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# Influence of Wave Parameters on Reshaping of Statically Stable Berm Breakwater in Shallow Water

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# INFLUENCE OF WAVE PARAMETERS ON RESHAPING OF STATICALLY STABLE BERM BREAKWATER IN SHALLOW WATER

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***Abstract****: This paper presents the results of laboratory investigation on the statically stable reshaped berm breakwater in shallow water and intermediate wave action. A new model configuration has been proposed with five layers of armor stones in the primary layer at the berm portion, and below the berm portion, and three layers above the berm portion. Armor layer thickness has been increased to account for initial reshaping. As equivalent surf similarity parameter increases and wave steepness decreases, both the profile parameters, the recession of the berm and eroded area of the berm decreases. The wave period has large influence on the recession of berm width and eroded area of the berm and greater the stability of the structure lesser will be the influence of wave period.*

***Keywords****: berm breakwater; recession of berm; eroded area of berm; profile parameter.*

## INTRODUCTION

Due to ever increasing dimensions of the breakwaters which are required to be constructed in deeper waters under more hostile environmental conditions, the requirement of the stable weight of protective armor unit also becomes large. This has necessitated designers and researchers to look into the new concepts of design to replace the traditional approach used in the past. The concept of “Berm Breakwater” is a step forward in this regard. The basic principle involved in the design of berm breakwater is provision of a wide berm at or around the water level with smaller size stones in the armor which are allowed to move till an equilibrium slope is achieved. The berm approach is based on the precept that the thicker the armor layer, smaller the stones needed be to protect against wave action. Due to high level energy dissipation in the berm the stone weight can be significantly reduced compared to the stone weight used for conventional rubble mound breakwaters.

Berm breakwaters have been adopted at several locations as an economic solution when large cover blocks of natural stones are not available (PIANC MarCom W.G. 2003, Baird and Hall 1984). The performance of the breakwater when subjected to waves exceeding the design condition is significantly better than the performance of a conventional structure exposed to similar condition (Baird and Hall 1984, Torum et al. 1999, Subba Rao et al. 2006, 2007). Hall

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and Kao (1991), Van der Meer (1992), Torum et al. (1999, 2003) performed basic tests on berm breakwaters.

This paper presents the results of laboratory investigation on statically stable reshaped berm breakwater in shallow water and intermediate wave action. In order to allow initial reshaping, a new model configuration has been proposed with five layers of armor stones in the primary layer at the berm portion, and below the berm portion, and three layers above the berm portion. The conventional rubble-mound breakwaters are statically stable structures characterized by the design parameter 'damage' whereas the berm breakwaters fall into the category of dynamically stable structures where profile development is accepted. Hence, the dynamic stability of the berm breakwater is characterized by the design parameter 'profile'.

## DETAILS OF EXPERIMENTAL WORK

The Fig.1 shows the sectional elevation of the breakwater model studied. Weight of armor stones used, $W_{50}$ = 52gm is about 30% lesser in weight than what is required if calculated by Hudson equation (CEM 2006) for a design wave height of 0.1m. The armor layer thickness has been calculated using layer coefficient as explained in the CEM (2006). The same number of layers are provided in the secondary layers with armor stone weight $W_{50}$=5.2gm. The minimum crest width adopted is so as to accommodate three stones, and a crest width of 0.15m is provided. A horizontal berm is provided at a constant depth of 0.32m above the seabed. The seaward slope above the berm and below the berm was kept same, 1.5:1.

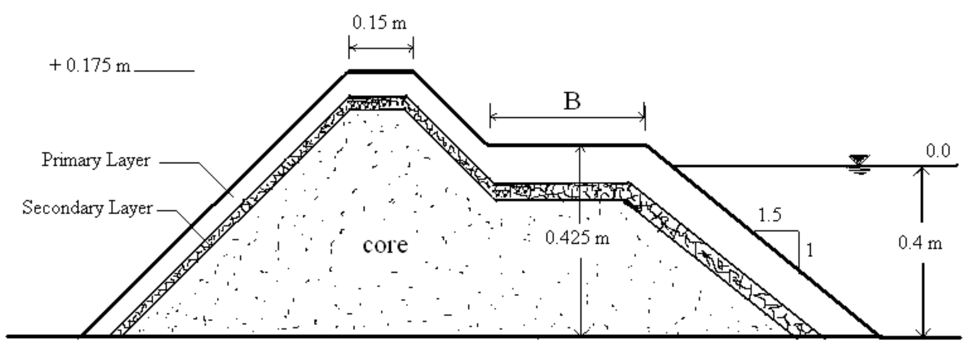


**Fig. 1 Cross-section of berm breakwater models studied**

### Gradation of armor units

The size distribution of the rubble material was determined in terms of weight. Armor stones used in the present test were taken from a local quarry. The aggregates were carefully hand picked so that they are roughly cubical in shape. The weight of the stones used for primary layer ranged from 0.75 $W_{50}$ to 1.25$W_{50}$ with a mean weight of $W_{50}$ = 52gm. The weight of stones used for secondary layer ranged from 0.7 times of ($W_{50}$/10) to 1.3 times ($W_{50}$/10) for the present investigation. Fig.2 shows the gradation curve for armor units used in the present test and the ratio ($D_{85}/D_{15}$) = 1.12 ($D_{50} = (W_{50}/\gamma_s)^{1/3}$ where $\gamma_s$ = unit weight of armor stone.

**Wave Flume**

The wave flume is 50m long, 0.71m wide, 1.1m deep and has a 42m long smooth concrete bed. Fig.3 shows the sketch of the wave flume used in the present work. A bottom-hinged flap generates waves at one end of the deep chamber which is 6.3m long, 1.5m wide and 1.4m deep. The flap is controlled by an induction motor of 11kW and 1450 rpm. This motor is regulated by an inverter drive (0-50Hz) rotating with a speed range of 0- 155 rpm. Regular waves of height 0.02m to 0.24m, and periods 0.8s to 4s can be generated with this facility.

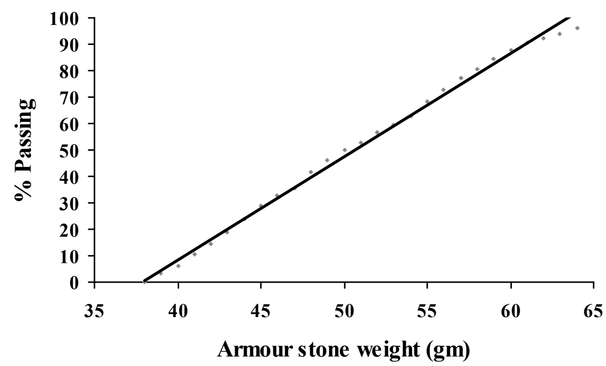


**Fig. 2 Gradation curve for armor units, $W_{50}$ = 52gm, $D_{85}/D_{15}$ = 1.12**

**Test Procedure**

Table1 and Table 2 show the details of the range of experimental variables. The model was constructed at a distance of 33m from the generator flap. The incident wave height was measured in front of the main breakwater. Before starting the experiment the initial seaward profile of the breakwater was recorded using a surface profiler system. The surface along the seaward side of the breakwater was measured at every 0.1m intervals. At every point, sounding was taken to an accuracy of 1mm. The tests were carried out in bursts of maximum of five waves at a time, to avoid reflection and re-reflection from the generator blade. The next burst was started after obtaining calm condition in the flume. Profiling of the damaged section was carried out initially after five hundred waves and thereafter for every one thousand waves. The model was rearranged to original configuration after every completed run and the experiment was repeated for other wave parameters.

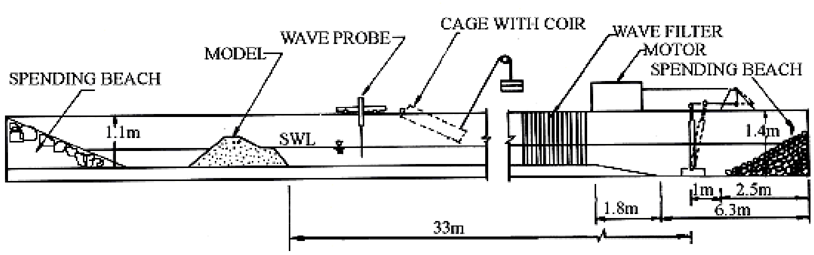


**Fig. 3 Wave Flume - Elevation**

**Stability criteria**

Profiling of the damaged section was carried out. The damage to the breakwater was quantified by measuring the eroded width of the berm (Rec) and eroded area (Ae) of the berm. In the present analysis a stable berm breakwater is defined when the reshaping process is completely stopped and recession of the berm (eroded berm width, Rec) is less than the initial berm width provided (Rec./B)<1 for the storm condition of 5000 waves. The term 'Rec' is the recession of the berm and 'B' is the initial berm width provided (Ref. Fig. 4).

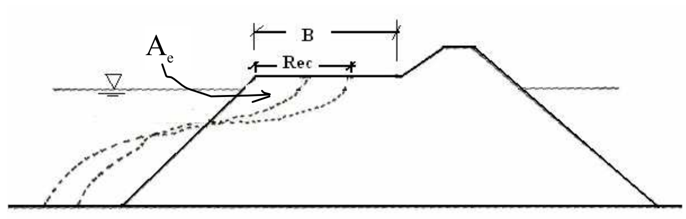


**Fig. 4 Recession, Rec, of berm breakwater**

**Table 1. Range of experimental non-dimensional variables for reshaped breakwater**

| Sl.No. | Non-dimensional variables | Expression | Range |
|---|---|---|---|
| 1 | Stability number (Wave height parameter) | $H/\Delta D_{50}$ | 2.15 – 3.49 |
| 2 | Wave steepness (Wave period parameter) | $s = H_o/L_o$ | 0.009 – 0.043 |
| 3 | Surf similarity parameter | $\xi_{om}=\tan\alpha/\sqrt{s}$ | 3.2 – 7 |
| 4 | Relative berm width | $B/L_o$ | 0.028 – 0.113 |
| 5 | Relative water depth | $d/L_o$ | 0.038 – 0.1 |
| 6 | Relative berm location | $h_B/d$ | 1.0625 |
| 7 | Wave height period parameter | $H_oT_o$ | 67-174 |

**Table 2. Range of wave and structural parameters for the model**

| Sl No. | Variable | Expre--ssion | Range |
|---|---|---|---|
| 1 | Wave height | H | 0.10, 0.12, 0.14,0.16m |
| 2 | Wave period | T | 1.6, 2.0, & 2.6 s. |
| 3 | Berm width | B | 0.3m,& 0.45m |
| 4 | Storm duration | N | 5000 waves |
| 5 | Angle of wave attack | θ | 900 |
| 6 | Water depth | D | 0.4m (constant) |
| 7 | Armor stone weight | $W_{50}$ | 52 gm |
| 8 | Armor stone Diameter | $D_{n50}$ | 0.0267m |
| 9 | Gradation factor | $D_{85}/D_{15}$ | 1.12 |
| 10 | Primary armor layer thickness : at berm portion and below the berm; seaward profile above the berm | | 0.153m; 0.092m |

| | | | |
|---|---|---|---|
| 11 | Secondary armor layer thickness :<br>at berm portion and below the berm<br>seaward profile above the berm | | 0.07m<br>0.042m |
| 12 | Shape of the armor stone | - | Angular, rounded & flat |
| 13 | Crest height | - | 0.15m |
| 14 | Slope | | 1:1.5 |
| 15 | Specific gravity of armor stone | $\gamma_s$ | 2.74 |

## RESULTS AND DISCUSSIONS

### Influence of $\xi_{eq}$ on the recession and eroded area of the berm

Figs. 5 and 6 show the variation in the recession of the berm as the equivalent surf similarity parameter ($\xi_{eq}$) changes from 1.67 to 3.66 for B = 0.3 m (B/d = 0.75) and B = 0.45 m (B/d = 1.125) respectively for the different stability numbers, where $N_s$ = stability number = $H/\Delta D_{50}$, $\Delta = (\gamma_s/\gamma_w - 1)$. Each model was subjected to, wave heights of 0.1m, 0.12m, 0.14m, 0.16m, and each wave height with periods 1.6s, 2.0s, and 2.6s. Water depth (d) in front of the model was kept constant for all the models tested. The Figs. 5 and 6 shows, for the same wave height, the recession values vary as wave period changes. The models tested with berm width of 0.30 m, as the $\xi_{eq}$ changed from 2 to 3.66, the recession value decreased from 11 to 3, and 15 to 6 for the stability numbers around 2.2 and 2.6 respectively. For the stability number 3.0, the recession was beyond the berm width provided for all the three wave periods tested. The models tested with berm width of 0.45 m, as the $\xi_{eq}$ changed from 1.67 to 2.96, the recession value decreased from 8 to 6, 12 to 6, 17 to 10 and 20 to 16, for the stability numbers around 2.2, 2.6, 3.01, and 3.5 respectively.

Table 3 shows the deep water wave steepness, deep water surf similarity parameter ($\xi_o = \tan\alpha /(H_o/L_o)^{1/2}$ and equivalent surf similarity parameter ($\xi_{eq}$) calculated using the method explained in CEM 2006 ($\xi_{eq} \approx \tan\alpha_{eq} / (H_o/L_o)^{1/2}$), for different wave parameters studied in the present work. The models tested with shorter wave period $H_o/L_o$ = 0.028 – 0.043, corresponding value of $\xi_o$ is 3.2 to 4 and $\xi_{eq}$ is 1.67 to 2.1, have shown greater damage when compared to the other wave periods studied. This may be due to the nature of wave breaking, which is of collapsing type for the shorter wave periods tested. From this it can be concluded that as the equivalent surf similarity parameter increases from 1.67 to 3.67 and the wave steepness decreases the recession value decreases.

Fig. 7 and Fig. 8 show the variation in the eroded area as the equivalent surf similarity parameter changes from 1.67 to 3.66 for B = 0.3 m and B = 0.45 m respectively. The eroded area was found decreasing as the $\xi_{eq}$ increases from 1.67 to 3.66. For lower wave heights studied ($N_s$ = 2.2), the model shows less variation in the eroded area as $\xi_{eq}$ vary. It can be concluded that as equivalent surf similarity parameter increases and wave steepness decreases the eroded area of the berm decreases. From the above discussion it can be concluded that wave period has large influence on the recession of berm width and eroded area of the berm.

**Table 3. Equivalent surf similarity parameter and $H_oT_o$ parameter for models tested with different berm width**

| $H_o/L_o$ | $\xi_o$ | $\xi_{eq}$ | $H_oT_o$ | $H_o/L_o$ | $\xi_o$ | $\xi_{eq}$ | $H_oT_o$ |
|---|---|---|---|---|---|---|---|
| B=0.3m | | | | B=0.45m | | | |
| 0.038 | 3.426 | 2.026 | 93 | 0.043 | 3.216 | 1.678 | 106 |
| 0.032 | 3.699 | 2.060 | 80 | 0.038 | 3.426 | 1.687 | 93 |
| 0.027 | 4.028 | 2.093 | 67 | 0.034 | 3.639 | 1.693 | 83 |
| 0.023 | 4.398 | 2.601 | 116 | 0.028 | 4.009 | 1.701 | 68 |
| 0.020 | 4.768 | 2.646 | 99 | 0.026 | 4.103 | 2.153 | 134 |
| 0.017 | 5.146 | 2.685 | 85 | 0.023 | 4.398 | 2.166 | 116 |
| 0.012 | 5.999 | 3.538 | 150 | 0.020 | 4.729 | 2.175 | 101 |
| 0.011 | 6.480 | 3.597 | 129 | 0.017 | 5.171 | 2.185 | 84 |
| 0.009 | 7.099 | 3.658 | 107 | 0.014 | 5.577 | 2.926 | 174 |
| | | | | 0.013 | 5.957 | 2.943 | 152 |
| | | | | 0.011 | 6.453 | 2.956 | 130 |
| | | | | 0.009 | 6.927 | 2.967 | 113 |

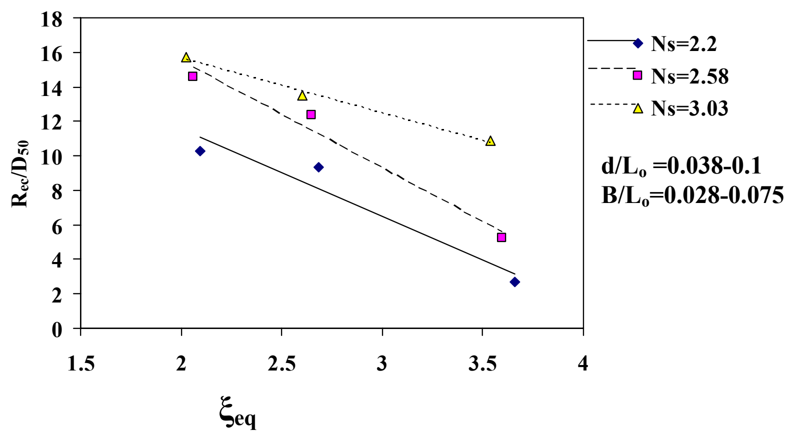


**Fig. 5 Influence of equivalent surf similarity parameter on recession of the berm, B = 0.3 m (B/d = 0.75).**

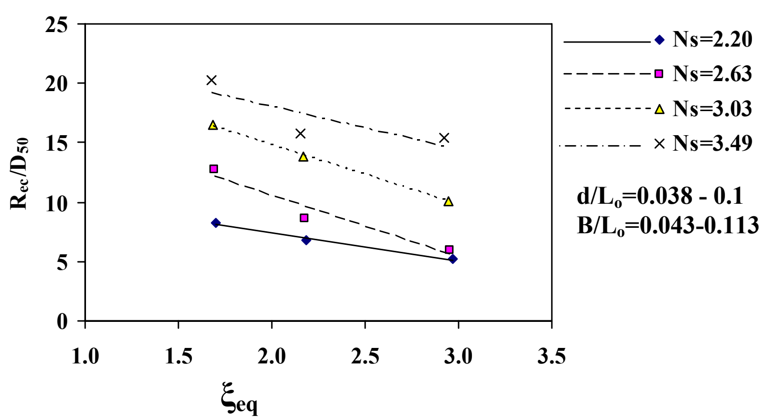


**Fig. 6 Influence of equivalent surf similarity parameter on recession of the berm, B = 0.45 m (B/d = 1.125).**

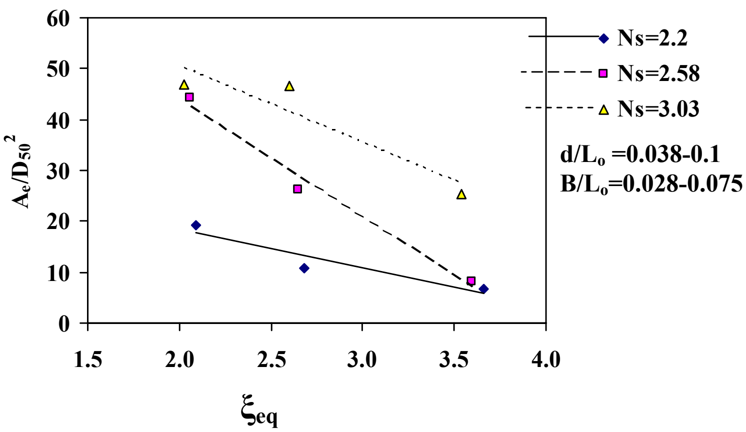


**Fig. 7 Influence of equivalent surf similarity parameter on eroded area of the berm, B = 0.3 m (B/d = 0.75).**

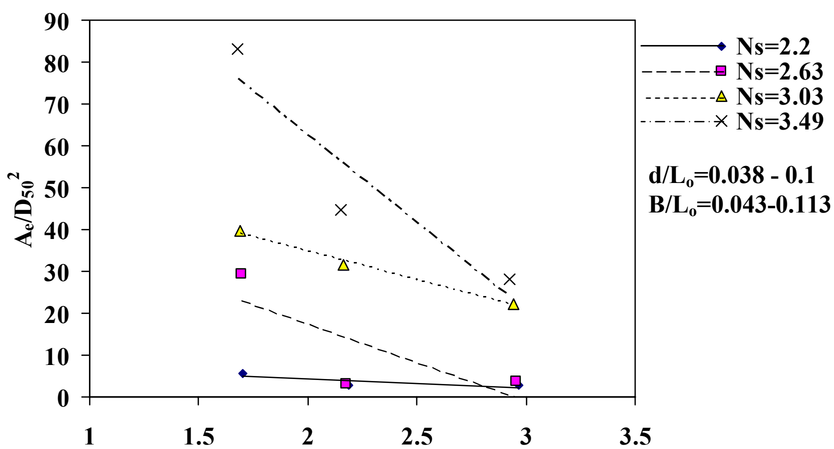


**Fig. 8 Influence of equivalent surf similarity parameter on eroded area of the berm, B = 0.45 m (B/d = 1.125).**

### Comparison of experimental $R_{ec}/D_{50}$ data with equation by Torum (1999)

Fig 9 shows the comparison of $R_{ec}/D_{50}$ values of the present experimental results and those calculated by using the equation (Eq.1) given by Torum (1999).

$$R_{ec}/D_{n50} = 0.0000027(H_oT_o)^3 + 0.000009(H_oT_o)^2 + 0.11(H_oT_o) - 0.8 \qquad (Eq.1)$$

Parameter $H_oT_o$ in the figure indicates the dimensionless wave height-wave period parameter. The analysis of data shows that, for B = 0.45 m (B/d = 1.125), for the longer wave period studied, $d/L_o$ = 0.038, and parameter $H_oT_o$ = 113 – 174, the experimental $R_{ec}/D_{50}$ values were 0.35 to 0.5 times the values obtained from the equation. For the wave period, $d/L_o$ = 0.064, and parameter $H_oT_o$ = 85 - 134, the experimental values were 0.7 to 0.9 times the values obtained from the equation. For the shorter wave period studied, $d/L_o$ = 0.1, and $H_oT_o$ = 68 – 93, the experimental values were 1.2 to 1.4 times the values obtained from the equation.

Torum (1999) found a significant scatter in the test results. The scatter of the dimensionless recession, $R_{ec}/D_{50}$, around a mean value seemed to be independent of $H_oT_o$. The coefficient of variation, $\sigma_{(Rec/D50)}$ / $(R_{ec}/D_{50})$, was 0.337, where $\sigma_{(Rec/D50)}$ is the standard deviation of dimensionless recession. The experimental recession values lie within the standard deviation mentioned above only for the models tested with shorter wave periods, $d/L_o$ = 0.064 to 0.1, (T = 2.0 s and 1.6 s). But for the longer wave period, $d/L_o$ = 0.038 (T = 2.6 s), the experimental values lie far from the values given by the equation. This may be due to the formation of shallow water condition for the longer wave period tested.

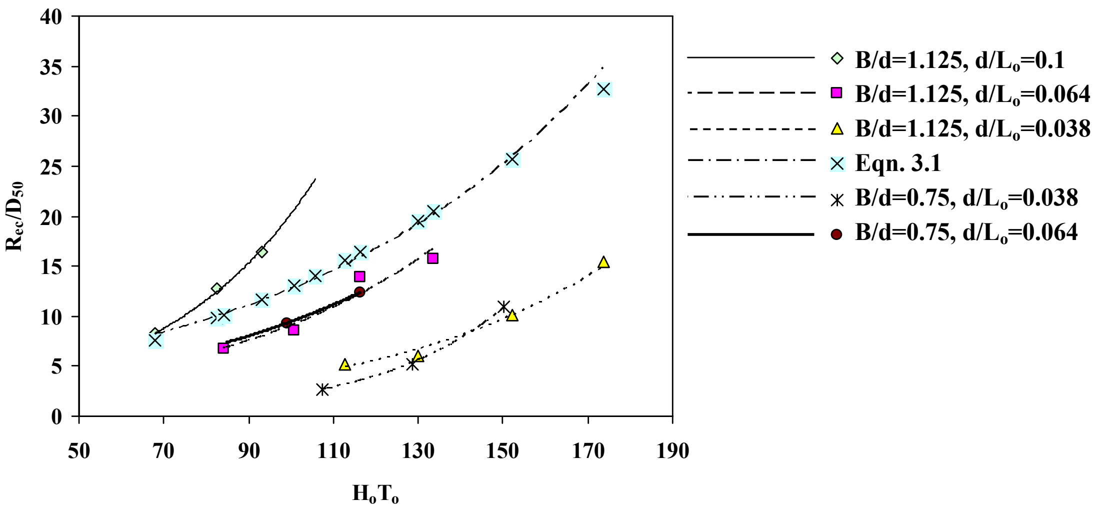


**Fig. 9 Comparison of $R_{ec}/D_{50}$ values of the present experimental work with Equation by Torum (1998)**

From the above discussion it can be concluded that the dimensionless recession value of the present experimental data fit the equation developed by Torum (1998) with coefficient of variation $\sigma_{(Rec/D50)}/(R_{ec}/D_{50})$, of 0.337 (Torum et al. 2003), for the wave periods, $H_o/L_o$ = 0.016 – 0.043, in the model. The models tested with longer wave period, $H_o/L_o$ = 0.009 – 0.014 ($d/L_o$= 0.038 - 0.10), show far less recession values than that obtained by the equation.

**Variation of wave runup with wave steepness for different berm width**

The variation in runup ($R_u/H_o$) with steepness ($H_o/L_o$) for the models tested with berm widths 0.3 m, and 0.45 m are shown in Fig. 10, where $H_o$ and $L_o$ indicate deep water wave height and wave length. From the figure it was observed that increase in berm width from 0.3 m to 0.45 m, lead to slight decrease in runup values. In the range of wave steepness studied, $H_o/L_o$ = 0.009 – 0.043, it was found that the relative runup, $R_u/H_o$ vary from 0.9 to 1.2. The trend line drawn for B = 0.3 m and B = 0.45 m, indicate that wider the berm width lesser will be the influence of wave steepness on the runup. The figure shows, the trend line corresponding to B = 0.45 m is almost horizontal. This indicates that in shallow and intermediate water depth ($d/L_o$= 0.038 - 0.10), the B/d ratio influence the runup values.

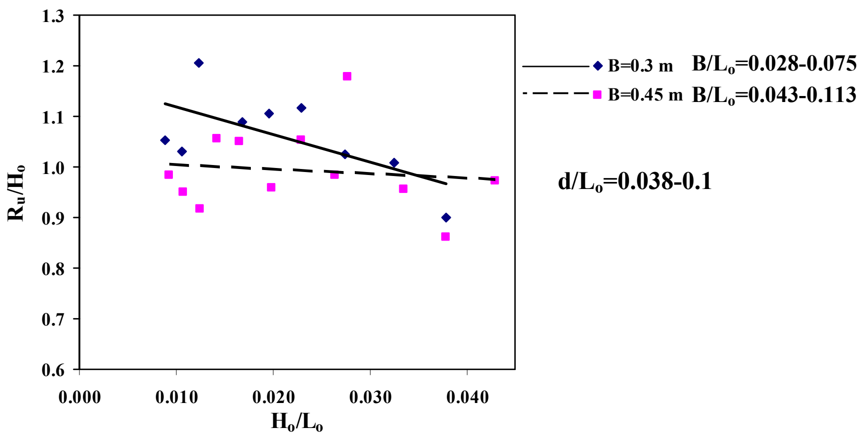


**Fig. 10 Variation of wave runup with wave steepness for different berm**

## CONCLUSIONS

Based on the present investigation, the following conclusions are drawn.

1. As the equivalent surf similarity parameter increases from 1.67 to 3.67 and as the wave steepness decreases the recession value decreases.
2. As equivalent surf similarity parameter increases and wave steepness decreases the eroded area of the berm decreases. The wave period has large influence on the recession of berm width and eroded area of the berm and greater the stability of the structure lesser will be the influence of wave period.
3. The dimensionless recession value of the present experimental data fit the equation developed by Torum 1999, with coefficient of variation $\sigma_{(Rec/D50)}/(R_{ec}/D_{50})$, of 0.337 for the wave periods, $H_o/L_o$ = 0.016 – 0.043, in the model. The models tested with longer wave period, $H_o/L_o$ = 0.009 – 0.014 ($d/L_o$= 0.038 - 0.10), show far less recession values than that obtained by the equation.
4. In the range of wave steepness studied, $H_o/L_o$ = 0.009 – 0.043, it was found that the relative runup, $R_u/H_o$ vary from 0.9 to 1.2. In shallow and intermediate water depth ($d/L_o$= 0.038 - 0.10), the B/d ratio influence the runup values.

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