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CROSS-SHORE SEDIMENT TRANSPORT DUE TO WAVE: A LABORATORY STUDY

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ABSTRACT

A study was carried out in the Hydraulics and River Engineering Laboratory of Water Resources Engineering Department, BUET to investigate the cross-shore sediment transport process by wave induced current. Wave is an important parameter for near-shore sediment transport. Morphological changes in the nearshore coastal area is governed by wave as it generates velocity, so in laboratory flume an artificial beach profile with a slope of 1:15 was developed to observe the sediment transport process. In this set-up non-breaking wave was generated by using wave maker in a glass sided laboratory flume (70 feet long and 30 inch width). In this flume waves were generated for 1 hr 15 minutes with different water depth and wave period to measure the velocity at different locations on the slope. A 3.0 cm thick sand bed was used on the slope with d50 value ranging from 0.11mm-0.2mm for each run. The final bed elevation was measured after completing each run at different locations to understand the sediment transport process. Comparing to others (tide and wind), wave generated velocity is the simplest one but is an important parameter for sediment transport. This study provides information regarding the process of sediment transport due to wave in the cross-shore direction due to varying water depth and wave parameters in the laboratory. The wave generated velocity depends on the wave height, water depth, wave period etc; hence the change of bed elevations also depends upon these parameters. In this paper the changing pattern of bed elevation (sediment transport) with different wave parameters is presented.

The results obtained from the laboratory experiment showed good agreement with the change of different initial parameter like wave period and water depth. From the analysis it is observed that the changes of bed level depend on water depth and wave period greatly as well as the wave height.

***Key words**: cross-shore, sediment transport, wave.*

1. INTRODUCTION

Nearshore and beach formation problems often require an understanding of sediment movement. Wave is the predominant factor for the sediment movement. Waves stir up the sediment with different threshold conditions. The current on the other hand carries the sediment to the long-shore direction. Such flows generate shear stresses on the bed which are modifications of the shear applied by either flow alone. Bed shear stress under either unidirectional or oscillatory flows is also another important factor for the sediment to move. For oscillatory flow, Bagnold (1963) reasoned that the wave-induced oscillatory water motion causes the sediment to be moved back and forth with a net expenditure of energy. Although no net transport results from the oscillatory flow, the energy dissipation acts to support the sediment in an amount proportional to the local energy dissipation rate. The governing parameter for sediment transport in the cross-shore direction is wave and its direction with the shoreline. The types of wave may be both breaking and non-breaking. This study has been conducted in the laboratory of Hydraulics and River Engineering Laboratory under the Department of Water Resources Engineering, BUET by forming non-breaking waves in the flume.

Wave-induced transport processes are related to the velocities generated by high and low-frequency wave phenomena. Net onshore transport is dominant in non-breaking wave conditions, whereas net offshore transport is dominant in breaking wave conditions (Van Rijn, 1990). In the non-breaking zone the sediment transport pattern is more or less simple, but for breaking zones the process exhibits rather complex and intricate pattern (Zhou, 2001). Few attempts to relate the sediment transport/erosion process in a controlled laboratory observation have been made. Threshold conditions for homogenous sands in combined flows have been examined for co-linear conditions (George and Sleath, 1979; Hammond and Collins, 1979) and for waves and currents acting perpendicular to each other (Lee-Young and Sleath, 1988). Likewise, co-linear interactions above a mixed sand bed have been studied to examine erosion processes rather than the associated flow parameters (Tomlinson, 1993). The mechanism of coastal sediment transport can be defined as: Wave stirs up sediment and current transports the sediment. This study is confined in a narrow scale as the only mode of sediment transport process is due to wave and wave generated current, which transports the sediment to the cross shore direction.

When mean currents due to current are weak, nearshore sediment transport is driven predominantly by wave-orbital velocities (Fredsoe and Deigaard, 1992). As waves shoal, their shapes become skewed (relatively sharp crests and broad, flat troughs) and asymmetric (pitched forward, with steep front faces and gently sloping rear faces) (Hsu et al., 2006). During the passage of the steep front faces of asymmetric waves, fluid is accelerated strongly as the orbital velocity rapidly changes from maximum offshore to maximum onshore (e.g., Elgar et al., 1988, and Gallagher et al., 1998). The symmetrical wave induced sediment transport is evaluated by energetic procedure. Energetics process for evaluating sediment transport process is driven with moments of time series of fluid velocities measured above the bottom boundary layer. It suggest that offshore bar migration or the sediment transport, observed when incident waves are energetic, is driven by strong offshore-directed mean currents that are maximum near the bar crest (Thornton et al., 1996; Gallagher et al., 1998). An energetic process explains that sediment transport is associated with the strong flow accelerations under steep wave faces (Hoefel and Elgar, 2003) which suggests that onshore sediment transport is observed when incident wave energy is moderate and mean currents are relatively weak. This is also related to the change in cross-shore gradients of beach profile. Hsu, et al. (2006) suggest that when mean-current-induced transport is small, wave-induced transport leads to the observed onshore bar migration, or the sediment transport. This experiment was carried out in the laboratory, where symmetrical waves were generated by wave generator with different wave period with varying water depth.

2. EXPERIMENTAL SETUP

The experiment was carried out in a 70 ft (21.34 m) long, 30 inch (0.762 m) wide and 30 inch (0.762 m) deep rectangular tilting flume (Fig.1) in the Hydraulics and River Engineering Laboratory under the Department of Water Resources Engineering, BUET. The side walls of the flume are made of glass and the bed is painted by water resistance color to avoid any unnecessary bed friction development. In this flume wave generator was set at one end and at the other end the defined 1:15 slope was placed. On the slope a 3.0 cm sand layer with d50 value ranging between 0.11 mm to 0.24 mm. The flume consists of a reservoir and a stilling chamber which is located behind the wave generator. Flume bed was kept horizontal and it is supported on an elevated steel truss. The height of the flume is limited to carry out runs in large-scale experiment. After the wave generator, several numbers of screens were set to reduce the wave reflections made of coarse wire mesh.

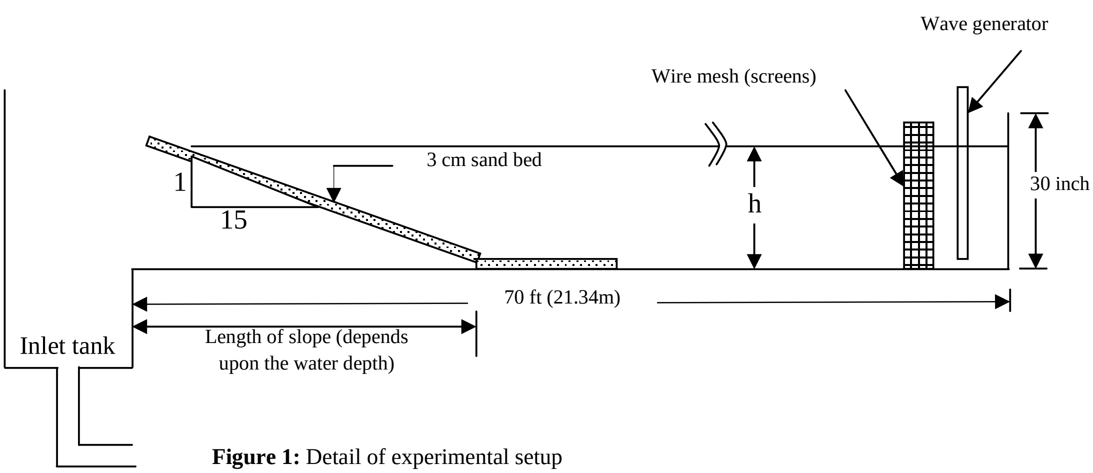

Figure 1: Detail of experimental setup

3. METHODOLOGY

The experiment was conducted with different test scenarios (Table1). The bed profile was measured with the help of point gauge after completing each run with different water level and wave periods. The run period was taken as 1 hour 15 minutes. This period was chosen after conducting several test runs. For different wave periods, the setting procedure of the wave generator was an essential task as the motor requires different number of rotation with changing wave period. Designated stepwise procedure was followed for generating non-breaking wave in the laboratory flume.

Table 1: Experimental Scenario

Water Depth (cm)	Wave Period (sec)	Wave Height (cm)
50	1	11.0
	2	12.0
40	1	11.0
	2	11.8
35	1	10.6
	2	11.9

4. DATA ANALYSIS

The bed elevation after each run was measured and the obtained data were plotted to calculate the final volume of the cohesion less sediment. Data were plotted in AutoCAD, where 270 cm length along the slope of artificial beach was taken as the area of interested.

Here, total 9 segments were taken (Fig. 2) and the length of each segment was 30 cm. The starting of first segment was from zero water depth (still water level) and it extends towards the deep water.

The measured wave run-up length was other point of concentration. The bed profile of wave run-up area (zero water depth to the end of wave run-up) was plotted by the same way and total volume of sand was calculated per unit width of the flume.

5. RESULTS AND DISCUSSION

The sediment movement pattern or the change of total sediment volume can be observed from Fig.3 to Fig.5. From these figures it may be stated that, along the cross-shore line (i.e. below the zero water depth) the onshore movement of sediment is prominent when the water depth is low, but for higher water depth the sediment movement characteristics is towards the off-shore area. This analysis shows that for higher water depth and wave period the sediment movement in the off-shore region increases (Table 2).

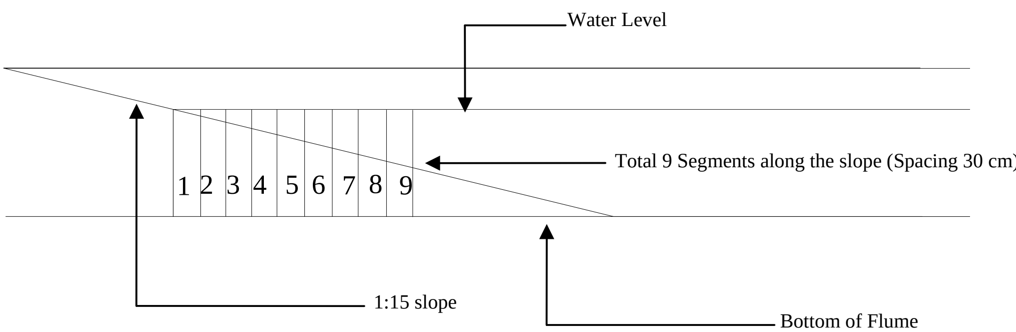

Figure 2: Schematic diagram of studied region

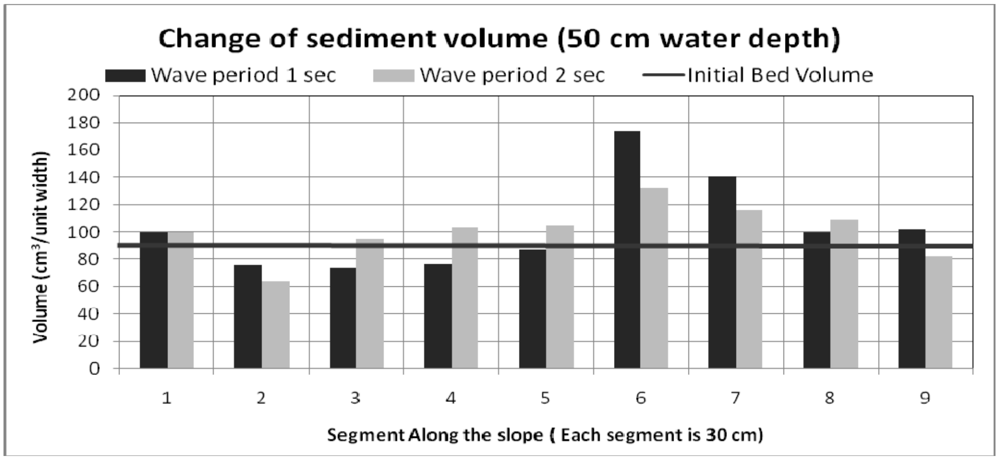

Figure 3: Change in sediment volume for 50 cm water depth

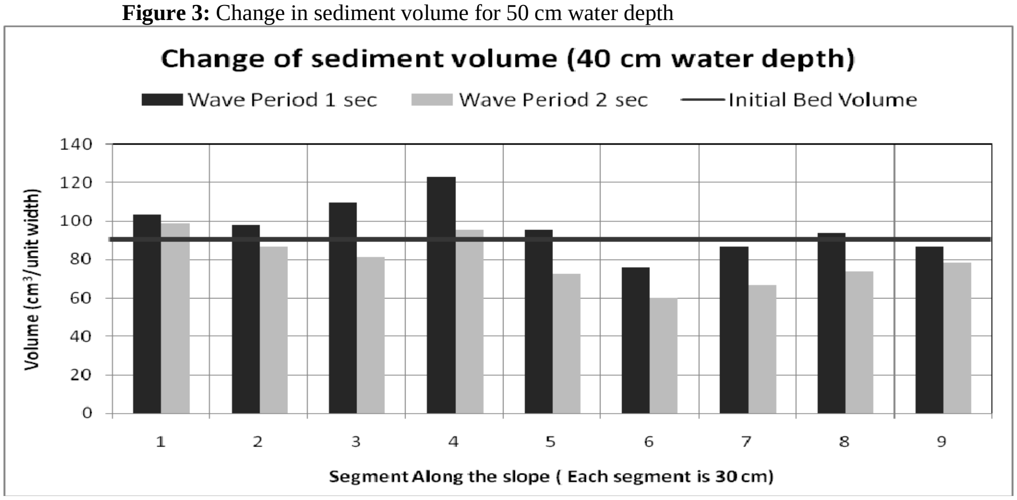

Figure 4: Change in sediment volume for 40 cm water depth

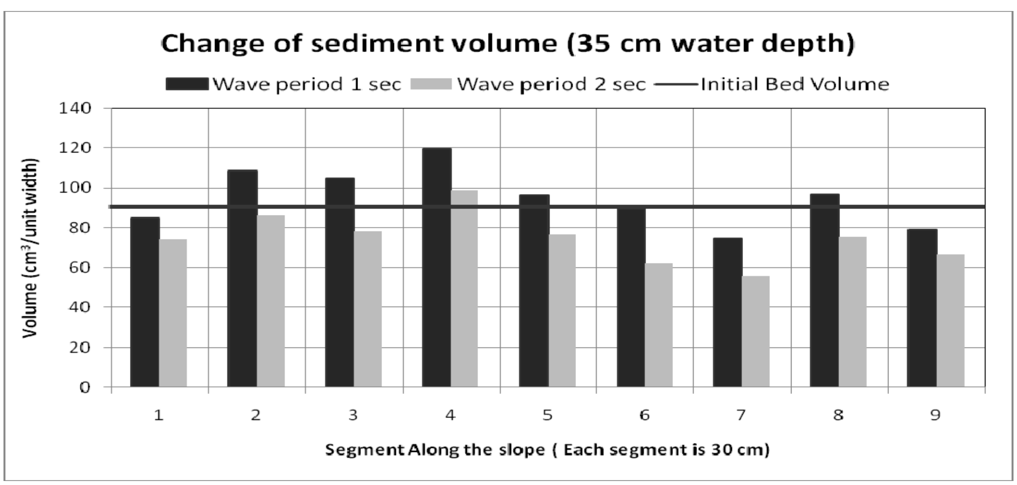

Figure 5: Change in sediment volume for 35 cm water depth

But for the same wave period (2 sec) the total volume of sediment or bed material decreases form the initial volume in case of lower water depth (35cm and 40cm) though the change of overall sediment volume is increased (Table 4). In the wave run-up zone the rate of accumulation of bed material is increased with the increase of wave period and water depth. This is due to the increase of wave energy which is active in the onshore area of the slope. In this zone the effect of wave period plays a significant driving force for sediment transport, as in this experiment only the fine cohesionless sand is used so, the effect of cohesive and coarser material on the transport cannot be interpreted.

Table 2: Change in volume below zero water depth upto 270 cm along the slope

Water Depth (cm)	Wave Period (sec)	Actual sand Volume (cm^3/ unit width)	Final sand volume (cm^3/ unit width)	Change in volume (cm^3/ unit width)
50	1	810	930.05	120.05
	2	810	906.90	96.90
40	1	810	893.77	73.77
	2	810	734.75	-75.25
35	1	810	855.07	45.07
	2	810	675.48	-134.53

From the data (Table 3) other important parameter, wave run-up value, about sediment transport in the nearshore zone can be identified. This experiment suggests that with lower wave period the wave run-up value is lower and vice-versa. Hence the onshore movement of sediment for higher wave period is more compare to lower wave period. This can be described as, the wave period increases the time of incident wave in the surf zone also increases and the orbital velocity also increases. Hence it gets more time for sediment mixing in the water and the suspended sediment is carried by the wave induced current towards the onshore zone. The experimental results also support this phenomenon. But for the off-shore zone there is a great deal of variation. As it is known that the wave orbital velocity increases with the increase of wave period but with the increase of water depth the propagating wave gets less sediment concentrated water. But when the waves move towards the opposite direction, it carries some sediment towards the deep water zone, so the sediment volume decreases in the off-shore zone for 35 and 40 cm water depth in higher wave periods. On the other hand for 50 cm water depth the change of sediment volume is positive but it is lower than that of 1 sec wave period.

Table 3: Change in volume above zero water depth

Water Depth (cm)	Wave Period (sec)	Distance of wave Run-up form initial water level (cm)	Actual sand Volume (cm^3/ unit width)	Final sand volume (cm^3/ unit width)	Change in volume (cm^3/ unit width)
50	1	50	150	156.05	6.046
	2	180	540	730.00	190.00
40	1	64	192	224.56	32.56
	2	145	435	603.67	168.67
35	1	60	180	202.80	22.80
	2	130	390	539.41	149.41

Table 4: Total change of sediment volume

Water Depth (cm)	Wave Period (sec)	Actual sand Volume (cm^3/ unit width)	Final sand volume (cm^3/ unit width)	Change in volume (cm^3/ unit width)
50	1	960	1086.10	126.10
	2	1350	1636.90	286.90
40	1	1002	1078.32	96.32
	2	1245	1318.41	73.41
35	1	990	1067.87	77.87
	2	1200	1244.88	44.88

6. CONCLUSION

The objective of this study was to investigate the amount of sediment movement under variety of wave parameter and water depth. Here only the effect of wave period on sediment transport is discussed keeping the wave height nearly same (Table 1). This experimental result suggests that the amount of sediment movement in two different zones is different for different water depth and wave period. The movement of onshore sediment volume increases with the increase of wave period, but for off-shore zone this value decreases with a significant scale. Hence wave period is an important parameter for sediment movement in the formation of beach profile or other onshore/off-shore bar as a whole the sediment load movement in the coastal areas.

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