論文の内容の要旨

Abstract of Dissertation

Laboratory Study on the Role of Steady Streaming in Oscillatory Sheetflow Transport

(シートフロー漂砂における定常流れの役割に関する実験的研究)

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Many coastal activities are concerned with the interaction of coastal sedimentary processes and coastal works, such as the construction of structures for shore protection and stabilization, and beach nourishment. It is important to measure sand properties, sediment moving processes and transport rates, as well as the resulted nearshore morphology to understand the sediment transport mechanism under various wave and current conditions. In this study, we are interested in understanding the sediment transport mechanism, especially the influence of wave-induced boundary layer streaming on sediment transport under combined wave and current conditions in the sheetflow regime.

Recently, sediment net transport rate measured through the large wave flume (LWF) experiments present a more onshore tendency, i.e., a larger onshore net transport, than the result from the small oscillatory flow tunnel (OFT) experiments. Various researchers argue that the wave-induce onshore streaming could be the reason to cause such difference. The objective of this research is to understand the physical features of this phenomenon and answer the question: Does onshore streaming really enhance the onshore sheetflow net sand transport? If so, then, how and how much does it affect the onshore transport? If not, what is the real reason behind? The second is to obtain new insights into the importance of the boundary layer onshore streaming and to understand the transport processes under wave and current conditions.

To achieve the objectives, laboratory experiments were conducted under the combined asymmetric wave-current conditions to quantitatively evaluate the influence from the onshore streaming. The second order Stokes’ wave theory with a velocity asymmetric index of 0.57 was applied for wave generation. The asymmetric flows with a wave period of T =3, 5 s and the maximum onshore velocity u_{max} varying from 0.8 to 1.6 m/s have been applied to three well-sorted sands with medium sand size of D_{50} =0.13 mm (very fine) , 0.16 mm (fine) and 0.3 mm (coarse). Sheetflow transport regime was confirmed for all experimental conditions and the sediment net transport rate was measured. For fine sand without onshore current, the net transport increases with increasing velocity, and it is directed to the onshore. However, for larger velocity case, the net transport rate decreases and the direction also changes to the offshore. As for the very fine sand, the net transport rate decreases and is directed to the

offshore even for a small velocity case. It is because of the phase-lag effect and suspension is also dominant for very fine and fine sand. Considering the coarse sand, the net transport is in the onshore direction due to the significant of bed-load.

To understand the effect of onshore streaming, a small current U_c of 10 cm/s and 20 cm/s was generated in the onshore direction. Experiment results for small current 10 cm/s indicate the magnitude offshore net transport rate reduces and the direction is to the offshore for the very fine sand and fine sand with large velocity case. When increasing the small current value to 20 cm/s, the net transport rate of fine and very fine sand increases and changes to onshore direction with small velocity case. But for large velocity case, even though the magnitude of offshore net rate reduces, the direction is still directed to offshore with fine sand case. Taking into account the net transport rate measured under the combined wave and current cases, the onshore net transport for coarse sand continuously increases. It is noted that the tendency of increasing of net transport rate is not observed in fine grains when the velocity becomes increases without the contribution of current. In case of the contribution of small onshore streaming, although the magnitude of offshore net transport rate of fine and very fine sand reduces, it still directs to offshore under large velocity case. It indicates that even the onshore streaming is contributed, it enhances offshore net transport rate for very fine sand and fine sand with large velocity case. On the other hand, the small onshore streaming may be partly important for the case of fine sand under small velocity condition as it produces the onshore net transport rate.

In order to know how the small net current effects on sediment transport process between oscillatory flow and surface wave, the measured net transport rates are compared with the results from surface wave under same flow conditions. For fine sand with onshore streaming U_c= 10 cm/s, the sediment rate under oscillatory flow tunnel can predict about 75 % of net rates under surface wave with small velocity case. Now, the new experiments indicate the difference of sediment rate between these is about 1.5 times for fine sand with onshore streaming. In addition, the results of coarse sand with streaming velocities of U_c= 10 and 20 cm/s produce larger onshore net sediment rate compared to surface wave. It means the contribution of streaming is quite large to enhance the more onshore net transport rate for the coarse sand. As a result, the streaming effect is very dependent on sand size.

Actually, in order to know the effect of onshore streaming, we contributed the small onshore current on the oscillatory flow and performed experiments under combined wave and current with different wave conditions. Therefore, it is the reason to investigate the streaming profiles for these conditions whether it can give an explanation about the cause of the increment of onshore net transport rate due to the addition of small onshore current. In order to obtain new insights into the meaning of the profiles of streaming, sediment particle velocity within the sand-laden sheetflow layer was measured by means of a Particle Image Velocimetry technique. The sediment particle velocity may reach about 72 % of free stream velocity when the level is far away (z = 25 mm) from the bed. By averaging the sediment particle velocity over one wave period, the mean flow velocity was also evaluated. From the mean velocity profile under pure wave conditions, it is found that, in case of the coarse sand, an onshore streaming is detected in the pick-up layer and leads to offshore in the upper sheet-flow layer. Nevertheless, in case of fine sand, the profiles show a negative streaming due to the strong phase-lag effect. The positive near-bed streaming is not observed. The large phase-lag can induce a negative (offshore) streaming. Thus, the phase-lag effect seems to play an important role for the sediment sheetflow transport in the OFT test. For coarse sand under combined wave and current conditions, a very small onshore current exists in the pick-up layer ($z < 0$ mm) and the mean flow velocity leads to onshore direction in the sheet flow layer. In the suspension layer, when the elevation is higher than 15 mm, the mean flow changes its direction from onshore to offshore. In the case of fine sand, the time-averaged velocity indicates the streaming is positive in the pick-up layer as well as in the sheet flow layer. After that, the velocity decreases for increasing the depth (z) mm. Clearly, the additional onshore current in the tunnel does contribute to more onshore sediment transport. Besides that, it is also confirmed that the phase-lag effect plays an important role in the sediment transport under the sheetflow conditions, especially for the fine sand case with large velocity case as it produces offshore net transport rate. The comparison results for mean flow velocity between surface wave and oscillatory flow shows that the positive streaming can be induced in the pick-up layer in the case of fine sand with onshore current under oscillatory flow. Therefore, by contribution of small onshore current, the onshore streaming is achieved in oscillatory flow like the surface wave. However, in the suspension layer, it indicates the different behavior between the surface wave and oscillatory flow. Considering the coarse sand with combined wave and current, the positive streaming is observed in the pick-up layer and sheet flow layer. When the depth is larger, the profile changes to offshore. Here also, the streaming profiles are very sensitive to sand size. Still now we cannot give the full explanation of the differences of transport rates in oscillatory flow and surface wave. Further investigation is needed to understand more details.

The maximum erosion depth was estimated from the temporal change of the measured erosion depth. A linear relationship was found between the relative maximum erosion depth δ_{em}/D and the maximum Shields parameter, θ_m. Time-varying sediment erosion depth was measured for two kinds of sand under wave and current conditions to determine the asymmetric of erosion depth under wave crest and trough. The erosion depth under crest is larger than under trough for fine sand and coarse sand under combined wave and current conditions. The influence of wave period and velocity on erosion depth was also measured for two types of sand.

To analysis and verify the experimental data, the measured net transport rates were compared with four existing sediment models. SANTOSS model gave better results and predicted well for both magnitude and direction of sediment rate. The calculated and measured net rates are within the factor of two for most of experimental cases. Moreover, in order to know how much the distribution of small onshore streaming enhanced the larger net rate, the results of net transport rate with onshore streaming are compared with SANTOSS model which include surface wave effects. In this study, SANTOSS model was also considered as streaming-related model including the streaming effect by analytically to represent the surface wave phenomenon. The comparison results showed that although the results of fine and coarse sand with onshore streaming overestimate compared to the results of streaming-related model, it lies with a factor of two differences.