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Effects of Seawall Slopes on Scour Depth

Sheng-Wen Twu and Wei-Miu Liao

Department of Hydraulic and Ocean Engineering
National Cheng Kung University
Tainan 701, Taiwan

ABSTRACT

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This paper is aimed to study effects of seawall slopes on the scour depth in front of seawalls. The study was performed by conducting a series of three dimensional hydraulic tests to produce short-crested waves, which is significant in the scour in front of the structure.

The scour depths in front of seawalls with varied front slopes were surveyed in the laboratory under different wave conditions. Results showed that the scour depth is closely related to the Ursell parameter and the front slope of the seawall. Besides, it is indicated that the scour depth in front of the seawall with front slope of tan $\theta = 1/4$ is much less than that with tan $\theta = 1/2$ or 1/3, but is only slightly more than that with tan $\theta = 1/7$. Since the seawall with tan $\theta = 1/7$ possesses much larger section than that with tan $\theta = 1/4$, the latter is suggested as a favourite option for the front slope of the seawall.

ADDITIONAL INDEX WORDS: *Front slope, scour depth, seawall, short-crested wave, Ursell parameter.*

INTRODUCTION

Seawall is a very common structure constructed in coastal area to protect land in the lee side. Especially, it is needed in reclamation areas. However, once the seawall is built up, the base at the seawall usually suffers serious erosion and thus become a troublesome problem for coastal engineers. This erosion could lead to a totally collapse of the seawall, if repairment has not been accomplished in time. There have been many evidences indicating that the failure of many coastal structures was attributed to the erosion in front of those structures. Therefore, the erosion in front of those seawalls has been a major concern for many coastal engineers.

SHIRAISHI *et al.* (1960) investigated the collapse of submerged breakwater outside Niigata coast and concluded that its failure had been caused mainly by erosion at the base of the structure.

ICHIKAWA (1967) studied the collapse of breakwater of Tagonoura Harbor in Japan. Its failure took place in 1964 when the Typhoon No. 24 hit that region. The investigation found that the base of the structure had been scourred to a depth of up to 8 meters. Since then, the erosion in front of coastal structures has been a popular study topic.

HERBICH and KO (1968) conducted both theoretical and two-dimensionally experimental studies on the erosion in front of the structure. It was concluded that the scour depth had been a function of characteristics of the incident waves.

SATO *et al.* (1968) carried out a two-dimensional test on the structure-base erosion. He indicated that the scour was closely related to incident wave characteristics and reflected waves from the structure. To verify this, Sato conducted a field investigation and found that the scour was closely related to the wave induced current.

JONES (1975) investigated the scour at the base of a vertical seawall in terms of wave induced current caused mainly by the incident and reflected waves.

HSU *et al.* (1980) indicated that the scour in front of a breakwater or seawall was in a close relation with the reflected waves being reflected from the structure. It is known that as reflected waves appear, the superposition of incident and reflected waves turns out to be short-crested waves. These superposed waves have been claimed to be the main force to cause the scour in front of the structure.

DEAN (1986) proposed an approximate principle indicating that the volume of the scour in front of a wall will be less than or equal to the volume that might be potentially scoured in the profile upland in the absence of the wall.

BARNETT and WANG (1988), KRAUS and PILKEY (1988), also investigated the scour problem in front of a coastal structure. They made the same conclusion indicating that the seawall scour problem seemed to be inevitable. However, the structure they studied was of vertical wall.

TOYOSHIMA (1988) proposed in 1981 that seawalls should have a gentle front slope (1:3) and be covered with armour units. Consequently, over one hundred field works have successfully been performed. In 1985, he proposed replacing those existing vertical seawalls with gentler slope (1:5 or 6) ones. This kind of gentle-slope seawalls were tested in the laboratory and some experimental field works were made. As a result, those structures had been proved to be successful in reducing the scour.

FOWLER (1992) described mid-scale laboratory tests of beach profile change at a vertical wall. The initial beach profile was a 1V:15H slope in all tests. Results from both random- and monochromatic-wave tests were compared with

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those from several previous laboratory studies conducted by other researchers. He concluded that the ratio of the water depth at the wall to the deep-water wavelength was an important factor to the scour depth.

MISELIS (1994) studied the beach profile and seawall interaction, including scour, produced by severe storm condition. It was simulated in a tank of 36.6m long, 0.9m wide, and 1.2m deep, for which both 0.09- and 0.18-mm sand was used in separate tests. Miselis found that the maximum scour depth always occurred during the peak storm-surge level. He concluded that a seawall's presence had little effect on the beach evolutionary process except for the immediate area around the seawall.

FITZGERALD *et al.* (1994) described beach change and severe damage along Massachusetts Bay associated with the Halloween storm of 1911. They indicated that all beaches (seawalled and nonseawalled) experienced erosion as a result of the storm, and that those beaches with wide berms or where adjacent dunes were scarped exhibited less overall change than sandy beaches backed by seawalls. Nevertheless, they also found that the seawalls provided some level of damage protection to the upland, serving their intended purpose.

KRAUS and SMITH (1994, 1995) conducted large-scale supertank laboratory tests with random significant wave height ranged between 0.4 and 1.0 m, and periods between 3 and 8 sec. Wave heights and periods were selected to correspond to destructive and constructive wave conditions. The profile typically had a local variation near the wall, but the majority of the profile remained similar to an unwalled profile. They suggested that the scour trench sometimes observed in the field after storms may be a result of longshore transport or combined cross-shore and longshore transport occurring during the time of the storm.

From those previous publications, it is known that the scour in front of a seawall is likely to take place after the seawall has been built up, and that the erosion is related to the reflected waves, thus also relating to the seawall slope. However, it is difficult to capture the exact effect of the seawall slope on the erosion in field investigation, due to the varied environment involved in different cases. Therefore, appeal is made to laboratory.

TWU and CHIOU (1994) conducted a series of two-dimensional moving-bed model tests to study the relation between the scour depth and the front slope of the structure. Four front slopes of $\tan\theta = 1/2$, 1/3, 1/4 and 1/7 were modelled in their laboratary. The result of these tests revealed that the scour depth in front of the seawall with front slope of $\tan\theta = 1/4$ is significantly less than that with $\tan\theta = 1/2$ or 1/3 but is only slightly more than that with $\tan\theta = 1/7$. Nevertheless, this observation has to be examined by a three-dimensional model test, because of a fact like HSU and SILVESTER (1980) indicated that the scour depth was mainly created by the short crested waves, and the short crested waves can be produced only in a three dimensional basin rather than a two dimensional wave channel.

DIMENSIONAL ANALYSIS

The scour depth has been a key topic in studing the scour related problems in front of coastal structures. It has been studied by numerous investigators. In general, the scour depth Δ h can be expressed as

$$\Delta h = F_1(\rho, \rho_s, D, \omega, d, U_0, \nu, T, L, \lambda, \tan\theta, \tan\alpha, X, X_b, H) \tag{1}$$

in which, ρ represents fluid density, ρ_s is sediment density, D is sediment diameter, ω is sediment fall speed, d is water depth, U_0 is water velocity on bed, ν is fluid kinematic viscosity, T is wave period, L is wave length, λ is the angle the incident wave makes with the seawall, θ is the angle the seawall face makes with the horizontal, α is the angle the bottom plane makes with the horizontal, X is the position of seawall relative to shoreline, X_b is the position of wave breaking relative to the seawall, H is wave height.

In this study a three dimensional wave basin was used and the bottom slope was fixed. Coal ash were selected as sediment material with a specific gravity of 1.97 and a median diameter of 0.16 mm. The experiment fluid was water. The incident wave made an angle of thirty degree with the seawall normal. Therefore, those factors such as ρ, ρ_s, D, ω, ν, $\tan\alpha$ remained unchanged in the experiment. In this circumstance they can be dropped out from the equation (1). Furthermore, U_0 can be expressed in terms of d, L, H. The factor X is assumed to be involved in water depth d, and only nonbreaking waves were generated in the experiments, hence U_0, X, X_b were also eliminated from equation (1).

For previous reasons(1) can be rewritten as

$$\Delta h = F_2(d, L, H, \tan\theta) \tag{2}$$

To express it in non-dimensional form, the scour depth may be expressed in terms of two parameters, such as

$$\frac{\Delta h}{H} = F_3(U_r, \tan\theta) \tag{3}$$

in which $U_r = HL^2/d^3$ is the Ursell parameter representing wave characteristics. Tan θ represents a physical property of the seawall.

As mentioned above, it was observed that the scour is closely related to the reflected wave from the wall. Furthermore, some authors suggested that the reflection coefficient is related to H. L. d and $\tan\theta$. In this circumstance, we may express (2) as

$$\frac{\Delta h}{H} = F_4(C_r) \tag{4}$$

Because wave reflection is a significant factor in producing the scour, another factor such as surf parameter (ξ) might be used instead. Thus we have

$$\frac{\Delta h}{H} = F_5(\xi) \tag{5}$$

in which $\xi = \tan\theta/\sqrt{H/L}$.

The wave height and wave length at seawall were used for *H, L* respectively.

EXPERIMENTAL TESTS

Laboratory tests were conducted in a wave basin with $17^m \times 9.6^m \times 1.5^m$. Two wave generators were installed at one

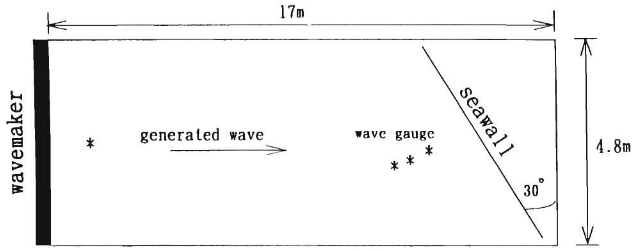

Figure 1. The sketch diagram of the wave basin.

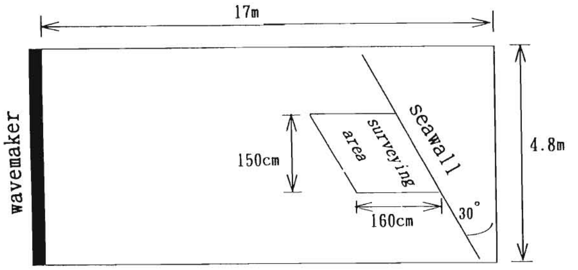

Figure 3. The sketch diagram showing bed surface surveying area.

end of the basin. They can make both regular and irregular waves.

In this study, only regular waves were made, due to an observation indicated by ULICZKA and DETTE (1987) that a regular wave case reached an equilibrium state faster than an irregular case. They indicated that the regular wave case needs 4000 waves to reach an equilibrium profile as opposed to about 7,000 waves for the irregular wave case.

In this study, seawalls with varied front slopes were modelled in the wave basin with its normal making an angle of thirty degrees with the generated wave direction. Because the moving bed has to be repaved after a wave condition test is finished, a lot of manpower has to be spent on it. To save some of this work, only a half of the basin was used and therefore only a wave generator was operated. In this circumstance, a wave guiding board was needed to be placed along the central line of the basin. Therefore, the actual testing area, shown in Figure 1, covered only one half of the basin.

As generated waves propagate and encounter the seawall with an angle to the seawall normal direction, the long shore current would take place. To avoid unwanted circulation from happening in front of the wall, two gaps with each located between the seawall and the side wall (or guiding board) were built. Thus they allowed the long shore current to flow into the gap at the down-flow end, passing through the lee side of the wall. Then, the flow came out from the gap at the up-flow end and joined the long-shore current again.

A bottom slope of tan α = 1/50 was adopted. Coal ash was used as the moving-bed material in front of the seawall. The thickness of the sediment ranges from 25 cm, at toe of the seawall, to 10 cm at a line located more than 200 cm away from the seawall. The profile of the sediment is shown in Figure 2.

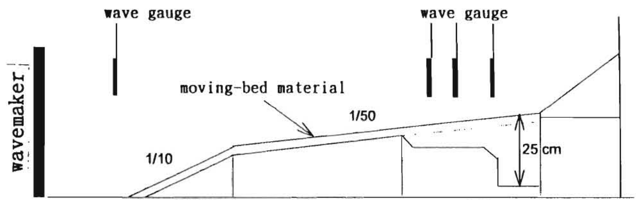

Figure 2. The profile of the test basin.

The front face of the seawall was built with wood plates with a layer of concrete block covered on its face. Beneath those wood plates was a hollow space, allowing water to pass by. The seawall crest height has such an elevation that the incident waves would never overtop. The seawalls with four front slopes of tan θ = 1/2, 1/3, 1/4 and 1/7 were installed, respectively.

The wave generator can generate waves with wave height of up to 25 cm and wave period between 0.75 to 4 sec. Four wave gauges of capacitor type were installed in the basin. Their locations are shown in Figure 1.

Water surface variation were detected with these wave gauges and recorded by PC through an AD converter. Wave data were collected every 0.025 sec. Three water levels were adopted in tests. They were 10, 16 and 24 cm in depth at the seawall, respectively. Wave periods in tests ranged from 1.0 sec to 2.0 sec and wave heights ranged from 3 to 8 cm.

Bed surface variations were surveyed with a sand surface

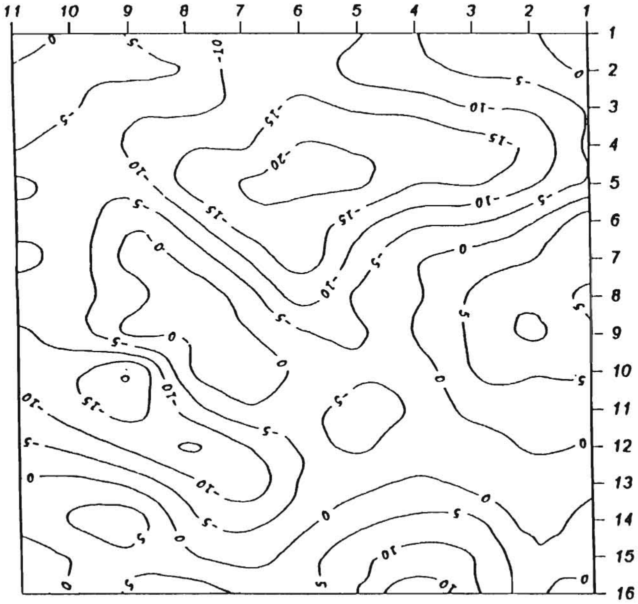

Figure 4. Contour lines of the scour depth or accretion height (tan θ = 1/2, d = 16 cm, H = 6 cm, T = 1.0 sec, surveyed at 6th hour).

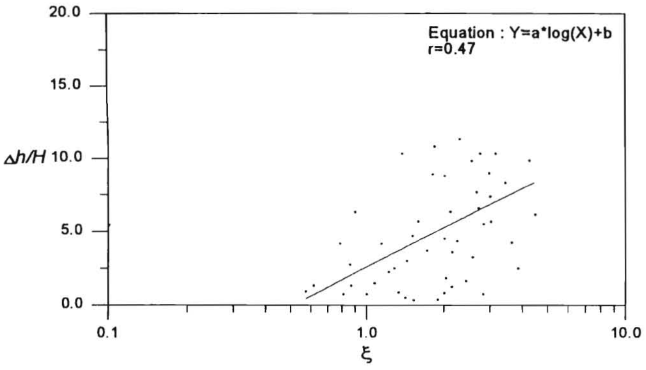

Figure 5. Nondimensional scour depth versus the surf parameter.

detector WH-201. The measured area, 150 cm × 160 cm, covered the middle third region in front of the seawall as shown in Figure 3. In this region eleven lines in line with the incident wave direction were surveyed. The spacing from line to line is 15 cm. Along each line, the bed surface was measured at an interval of 10 cm. These bed-surface surveyings were carried out before waves started and at 1st, 3rd, 6th hours, respectively, after waves were generated.

RESULTS AND DISCUSSIONS

It was mentioned above that bed elevation was surveyed whenever at the 1st, 3rd and 6th hour after waves were generated. The surveyed bed elevation was then compared with the original elevation at correspondent points, thus the scour depth or the accretion height can be obtained. Based on these results isoclines were drawn showing lines of the same scour or accretion depth. Figures 4 represents one of them. Since maximum scour in front of the seawall was focused in this study, the deepest scour depths were picked up from these figures. These deepest scour depths obtained at different stages under a wave condition were compared. It was observed that the maximum scour depth took place either at the 3rd or 6th hour. Then the maximum one was considered as the maximum scour depth under that wave condition.

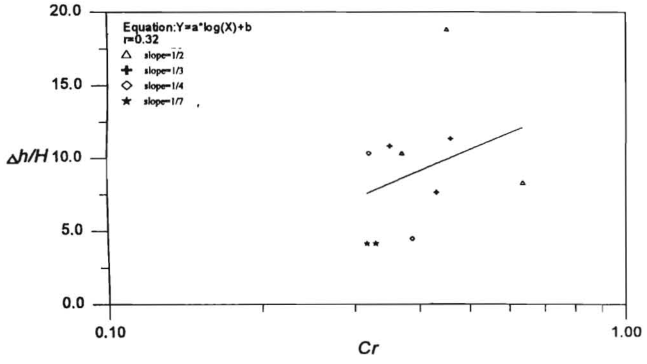

Figure 6. Nondimensional scour depth versus the reflection coefficient (d = 10 cm).

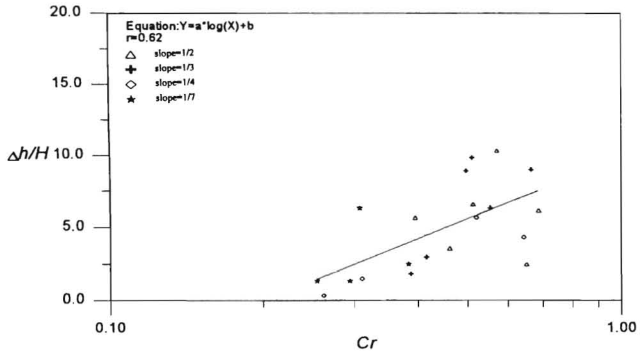

Figure 7. Nondimensional scour depth versus the reflection coefficient (d = 16 cm).

They are designated as Δh and first plotted against the surf parameter based on (5). The results are shown in Figure 5. It can be seen in this figure that generally, the larger the surf parameter the deeper the scour depth, but, they are not well related. Note that the wave heights used in this paper were obtained based on the three wave gauges located in front of the seawall. Therefore, the wave heights are of shallow water wave. And the wave lengths are calculated according to water depth at seawall toe. Both of the wave height and period are not considered to be affected significantly by the local scour, because the scour appeared in a form of pits and trenches and took place only in the very vicinity of the seawall.

Many investigators claimed that the scour depth has a close relation with the reflection coefficient. Therefore, we may try to examine (4) by plotting the scour depth against the reflection coefficient. Results are presented in Figure 6, 7 and 8 with water depth of 10, 16 and 24 cm, respectively. The regression curves are also shown in these figures. They indicated that the scour depth increases with increasing reflection coefficient. However, the two parameters are not closely related.

Finally, we would like to examine the expression of (3),

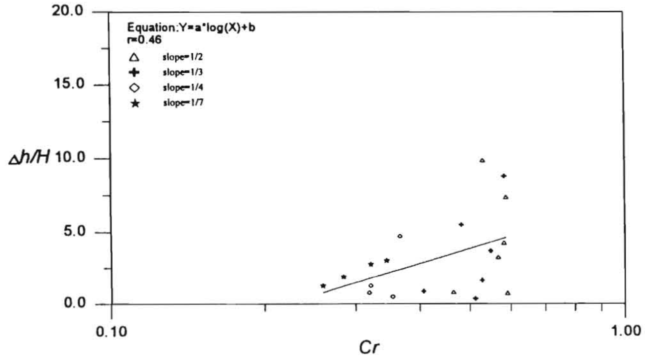

Figure 8. Nondimensional scour depth versus the reflection coefficient (d = 24 cm).

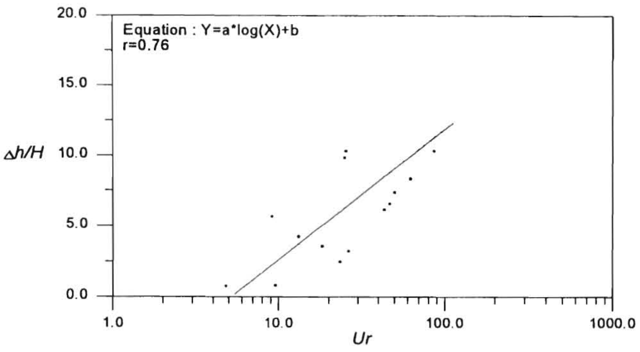

Figure 9. Nondimensional scour depth versus the Ursell parameter for tan θ = 1/2.

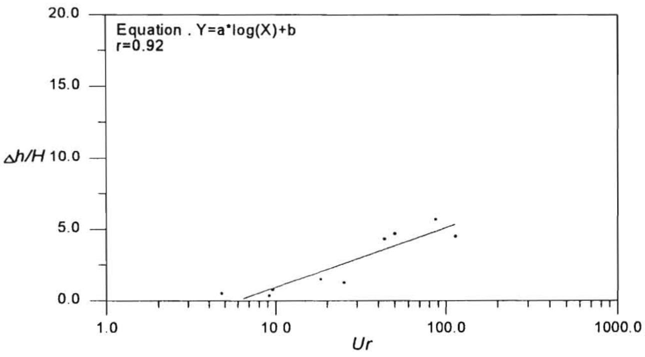

Figure 11. Nondimensional scour depth versus the Ursell parameter for tan θ = 1/4.

with Δ h/H versus the Ursell parameter (Ur) for varied tan θ. The results are shown in Figures 9 to 12 with front slopes of tan θ = 1/2, 1/3, 1/4 and 1/7, respectively. It is observed that the maximum scour depth increases with increasing Ursell parameter. The relationship between Δh/H and the Ursell parameter for varied front slopes is well related. Therefore, it is concluded that the scour depth in front of the seawall could be described by the Ursell parameter and the front slope of the seawall. To compare the scour depth in front of the seawalls with different front slopes, four curves shown in Figures 9–12 are plotted together in Figure 13. It can be clearly seen that the scour depth in front of the seawall with tan θ = 1/4 is much smaller than that with tan θ = 1/2 or 1/3, but slightly deeper than that with tan θ = 1/7. Since the seawall with front slope of tan θ = 1/7 has much larger section than that with tan θ = 1/4, the seawall with tan θ = 1/4 may gain an advantage over the one with tan θ = 1/7 if an economic factor is considered. This trend is just the same as that observed by Twu and Chiou (1994) in their two-dimensional hydraulic tests.

CONCLUSIONS

The scour depth in front of the seawalls with varied front slopes was studied. A three-dimensional wave basin was used to conduct a series of moving bed hydraulic tests in an attempt to produce short-crested waves in front of the seawall, which is believed to be significant in causing the scour. The relation of the scour to several parameters has been examined. Experimental results showed that the scour increases with increasing either the surf parameter or reflection coefficient, but they are both not well related. However, if we express the scour in terms of the Ursell parameter as well as the front slope of the seawall, a better relation of the scour with the two parameters are found.

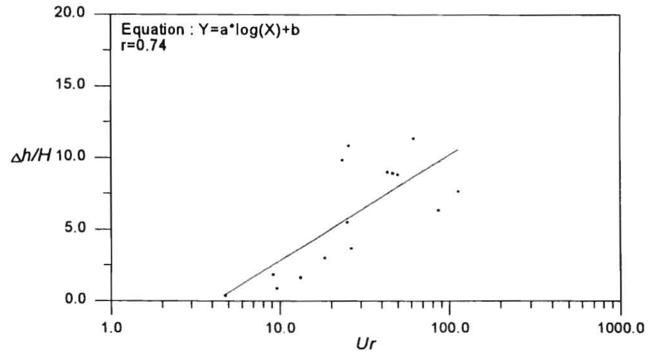

Figure 10. Nondimensional scour depth versus the Ursell parameter for tan θ = 1/3.

Increasing either the Ursell parameter or the wall slope would make the scour worse. Nevertheless, it is realized that the scour depth in front of the seawall with tan θ = 1/4 is much less than that with tan θ = 1/2 or 1/3, but is only slightly more than that with tan θ = 1/7. This trend observed in three-dimensional tests is just the same as that obtained in two-dimensional tests conducted by Twu and Chiou (1994).

Since the seawall with tan θ = 1/7 possesses much larger section and occupies more base area than tan θ = 1/4, the latter may be suggested as a favorite option for the front slope of the seawall if both the scour depth and economical cross-section factor are taken into consideration.

Kraus and Mc Dougal (1996) recommended to cease conducting small-scale physical models due to scale effect. Nev-

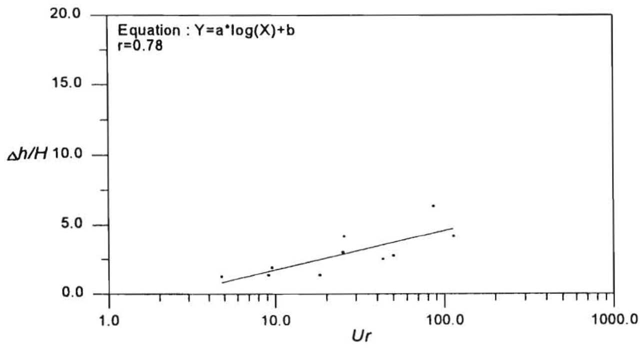

Figure 12. Nondimensional scour depth versus the Ursell parameter for tan θ = 1/7.

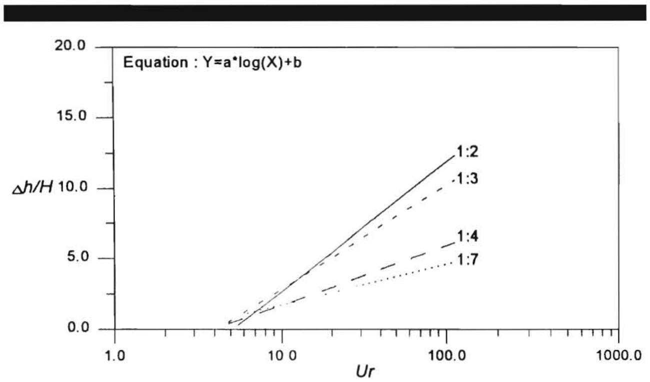

Figure 13. Nondimensional scour depth versus the Ursell parameter for varied tan θ.

ertheless, the result obtained in this study is believed to be informative, because both two dimensional tests conducted by Twu and Chiou (1994) and three dimensional tests presented in this paper have shown the same trend. Besides, it is known that the small-scale model has the advantage of less consumming in both manpower and money compared to a large-scale model, especially for a three dimensional model. A large scale model is, of course, suggested to be conducted to verify the information provided by this paper, if any institute has the budget to carry out tests on this topic.

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