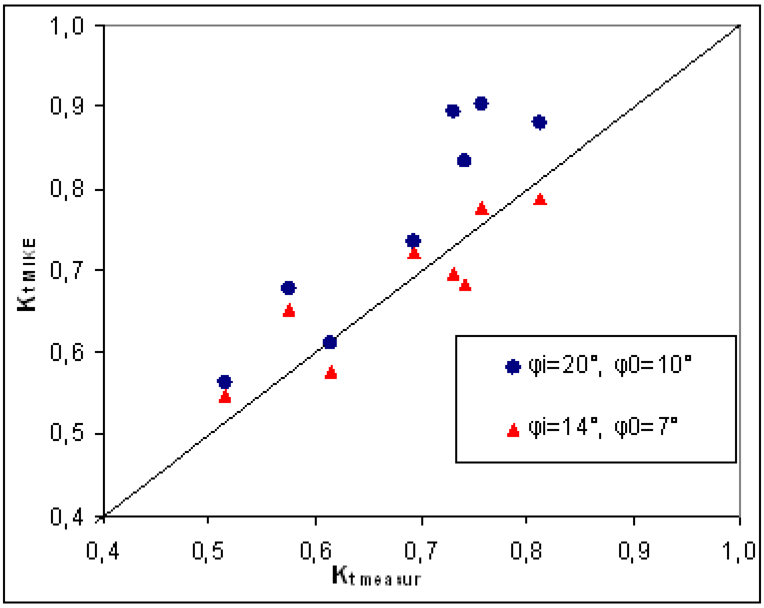

Figure 3. Comparison of transmission coefficients obtained by numeric model $K_{t\ MIKE}$, and by laboratory tests $K_{t\ measur,}$ for different initial (F_i) and final (F_0) wave breaking angles. $MSE_{(Fb=14°;F0=7°)}=0.05$; $MSE_{(Fb=20°;F0=10°)}=0.09$.

The results match better for applied breaking angles $F_b=14°$ and $F_0=7°$, as recommended in the paper by Madsen et al., 1997. Calculated mean square error is $MSE_{(Fb=14°;F0=7°)}=0.05$. For standard breaking angles ($F_b=20°$, $F_0=10°$) numeric model overestimates the transmission coefficients, and mean square deviation is $MSE_{(Fb=20°;F0=10°)}=0.09$. When smaller initial and final breaking angles are used, the waves start to break earlier than in the case of standard parameters. This increases dissipation of wave energy for all tests, and the largest influence is exerted on waves with lower wave heights. (Test 21, 35, 22 i 36). Matching of transmission coefficients is satisfactory for applied breaking angles $F_b=14°$ and $F_0=7°$.

Comparison 2): In Fig. 4, laboratory results are compared with empiric transmission coefficients. The best agreement with measurings is shown by results obtained bu the Buccini equation, ($MSE_{Buccino.}=0.06$), and the results are slightly underestimated. Transmission coefficients calculated by the Searbrook and Hall equation are also underestimated, and they have the mean square error, $MSE_{Seabrook}=0.09$. The results by d'Angremod show comparatively good agreement, except for two values (Tests 35 and 36) calculated by equation (3). Therefore the data agreement is the worst, $MSE_{d'Angrem}=0.1$.

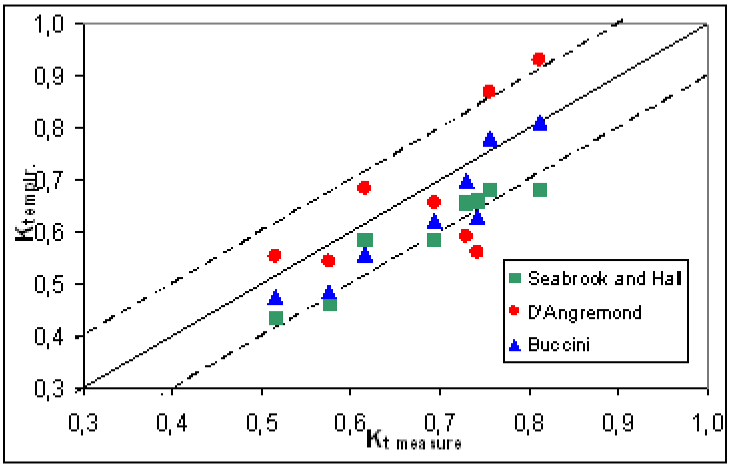

Figure 4. Comparison of transmission coefficients obtained by empiric equations, $K_{t\ empiric.}$, with those obtained by laboratory tests, $K_{t\ measur.}$

Comparison 3): Fig. 5. presents the comparison between transmission coefficients obtained by numeric model and by empirical equations for wave parameters given in Table 2. Numeric model was set up as described in Chapter 4. Due to reflection from the breakwater, incidental significant wave height, H_{is}, is defined at sufficient distance from the breakwater to avoid influence of reflection. The averaging zone from point 80 to 100 (Fig. 2.) was defined where there is no influence of reflection even at longest waves. In this section, the values of relevant wave heights were averaged. H_{st} was obtained by averaging on the section from point 180 to 200.

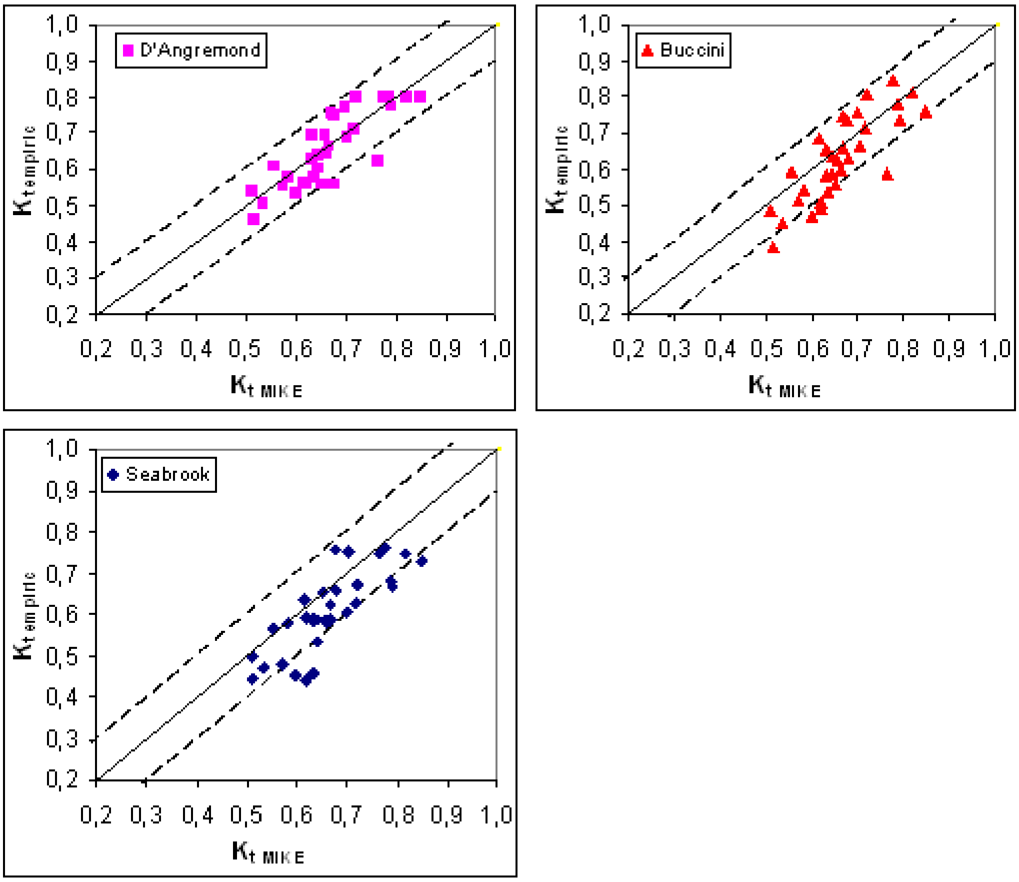

Figure 5. Comparison of transmission coefficients obtained by empirical equations and by numeric model. MSE$_{d'Angrem}$=0.06, MSE$_{Seabrook}$=0.08, MSE$_{Buccino.}$=0.08; MSE was calculated by introducing into equation (6): y-result of empirical model ($K_{t\ empiric.}$), $\hat{y}$ -result of numeric model ($K_{t\ MIKE}$).

The best agreement of the numerical model is that for d'Angremond empirical equation, while according to the other two equations, Seabrook and Buccino, the numeric model slightly underestimates the results.

7. Conclusion

In this paper, calibration of numerical model MIKE21-1D was conducted using laboratory results. Calibration was conducted by fitting of breaker angles (initial-F_i, final-F_0). Numerical results have shown good agreement with laboratory results for breaking angles F_b=14° and F_0=7°.

Also, comparison between laboratory results and empirical formulas (d'Angremond, Seabrook and Buccino). were made and agreement was satisfactory.

Validation of numerical model was conducted with previously defined empirical formulas. Results indicate that the greater part of numerical transmission coefficients falls inside limits defined by +/-0.1 of average values of transmission coefficients according to different authors.

Based on everything mentioned above, it could be concluded that appliance of MIKE21 for calculation of waves over the submerged breakwater has a limited level of accuracy +/- 0.15 in relation to average transmission coefficients obtained by empirical equations.

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