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TURBULENCE STRUCTURE OF BOUNDARY LAYER UNDER NON-LINEAR WAVE MOTION

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1. INTRODUCTION

Turbulence structure in the bottom boundary layer under wave motion has crucial importance in the analyses and modeling of near-shore sediment transport. Sediment transport at a point in the near-shore zone can be considered in terms of cross-shore and long-shore component. The transport is dominated by either the cross-shore or long-shore component causing beach erosion or accretion. Most of flows transporting sediment are turbulent boundary layer shear flows and the forces exerted on the sediment governed by turbulent characteristic. Bottom shear stress and turbulence motion in wave motion are key parameters for moving the sediment and keeping it in suspension. To understand the sediment suspension in the turbulent flow is very important to analyze the influence of turbulence structure on the particle settling and pick up through turbulence. Erosion and sediment transport is initiated by cycles of downward sweeps and upward bursts denoting result from turbulent motions in the wave boundary layer.

When waves close to breaking in near-shore, they become non-linear, hence the simple harmonic variation as sinusoidal wave can not describe the boundary layer behavior occurring in the surf zone in which major part of near-shore sediment are transported. Schäffer and Svendsen (1986) had shown that a simplified approach of skewed wave or saw-tooth wave could be used to represent the non-linear shape of breaking wave. Samad and Tanaka (1998) had investigated the flow behavior in bottom boundary layer under saw-tooth wave for both laminar and turbulent flow condition by numerical model for smooth bed.

Many researchers have studied the turbulence structure by a viewpoint of the bottom roughness degree, however the majority of studies were conducted under sinusoidal wave and only a few of them studying it by the viewpoint of the turbulence motion under non-linear wave (e.g., Samad and Tanaka (1999)). In this present study we investigate the turbulence structure in the bottom boundary layer under non-linear wave motion having a saw-tooth wave shape with different wave skew-ness parameter, α. The turbulent bottom boundary layer flow experiments are conducted in oscillating wind tunnel over rough bed under non-linear wave having a saw-tooth wave shape by laser Doppler velocimeter (LDV) to measure velocity distribution.

2. VELOCITY MEASUREMENT AND EXPERIMENTAL CONDITION

The flow measurement unit comprised of a wind tunnel and one component laser Doppler velocimeter (LDV) for flow measurement. The wind tunnel is connected to the piston system that has a dimension of 5 m length, 20 cm and 10 cm in height and width, respectively. The bottom roughness elements used in this experiment are the triangular shape elements having a dimension of 5 mm height and 10 mm width, which are pasted over the bottom surface of the wind tunnel with distance of 12 mm along the wind tunnel. Near the measuring section the sidewalls of the wind tunnel were made of transparent fiberglass sheets to facilitate LDV measurements.

Table 1 Experimental conditions

Exp.	Case 1	Case 2	Case 3
U_c (cm/s)	199	400	400
R_e	1.35 x 10^5	5.42 x 10^5	5.42 x 10^5
T (s)	3.0	4.0	3.0
α	0.35	0.31	0.52
Flow	Saw-tooth	Saw-tooth	Sinusoidal

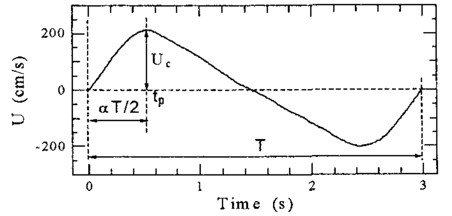

Fig.1 Saw-tooth wave definition

Experiments have been carried out for three cases; namely Case 1 and Case 2 are for non-linear wave cases and Case 3 is for sinusoidal wave case, as presented in **Table 1**. Where, U_c: the velocity at wave crest, T: the wave period, R_e: the Reynolds number ($R_e=U_c^2/\nu\omega$), ω: the angular frequency, ν: the kinematics viscosity (ν=0.141 cm^2/s). And α: the wave skew-ness parameter, where an increase in α indicates a decrease in wave skew-ness ($\alpha= 2t_p/T$), t_p: the time interval measured from the zero-up cross point to wave crest in the time variation of free stream velocity, as shown in **Fig. 1.** The Reynolds number magnitude defined for each case has sufficed to locate these cases in the rough turbulent regime.

3. RESULTS AND DISCUSSIONS

Turbulence intensity and inflection point of the vertical profile of the mean velocity are expressed in the following equations, respectively:

$$\sqrt{\overline{(u')^2}} \quad (1)$$

$$\frac{\partial^2 u}{\partial z^2} = 0 \quad (2)$$

where , u': the fluctuating velocity and u: the mean velocity in x direction. **Figs.** 2, 3 and 4 show the contour of turbulence intensity and the inflection point of the vertical profile of the mean velocity for Case 1, Case 2 and Case 3, respectively. The lie of the turbulent intensity peak depends on both the magnitude of Reynolds number and the type of wave motion. In the smaller Reynolds number case, Case 1, the peak of turbulent intensity appears at the region more far from the bottom, whereas for the non-linear wave case, Case

2 is more close to the bottom than the sinusoidal case, Case 3, though both in the same Reynolds number. This region was found to correspond to the inflection point of the mean velocity due to turbulent generation by an inflection instability mechanism depending on the time variation, namely at the distance from the bottom z_1=0.85 cm, z_2=0.25 cm and z_3=0.45 cm for Case 1, Case 2 and Case 3, respectively, as shown in **Figs.** 2,3 and 4.

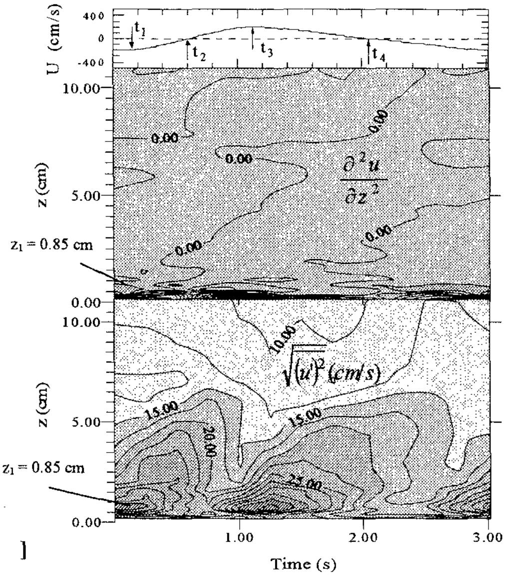

Fig.2 Inflection point of the vertical profile of the mean velocity and turbulent intensity contour plot, Case 1

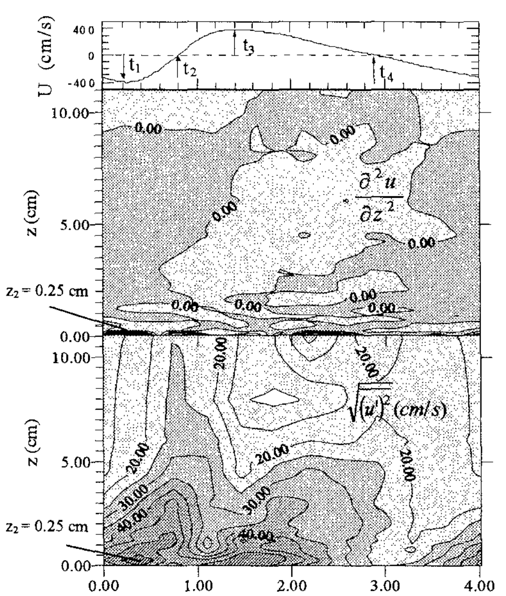

Fig.3 Inflection point of the vertical profile of the mean velocity and turbulent intensity contour plot, Case 2

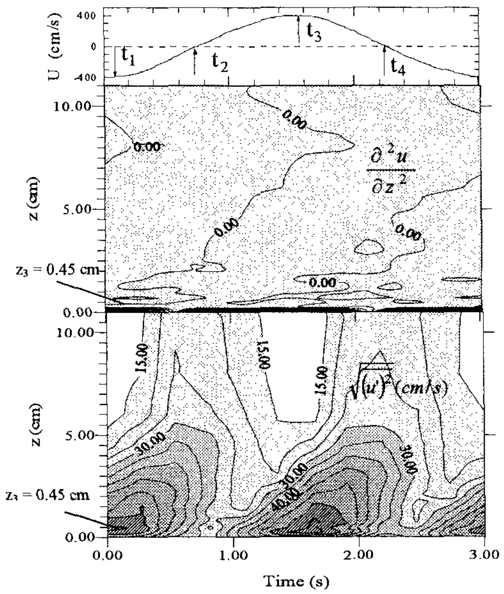

Fig.4 Inflection point of the vertical profile of the mean velocity and turbulent intensity contour plot, Case 3

A larger level of turbulent intensity in the negative cycle flow for the non-linear wave case of higher Reynolds number (Case 2) was attained at the beginning of acceleration phase, while in the positive cycle flow occur at the beginning of deceleration phase, however this phenomenon was different with both Case 1 and Case 3, in which a larger level of turbulent intensity in the negative cycle flow was attained at the end of deceleration phase for both cases, while in the positive cycle flow occur at the beginning of deceleration phase and at the end of acceleration phase for Case 1 and Case 3, respectively.

4. SUMMARY

It can be concluded that a significant turbulent production for the higher Reynolds number is close to the beginning of acceleration phase and its distribution in cross-stream direction occur during this acceleration phase (t_1-t_3). The region under influence of the turbulence in cross-stream direction increases as increasingly the Reynolds number magnitude. Moreover, the turbulence structure under non-linear wave motion has a different characteristic with that of under sinusoidal wave motion.

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