INVESTIGATION ON LAMINAR TO TURBULENT TRANSITION UNDER SOLITARY WAVE

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1. INTRODUCTION

The exact prediction of transition point in the wave boundary layer is very important to avoid substantial error into the simulation. Because of this reason laboratory and numerical experiment of bottom boundary layer under non-linier wave have been done by many researchers, but only several researchers have conducted experimental and theoretical studies to describe the wave boundary layer under solitary wave motion (e.g. Sumer et al., 2010; Vittori and Blondeaux, 2008). The present study is concern on investigation of behavior of laminar to turbulent transition under solitary wave boundary layer to achieve the appropriate critical Reynolds number.

2. LABORATORY EXPERIMENT

Boundary layer flow experiment under solitary wave was carried out in a conduit water tunnel. The instantaneous velocity was measured at 17 points in the vertical direction by Laser Doppler Veloci-meter (LDV) installed at 1.3 m from the downstream end. The measured flow velocity record was collected by means of an A/D converter at 10ms interval and the mean velocity was obtained by averaging over 50 wave cycles. The laboratory experiments have been done for various value of maximum velocity and it's summarized in **Table 1**. In this table the solitary wave Reynolds number (R_e) is defined by the following equation based on U_c and α (Suntoyo et al., 2009).

$$R_e = \frac{U_c^2}{\alpha \upsilon} \qquad (1)$$

where U_c is maximum velocity under wave crest and equal to:

$$\frac{U}{U_c} = \sec h^2(\alpha t) \qquad (2)$$

where U is free stream velocity, υ is kinematics viscosity and α is parameter in connection with water particle displacement is

$$\alpha = \sqrt{\frac{3H}{4h^3}}c \qquad (3)$$

where H: the wave height, h: the water depth and c is wave celerity.

Table 1 Experimental condition

	υ (cm²/s)	U_c (cm/s)	α (s⁻¹)	R_e
Case 1	0.0100	42.6	0.79	2.25×10^5
Case 2	0.0116	78.7	0.95	5.64×10^5

As mentioned before, the flow velocity was measured at 17 points in the vertical direction and in **Fig. 1** shows the measured instantaneous velocity of present experiments at 2 measurement point in the near bottom region and 1 point as free stream velocity. The notation z is cross stream distance from the theoretical bed level

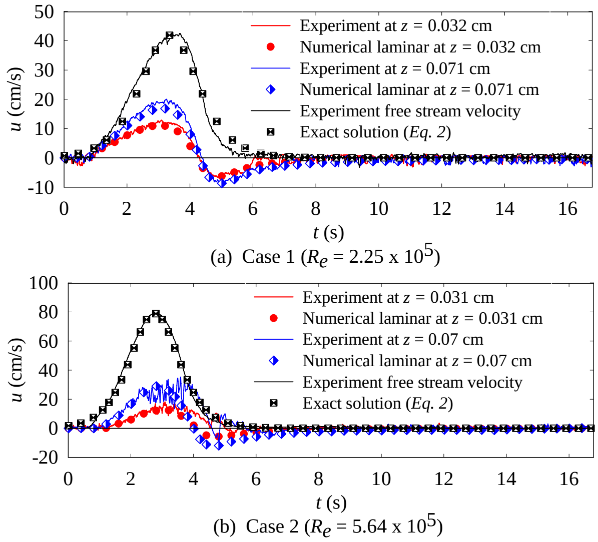

Fig. 1 The measured instantaneous velocity; **(a)** Case 1, $R_e = 2.25 \times 10^5$ and **(b)** Case 2, $R_e = 5.64 \times 10^5$

4. RESULT AND DISCUSSION

The behavior of laminar to transition turbulent will be discussed based on the laboratory experiment data in term of horizontal and vertical velocity distribution. Because of slight deviation of free stream velocity measurement with exact solution (**Eq. 2**) as seen in **Fig. 1**, numerical laminar for measured free stream velocity, instead of Keulegan's (1948) theoretical laminar solution will be used in the purpose of investigating velocity distribution of present experiment data.

From **Fig. 1(a)**, we can observe clearly that excellent agreement in term of horizontal velocity time variation is achieved between numerical laminar and experimental result. Different phenomenon can be seen apparently when $R_e = 5.64 \times 10^5$, deviate from numerical laminar and also small fluctuation in decelerating phase occurred (**Fig. 1(b)**). From **Fig. 1**, we can also notice a slight deviation of free stream velocity experiment with exact solution (**Eq. 2**).

At $R_e = 2.25 \times 10^5$, the experiment result coincide well with the numerical laminar, including the near bottom flow reversal at the end of decelerating phase (**Fig 2(a)**). When R_e increase to 5.64×10^5 (**Fig 2(b)**), velocity profile during accelerating phase has a good agreement with numerical laminar but during decelerating phase, it starts to deviate slightly from

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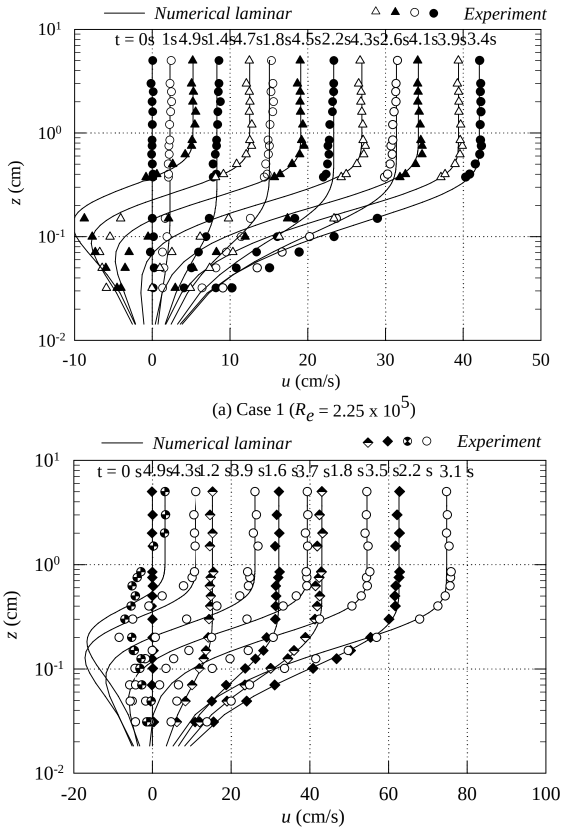
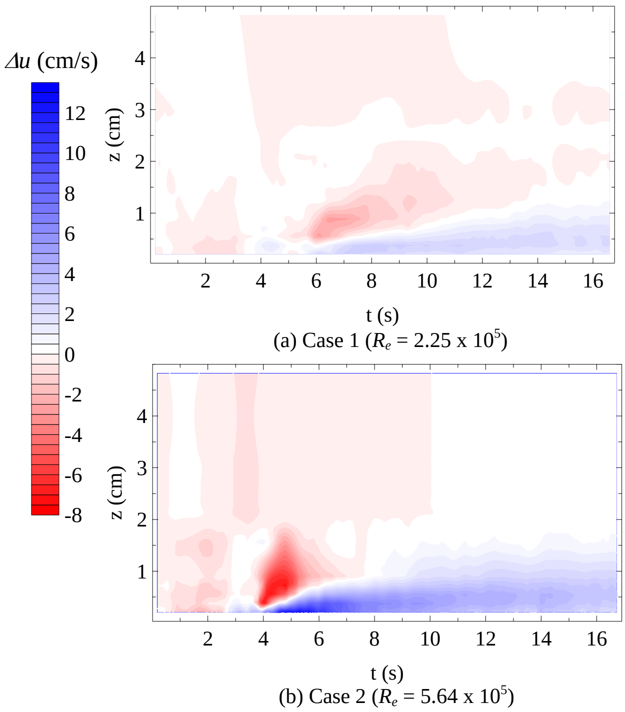
numerical laminar. From **Fig. 2**, it is noted that distinct reduction of flow reversal in the near bottom because of turbulence generation. Parameter Δu is used to know the quantitative difference value among those 2 types of velocity in variation of time and defined as subtraction of numerical laminar velocity from measurement velocity ($\Delta u = u_{experiment} - u_{numerical\text{-}laminar}$). The Δu values in time variation for 2 cases are performed in **Fig. 3**.



(a) Case 1 (R_e = 2.25 x 10^5)

(b) Case 2 (R_e = 5.64 x 10^5)

Fig. 2 Vertical velocity distribution; **(a)** Case 1, R_e = 2.25 x 10^5 and **(b)** Case 2, R_e = 5.64 x 10^5



(a) Case 1 (R_e = 2.25 x 10^5)

(b) Case 2 (R_e = 5.64 x 10^5)

Fig. 3 Quantitative value of Δu

From **Fig. 3**, it can be clearly observed that velocity during accelerating phase is recover to laminar, Δu value is in between -0.7 cm/s to 0.5 cm/s for Case 1 and -3 cm/s to 3 cm/s for Case 2. During decelerating phase Δu value is getting higher, it is in between -3 cm/s to 3 cm/s for Case 1 and -10 cm/s to 18 cm/s for Case 2. This condition is clearly indicating reduction of flow reversal in the near bottom due to turbulence generation occurred in Case 2.

The critical Reynolds number thus obtained is plotted in a stability diagram (**Fig. 4**) proposed by Sumer et al., (2010) along with numerical simulation result by using DNS, Vittori and Blondeaux, (2008) and experiment result of Sumer et al., (2010). In this figure, h is the water depth or half of the closed conduit tunnel height and δ_1 is conventional thickness equal to $(2\upsilon/\alpha)^{1/2}$. The present experiment of Case 2, R_e = 5.64 x 10^5 seems to be in a good agreement with previous studies and it can be regarded as critical Reynolds number.

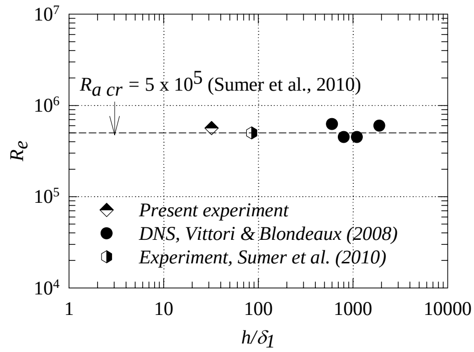


Fig. 4 Stability diagram

CONCLUSION

Investigation of laminar to turbulent transition behavior under solitary wave has been done based on the present experiments data. The critical Reynolds number obtained from the present study shows in good agreement with the finding of previous researchers.

ACKOWNLEGEMENTS

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