BOUNDARY LAYER DEVELOPMENT UNDER EFFECT OF SURFACE BORE

Tohoku University	Student Member	Nguyen Thai BINH
Tohoku University	Fellow Member	Hitoshi TANAKA
Tohoku Gakuin University	Regular Member	Yuta MITOBE
Tohoku University	Regular Member	Nguyen Xuan TINH

1. INTRODUCTION

Dam break wave, tsunami bore and tidal bore are all similar phenomena which involve movement of huge water body, causing severe damage upon their path. At the moment, attempts to describe the breaking, turbulence and debris pick-up of a tsunami bore on land is still very crude and needs lots of development.

Some studies investigated the unsteady turbulence induced by the bore (Koch and Chanson 2009) and the results highlighted the intense mixing beneath the bore front. To date, however, no systematic study was performed in highly-unsteady open channel flows. In order to achieve this, laboratory experiment is the appropriate choice, as it is simple to setup, as well as be able to represent the hydrology condition of a bore flow. In this paper, a dam break experiment was conducted to demonstrate the propagation of a bore from offshore to inland and further analysis were made to understand the process of turbulence and layer development in this particular flow.

2. EXPERIMENT SETUP

The experiment was conducted in the Civil Engineering hydraulic lab of Tohoku University in Japan, using a rectangular horizontal channel of 14 m long, 0.30 m wide, and 0.50m high, as shown in Figure 1. The bore generation was induced by the sudden open of the upstream sludge gate. The water level gauge sampled the water surface elevation along the channel centreline, and the high speed camera sampling the hydraulic regime in region of interest (ROI) was located on the channel centreline at x=17 m.

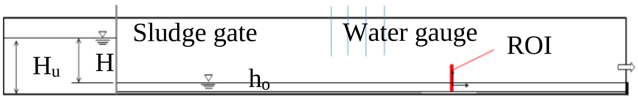


Figure 1. Experiment setup

Table 1 shows 5 different experiment cases which simulate the propagation of bore on inundated and dry bed (h_o and H_u: water level downstream and upstream). The turbulent velocity measurements were performed using particle image velocimetry (PIV) technique; videos recorded inside ROI shows turbulent movement of mixed particles during 3 seconds and computational analysis were made to obtain instantaneous flow field.

Table 1. Experiment condition

case	run	h_o (cm)	H_u (cm)	$H=H_u-h_o$ (cm)
1	1~5	5	20	15
2	6~10	3	18	15
3	11~15	1	16	15
4	16~20	0	15	15

3. RESULT AND DISCUSSIONS

3.1 Average velocity profile

In order to make further analysis, average velocity proilfe is needed to show the hydraulic regime in a bore flow. From raw velocity data of each instance, an instantaneous velocity profile for 61 different elevations from bottom to surface can be obtained using the interpolation method. The result of instaneous velocity in a sample elevation (y=3cm) is shown in Figure 2. From this instantaneous velocity profile, using moving average method, Renold decomposition can be done for velocity time series in each elevation, and mean velocity profile will be used for further analysis.

u = U + u' (cm/s)

u,U,u': instaneous, mean and fluctuate velocity (cm/s)

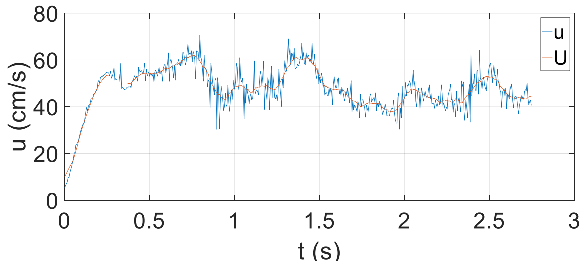
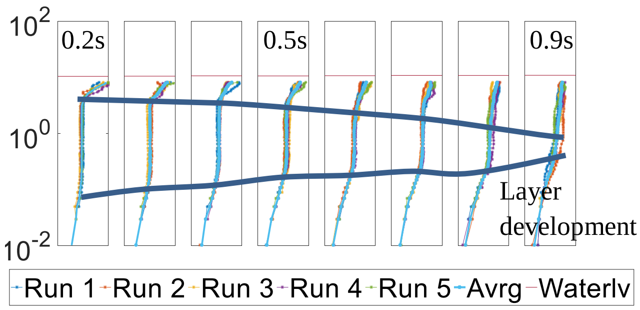


Figure 2. Average velocity profile

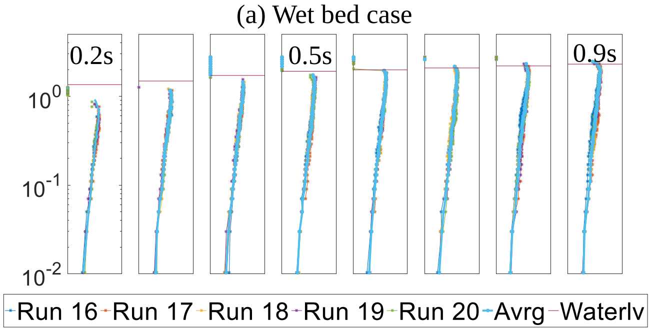
3.2 Boundary layer development

Layers development

Results of average velocity profile for 2 different bed conditions (wet bed and dry bed) is shown in Figure 3. As can be seen from the graph, in wet bed case, velocity profile can be seperated in to 3 distinct layers: surface region which has a polynomial distribution, an uniform middle layer and bottom boudary layer which follows log-law velocity distribution. The development of these 3 layers from 0,2s to 0,9s shows the tendency to mix of flow momentum; after mixing phenomenon took place, the difference between those 3 layers can not be clearly determined. For dry bed case, this process is not the same however; since the beginning, the velocity profile already follows the log law distribution and will not show any changes afterwards.



(a) Wet bed case



(b) Dry bed case

Figure 3. Velocity profile development

Key words: Boundary layer, PIV, Dam break experiment, Tsunami
Address (6-6-04, Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi 980-8579, Japan Tel 022-795-7453)

The concept of layer development is expained in Figure 4. Peregrine & Svendsen (1978) has shown that turbulence continues to spread downward from its initiation at the toe of bore. Alongside with the spearing of turbulent wedge (δ_1) from surface after bore passage, boundary layer (δ_2) is also developed from the very beginning, as seen in experiment results.

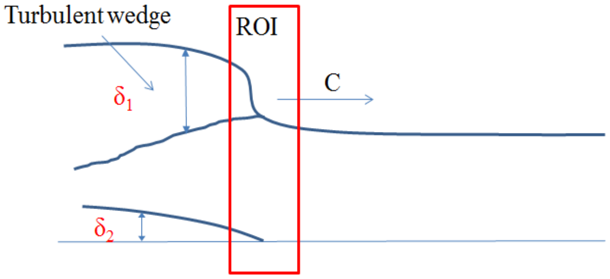


Figure 4. Development of layers in turbulent bore

The 4/5 power rule for boundary layer development

Using regression method (Figure 5), it is shown that development of boundary layer can be describe as:

$\delta_2 = At^{4/5}$ (cm)

A: coefficient

t: abitrary time, from beginning of bore passage

Results from experiment shows agreement with analytical solution for development of turbulent boundary layer over a flat plate which also follows the 4/5 power rule.

Transition of velocity profile

2 different flow regime can be observed from velocity profile (Figure 6). Profile A shows 3 distinct layers while profile B shows a distribution of velocity only follows the logarithmic law. These 2 different profile is the result of the momentum transference process; in the beginning, surface velocity which contains the bore flow has high velocity, while below regions which is dragged by this has smaller velocity. Interraction with bed is the same as any turbulent flow over a flat plate. Afterwards, mixing effect will take place, and momentum is transferred from top to bottom, which result in a different velocity profile. Mixing time should be related to difference between the bore flow layer and initial water level. By comparing with other experiments, relationship between dimensionless parameters can be onbtained to show process of the profile transition (Figure 7).

$h^* = h_o/H_u$

$t^* = (t-t_o)(g/H_u)^{1/2}$

h_o: initial water level downstream

H_u: initial water level upstream

t: total time from bore manifestation

t_o: time from bore manifestation to measurement

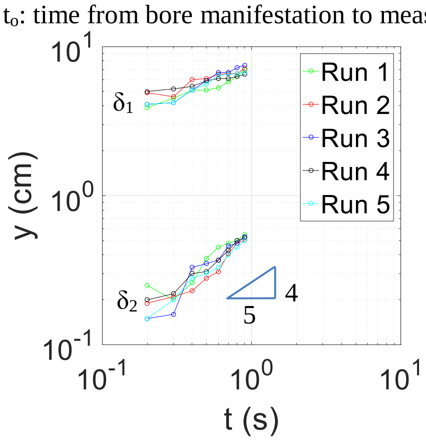


Figure 5. Development of layers over time

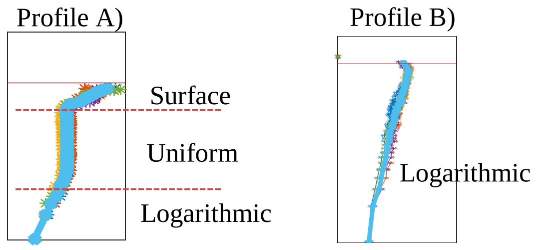


Figure 6. Profile categorization

Profile A	Profile B	Authors
------------	————	Present study
◆	◆	Shimozono (2011)
●	●	Lin et al. (2018)
■	■	Wuthrich et al. (2018)

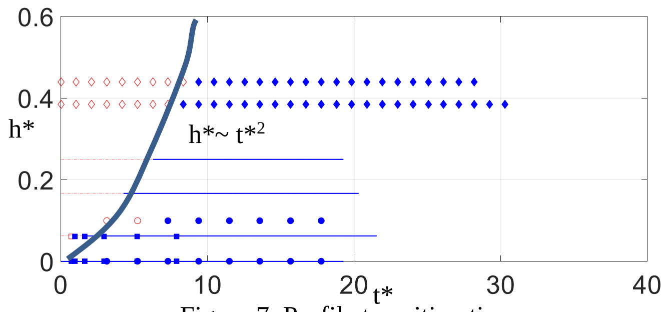


Figure 7. Profile transition time

4. CONCLUSIONS

Dam break experiment can represent a real tsunami or tidal bore propagation with acceptable accuracy. The velocity profile shows 3 distinct layers with different particle speed before mixing and a log law distribution after momentum is transferred from surface to bottom. The development of boundary layer also has two phases: initially follows the 4/5 rules of a turbulent boundary layer before mixing process and after receiving momentum from surface bore, the delevoment of bottom layer becomes more complex, but the shear inside the region becomes smaller as a result.

ACKNOWLEDGEMENT

This study was support by JSPS KAKENHI (No.16H04414).

REFERENCES

Chanson, H. and Koch, C. (2009). Turbulent mixing underneath an undular bore front, *Journal of Coastal research*, Vol.24, pp.999-1007.

Lin, P. et al. (2018). Bed shear stress and turbulence characteristic under unsteady flows, *Journal of Hydro-environment Research*, Vol.21, pp.1-20.

Madsen, P.A and Svendsen, I.A (1983). Turbulent bore and hydraulic jump, *Journal of Fluid mechanic*, Vol.129, pp.1-25.

Wuthrich, D. et al. (2018). Experiment study of Tsunami-Like Waves Generated with a Vertical Release Technique on Dry and Wet Beds. *Journal of Waterway, Port, Coastal and Ocean Engineering*, Vol.144, Issue 4.

Key words: Boundary layer, PIV, Dam break experiment, Tsunami

Address (6-6-04, Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi 980-8579, Japan Tel 022-795-7453)