CHAPTER 177

EFFECTS OF CONTROLLED WATER TABLE ON BEACH PROFILE DYNAMICS

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ABSTRACT

The purpose of this study is to improve general understanding of beach profile dynamics as affected by the interaction between the beach profile and the water table level within the beach by presenting the results of laboratory and numerical studies. Two series of laboratory experiments were conducted in "large" and "small" wave tank facilities. Special attention was given to elevated water table levels to investigate whether or not erosion of the beach face is enhanced. The results of the large wave tank experiments demonstrated a surprising influence of beach water table on profile dynamics including changes in the bar region. Although the experiments in the small wave tank used correctly scaled sand, it was found that the effects documented in the large scale tests could not be duplicated. Furthermore those results were supported by numerical simulation of the internal flow inside the beach. One possibility for the difference is that the sand in the large scale tests was more poorly-sorted than that in the small scale experiments.

INTRODUCTION

For a permeable beach, we would expect an internal flow within the beach, which might be driven by the mean pressure due to the ground water table level inside the beach and/or wave induced set-up. If the mean pressure gradient is large enough to stabilize or destabilize the sand particles, it may affect the sand transport and resulting profile evolution.

Attempting to demonstrate the effect of percolation, Bagnold (1940) prevented free percolation through the sand by placing an impermeable steel plate just below the sloping beach surface. The thin layer of the sand above the plate was at once removed as soon as waves attacked, resulting in erosion of the beach.

Grant (1948) noted, by observations of the fluctuations in the width and slope of beaches in southern California, that the position of the ground water table

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within the beach played an important role on deposition and on erosion of the foreshore and backshore. He suggested that a higher water table than mean sea level accelerated beach erosion, and conversely, a lower water table might result in pronounced aggradation of the beach. Emery and Foster (1948) found that the escape of water from the lower part of the beach may exert an appreciable upward force on the sand particles, sufficiently large to destabilize them, resulting in erosion of the beach.

Based on possibilities of beach stabilization, test installations of the beach drain system have been conducted in the laboratory and in the field; this approach consists of burying a pipeline along the beach to maintain the water table level at a lower one than the mean sea level by pumping.

Machemehl, French and Huang (1975) conducted laboratory experiments to determine the effects of a sub-sand filtering system on the stability of a beach profile, which consisted of well pipes buried perpendicular to the shoreline and pumping 136.3 $cm^3/s/$(m of beach). The results showed that the drain system caused deposition on the beach face and stabilized the sand at the offshore zone by inducing a flow into the beach, but it had a negligible effect in the breaking zone since turbulence by wave breaking was too strong to be controlled by the drain system.

Kawata and Tsuchiya (1986) performed laboratory experiments to examine the effects of beach drain for the case of solitary and regular waves on the beach face. With a relatively fine sand for the solitary wave tests, the beach face was much steeper with pumping than non-pumping cases. With much coarser sand for the regular wave cases, it was recognized that the pumping system was effective under storm wave conditions by reducing the sand transport, thus stabilizing the beach near the shoreline.

Terchunian (1988) reported on a prototype beach drain system installed along 180 m of the beach at Sailfish Point on Hutchinson Island, Florida. The system had been in operation over two years and beach profiles were taken monthly to determine the efficiency of the system. The system appeared to result in a stabilization of the beach as moderate accretion occurred while the updrift and downdrift beaches showed erosion.

However, the interaction mechanism of beach drain system is not obvious since some laboratory results appeared to result in no significant effects of water table levels on the beach profile changes. Bruun (1989) claimed that the method ought to be more effective in mild conditions than storm conditions as the velocities (and energy levels) are far higher in the surf zone during a storm. Ogden and Weisman (1991) performed two-dimensional laboratory experiments to assess the effectiveness of a beach drain system on stabilization. Tests were carried out with a very fine sand (median diameter of 0.145 mm) under irregular waves. Even with a fairly long duration of waves, they could not find any significant differences in the final profiles. They suggested that the beach drain would not be effective where there is a negligible tide.

This paper presents the results of laboratory studies to investigate the effects of controlled water table on beach profile dynamics. To achieve this goal, two series of experiments were conducted in "large" and "small" wave tanks at three different water table levels while the other factors (e.g., wave height, wave period, water depth, initial beach slope, etc.) were fixed to constant values with regular waves. The water table levels included : (a) normal water table level which is the same as mean sea level, (b) a higher level and (c) a lower level than the mean sea level. Special attention was given to elevated water table levels to investigate whether or not erosion of the beach face is enhanced. The results of numerical studies are also presented to simulate the internal flow inside the beach and to understand the interaction mechanism.

LARGE WAVE TANK EXPERIMENTS

The first experiment was conducted in the "large" wave tank facility of the Department of Coastal and Oceanographic Engineering at the University of Florida, which is approximately 36 *m* long, 1.8 *m* wide and 1.8 *m* deep. A long partition has been constructed along the tank center line dividing it into two channels each of 0.9 *m* width. A planar beach was formed with initial slope 1:18 and composed of poorly-sorted fine sand with a median diameter of 0.24 *mm* and a sorting coefficient of about 1.0. (At first, the beach was considered as composed of well-sorted fine sand with a median diameter of 0.2 *mm* and a sorting coefficient of 0.5. However, it was found that the fine sand was underlain by well-sorted coarse sand with a mean diameter of 0.4 *mm*, which appeared to affect the overall permeability of the beach.) Regular waves with a period of 2.0 *seconds* and height of 0.16 *m* were generated. The water depth at the toe of the beach slope was 0.47 *m* at mean sea level. Details are provided in Oh and Dean (1992).

The experiment was conducted at three different water table levels, which were regulated sequentially to: (1) normal water table level which was the same as mean sea level (1.5 *hours*), (2) a higher level (+11.0 *cm* during 2.0 *hours*) and (3) a lower level than the mean sea level (-11.0 *cm* during 1.5 *hours*). The duration of each test with the same water table level was determined based on an assessment that the beach profiles were near equilibrium and would not significantly change beyond this test duration. Throughout the test program, the beach profiles were monitored at one-half hour intervals.

The higher water table (at 1.5 *hours*) was established by raising the entire water level in the wave tank and allowing the ground water table to equilibrate with no waves acting. The tank water level was then lowered and the water table level in the beach was maintained by excavating a small depression in the berm below the desired water level, which was then maintained by filling periodically with a hose. For the lower water table, the procedure described above was followed except that water was siphoned out of the excavated hole in the beach berm to maintain the desired level.

SMALL WAVE TANK EXPERIMENTS

A total of 8 "small" wave tank experiments was carried out (1) to evaluate the repeatability of the large wave tank experiments and (2) to illustrate beach profiles that would have occurred if the water table had not been altered or regulated with different sequences from the first experiment. This tank is 15 *m* long, 0.9 *m* high and 0.6 *m* wide, and is equipped with a piston type wavemaker with a mechanically controlled motion and with one glass wall panel and one steel wall.

Table 1 lists the experiment identification number, total wave run duration, water table level condition, and a brief description of each experiment. The experiments were scaled from the large wave tank experiment according to the fall velocity parameter (Dean, 1985) for a well-sorted fine sand with mean diameter of 0.21 *mm* and a sorting coefficient of 0.5 with a length scale of 1:1.7, and the waves were modelled according to the Froude relationship. Regular waves with a period of 1.5 *sec* and a height of 11.0 *cm* (rather than 9.5 *cm* as would be required by scaling) were used due to wavemaker limitations, and were measured by a capacitance-type wave gage. Figure 1 presents a schematic diagram of the initial profile and other experimental details.

Table 1: Description of Small Wave Tank Experiments

Exp.	Water Table Level		Note
No.	Duration(*min*)	Level(*cm*)*	
SW01	230	0.0	Reference test
SW02	230	+6.5	High water table level
SW03	230	-6.5	Low water table level
SW04	0-69 69-161 161-230	0.0 +6.5 -6.5	Repeat test of Large wave tank experiment
SW05	0-69 69-161 161-230	0.0 -6.5 +6.5	Effect of sequence of changing water table level
SW06	0-69 69-545	0.0 +11.0	Elevated water table level
SW07	0-1166	+16.5	Elevated water table level
SW08	0-890 890-2201	-11.0 +11.0	Lowered water table level Elevated water table level

* Zero refers to the mean sea level (MSL). Hence, positive vale represents the water table level above MSL.

The desired water table level in the berm was maintained by excavating 2-D depressions across the tank. These excavations were connected to a constant

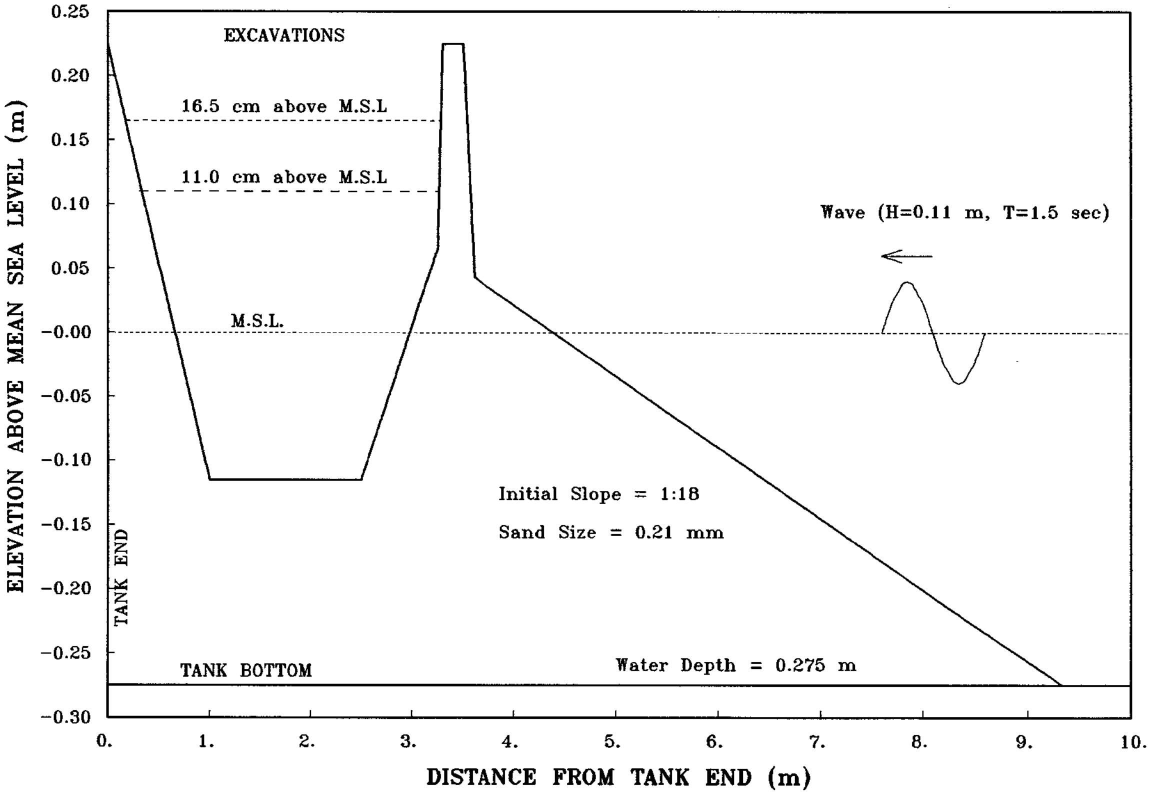


Figure 1: Schematic Diagram of the Initial Profile and Other Experimental Details

head reservoir through plastic tubes so that water was siphoned out of or into the excavated holes to maintain the desired water table level. During the experiments, this method worked very well. However, bubbles appeared sometimes inside the tubes due to prolonged experimental duration; at which time, they were removed by allowing a small amount of flow from the excavated holes to the reservoir, or vice versa.

INTERACTION MECHANISM

Consider a sand particle, as shown in Figure 2, on the bed which has a slope θ and experiences a lift force F_L, a portion of which is due to an upward or inward flow perpendicular to the sand surface.

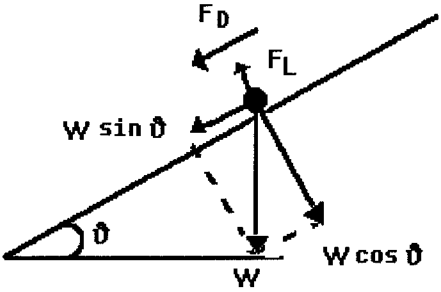


Figure 2: Free Body Diagram for a Sediment on a Sloping Bed with an Internal Flow System

The critical Shields parameter for motion downslope can be written as;

$$\frac{W \sin\theta + F_D}{W \cos\theta - F_L} = \tan\phi_s \tag{1}$$

where, W is the submerged weight of the sediment, θ is the bed slope, ϕ_s is the angle of repose of the sediment, and F_D is the drag force acting on the particle. The lift force component due to the flow out of bed, F_L', can be expressed as;

$$F_L' = \frac{u}{K}\rho g V \tag{2}$$

in which, u is the average flow velocity perpendicular to the sand surface, K is the hydraulic conductivity (or permeability), ρ is the mass density of water, g is the gravitational acceleration, and V is the volume of the sediment. Finally, the critical Shields parameter, ψ_c, as affected by both the bed slope and the internal flow system, can be given as;

$$\frac{\psi_c}{\psi_{c0}} = \cos\theta \left[1 - \frac{\tan\theta}{\tan\phi_s} - \frac{u/K}{(s-1)\cos\theta} \right] \tag{3}$$

where, ψ_{c0} represents the critical Shield parameter on the impermeable bed with no slope, and s is the ratio of mass densities of sediment to water. In order to reduce the effective weight of the sand particles and therefore their stability, hence, the upward flow velocity should be sufficiently large or local slopes of the beach should be quite steep, where the sand particles had marginal stability.

NUMERICAL MODELING

Considering a beach of uniform porosity with internal flow velocity that obeys Darcy's law, the internal flow system is governed by the Laplace equation;

$$\nabla^2\phi = 0 \tag{4}$$

where, ϕ is the hydraulic head defined as;

$$\phi = z + \frac{p}{\rho g} \tag{5}$$

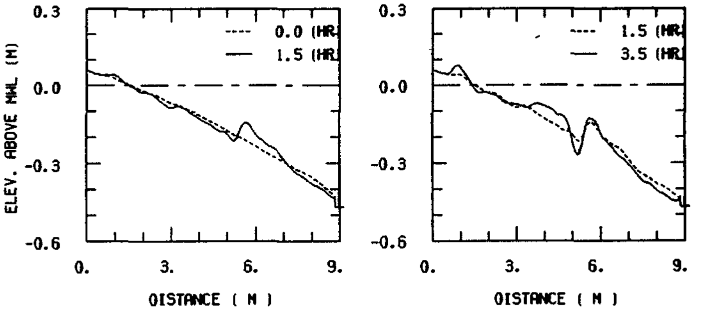
in which, z is the elevation from the tank bottom, p is the pressure, ρ is the mass density of water, and g is the gravitational acceleration. Equation (4) can be solved efficiently by the Boundary Integral Equation Method (BIEM) if the proper boundary conditions are given at the tank bottom, beach profile, seepage face, phreatic surface inside the beach and lateral ends of tank. The transient state can be included in Equation (4) through the time-varying boundary conditions at the beach profile and phreatic surface; however, steady-state was considered in this paper. If ϕ is known, then the internal flow velocity can be computed from Darcy law;

$$\mathbf{u} = -\mathbf{K}\nabla\phi \tag{6}$$

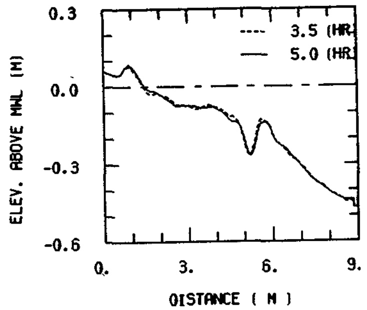
where, $\mathbf{u}$ is the average velocity across a given area of sand, and K is the hydraulic conductivity. In this paper, hydraulic conductivity was measured by using a permeameter based on constant/variable method, and was found to be 0.022 *cm/sec* for the sediment used in the small wave tank experiments.

RESULTS AND DISCUSSIONS

As illustrated in Figure 3, the results of the large wave tank experiments demonstrated a surprising influence of beach water table on profile dynamics including changes in the bar region. Figure 3 shows the profiles during normal, higher and lower water table levels. During normal water level, sand was transported both onshore and offshore resulting in deposition at the berm and at the bar, and the profiles were approaching an equilibrium. As soon as the higher level was established, however, very large changes occurred at the bar crest with relatively smaller changes at the bar trough; the bar started to move landward rapidly at the initial stages and stayed stationary at the later times. During the higher level, sand was transported onshore and deposited at the berm and at the depositional area located immediately landward of the bar trough. The increased water table level caused a strong landward transport, which is contradictory to previous studies that higher water table level enhances erosion. However, there was erosion immediately seaward of the berm. Also it can be seen that relatively small changes occurred with the lower water table level. The only noticeable trend was a limited deposition in the scour hole at the base of the beach face.



(a) NORMAL WATER TABLE (b) HIGHER WATER TABLE



(c) LOWER WATER TABLE

Figure 3: Profiles during Normal, Higher and Lower Water Table Levels in the Large Wave Tank Experiment

Based on the results of the large scale tests, the following can be concluded: (1) the effect responsible for the changes in the profiles appeared to be a destabilization of the bottom particles in areas of pre-existing marginal stability with the eroded particles transported to stable areas, (2) the increased water table appeared to be effective far offshore, which was somewhat surprising, and (3) the lowered water table appeared to result in a much more stable beach by introducing a downward flow into the beach and the resulting effects were much less.

Although the experiment in the small wave tank used correctly scaled sand, it was found that the effects documented in the large scale tests could not be duplicated. In fact, all of the various small scale test results were nearly the same up to a testing time in excess of 3 *hours*. Based on the conclusions drawn above, several possible causes can be considered: (1) effects of coarser sand layer overlain by fine sands in the large wave tank experiments, (2) more poorly-sorted sand in the large scale tests than that in the small scale tests, (3) different wave height from that required by scaling, and (4) microorganisms inside the beach under prolonged submergence, which may influence the sand permeability. Other possibilities could be explained by the numerical studies.

As shown in Figure 4, calculations demonstrated that a small upward flow of water emerged through a porous sand bed, which is driven by wave-induced set-up only within a linear beach. However, the magnitude of the ratio $\frac{u}{K}$ appears too small to reduce the effective stability of the sand particles. Even with a fairly steep beaches, as shown in Figure 5, the effect of upward flow was not significant although the overall stability of the bottom particles on the steep beaches was reduced due to the effect of the slope. Higher water table levels intensified the magnitude of the internal flow, as shown in Figure 6; however, the effect of upward flow appeared to be small compared with the effects of steep slope. Hence, these results of the small scale tests suggested that the altered water tables had no effects on the beach profile dynamics, which is contradictory to the conclusions from the large scale experiments. More definite conclusions can be reached only by further research including a more comprehensive comparison of numerical modeling results with measurements.

CONCLUSIONS

Based on the present laboratory and numerical studies, the following conclusions and recommendations are described.

Large scale tests demonstrated that upward flow of water emerged through a porous sand bed due to both the higher water table level and wave-induced set-up and appeared to destabilize the bottom particles in areas of pre-existing marginal stability with the eroded particles transported to stable areas. However, the effects documented in the large wave tank experiments were not verified by the small scale experiments even with the correctly scaled sand. Furthermore, numerical results on the steady-state beach system supported the small scale test results. Several possible reasons were suggested, which need further study.

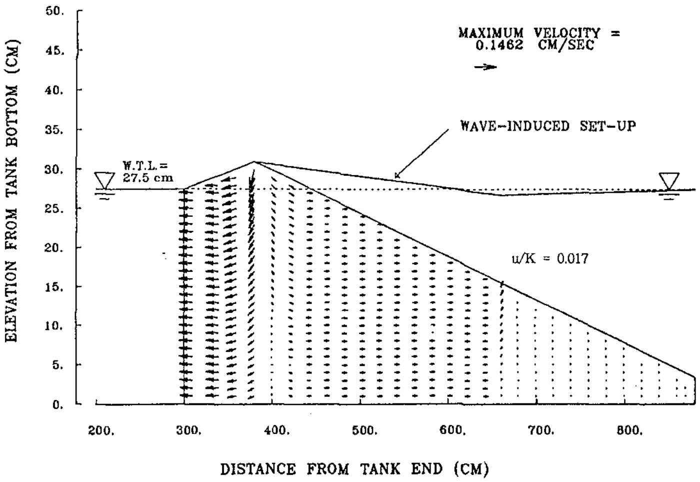


Figure 4: Internal Flow by Wave-Induced Set-Up within a Beach of Uniform Slope

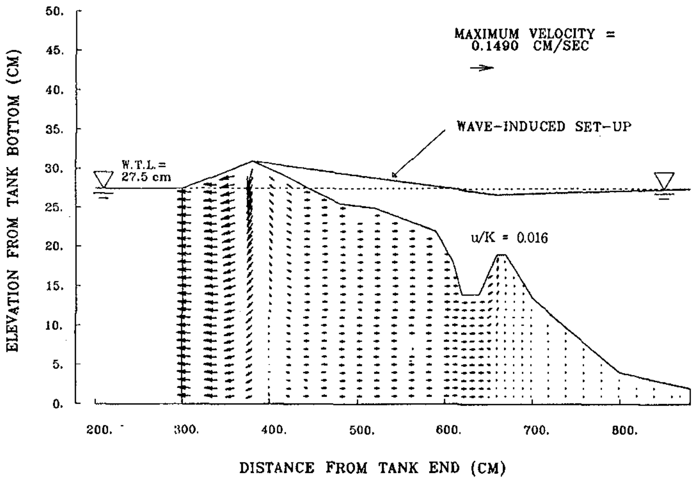


Figure 5: Internal Flow by Wave-Induced Set-Up for a Typical Beach Profile

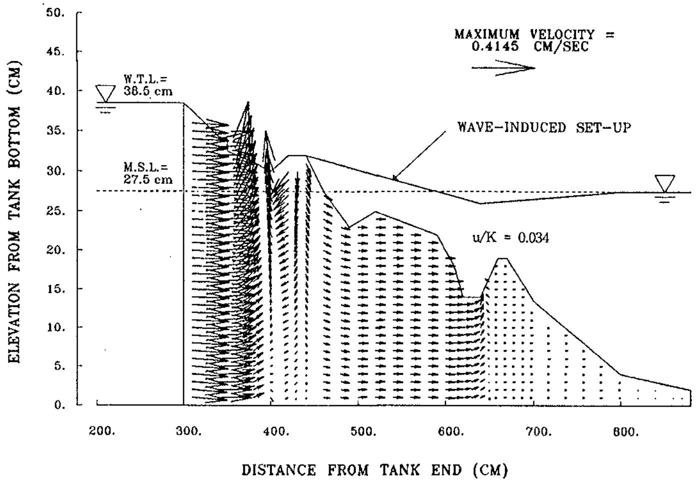


Figure 6: Internal Flow by Wave-Induced Set-up and Elevated Water Table Level for a Typical Beach Profile

There is a substantial need for additional carefully controlled laboratory experiments with different range of sediment sizes and sorting (thus permeabilities) from the present experiments. The numerical modeling should be improved to include the transient state boundary conditions and the effects of coarser sand layer overlain by fine sands as in the large scale tests.

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