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ARAŞTIRMA MAKALESİ

INVESTIGATION OF THE SCOUR AROUND THE VERTICAL WALL BREAKWATER

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DÜŞEY YÜZLÜ DALGAKIRAN ETRAFINDAKİ OYULMA OLAYININ ARAŞTIRILMASI

ÖZET

Bu çalışmada düzenli dalga şartlarında düşey yüzlü bir dalgakıran etrafındaki oyulma olayı araştırılmış ve düşey yüzlü dalgakıran etrafındaki oyulma olayına bağlı olarak iki anahtar mekanizma belirlenmiştir. Deneyler once kırılmayan dalga şartlarında daha sonra ise sığ su bölgesinde 1/5 eğimli kum kıyı üzerinde düşük Keulegan-Carpenter (KC) sayıları için kırılan dalga şartlarında gerçekleştirilmiştir. İlk mekanizma için KC sayısı, ikinci mekanizma için periyot parametresi (T*) esas alınmıştır. KC sayısı ve periyot parametresi büyüdükçe oyulma derinliğinin arttığı belirlenmiştir. Bununla birlikte değiştirilmiş Ursell sayısının kırılan ve kırılmayan dalga şartlarında rölatif oyulma derinlikleri ile bir ilişkiye sahip olduğu bulunmuştur.

SUMMARY

In this paper, scour process around the vertical wall breakwater was investigated, under regular waves. In this study, two key mechanisms were identified, depending on scour process around the vertical wall breakwater. First step was carried out under non-breaking wave conditions after that breaking wave conditions were investigated for low KC numbers on 1/5 sloping sand beach in shoaling water region. The KC number for the first mechanism and period parameter (T*) for the second mechanism were based on the experiments. It was determined that the scour depth increases with increasing the KC number and period parameter. However, it was found that modified Ursell number gave a correlation with relative scour depths under both breaking and non-breaking wave conditions.

1. INTRODUCTION

The scour around breakwaters is one of the important parameters for the breakwater design and investigated by several researchers.

In the three-dimensional case where waves attack at an angle to the breakwater has been investigated by De Best et al. [2], Xie [7, 8], Irie and Nadaoka [5], Hughes and Fowler [4], Fredsøe and Sümer [3]. In this case the key mechanism is the action of standing waves, leading to a steady streaming in the vertical plane.

Scour around the vertical wall breakwater head under the normal and near-normal (60° and 120°) incidence of waves, including a co-directional current, can be predicted from the results of Sümer and Fredsøe [6] for non-breaking wave conditions.

The scour mechanism around the head of a vertical wall breakwater may be different from two-dimensional case. In three-dimensional case, vortices forming at the lee side of the breakwater may play an important role. Although this study is confined to the two-dimensional scour, no detailed study of the three-dimensional scour at the head of a vertical wall breakwater is yet available in shoaling region.

Scour around the pile seems to have a similar mechanism as the scour around the vertical wall breakwater. In both cases, the main flow patterns, which cause scour, are the vortices. Çevik and Yüksel [1] investigated scour around the pipelines and they determined scour effect in shallow water conditions. They found a general formula even in shallow water condition for scour depth around pipelines. It is indicated that scour depths depend on modified Ursell number which may be used more easily than KC number.

The purpose of the present study is to extend the investigation of breaking and non-breaking wave effects on scour around the head of a vertical wall breakwater. The experiments were carried out for low KC numbers.

2. EXPERIMENTAL SET-UP AND PROCEDURES

Experiments were carried out in a wave basin, which is 24.5 m length, 5.40 m width and 1 m depth. The experimental set-up is illustrated in Fig. 1. The mean water depth in the experiments was used constant as 0.70 m. Regular waves were produced by a flap type wave generator. The wave generator is located at one end of the basin and a sandy beach with 1/5 uniform slope is located at the other end of the basin. The range in the tests is between 1-1.62 s for periods, 0.0428-0.095 m for incident waves and KC numbers vary between 0.75-1.71.

The vertical wall, with 1.70 m length and 0.90 m height, is placed on the sand bed. The vertical wall has a circular round head, with the diameter of 0.15 m in the experiments. The vertical wall extended down to the bottom of the basin in the vertical section. Scour around the head of a vertical wall breakwater was investigated by a point gauge.

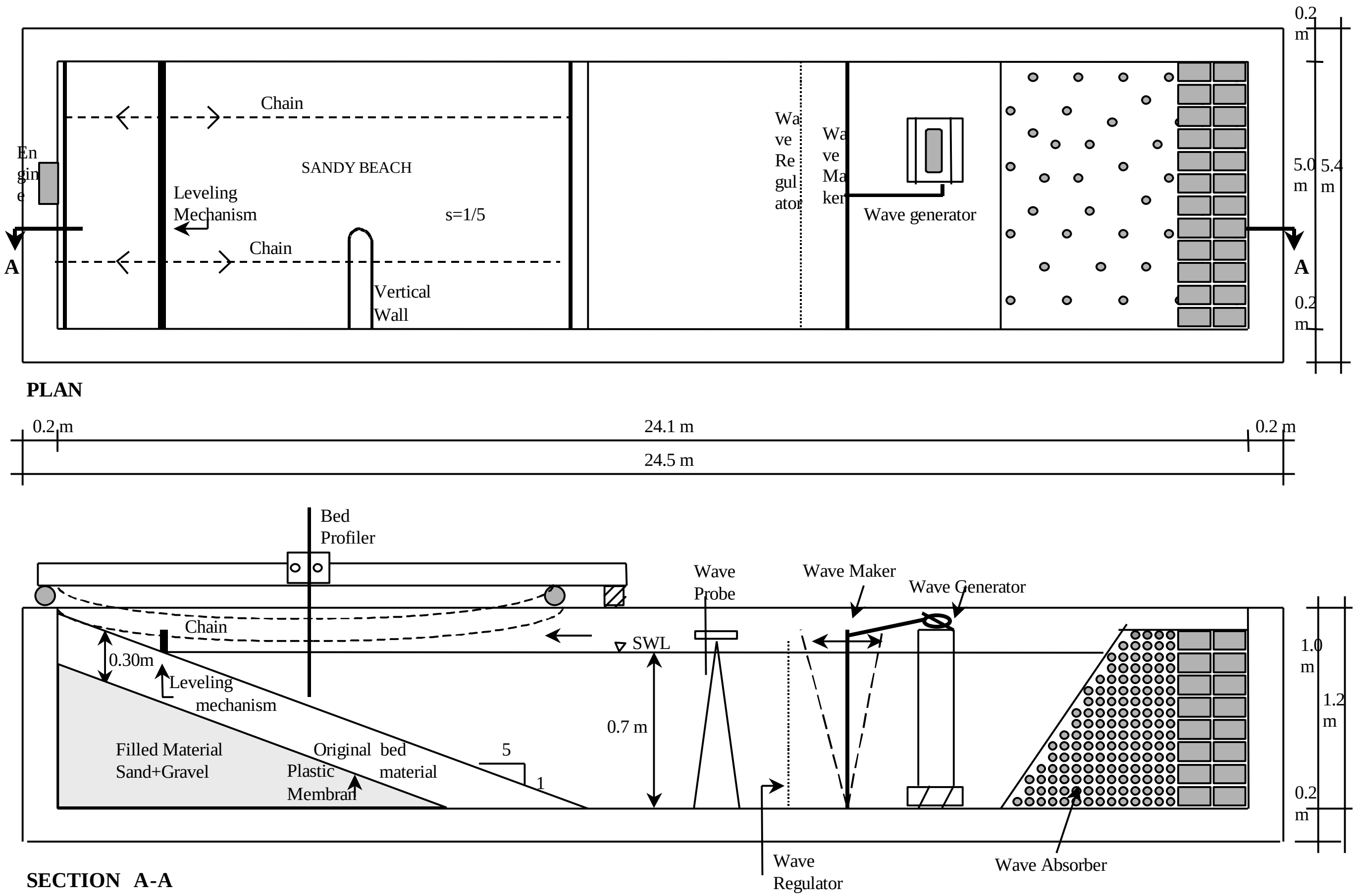


Figure 1 Experimental set-up

Nine different wave conditions were considered and tabulated in Table 1. The experiments were carried out by following the similar test procedure of Fredsøe and Sümer [3], Sümer and Fredsøe [6].

Scour and deposits around the head of the vertical wall breakwater were measured manually by limnimeter. Measurements were carried out at the sides and at the head of the breakwater. The beach profile of the eroded bed was recorded by a PV-07 type profiler with errors of ± 0.1 mm until reaching the dynamic stability condition at each test. Hence the interaction problem between scour hole mechanism and profiles was investigated. All the experiments were carried out by waves approaching parallel to the breakwater. Wave reflection observations were also done and it was found that the incident wave conditions were not affected by the vertical breakwater for present wave conditions. The nominal diameter of the sand was d_{50}=0.67 mm. Figure 2 shows the locations of the vertical wall according to the wave conditions. The wall was located at two different wave conditions, these were breaking and non-breaking depths. In Fig. 2 line I shows locations of the wall, line II shows breaking depths for the test conditions in Table 1 and line III shows scour depth measurements. For example the wall was under only breaking waves at 0.07 m in depth and scour depth characterized only breaking wave conditions. However the wall was under breaking and non-breaking wave conditions at 0.13 m in depth and the wall at 0.26 m in depth was only non-breaking wave conditions. In this work, twenty experiments were carried out. Hence interaction between the wall and beach profiles was also observed.

All the experiments were done for 1000 waves. Because scour depth variations reach to equilibrium condition after 1000 wave attacks.

Table 1 The wave characteristics and related parameters

Wave	**T**	**H_i**	**L_i**	**H_0**	**H_d**	**L_0**	**h**	**u_m**	**KC**	**H_b**	**Remarks**
Case	**(s)**	**(cm)**	**(m)**	**(cm)**	**(cm)**	**(m)**	**(m)**	**(cm/sn)**	**-**	**(cm)**	
11	1	4.61	1.55	4.7	4.88	1.56	0.07	0.143	0.89	5.74	Breaking wave
21	1.22	4.28	2.17	4.5	5.02	2.25	0.07	-	-	6.3	Breaking wave
11	1	4.61	1.55	4.7	4.45	1.56	0.13	0.173	1.08	5.74	Non-breaking wave
12	1	7.61	1.55	7.7	7.35	1.56	0.13	0.254	1.59	7.977	Breaking wave
13	1	9.5	1.55	9.7	9.17	1.56	0.13	-	-	9.304	Breaking wave
21	1.22	4.28	2.17	4.5	4.49	2.25	0.13	0.195	1.22	6.3	Non-breaking wave
22	1.22	6.67	2.17	7	7	2.25	0.13	0.273	1.71	8.458	Breaking wave
23	1.22	8.72	2.17	9.2	9.15	2.25	0.13	-	-	10.15	Breaking wave
24	1.22	11	2.17	11.5	11.54	2.25	0.13	-	-	11.78	Breaking wave
31	1.62	5.83	3.43	6.4	7.07	4	0.13	0.274	1.71	9.651	Breaking wave
32	1.62	7.17	3.43	7.8	8.7	4	0.13	0.284	1.75	11.01	Breaking wave
11	1	4.61	1.55	4.7	4.28	1.56	0.26	0.127	0.79	5.74	Non-breaking wave
12	1	7.61	1.55	7.7	7.1	1.56	0.26	0.182	1.14	7.977	Non-breaking wave
13	1	9.5	1.55	9.7	8.8	1.56	0.26	0.208	1.3	9.304	Non-breaking wave
21	1.22	4.28	2.17	4.5	4.15	2.25	0.26	0.12	0.75	6.3	Non-breaking wave
22	1.22	6.67	2.17	7	6.46	2.25	0.26	0.172	1.08	8.458	Non-breaking wave
23	1.22	8.72	2.17	9.2	8.45	2.25	0.26	0.212	1.33	10.15	Non-breaking wave
24	1.22	11	2.17	11.5	10.66	2.25	0.26	0.25	1.56	11.78	Non-breaking wave
31	1.62	5.83	3.43	6.4	6.3	4	0.26	0.186	1.16	9.651	Non-breaking wave
32	1.62	7.17	3.43	7.8	7.75	4	0.26	0.226	1.41	11.01	Non-breaking wave

In the Table 1, the parameters are; T the wave period, H_i the incident wave height, L_i the incident wave length, H_0 the deep water wave height, H_d the wave height in front of the vertical wall, L_0 the deep water wave length, h the depth of the wall location, u_m the maximum horizontal orbital velocity, H_b the breaking wave height.

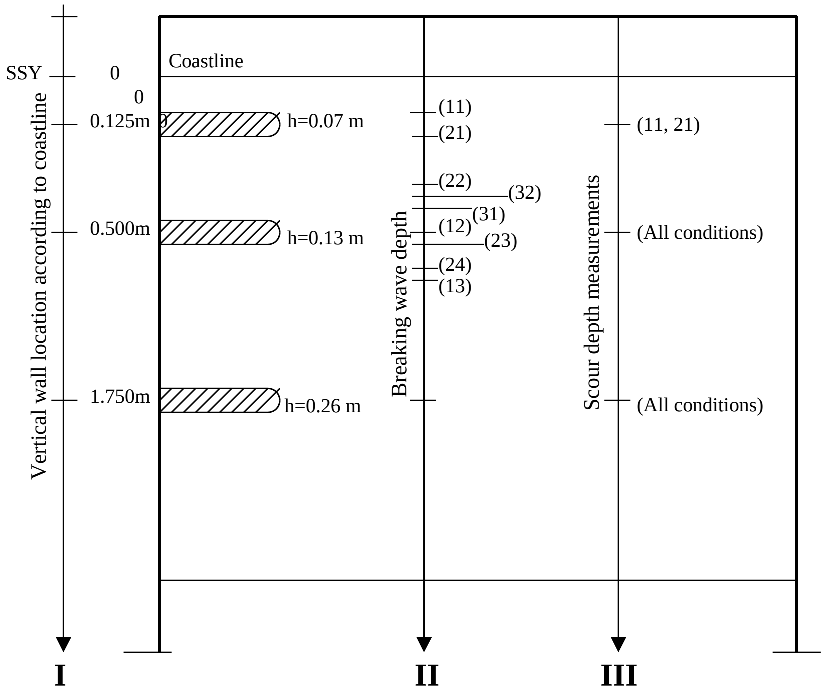


Figure 2 Scour depth measurements around the head of the vertical wall, where the numbers in bracket show the wave condition cases in Table 1

3. SCOUR EXPERIMENTS

Figure 3 illustrates the bed topography around the head of vertical wall after the experiment under one of the breaking wave conditions. The locations of maximum scour and maximum deposition are seen from Fig. 3. The location of maximum scour is around the offshore side of the breakwater head while maximum deposition is located in the opposite side. Similar topography is observed for the other breaking conditions. The plunging jet impinges on the bed and mobilizes the sand grains there, leading to a scour hole. The generated scour hole is located at the lee-side of the breakwater at the junction between the head and the trunk sections as it was obtained for rubble-mound breakwaters by Fredsøe and Sümer,[3]. The plunging breaker occurs in front of the breakwater and plunging jet impinges to the front water for low KC numbers. It is found that scour hole mechanisms are more dominant rather than beach profile developments.

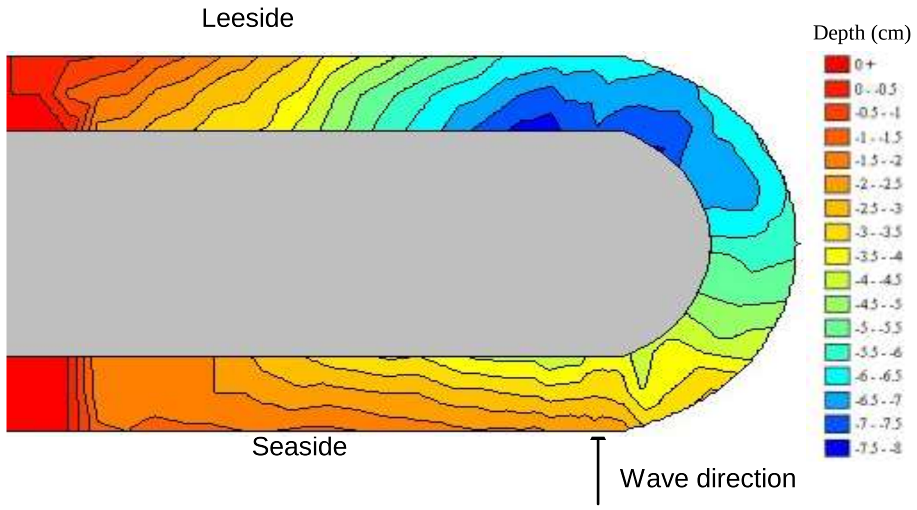


Figure 3 Bed morphology around the head of the vertical wall for breaking wave conditions (Case 13)

Figure 4 shows one of the non-breaking wave conditions in shallow water of the scour profiles measured around the head of the breakwater. The maximum scour depth corresponding to the equilibrium stage occurs at the front tip of the breakwater. The maximum scour depths are indicated by the darker colour in the Fig. 4. The sediment stirred up by waves and mass flow current to the onshore direction. The scour occurs even for low KC numbers because the experiments were carried out in shallow water conditions on 1/5 sloping sandy beach. Hence stream flow under waves due to non-linearity causes and sand transport around the breakwater.

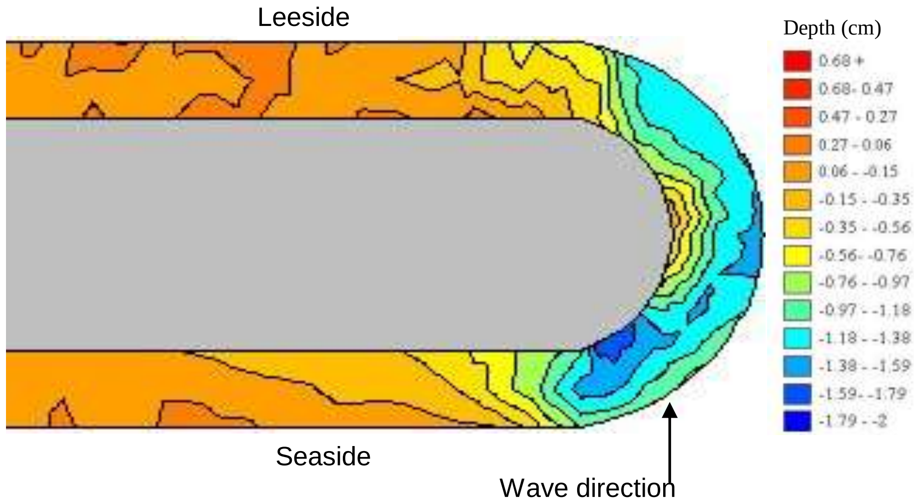


Figure 4 Bed morphology around the head of the vertical wall for non-breaking wave conditions (Case 24)

4. EXPERIMENTAL RESULTS

By following the dimensional analysis, the maximum scour depth can be found to be dependant on the following parameters.

(i) Non-breaking wave conditions

$$F_1(Re_*, \frac{H}{B}, KC, \theta, Fr_*, \frac{S}{B}, \frac{h}{B}, s, \frac{\rho_s}{\rho}) = 0 \qquad (1)$$

(ii) Breaking wave conditions

$$F_2(Re_*, \frac{S}{H}, KC, \theta, Fr_*, T^*, \frac{S}{B}, \frac{h}{B}, s, \frac{\rho_s}{\rho}) = 0 \qquad (2)$$

where $Re_* = \frac{\nu}{u_m B}$ Reynolds number of breakwater, $\frac{H}{B}$ relative wave height, $KC = \frac{u_m T}{B}$ Keulegan Carpenter number, $\theta = \frac{\tau}{\rho u_m^2}$ Shields parameter, $Fr_* = \frac{Bg}{u_m^2}$ Froude number of breakwater, $\frac{S}{B}$ relative scour depth, $\frac{h}{B}$ relative water depth, s beach slope, $\frac{\rho_s}{\rho}$ relative density, $T^* = \left(\frac{T\sqrt{gH}}{h}\right)$ dimensionless period parameter and $\frac{S}{H}$ dimensionless scour depth, ρ is the water density, ρ_s is the sediment density, ν is the kinematic viscosity, H is the wave height, B is the width of the vertical wall, T is the wave period, S is the scour depth, u_m is the maximum orbital velocity, s is the bed slope.

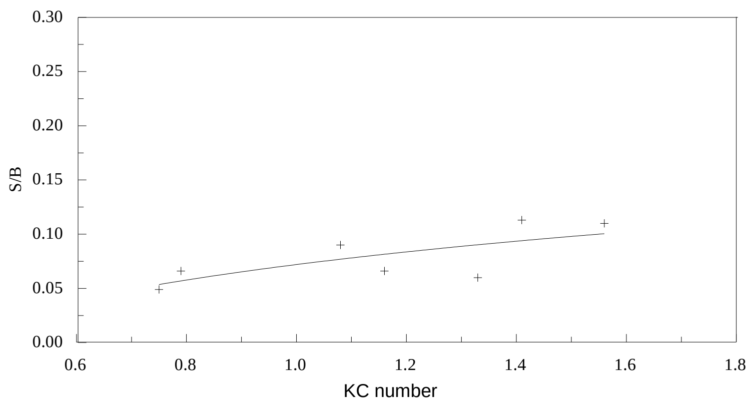


Figure 5 Relative scour depth versus KC number for non-breaking wave conditions

The variation of relative maximum scour depth with KC number under non-breaking wave conditions are shown in Figure 5. The scour depths shows a good relation with KC number. The S/B versus KC relationship in Fig. 5 may be approximated by the following empirical expression;

$$\frac{S}{B} = 0.064 \log(KC) + 0.072 \quad (3)$$

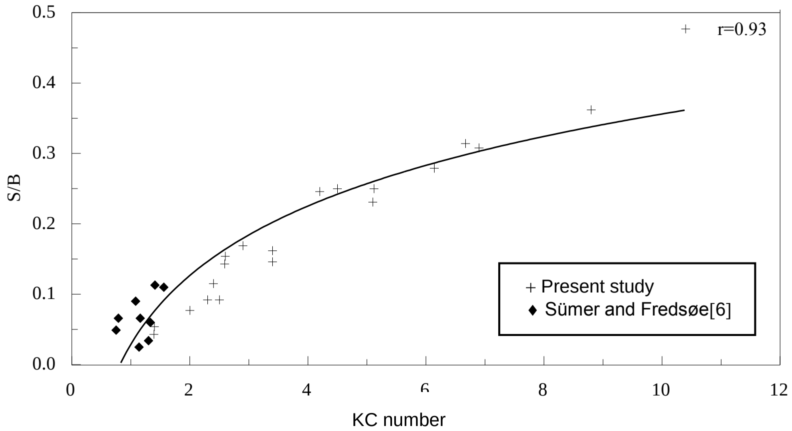


Figure 6 Relative scour depth versus KC for non-breaking wave conditions (The experimental results and Sümer and Fredsøe [6]'s results)

The experimental results compare with Sümer and Fredsøe [6] in Fig. 6. Fig. 6 shows that there is a good agreement between the experimental results and Sümer and Fredsøe [6] for non-breaking wave conditions.

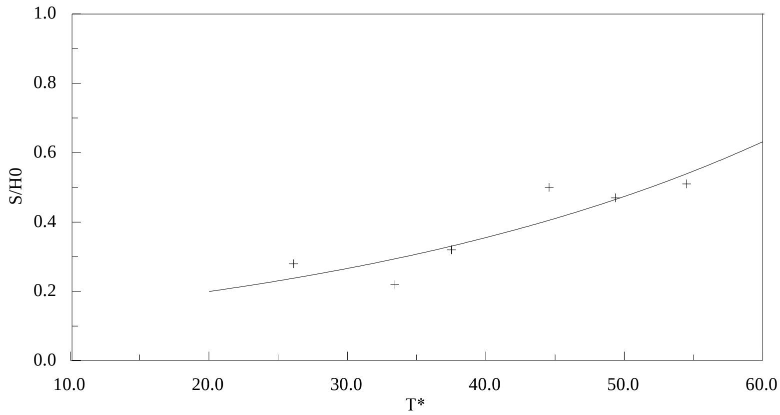
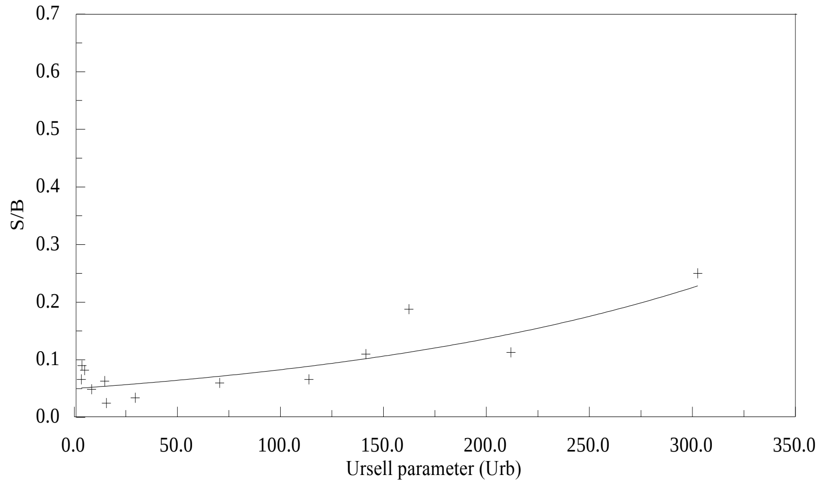


Figure 7 Relative scour depth versus T* (period parameter) for breaking wave conditions

Relative scour depth versus T^* (period parameter) are plotted for breaking wave conditions. Scour data obtained for breaking wave conditions are compared with the data presented in Fredsøe and Sümer [3]. Fig. 7 shows that there is a good agreement between the experimental results.



Modified Ursell number (Urb)

Figure 8 Relative scour depth versus modified Ursell number for breaking and non-breaking wave conditions

The relation between the relative scour depths and modified Ursell number ($U_{rb} = \frac{H_d^3 L_d^2}{h^3 B^2}$) for all wave conditions (non-breaking and breaking) are seen in Fig. 8. It is seen from Fig. 8 that the maximum scour depth has a relation with modified Ursell number. An empirical equation (Eq. 4) represent this relation.

$$\frac{S}{B} = 0.053 \exp(0.005 U_{rb}) \qquad (4)$$

5. CONCLUSIONS AND RECOMMANDATION

The experiments were carried out with regular waves on 1/5 sloping sand beach in shoaling water conditions for low KC numbers to investigate the scour around vertical wall breakwaters. The following results were obtained from this study:

1) The maximum scour depths are formed seaside of the breakwater under non-breaking waves. The maximum scour depths are located at the lee side of the breakwater head for breaking waves.

2) It is found that the scour hole mechanism is dominant rather than beach profile formation around the head of breakwater in shoaling conditions. Because the beach profile does not affect the equilibrium scour depth for observed both non-breaking and

breaking wave conditions. The results for non-breaking wave conditions show a good agreement along the beach profiles in the experiments but for flat bed condition in Sümer and Fredsøe [6]'s work.

3) The maximum scour depth has a relation between modified Ursell number.

4) More experimental work should be extended to cover wide range of parameters in order to generalize the results.

REFERENCES

[1] ÇEVİK, E. ve YÜKSEL Y., "Scour Under Submarine Pipelines in Waves in Shoaling Conditions", Accepted for Publication in 1998 Journal of the Waterways, Ports, Coastal and Ocean Div., 1998.

[2] DE BEST, A., BIJKER, E.W. ve WICHERS, J.E.W., "Scouring of Sand Bed infront of a Vertical Breakwater", In: Proc. Conf. On Port and Ocean Eng. Under Artic Conditions, NTH, Trondheim, pp. 1077-1086, 1971.

[3] FREDSØE, J. ve SUMER, B.M., "Scour at the Round Head of a Rubble–Mound Breakwater", Costal Eng., 29: 231-262, 1997.

[4] HUGHES, S.A. ve FOWLER, J.E., "Wave-induced Scour Prediction at Vertical Walls", In: Proc Conf. Coastal Sediments '91. ASCE, pp. 1886-1899, 1991.

[5] IRIE, I. ve NADAOKA, K., "Laboratory Reproduction of Seabed Scour in front of Breakwaters", In: Proc. 19th ICCE Houston TX. ASCE, pp. 1715-1731, 1984.

[6] SUMER, B.M., FREDSØE, J., "Scour at the Head of a Vertical Wall Breakwater", Coastal Eng., 29: 201-230, 1997.

[7] XIE, S.L., "Scouring Patterns in front of Vertical Breakwaters and their Influence on the Stability of the Foundations of Breakwater", Report, Dept. of Civil Eng., Delft University of Technology, 61 pp, 1981.

[8] XIE, S.L., "Scouring Patterns in front of Vertical Breakwaters", Acta Oceanolociga Sinica, 4(1): 153-164, 1985.