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Experiment Research on Geometry and Evolution Characteristics of Sand Wave Bedforms Generated by Waves and Currents

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Abstract. Sand waves generated under waves and wave-current have been investigated experimentally in a wave flume. The evolution of bedforms were measured by a Trasonic Terrain automatic Measurement and analysis System (TTMS). With the data measured, the configuration of the bed was analysed. With long time wave action, a large-scale bedforms as sand waves can be formed and many ripples superimposed upon them. Ripples with 2D or 3D patterns can be formed at different locations. The growth rate of sand waves was increased at the beginning and then decreased with the increase of the time. Moreover, it has been found that the sand wave features as sand wave length and height have relationship with hydrodynamics. In general, the sand wave height increases with the increasing of wave height and residual current respectively. The sand wave length increases with the increase of residual current and decrease of wave height. The sand wave growth rate increases with the increase of the hydrodynamic conditions.

1. Introduction

Tidal sand waves are dynamic large-scale rhythmic bed forms observed in many tide-dominated shallow seas that have a sandy seabed [1]. Sand waves develop in response to a dynamic balance between available sand, tidal currents and wave energy [2]. Sand waves can migrate up to tens of meters per year and are formed at a time scale of 1-10 years [3]. The dynamic behavior of sand waves such as migration and growth can cause huge damage because they tend to interfere with cables, pipelines and navigation. It is necessary to require knowledge of sand wave dynamics.

The research methods are mainly theoretical model study, numerical modelling, field survey and physical experiments. The formation of sand waves can be explained as a free instability system of the sandy seabed subject to tidal motion. Hulscher [4] used the shallow water equations to describe the hydrodynamics interaction between tidal bedforms and oscillatory character. And the mechanism giving rise to sand waves formation was the interaction of the tidal current with a bottom perturbation induces the steady recirculating cells. Then Hulscher's work was extended by regarding various physical mechanisms. In order to predict the growth and migration of the fastest growing mode of a random perturbation of the flat sea bed forced by the tidal current and wind waves, a model based on a linear stability analysis was presented [5]. Sand wave migration can be caused by pressure- or winddriven residual currents [6] and by tidal asymmetry [7]. Numerical simulation models have been performed in recent days, Borsje used a numerical process-based model to investigate the role of suspended load transport mechanisms in formation of sand waves [8]. He found that suspended load transport can cause suppression of long sand waves, resulting in a finite range of wavelengths that experience growth. Later, Gerwen used the model as presented in Borsje [8] to model the effect of suspended load transport and tidal asymmetry on the equilibrium tidal sand wave height [9]. It is shown that both suspended load transport and tidal asymmetry reduce the equilibrium sand wave height. Doré used a 2D RANS numerical model to simulate the morphodynamic evolution of a flat non-cohesive sand bed submitted to a tidal current, reproduces the bed evolution until a field of sand bedforms is obtained that are comparable with observed superimposed ripples in terms of geometrical dimensions and dynamics [10].

To investigate the formation and migration of sand waves with physical experiment is very difficult because the similarity scales are hard to match with the field conditions. Faraci investigated the ripples generated by regular and irregular waves experimentally and analyzed the geometry at the equilibrium [11]. Cataño-Lopera performed a systematic study on the geometric and migration characteristics of sand waves generated under the combined effect of waves and currents in a wave tank [2]. However, the influence of different currents with wave has not been investigated. Jiang develops a numerical model to research the bilateral reverse migration of one-group seabed sand waves around a sand ridge in a small shallow shelf sea of the South China Seas [12]. It is found that long-term sand wave migration trend is mainly controlled by both tidal constituents and residual velocity.

The aim of this paper is to illustrate the formation and evolution of sand waves generated by waves and combined different flows in a wave flume. The paper is organized as follows. Section 2 describes the experiment procedure. The third section and describes the test conditions and some computed parameters. The bedform configurations are also described in section 3. The main findings of this paper are discussed in section 4, and finally the conclusions are presented in section 5.

2. Experiment Setup

A series of experiments was conducted in a wave tank in the Hydraulic Lab at Ocean University of China. Figure 1 shows the schematic diagram of physical experiment layout, the wave tank is 60 m length, 0.8 m width and 1.5 m deep. The waves were generated by a piston type wave maker. The maximum wave height can be generated up to 0.3 m and the wave period up to 3.0 s. The currents with directions of positive and negative were generated by two circulating pumps. Porous medium as wave absorbing was placed at the opposite side of the wave tank. In the central part of the tank, the bottom was covered by a sand bed 15 m in length, 0.8 m in width, and 0.4 m in thickness with uniform grain size sand. Two 1:5 concrete slope was built at both sides of the sand bed in order to make the wave and current more stable. The median grain diameter d_{50} is 0.17mm (figure 2) and the repose angle is 33°.

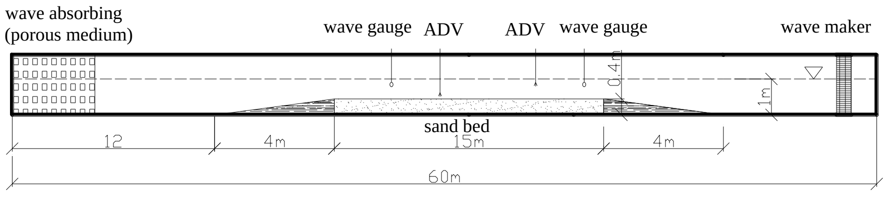

Figure 1. Schematic diagram of model experiment layout.

The depth-averaged velocity was measured by ADV (Acoustic Doppler Velocimetry). The wave height and wave period were determined by two wave gauges with a sampling rate of 50 Hz, which can meet the demands of the measurement with water surface elevation. The evolution of bed features was measured by a Trasonic Terrain automatic Measurement and analysis System (TTMS). The measurement accuracy of TTMS can reach 1mm. The water temperature was measured for each experiment and ranged between 6.3 ℃ and 8.2 ℃ with a mean value of 7.5 ℃. The sand bed must be flat before each experiment. To obtain the stable bedforms, each experiment performs for 5 hours.

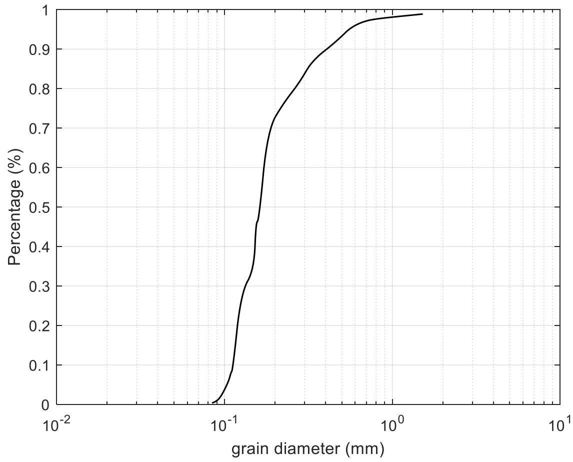

Figure 2. The distribution curve of sediment grain diameter.

3. Results

8 experimental scenarios were designed with different wave heights and currents. The water depth over the sand bed and the wave period are same 0.6m and 2s respectively for all scenarios. More details can be found in table 1. The variables in Table 1 are: H – wave height; T – wave period; u_0 – velocity of flow; u_m – maximum fluid orbital velocity at bed, a – wave orbital amplitude at bed, Re_d – the sediment Reynolds number; Re_w – flow Reynolds number, $Re_w = (u_m a)/\nu$, ν is the kinematic viscosity of water; l_{sw} – measured sand wave length; h_{sw} – measured sand wave height.

Table 1. Hydrodynamic characteristics and bedform characteristics of experiment scenarios.

Run number	H(cm)	T(s)	u_0(ms^{-1})	u_m(cms^{-1})	a(cm)	Re_d	Re_w	l_{sw} (cm)	h_{sw}(cm)
1	10	2	0	23.52	7.49	37.84	17487	228	1.0888
2	12	2	0	28.22	8.98	45.41	25181	220	2.79
3	14	2	0	32.92	10.48	52.98	34274	196	3.1816
4	16	2	0	37.63	11.98	60.55	44767	178	3.7923
5	14	2	-0.2	28.86	9.19	46.44	26335	184	2.6532
6	14	2	0.2	36.93	11.76	59.43	43123	204	3.6675
7	14	2	0.25	37.92	12.07	61.02	45468	241	5.6358
8	14	2	0.35	39.89	12.70	64.19	50310	241	3.8079

From figure 3, which shows the wave height with scenario 3 is no longer linear as the water is shallow. The Cnoidal wave theory should be used to compute all related wave parameters. However, as an approximation the small wave theory was still used here following Cataño-Lopera [2]. So, the orbital velocity and amplitude in Table 1 were still computed assuming that the small amplitude wave theory is applicable.

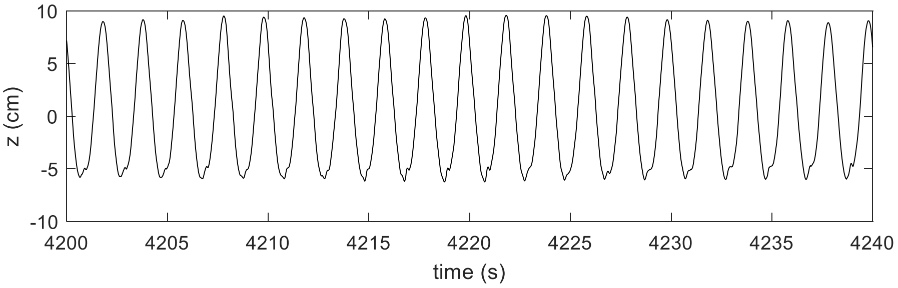

Figure 3. Water elevation measured as the function of times.

Figure 4 shows the bed configuration after 10 hours under the scenario 3 wave condition, and many features can be found from the figure. After a long time wave action, an obvious large-scale bedform as sand wave was formed. The sand wave length is about 200cm, and height is about several centimeters. We can also notice that many ripples superimposed upon sand waves, and ripples present different patterns. In general, 2D ripples often present at the crest and trough location of sand wave while 3D ripples form between the crest and the trough nearer the crest. The ripples at the crest usually larger than that at the trough.

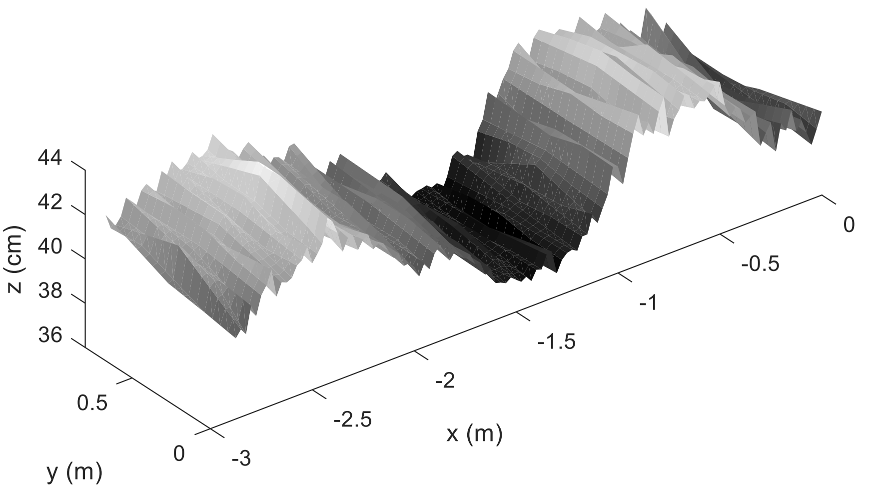

Figure 4. Bed configuration after 10 hours under the wave condition: H =14cm, T = 2s, u0 = 0.

Flat sand bed will form sand wave gradually under some hydrodynamic conditions. From figure 5, sand wave grows obviously in first 5 hours and almost remain the configuration between 5 hours to 10 hours which means that the bedforms has achieved equilibrium state at 5 hours. As the range of Reynolds number is small from about 15000 to 50000, so we performed 5 hours wave action with all other experimental scenarios.

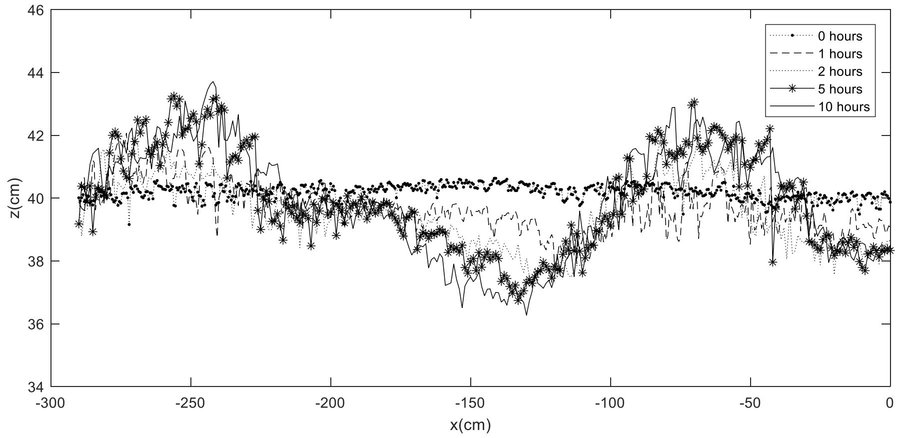

Figure 5. Bottom evolution over time: the generation of sand wave.

Figure 6 shows sand wave growth rate quantitively, in first hours, the sand wave growth rate reaches about 0.5cm/hour, and then the growth rate decreases. After 5 hours, the growth rate reduces to about 0.1cm/hour, and then the sand wave height almost remains the same after 7 hours. So, it is reasonable for 5 hours wave action on sand bed.

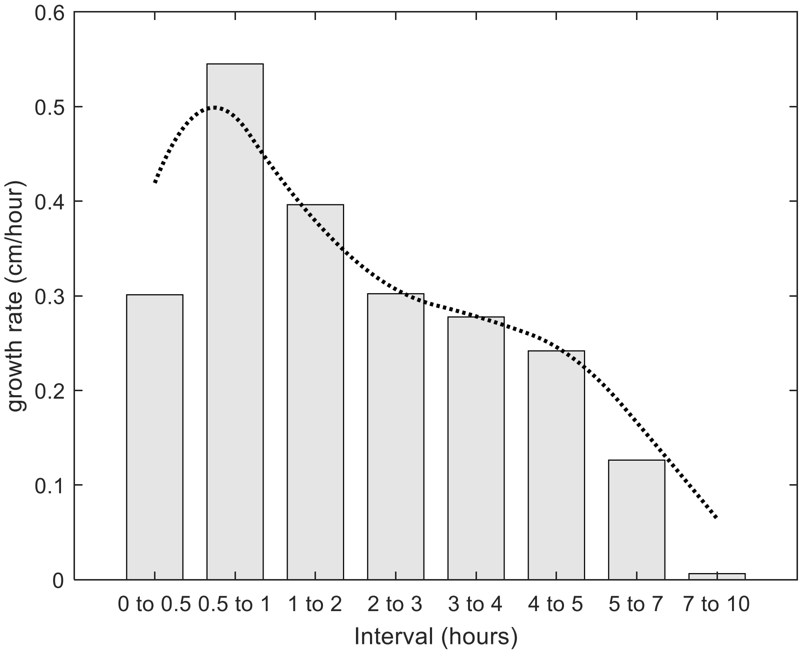

Figure 6. The growth rate of sand wave as a function of time.

4. Discussion

4.1. Configuration of Sand Wave

From figure 7, the relationship between sand wave characteristics and wave height can be discussed. The circle in the figure denotes experiment data while the red line denotes the fitting line. The sand wave height increases with the increase of wave height, and the sand wave length decreases with the increase of wave height.

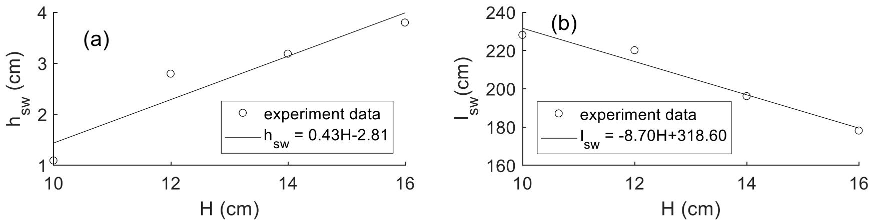

Figure 7. The relationship between sand wave characteristics and wave height.

Figure 8 shows the sand wave characteristics under the same wave condition with different residual current action. With the increase of the velocity, the sand wave height and length both increase respectively though the data is not ideal when velocity is 0.35m/s. While the direction between the current and the wave is opposite, the sand wave height and length both decreased.

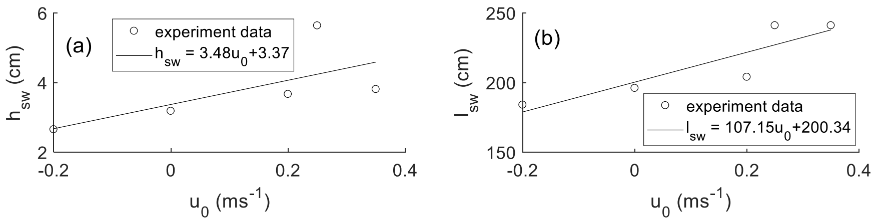

Figure 8. The relationship between sand wave characteristics and current under the same wave conditions.

4.2. Sand Wave Growth Rate

Figure 9 shows the sand wave growth rate increases with the increase of the wave height and residual current respectively. Similarly, the growth rate reaches too high when velocity is 0.35m/s which makes the trench not quite ideal. With the current increased, the wave will be deformed more obviously. So, the flow characteristics near the bottom become more complicated which need more detailed measurement data in future.

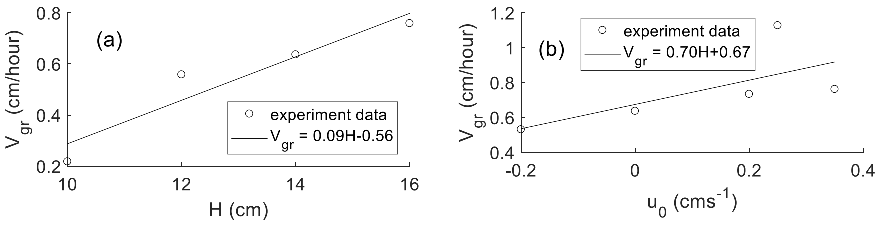

Figure 9. The relationship between sand wave growth rate and hydrodynamic characteristics.

It should be noticed that the fitting equations in figures 7 to figure 9 just show the trend of relationship between sand wave characteristics and hydrodynamics. The equations should be verified by more scenarios.

5. Conclusion

In this paper, the sand wave bed configuration generated by waves alone and combined different flows were experimentally investigated in a wave tank. After several hours wave action, small-scale bedforms as ripples and large-scale bedforms as sand waves coexist on the bed. The main conclusions from the experiments are that:

(1). The growth rate of sand wave increases first and then decreases over time. under the Reynolds number of 50000, it may take about 5 hours to reach the equilibrium state.

(2). In the range of Reynolds number from 15000 to 50000, the sand wave height increases and sand wave length decreases with the increase of wave height respectively. Both the sand wave height and sand wave length increase with the increase of the residual current under the same wave condition.

(3). The sand wave growth rate increases with the increase of wave height and residual current respectively.

6. References

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