# SEAWALL AND BEACH PROFILE INTERACTION IN RUN-UP REGION

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Seawalls are the most common form of coastal defence, they are the physical barriers between land and sea. They are parallel to the beach used to prevent overtopping and flooding due to storm waves. They can be constructed in the front or back of the shoreline. However, the front face of a seawall is subjected to high energy wave action, which can induce the problem of toe scour. Scours in front of the breakwaters and the seawalls have been investigated heavily in the past, but it still remains a concern for coastal engineers. In those previous studies, the sea bottom was considered as flat or having a very mild slope. These may not be valid for steep slope beach in front of a structure. The seawall stands in run-up region in this study. The seawall and the beach profile interaction was investigated by experimentally. The beach slopes were 1/5 and 1/10 in the experiments.

*Key words; Seawall, run-up, beach profile, toe scour*

## INTRODUCTION

There are many ways of protection against coastal erosion for coastal areas. Breakwaters, groins and seawalls are a few of these methods. Seawalls are frequently used as coastal protection method to prevent overtopping and coastal flooding. Reflection of incident waves from vertical walls causes building of waves in front of the structure due to the increase of the orbital velocities. Toe scouring problem is thought to be the main cause of failure of a seawall rather than the structural design. The failure of the toe will generally lead the failure of the entire structure. Toe scour is a complex process. Factors that affect the severity of toe scour include wave breaking, wave run-up, backwash, wave reflection, and the grain size distribution of the beach or bottom materials (Herbich, 1999). Silvester and Hsu (1997) have provided a variety of examples of collapse of coastal structures due to toe scour from around the world. Thus, effective scour protection is an essential part of the coastal structure design (Tsai, 2009).

In Turkey similar to the other countries, there is a trend for seaside holidays and a fashion for promenades – walkways along the coastline which combine public amenity with coastal defence structures. These often flanked the shoreline, with vertical walls. However, they can lead to many problems such as toe erosion or beach level changes.

Tsai et al. (1998) investigated the characteristics of down rush flow from breaking waves on sloping seawalls, which cause toe scour. Flow visualization techniques were employed in their experiments. The velocity and the pressure of down-rush flow at the toe were analyzed. They obtained that the intensity of the flow reduces as the structure slope decreases. They concluded that the flow intensity increases when the wave run-up height increases.

Tsai et al. (2009) conducted an experimental study for the toe scour of seawall on a steep seabed with slope of 1:5 under the action of breaking waves. It has been revealed that the depth of toe scour increased as the steepness of the incoming wave increased, but decreased with an increase in the water depth at the toe. Also the scour depth due to a plunging breaker is larger than that of a spilling breaker or a nonbreaking wave in front of the seawall. The scour depth increased as the down-rush flow velocity induced from the wave run-down increased.

Yuksel et al. (2012) investigated the deposition process at toe of the seawall in run-up region in various locations over the 1/10 sloping beach. They concluded that the process depends on wave steepness, run-up height, and location of the wall.

The scour pattern in front of a breakwater was expressed mainly as due to the action of partially or fully standing waves that leads to a form of alternating scour and deposition areas parallel to the breakwater by Xie (1981), Irei and Nadaoka (1984), Hughes and Fowler (1991), Fowler (1992), Oumeraci, (1994), Gao and Inouchi (1998), O'Donoghue, (2001).

Sumer and Fredsøe (2000) investigated scour at the trunk section of a rubble-mound breakwater both with regular and irregular waves. They obtained that the scour and the deposition pattern in front of the rubble-mound breakwater emerges in the form of alternating scour and deposition areas lying parallel to the breakwater, similar to the case of the vertical wall breakwater.

The seawalls can be constructed in front or back of the shoreline. In case of vertical seawalls for the coastal defense constructed in the run-up region which is the back of the shoreline, there is lack of knowledge. Besides, the sea bottom was considered as flat or having a very mild slope in those previous studies. These may not be valid for steep beach slope in front of a structure. When comparing

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with waves on the mild seabed, the surf zone is narrow over a steep bottom and the plunging breaker is more likely to occur. The purpose of this study was to investigate the interaction of the vertical wall which was at the back of the shoreline and the beach profiles, and to investigate the toe erosion/deposition of seawall experimentally.

The toe scour/deposition variation pattern of coastal protection by the vertical seawall built in run-up region has been investigated experimentally with small-scale model tests. The tests were performed with seawalls placed at different locations of 1/10 and 1/5 sandy beach slopes in run-up zone under irregular wave attack. The equilibrium depositions and the scour of the toe were analyzed and defined by dimensionless parameters. In this study, the considerations are;

- Wave run-up in a sand bed
- Beach profile definitions
- Toe scour or deposition mechanism
- Irregular incident waves

The limitations are;

- The seawalls were installed on the shoreline and over the run-up region.
- The steep seabeds in front of the seawall were considered (1/5 and 1/10).
- The suspended mode of sand transport was not found in the experiments. Sand bed was coarse sand.
- The seawall has vertical front face.
- Incident waves were parallel to the wall.

## EXPERIMENTAL STUDY

The experiments were carried out in the Coastal and Harbor Engineering Laboratory in Yildiz Technical University. The two dimensional wave flume has a length of 26m, width of 1m, and a depth of 1m was used. The flume is equipped with a regular/ irregular wave generator and HR Wave Data software for the data acquisition and analysis. A displacement piston wave maker was used to generate waves. It consists of two interconnected shapes that rotate relative to each other. The rear surface of each of the components forms part of a cylinder centered on its axis of rotation, so no back wave is formed when the structure rotates. The wave maker measures the incoming wave and corrects the paddle motion to absorb it. The resultant wave field is totally predictable even with highly reflective models. The wave maker can generate both sinusoidal and random waves. HR Wave Data is a spectral analysis program that produces the wave spectrum and associated spectral parameters; in addition it includes a wave counting technique by using wave down crossing which gives some statistical values.

Both sides of the flume were made of glass for observations. The beach was modeled using 1/10 and 1/5 steel ramps and sand lay on for a uniform beach slope.

Sand with characteristics of $d_{50}$=1.28mm, $d_{90}$=1.89mm, and $\sigma$=1.57 (where $\sigma$ is standard deviation) was used for bed conditions. Specific weight of the sand was $\gamma$=26500 N/m$^3$.

The tests have been carried out with 25 different irregular wave conditions. For irregular waves the incident wave spectrum used was the Bretschneider spectrum. The significant wave height was in between 5.06-15.19 cm and the wave period was in between 0.90-1.77s (Table 1). These waves were generated without seawall and the beach profiles were recorded. The profiles were obtained as normal and storm. During the storms maximum run-up values ($Ru_{max}$) for all wave conditions were also measured.

The seawall model made of plexiglass was vertical, smooth and impermeable. The vertical seawall was placed at three different locations in between run-up region which are at the shoreline, at 20cm and 40cm back of the shoreline (Fig.1). The interaction between the movable bed with the vertical walls at different locations in the run-up zone was identified.

The interaction of the seawall and the beach were observed as sand deposition and scour at the toe of the wall. In the tests the deposition and the scour process was monitored visually. When the deposition and the scour reached its equilibrium stage the waves were stopped and the deposition height and scour depth were measured at the centerline of the flume using an automatic point gage. The observations were defined by the dimensionless parameters.

**Table 1 Experimental conditions**

| | 1/10 slope | | 1/5 slope | |
|---|---|---|---|---|
| Test No | $T_m$ (s) | $H_{m0}$ (cm) | $T_m$ (s) | $H_{m0}$ (cm) |
| 1 | 0.960 | 5.204 | 0.91 | 5.06 |
| 2 | 0.957 | 7.176 | 0.90 | 6.76 |
| 3 | 1.163 | 7.826 | 0.92 | 6.91 |
| 4 | 1.174 | 11.806 | 1.05 | 7.78 |
| 5 | 1.440 | 8.639 | 1.64 | 9.11 |
| 6 | 1.390 | 12.273 | 1.65 | 9.05 |
| 7 | 1.613 | 11.304 | 1.09 | 9.45 |
| 8 | 1.636 | 12.907 | 1.59 | 9.24 |
| 9 | 1.643 | 15.421 | 1.36 | 10.24 |
| 10 | 1.665 | 11.619 | 1.27 | 10.50 |
| 11 | 1.767 | 15.190 | 1.07 | 11.84 |
| 12 | | | 1.55 | 13.84 |
| 13 | | | 1.61 | 13.18 |
| 14 | | | 1.41 | 14.46 |

## DISCUSSION and RESULTS

The purpose of the study was the investigation of the scour/deposition at the toe of the seawalls which were deployed at the back of the shoreline at different locations (Fig. 1).

Before the seawall was placed, the beach had been exposed to the mentioned waves in Table 1 to observe how the profile change occurs. In this experimental study the profiles before and after a storm were measured and drawn together. Fig.2 is an example of the seabed profiles obtained in this study.

Run-up was observed without the seawall and evaluated using previous works Mase and Iwagaki (1985), Mase et al., (2013) and Pena et al. (2013). Profiles were classified by profile parameter (Dalrymple, 1992), Sunamura and Horikawa formula (1974) and Hattori and Kawamata (1980).

To determine the seawall locations, the maximum run-up values were measured for all wave conditions before the seawall was placed. The locations of the seawall are as follows:

1) At the shoreline, X=0
2) At X=20cm behind the shoreline
3) At X=40cm behind the shoreline

For all tests with 1:10 beach slope normal profiles occurred and then toe variation of seawall was observed as deposition. But both normal and storm profiles developed for the test with 1:5 beach slope then deposition and scour observed at the toe of the seawall respectively. The magnitude of the scour and the deposition varied for different wave conditions and locations.

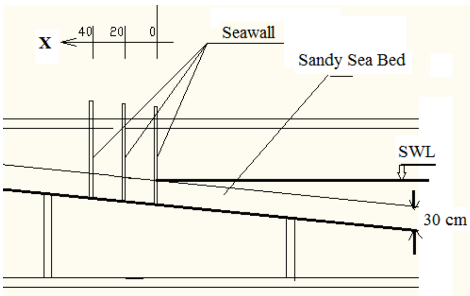
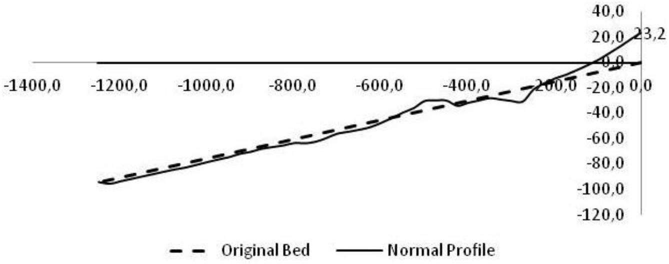


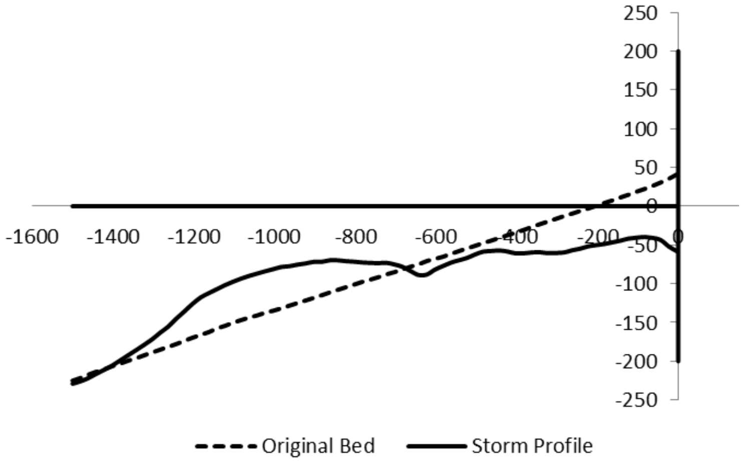

**Figure 1 Seawall locations**

Equilibrium profile of toe scour and deposition: The evolution of the sand-bed configuration was fast at the first stage of the wave action, which is similar to Tsai et al. (2009), but it settles to an equilibrium status over time.

Experiments were stopped when last three successive measurements gave the same results with intervals of 15 minutes. It was around 7000 wave number for each test. Maximum scour/deposition is found at the toe of the walls.




(a) Normal type profile and deposition at the toe of the wall




(b) Storm type profile and scour at the toe of the wall

**Figure 2 Development of the beach profile with the seawall in run-up region**

**i) 1:10 Beach Slope**

Fig.3 gives the variation of the toe deposition height with the wave steepness for different locations. As seen from the figure the deposition height (D) increases as the wave steepness decreases. The deposition heights of the seawall at the shoreline were observed less than the depositions for the walls of behind the shoreline (X=20cm and X=40 cm).

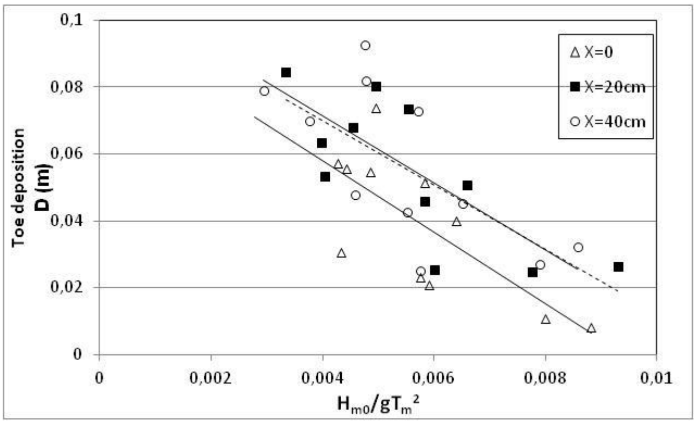



**Figure 3 Variation of the toe deposition height with the wave steepness**

Fig.4 indicates the variation of dimensionless toe deposition with the wave steepness. The toe depositions were normalized with highest 2% run-up, $Ru_{2\%}$. The same trend is observed again as in Fig.3. The least deposition is observed when the seawall is at the shoreline but the toe deposition increases in the case of the run-up region.

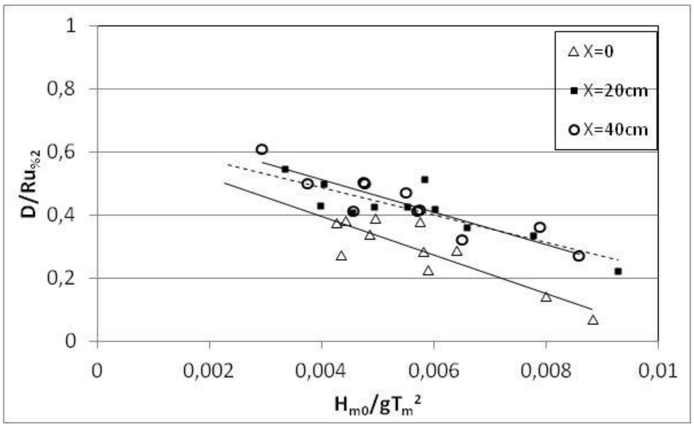



**Figure 4 Dimensionless toe depositions against the wave steepness**

The best known parameter defining the breaker type is the surf similarity parameter;

$$\xi_0 = \frac{\tan\beta}{\sqrt{H_0 / L_0}} \qquad (1)$$

Fig.5 shows the normalized toe deposition with respect to the location against the surf parameter. The results indicate that the toe deposition increases as the surf parameter increases. Fig. 6 shows the normalized toe deposition with respect to the run-up against the surf parameter. From the figure it is understood that the normalized deposition increases as the surf parameter increases. The toe deposition increases in the run-up region.

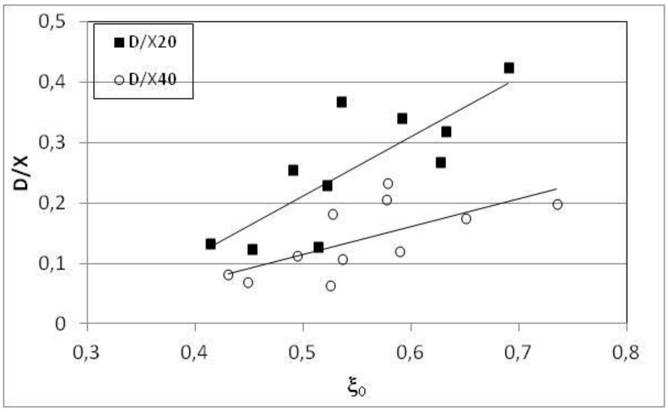



**Figure 5 Dimensionless toe depositions against the surf parameter**

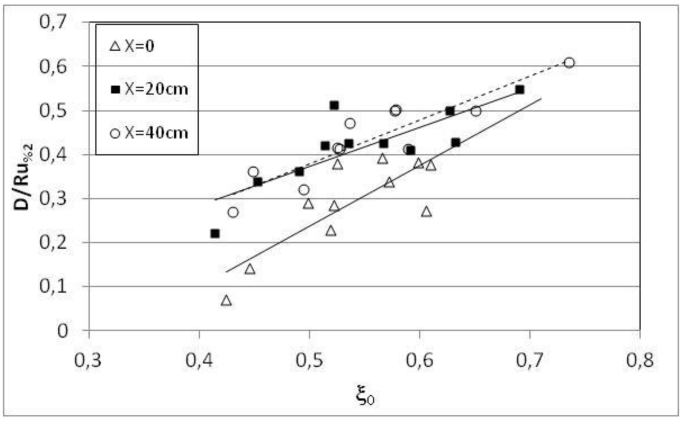



**Figure 6 Dimensionless toe depositions against surf parameter**

**ii) 1:5 Beach Slope**

Fig. 7 shows the variation of the sea slope bed level at the wall toe which is located back of the shoreline X=20cm for the beach slope with 1:5 where $\varepsilon$ is bed level change (which indicates both scour remarked by " -" and deposition remarked by "+"). Both deposition and scour were observed at the toe of the wall for 1:5beach slope.

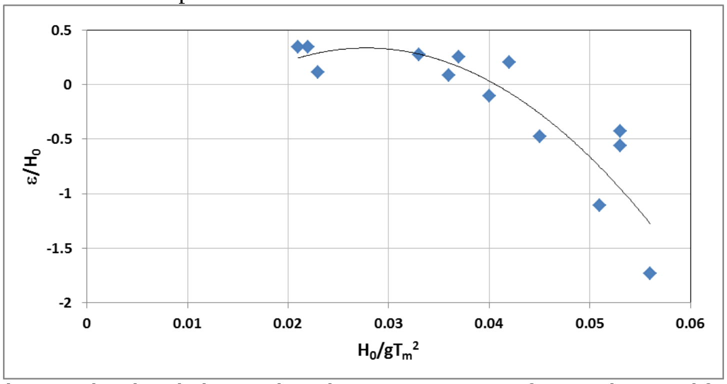



**Figure 7 Dimensionless toe level variation against the wave steepness for 1:5 slope and for location X=20cm**

From the experimental results, the dimensionless maximum scour depth ($\varepsilon/H_0$) increases as the wave steepness increases. When the sea bed level decreases, more wave energy transformed in front of the wall then it produces larger scour depths. It leads to similar scour process in front of the submerged vertical structures such as vertical wall breakwaters.

**iii) Both 1:10 and 1:5 Beach Slopes**

Experiments showed that the form of the beach profiles were not affected from the seawalls but the sand volumes of the profiles differed. Figure 8 shows the variation of the dimensionless bed level variation at the toe of the wall with the wave steepness for both beach slopes where the wall was at 20cm behind the shoreline. Sea bed level at the toe is the function of the wave steepness and the beach slope. Fig. 8 indicated that the deposition decreases as the wave steepness increases while the scour increases. Steeper beach slope causes narrow surf zone because wave breaks near the shoreline and then wave run-up and downrush caused more intraction with seawall.

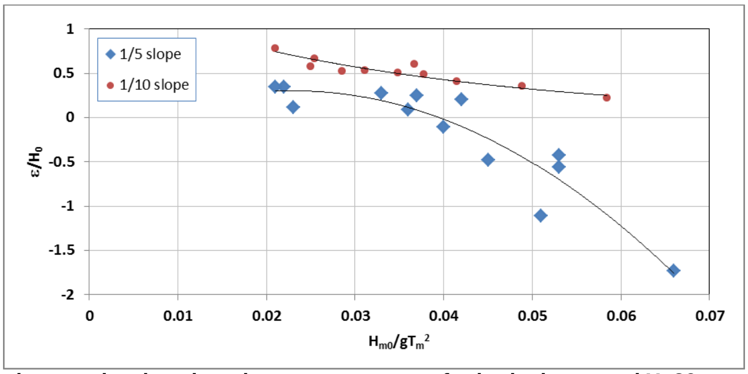



**Figure 8 Dimensionless toe level against the wave steepness for both slopes and X=20cm**

The beach slope and the wave steepness were presented by the dimensionless parameter $m(H_{m0}/L_{m0})^2$. The dimensionless bed level variation at the toe of the wall gave good correlation with the parameter of $m(H_{m0}/L_{m0})^2$ as shown in Fig. 9. Bed level decreases as increasing of the parameter $m(H_{m0}/L_{m0})^2$. The bed level variation is function of the square of the wave steepness and the beach slope. The variation was also found almost linear.

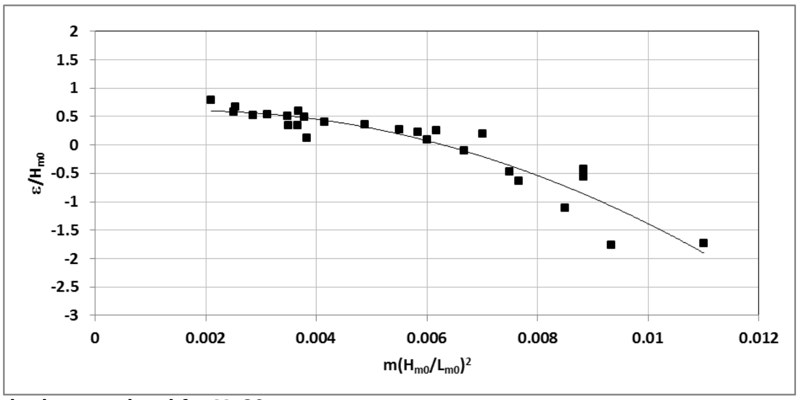



**Figure 9 Dimensionless toe level for X=20cm**

## CONCLUSIONS

An experimental study was conducted to investigate the scour/deposition at the toe of a vertical seawall placed behind the shoreline in run-up region on a 1:10 and 1:5 sloping beaches with a constant bed material under irregular wave attack. The following conclusions can be made;

- Beach profile type controls the scour and the deposition process at the toe of seawall. Normal type causes deposition while storm produces scour in the run-up region.
- Critical wave steepness was observed around 0.04 between the deposition and the scour process in front of the wall. Critical $m(H_{m0}/L_{m0})^2$ parameter was found around 0.006 between the deposition and the scour process in front of the wall.
- For all test conditions with beach slope as 1:10, the profiles were developed as normal profile, and then deposition was observed in front of the seawall in all positions. The deposition height in front of the seawall increased with the decreasing wave steepness since the long waves are more effective in the nourishment of beach. The deposition height increased with the increasing surf similarity parameter. The deposition height in front of the seawall at the shoreline is less than the deposition that of the seawall behind the shoreline in run-up region.
- Sea bed level at the toe is the function of the wave steepness and the beach slope. The dimensionless bed level variation at the toe of the wall gave the good correlation with both wave steepness "$m(H_{m0}/L_{m0})^2$" and beach slope (1:5 and 1:10).
- Scour process at front of the seawall toe becomes similar to the toe scour of vertical breakwater when erosion increases for storm type profile.

## ACKNOWLEDGEMENT

Authors wish to express their sincere appreciation to TUBITAK for funding for research project no 113M426.

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