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EXPERIMENTAL STUDY ON BOTTOM BOUNDARY LAYER PROPERTIES UNDER IRREGULAR WAVES

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1 Introduction

Oscillatory boundary layer flows have been the subject of numerous experimental and theoretical investigations over the years. Most of these studies mainly considered regular sinusoidal wave motion in the free stream [1]. Recently, with increasing interest among coastal engineers to apply spectral wave theories for more accurate representation of natural environment, advanced experimental facilities have also been developed to measure irregular wave profiles. However, measurement of detailed boundary layer properties under irregular waves has not been reported as yet. Present paper describes the experimental facility developed in order to measure bottom boundary layer properties under irregular waves. A set of experimental data for smooth laminar flow conditions has also been presented along with corresponding bottom shear stress variation.

2 Experimental Set-up

The experimental system consists of two separate components, a) the signal control unit including piston mechanism, and b) the wind tunnel unit along with laser Doppler velocimeter (LDV).

The signal control unit: The irregular wave piston displacement signal is applied to the instrument through a PC. Input digital signal is then converted to corresponding analog data through a digital-analog (DA) converter. This analog signal then drives the servo motor connected through a servo motor driver. The piston mechanism is mounted on a screw bar which is connected to the servo motor. Piston displacement feed-back is achieved through a potentiometer that compares the position of the piston at every instant to that of input signal, and subsequently adjusts the servo motor driver for position at the next instant through a signal controller. A schematic diagram of experimental set-up is shown in Fig.1.

The wind tunnel unit: The piston system is connected to a wind tunnel 5m long, 20cm wide and 10cm high, as shown in Fig.1. Flow measurements have been carried out through a one component LDV at the middle of the wind tunnel.

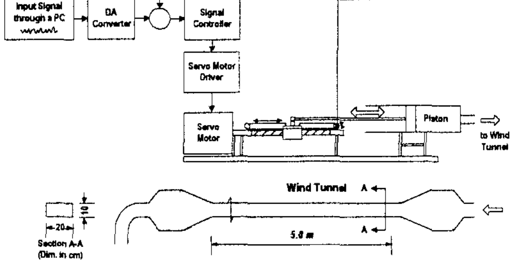

Fig.1: Schematic diagram of experimental set-up.

3 Data Analysis

3.1 Input parameters

The input piston displacement has been derived from generated irregular wave free stream velocity (details of which can be found in [2]). A wave terrain of 18.02sec. has been used cyclically in the experiment. For smooth conversion of digital data, a very small input time increment has been specified. The experimental condition for the present case, that falls in laminar flow region, is shown in Table 1.

Table 1: Experimental Conditions

	$T_{1/3}$	$U_{1/3}$	$RE_{1/3}=U_{1/3}^2/(\nu\omega_{1/3})$
Case 1	2.0	33.33	2.51×10^3

where $T_{1/3}$ and $U_{1/3}$ are significant wave period and free stream velocity respectively, $RE_{1/3}$ Reynolds number, ν kinematic viscosity and $\omega_{1/3}$ is wave frequency ($=2\pi/T_{1/3}$).

3.2 Accuracy of experimental data

In order to assess the accuracy of experimental data measured piston displacement and free stream velocity have been compared with input piston displacement and generated free stream velocity respectively. It can be seen in Fig.2 that although experimental piston displacement is nearly perfect, the free stream velocity shows less influence of high frequency components. This is reflected at points marked with an arrow in the figure.

3.3 Velocity time variation at different elevations

Velocity has been measured at 22 elevations in the wind tunnel, closely spaced near the bottom. Ensemble averaged velocity time variation at selected elevations are shown in Fig.3. A phase shift in velocity between different elevations can be well observed here. Near the bottom double peaked behavior (marked with arrows in Fig.3) can be seen both in a wave trough and a peak. Influence of this high frequency components can be observed to reduce rapidly just outside the boundary layer.

3.4 Vertical velocity distribution

Vertical velocity profiles corresponding to different phases

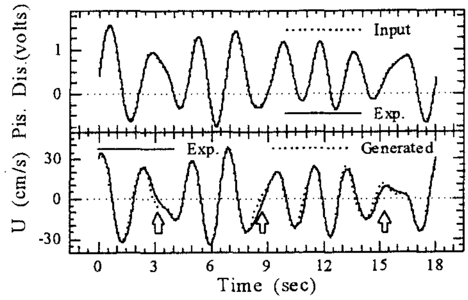

Fig.2: Accuracy check for experimental data.

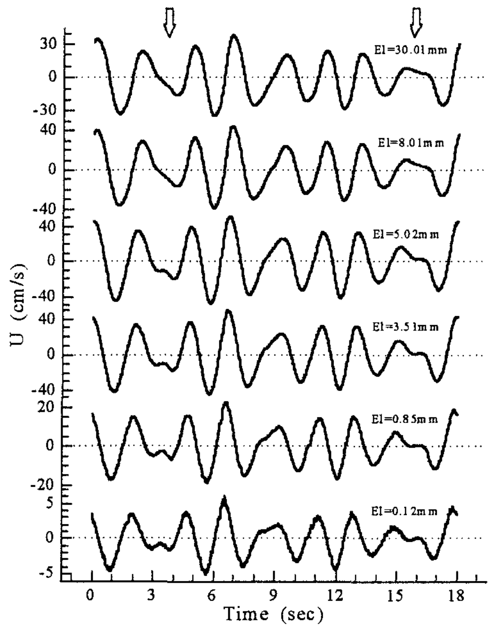

Fig.3: Velocity time variation at selected elevation.

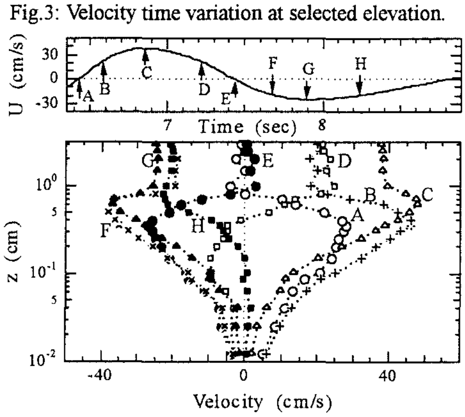

Fig.4: Vertical velocity profiles at selected phases.

of the highest wave are shown in Fig.4. Very high velocity overshooting can be observed at the edge of the boundary layer. The overshooting velocity depends on flow acceleration, as such, the maximum overshooting in accelerating and decelerating phases can be observed at B and F respectively although corresponding maximum and minimum velocities occur at C and G.

3.5 Bottom shear stress

Bottom shear stress has not been measured directly during the experiment. However, it has been calculated from vertical velocity distribution such that:

$$\frac{\tau_0(t)}{\rho} = \nu \frac{\partial u(t)}{\partial z} \tag{1}$$

where, τ_0 is bottom shear stress, ρ fluid density, u velocity and z is the distance from the bottom. Velocity gradients have been computed based on data from 8 elevations from

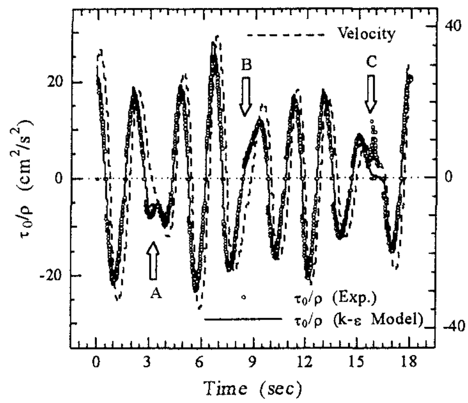

Fig.5: Variation of bottom shear stress.

the bottom and by using least square method. As the estimation of velocity gradient by slope fitting gives unrealistic result during flow reversal, only the bottom shear stress near wave crests and troughs have been considered for comparison. Bottom shear stress thus obtained is presented in Fig.5 along with those computed applying Jones and Launder [3] k-ε model and with free stream velocity. Double peaked shapes, which is characteristics of laminar bottom shear stress [4], has been very well reflected in the experimental results as can be seen at locations A and C. The fine variation at B is also very well represented. A very good agreement of bottom shear stress has also been observed when compared with k-ε model result.

4. Conclusion

An experimental set-up consists of a signal control unit connected to a wind tunnel, has been developed to measure bottom boundary layer properties under irregular waves. A very high level of accuracy in piston movement has been achieved.

Experimental results for one case of laminar flow conditions shows a very high velocity overshooting at the edge of the boundary layer. The bottom shear stress obtained from velocity distribution shows typical characteristics of irregular waves under laminar motion.

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