Experimental Study on Suspended Sediment Concentration and Powder Bed Deformation under Wave-Only and Wave-With-Current Scenarios

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Abstract. In this paper, the suspended sediment concentration and bed geometric characteristics of powder sediment under the wave-only and wave-with-current are described. 9 experimental scenarios with the different wave height \( H \) and mean flow velocity \( V \) were investigated. It is found that under the wave condition the suspended sediment concentration \( S \) increases with the increase of wave height \( H \), however it increases with the increase of flow velocity \( V \) under the wave-current condition. The sediment concentration in the near-bottom area is very high for both wave and wave-current condition. The sediment wave length \( L_{sw} \) increased slightly with the increasing of the \( H \), but it does not change much in general, while it increased with the increasing of the \( V \). The sediment wave height \( H_{sw} \) increased with the increasing \( H \), and it increased firstly and then decreased with increasing \( V \).

1. Introduction

Powder sediment is one of common forms of coastal area, and its motion laws have been studied by many scholars. The geometric and transport characteristics of non-cohesive sand wave generated by waves and currents are conducted by Cataño-Lopera[1], the relationship between the sand wave parameters and the Reynolds number is discussed. The empirical formulas also have been developed by Wu and Lin[2], in order to calculate the nonuniform sediment transport rates and near-bed suspended sediment concentration (SSC) \( S \) under non-breaking waves and currents conditions. The suspended sediment transport experiments induced by long waves and wave groups conditions are investigate by Cáceres and Alsina[3], and it was found wave–backwash interactions in the swash zone was a key parameter in controlling the sediment stirring, water velocity magnitudes and the suspended sediment fluxes in the inner surf and outer swash. The motion law of silty sediment under the action of wave and current is different from the above-mentioned, a series of erosion tests conducted by Roberts et al.[4] suggested that the silt-enriched mixtures exhibit cohesive-like behavior. And an expression for sediment incipient motion for both silt and sand under conditions is proposed by using the derivation method for the Shields curve by Zuo et. al.[5], and the formula was verified by a number of experimental datasets as well as field data. A series of flume experiments has been conducted by Yao et.al.[6], in order to investigate sediment transport of sand–silt mixtures in both wave-only and wave-with-current conditions, and a high concentration layer was observed near the bottom together with ripples under wave only conditions. The study of sediment movement not only includes
laboratory studies, but also has a lot of field observation. A series of field observations were carried out by Zuo et.al.[7] in the northwest Caofeidian sea area in the Bohai Bay, the water hydrodynamic and sediment concentration process with high spatial and temporal resolution in the bottom boundary layer (BBL) was obtained, and it was found that the suspended load sediment concentration is mainly influenced by wave-induced sediment suspension. A new field data on cohesive sediment erosion was discussed by Debnath et.al.[8], the results show that bed load plays a significant role in cohesive sediment erosion. Except the experimental research, numerical simulation also plays an important role in the study of sediment movement. The numerical simulation of sediment suspension and transport under plunging breaking waves was conducted by Yang et.al.[9], and both instantaneous and statistical results on the sediment concentration with different water depth and wave steepness are analyzed to investigate the processes of sediment suspension and transport. A numerical model to investigate the influences of breakwater layout on coastal waves, wave-induced currents, sediment transport and beach morphological evolution in the vicinity of breakwater are provided by Tang et.al.[10], after verifying the measured data, the model is used to study the influences of breakwater layout on coastal waves, wave-induced currents, sediment transport and beach morphological evolution.

A great deal of contribution has been paid to the sediment motion aforementioned. However, there still lacks adequate powder sediment movement for different waves or currents conditions. The paper studies powder sediment bed deformation and SSC under the wave-only and wave-current conditions experimentally to provide our insight on the powder sediment motion.

2. Experiments

2.1. Experimental Facilities and Setup

A series of experiments were conducted in a wave tank at the Hydraulic Lab of the Ocean University of China, and it is 30 m for length, 0.6 m for width and 1 m for depth. Its bottom was made of steel and its sidewalls were made of the stalinite. A current was produced by recirculating water in the wave tank with a water pump, while regular waves were generated by a piston type wave maker. In the central area of tank bottom, the powder sediment was covered for 0.1 m thickness and 4 m length higher than the wave length of all the experimental scenarios, and two 1:10 slopes made of iron were used to connect the sediment and the bottom smoothly, avoiding the excessive effect of the sediment topography, see figure 1. And the sediment median grain diameter $d_{50}$ is 0.02 mm; however, the sediment contains about 5% organic matter, so that it showed a slight cohesive.

Three wave gauges and one ADV were placed in the wave tank, one wave gauge was placed 6 m away from the wave generator to measure the incident wave height. The ADV was placed in the middle of the sediment bed, and the other two wave gauges were arranged symmetrically in front of and behind it, for measuring the flow velocity and the wave heights, respectively.

![Figure 1. Experiment sketch.](image)

2.2. Experimental Procedure

9 experimental scenarios were investigated with the different wave height $H$ and mean flow velocity $V$. The still water depth $d$ and wave period $T$ are same 0.4m and 1.6s respectively for all experimental scenarios. The detailed experimental parameters are shown in Table 1.

| Scenarios | $d$(m) | $T$(s) | $H$(m) | $V$(m s$^{-1}$) |
|-----------|--------|--------|--------|-----------------|
Before the start of an experiment, the topography of the sediment bed must be leveled, and then add water to the tank to a fixed level. After the waves or wave-current have acted on the bed for more than an hour, the SSC at five different water depths is measured by siphon sampling method, and the water in the wave tank is subsequently released. The deformation of bed surface is measured by a laser gauge.

3. Analysis and Result

3.1. SSC

Figure 2 shows the distribution of SSC along the water depth under pure wave conditions with different wave height, and it was found that in the case of small wave height (scenarios 1-3), the SSC does not change much with the increase of water depth, and the SSC at the bottom is slightly larger than that of upper water body, indicating that sediment has not yet reached the start motion conditions. However, as wave heights continue to increase (scenarios 4-6), the SSC in the water body increases sharply, and the sediment concentration in the near-bottom zone is much higher than that in the upper water body, resulting in the formation of high concentrations of powder sediments, which is consistent with the conclusions reported by Yao et. al[6].

![Figure 2. SSC distribution profile under pure wave conditions.](image)

Figure 3 shows the relationship between SSC along the water depth and flow velocity under the condition of wave-current. It was observed that the same trend appears as the pure wave condition, including a sudden increase in sediment concentration with increasing flow velocity and a high sediment concentration at the bottom. Comparing figure 2 and figure 3, it is found that the SSC under the condition of wave-current is slightly larger than that of the pure wave. And even under the condition of smaller wave height, the more obvious SSC distribution can be observed, which indicates that the sediment is easier to start under the conditions of wave-current.
3.2. Sediment Bed Deformation

Figure 4 (a) and (b) show the variation of the sediment wave length $L_{sw}$ with the wave height $H$ and the flow velocity $V$ respectively. It can be seen from figure 4 (a) that the $L_{sw}$ increases slightly with increasing $H$, except for $H=11.5$ cm scenario. As can be seen in figure 4 (b), $L_{sw}$ increasing with increasing $V$. Figure 4 (a) and (b) show that $L_{sw}$ under the wave-current conditions is obviously larger than the pure wave conditions.

Figure 5 (a) and (b) show the variation of the sediment wave height $H_{sw}$ with the wave height $H$ and the flow velocity $V$ respectively. It can be seen from figure 5 (a) that $H_{sw}$ increased with the increasing $H$. However, $H_{sw}$ increased firstly and then decreased with increasing $V$ as shown in figure 5 (b). By compared with figure 5 (a) and (b), the ranges of variation of $H_{sw}$ differ little for the pure wave condition and wave-current conditions.
Figure 4. the variation of $L_{sw}$ with $H$ and $V$.

Figure 5. the variation of $H_{sw}$ with $H$ and $V$. 
4. Conclusion
In this paper, the SSC and bed geometric characteristics of powder sediment under the combined effect of waves and currents are described. A series of experimental were conducted with the different pure wave conditions and wave-current conditions. The SSC at 5 different water depths, and the average sediment wave height $H_{sw}$ and wavelength $L_{sw}$ within the range of bed area were measured by siphon sampling method and laser range finder, respectively. It is found that:

(1). The SSC increases with the increase of wave height $H$ under the wave condition. In addition, it increases with the increase of flow velocity $V$ under the wave-current conditions. 

(2). SSC in the near-bottom area is very high for both wave and wave-current condition.

(3). The sediment wavelength increases slightly with the increase of the incident wave height, however it increases with the increase of the flow velocity $V$.

(4). The sediment wave height increased with the increasing $H$, however it’s increased firstly and then decreased with increasing $V$.

5. References
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