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Author(s): E. Irtem, E. Seyfioglu and S. Kabdasli

Source: *Journal of Coastal Research*, Special Issue 64: PROCEEDINGS OF THE 11th INTERNATIONAL COASTAL SYMPOSIUM ICS2011 (2011), pp. 516-520

Published by: Coastal Education & Research Foundation, Inc.

Stable URL: https://www.jstor.org/stable/10.2307/26482226

Journal of Coastal Research	SI 64	516 - 520	ICS2011 (Proceedings)	Poland	ISSN 0749-0208

Experimental Investigation on the Effects of Submerged Breakwaters on Tsunami Run-up Height

E. Irtem†, E. Seyfioglu† and S.Kabdasli‡

†Department of Civil
Engineering,Balıkesir
University, 10136
Balıkesir,Turkey
mirtem@balikesir.edu.tr
ezgiseyfioglu@gmail.com

‡ Department of Civil
Engineering, Istanbul
Technical University,
Istanbul,Turkey
kabdaslis@itu.edu.tr

ABSTRACT

Irtem,E., Seyfioglu,E. and Kabdaslı,S., 2011. Experimental Investigation on the Effects of Submerged Breakwaters on Tsunami Run-up Height. Journal of Coastal Research, SI 64 (Proceedings of the 11th International Coastal Symposium), 516 - 520. Szczecin, Poland, ISSN 0749-0208

Tsunamis are more effective in the run-up area at the shoreline. It was developed various measures to reduce tsunami damage. One of the tsunami protection is submerged breakwaters. In this study, it was investigated the effect of submerged breakwaters on tsunami run-up height as experimentally. Experiments were carried out in the glass-side wall wave flume of 22.5 m. length, 1 m. width, and 0.50 m depth at the Hydraulic Laboratory Istanbul Technical University. In order to determine the effect of submerged breakwaters on tsunami run-up height with various cases were used. Experiments were carried out for permeable and impermeable surfaces. Submerged breahwater's run-up height reduction conditions and percentages in comparison with the case without breakwater was given. It is shown that the effects of submerged breakwaters on tsunami run-up depend on submerged breakwater geometry. It has been obtained that submerged breakwaters will be an effective tsunami protection measure if it will save its structural stability.

ADDITIONAL INDEX WORDS: *tsunami protection works, hard structure, impermeable and permeable breakwater*

INTRODUCTION

Coastal regions are under the threat of coastal disasters created by various factors. One of the most devastating coastal disasters are the tsunamis created by mass water movements resulting from ground movements triggered by earthquakes, submarine landslides and collapses. Risks posed by the tsunamis, which are in fact a type of long waves, may reach very high proportions by the increase in the socio-economic activity in the coastal regions, and the earthquake that affected 11 countries and left 250.000 people dead on December 24, 2004 is striking example of the high risk posed. In that earthquake, the fact that the number of lives claimed by the tsunami was higher than the number of deaths as a direct result of the earthquake has resulted in a sharp understanding of the high risk of tsunamis among the public.

With the change of nearshore bathymetry these waves progress towards inland and causes large damage and it has caused great damage. Tsunamis are more effective in the run-up area at the shoreline. Therefore, it was developed various measures to reduce tsunami damage. Tsunami protection works can be categorized as hard structures likes tsunami breakwaters, sea walls etc. and natural barriers including coastal forest etc (Irtem *et al.*, 2009).

Although the general characteristics of hard structures are the same, different criteria of sizing are used against tsunamis, and research on these criteria are currently in progress. As is known, classical coastal structures can be very effective against steep waves like those created by storms, but may remain ineffective against long waves with their sizes shaped by classical sizing criteria. Of these structures, concrete sea walls and breakwaters are the most commonly used for protection against the effects of tsunami. However, concrete sea walls and breakwaters may decrease water circulation thus causing eutrophication and various environmental problems.

Another way of reducing waves is by submerged structures (breakwaters, artificial reefs, etc.). Submerged structures have a crest level lower than the Still Water Level. The advantages of submerged breakwaters as compared to subaerial breakwaters include their low cost, aesthetics, and effectiveness in triggering breaking of high waves without eliminating the landward flow of water, which may be important for water quality considerations (Kobayashi and Wurjanto, 1989). The effectiveness of a submerged structure depends on the ratio B/L and R/H, where B is crest width, L is wave length, R is the distance between water level and breakwater crest and H is wave height. Decreasing these rations will increase the transmission and thus decrease the effectiveness of the structure. Therefore, it is expected that for tsunami with wave lengths in the order of kilometres, the effectiveness of submerged structures is limited. The ratio B/L is almost zero, which corresponds with a high transmission (Van Der Plas, 2007).

Many experimental and theoretical studies have investigated the wave transformation over the submerged structures. Kobayashi and Wurjanto (1989) presented to examine the hydrodynamic processes involved in monochromatic wave reflection, breaking, and transmission over a submerged impermeable breakwater. The numerical model is shown to be in agreement with a set of data on wave reflection and transmission coefficients. Huang, Dong, (2001) provided a systematic study on the viscous interaction between a solitary wave and submerged rectangular dike. Their numerical results showed that even though the induced local shear stress on the top surface of the dike is large at some particular locations, the resultant pressure drag is much larger than the friction drag. Huang *et.al.* (2003) solved the Navier-Stokes equations and Navier-Stokes type model equations for porous flows numerically to simulate the interaction between a solitary wave and a submerged porous breakwater. The accuracy of the numerical model was verified by comparing the numerical results with the experimental data. It is concluded that if the breakwater width is small compared with the effective wave length, the structure permeability has no apparent effect on wave transformation. For wide porous breakwaters, if the structure porosity is small, the increase in the porosity results in the reduction of the transmission coefficient; otherwise the transmission coefficient increases with porosity. Hur *et al.* (2003) investigated the breaking wave height of multi- directional random waves passing over an impermeable submerged breakwater as experimentally. Comparisons have also been made with the results of regular waves. They presented empirical formulae to estimate the breaking limit of multi-directional random waves based on the experimental records. Rambau *et al.* (2005) presented the results of numerical model study on the transmission characteristics of a submerged breakwater. They determined the effect of depth of submergence, crest width, initial wave conditions and material proporties on the transmission characteristics of the submerged breakwaters. Tsai *et al.* (2006) investigated the wave transformation over a submerged permeable breakwater on a porous slope seabed. They derived the time-depend mild-slope equation for waves propagating over two layers of porous medium. The validity of the present model is verified based on the comparisons with the previous experiments. Chang, Liou (2007) determined the reflection and transmission of long waves from a trapezoidal breakwaters and a series of trapezoidal breakwaters, using the matching method. Calabrese *et al.* (2008) presented a new method for calculating the 2D wave setup behind a submerged breakwater. They examines such a leading hydraulic parameter under the simplified hypothesis of 2D motion and presents a prediction model that has been validated by a wide ensemble of experimental data.

In this study, it was investigated the effect of submerged breakwaters on tsunami run-up height as experimentally. Tsunami run-up heights were measured for different submergence rate location and breakwater geometry. It is shown that the effects of submerged breakwaters on tsunami run-up depend on submerged breakwater geometry. It has been obtained that submerged breakwaters will be an effective tsunami protection measure if it will save its structural stability.

METHODS

Experimental set up

Experiments were carried out in the glass-side wall wave flume of 22.5 m. length, 1 m. width, and 0.50 m depth at the Hydraulic Laboratory Istanbul Technical University. The beach was formed by natural beach sand and had a slope of 1 vertical to 5 horizontal. The specific gravity of sand used was 2.63 and the diameter of sand was 0.35 mm. The slope of the beach was 1:5, as shown in Fig. 1, where R is the wave run-up height, d is the water depth, H is the wave height, c is distance between still water level and crest , a is crest width. The tsunami generation mechanism consists of a piston, a PHS16B bearing and a horizontal plate (0.97×2.00×0.002 m). The piston was a pneumatic cylinder, driven by a manually controlled system. As the piston moves vertically, the plate lifts off and displaces the adjacent fluid, thereby generating long waves (Gedik *et al*., 2004).

The water surface elevations were measured by resistance type wave gauges. The wave gauge W1 was installed on the sloping beach and the other wave gauges were installed between the toe of the beach slope and the centre of the wave channel. All the wave gauges were calibrated before the experiments to ensure the accuracy of the measurements. The maximum run-up height of the tsunami wave was measured both manually and by using a video camera.

Experiments

In order to determine the effect of submerged breakwaters with various configurations on tsunami run-up height were used. Experiments were carried out for cases that crest width is 25 cm, 40 cm for permeable and impermeable surfaces, distance between still water level and crest is 0 cm, 5 cm and 10 cm. Permeable surface was prepared by laying fine material with diameters of 5-8 cm on coarse core material with diametrs of 10-13 cm approximately. The core of impermeble submerged breakwater was prepared by applying a material with diameters of 5-8 cm on gravel dust material which was firmly compressed.

Experiments were carried out for the following cases:
CASE I : submerged breakwater with permeable surface whose crest point is on still water level,
c= 0 cm , a= 25 cm
CASE II : submerged breakwater with permeable surface
c= 5 cm , a= 25 cm
CASE II' : submerged breakwater with permeable surface
c= 5 cm , a= 40cm

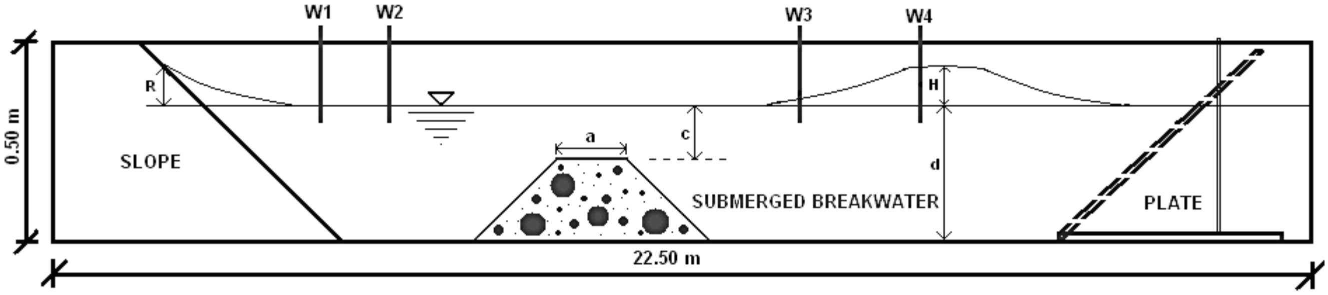


Figure 1. Experimental setup.

CASE III: submerged breakwater with permeable surface
c= 10 cm , a= 40 cm
CASE IV : submerged breakwater with impermeable surface
c= 0 cm , a= 25 cm
CASE V : submerged breakwater with impermeable surface
c= 5 cm , a= 25 cm
CASE V' : submerged breakwater with impermeable surface
c= 5 cm , a= 40cm
CASE VI: submerged breakwater with impermeable surface
c= 10 cm , a= 40 cm

RESULTS

Data of experiment were evaluated and the change of runup height and wave height for the cases above was given in Fig. 3-10. Following are the results of these evaluations:

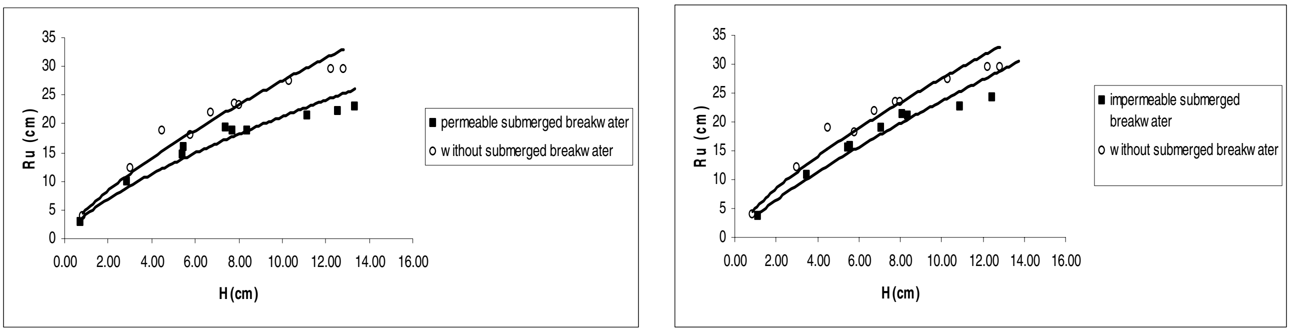
When a=40 cm, c=10 cm, according to the case of without submerged breakwater, submerged breakwater with permeable surface reduced its run-up height for 21% while the other one with impermeable breakwater reduced its run-up height for 19 %.

When a=40 cm, c=5 cm, according to the case of without submerged breakwater, submerged breakwater with permeable surface reduced its run-up height for 26 % while the other one with impermeable breakwater reduced its run-up height for 21 %.

When a=25 cm, c=5 cm, according to the case of without submerged breakwater, submerged breakwater with permeable surface reduced its run-up height for 25 % while the other one with impermeable breakwater reduced its run-up height for 23 %.

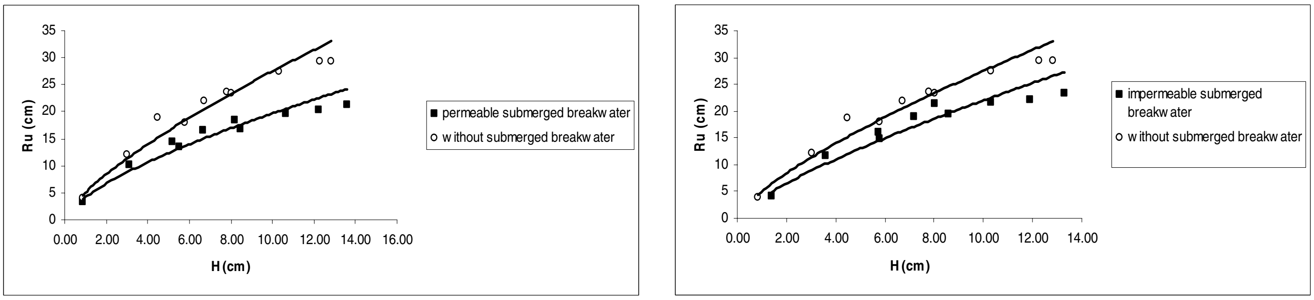
When a=25 cm, c=0 cm, according to the case of without submerged breakwater, submerged breakwater with permeable surface reduced its run-up height for 43 % while the other one with impermeable breakwater reduced its run-up height for 37 %.

Comparisons of all cases to each others were given in Table 1. In Table 1, the up arrows show the increasing of run-up height, and the down arrows show the decreasing of run-up height. For example run-up height in Case I is 27% smaller than Case II.



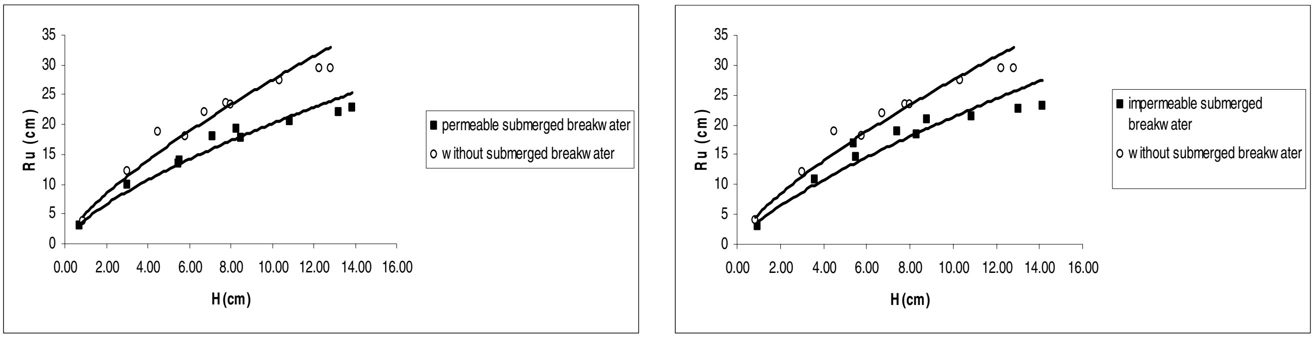
(a) **(b)**

Figure 2. Variation of runup height and wave height according to the cases with and without submerged breakwater
(a)- With permeable submerged breakwater (for a=40 cm., c=10 cm.)
(b)- With impermeable submerged breakwater (for a=40 cm., c=10 cm.)



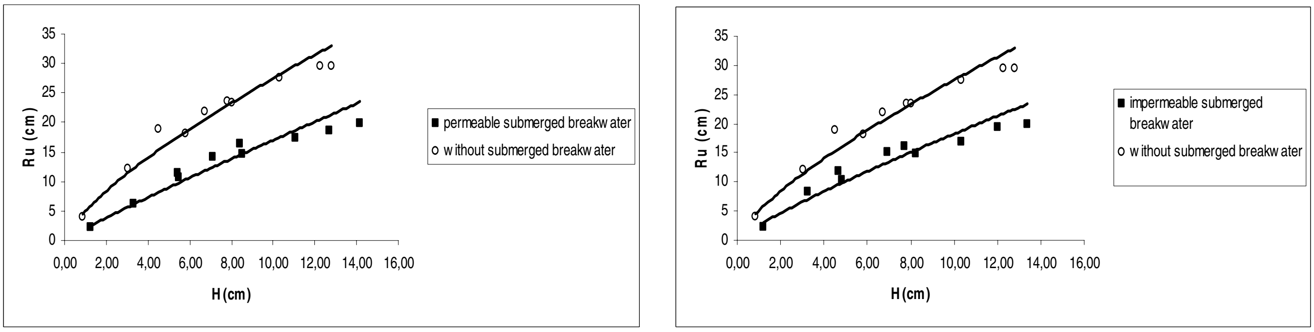
(a) **(b)**

Figure 3. Variation of runup height and wave height according to the cases with and without submerged breakwater
(a)- With permeable submerged breakwater (for a=40 cm., c=5 cm.)
(b)- With impermeable submerged breakwater (for a=40 cm., c=5 cm.)



(a) **(b)**

Figure 4. Variation of runup height and wave height according to the cases with and without submerged breakwater
(a)- With permeable submerged breakwater (for a=25 cm., c=5 cm.)
(b)- With impermeable submerged breakwater (for a=25 cm., c=5 cm.)



(a) **(b)**

Figure 5. Variation of runup height and wave height according to the caseswith and without submerged breakwater
(a)- With permeable submerged breakwater (for a=25 cm., c=0 cm.)
(b)- With impermeable submerged breakwater (for a=25 cm., c=0 cm.)

Table 1: Comparisons of run-up heights for all cases

		Permeable				Impermeable			
		case l	case ll	case II'	case lll	case lV	case V	case V'	case Vl
Permeable	case l	-	↓0.2700132	↓0.257570	↓0.259341	↓0.1412311	↓0.295988	↓0.314517	↓0.333100
	case ll	-	-	↑0.01414	↓0.049931	↑-0.20604	↓0.028335	↓0.051712	↓0.335828
	case ll'	-	-	-	↓0.062944	↑0.19165	↓0.041153	↑0.04257	↓0.087447
	case lll	-	-	-	-	↑0.269	↓0.02263	↓0.0020031	↓0.027112
Impermeable	case lV	-	-	-	-	-	↓0.186565	↓0.207063	↓0.227870
	case V	-	-	-	-	-	-	↓0.024473	↓0.049343
	case V'	-	-	-	-	-	-	-	↓0.025601
	case Vl	-	-	-	-	-	-	-	-

CONCLUSIONS

In this study, the effect of submerged breakwaters on tsunami run-up height was investigated experimentally. The results of this study could be summarized as follows:

1. Permeable submerged breakwater is more effective than impermeable breakwater at reducing runup heigt. Wave passes through the permeable breakwater and an amount of it enters into the porous structure of breakwater, thus reduces the runup height.
2. Crest width is constant at permeable or impermeable submerged breakwaters when the distance between crest and still water level decreases, the run-up height decreases. (Fig. 3,5 and Fig 4,6).
3. Crest width of submerged breakwater does not substantially affect run-up height. (Fig 5,7 and Fig 6,8). For instance, permeable breakwater with crest width a=40 cm reduces run-up height at a rate of 26 % according to without breakwater while the breakwater with crest width a=25 cm reduces run-up height at a rate of 25 %. These percentages are 21 % at a=40 cm, 23 % at a=25 cm for impermeable breakwaters (Fig 6,8).
4. Submerged breakwater's run-up height reduction conditions and percentages in comparison with the case without breakwater are as follows in descending order:
    a. Submerged breakwater crest is on still water level and permeable (%43)
    b. Submerged breakwater crest is on still water level and impermeable (%37)
    c. Submerged breakwater crest is 5 cm. lower than still water level and permeable (%25)
    d. Submerged breakwater crest is 5 cm. lower than still water level and impermeable (%23)
    e. Submerged breakwater crest is 10 cm. lower than still water level and permeable (%21)
    f. Submerged breakwater crest is 10 cm. lower than still water level and impermeable (%19)

In conclusion, submerged breakwaters are efficient at reducing runup height of tsunami. It's obvious that they will be more effective when using with other precautions for reduction of tsunami damages (including coastal walls, coastal forests).

ACKNOWLEDGEMENTS

This research was supported by the Research Foundation of Balikesir University, under Project No. 2010/02. The authors would like to thank Dr. Nuray Gedik from Balikesir University and Mr. Hasan Yalcin from the technician staff of Istanbul Technical University Hydraulic Laboratory.

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