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EXPERIMENTAL INVESTIGATION ON CHANGES OF WATER SURFACE PROFILE WITH BOTTOM ROUGHNESS

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Abstract- *The water surface profile changes with the bed surface and bed roughness of a channel. Depending on the height of the bed roughness, bed slope, flow velocity and discharge the characteritics of the flow profile can be determined. By making flow in a laboratory tilting flume while changing the different triangular wooden roughness and other functions the flow profile is experimented. One important findings is that the the maximum fluctuation of the water surface is increased with the increase of Froude number. The length of the roughness also create changes on the patteren of the flow profile.*

Keywords: Effect of bed roughness on flow profile, Changes of flow profile, Triangular bed roughness

1. INTRODUCTION

1.1 Preliminatives

The interruption problem between the boundary and the water surface profile of open channel flow such as the formation of sand waves in river and seas are still one of the most interesting subjects. The water surface profile mainly depends on the bed surface and bed roughness of the channel. Nabi reported that the water levels during river floods, and hence the risk of flooding, depend on the hydraulic roughness of the river [1]. One of the examples of this type of periodic irregularities on the river bed is “dunes”. The development of dunes and the associated hydraulic roughness during a flood is complex. Initially dunes grow higher and make the river bed rougher, but in later stages the dunes grow longer with the opposite effect of making the river bed smoother.

If the bed surface is wavy or highly rough, how the water surface profile changes in the crest and near the trough is the main focus of this study. Figure 1 shows the photo of double triangular roughness used in this study. A series of experiments were performed using the Tilting flume in the Hydrology lab for different flow conditions.

1.2 Statement of the project

The statement of the project is to experimentally investigate the changes of water surface profile with bottom roughness in the laboratory tilting flume.

1.3 Justification

The characteristics of the flow profile depend on the height of the bed roughness, bed slope, velocity and discharge of the open channel. To know how the fluctuation of the water surface changes with the different heights and widths of triangular roughness and for different flow condition the research activities are necessary.

1.4 Objectives of the study

The objectives of the study are given below:

i) To study the fluctuation of water surface for different heights of triangular roughness.

ii) To study the fluctuation of water surface for different widths of triangular roughness.

iii) To investigate the fluctuation of water surface with different flow conditions.

2. EXPERIMENTAL TECHNIQUES

In this chapter the preparation of the different triangular roughness and how the experiments were done are described. After preparing the roughness the water surface profile was determined for different cases.

2.1 Preparation of triangular bottom roughness

Seven different types of triangular bottom roughness are made by wood. The dimensions of the different types of roughness are given below in the Table 1. Figure 1 shows the pictorial view of triangular roughness of 2inch, 4inch, 6inch height. Three thin gates are made by wood which are inserted in to the downstream of the channel to control the depth of the flow.

Table 1: Dimensions of the different types of triangular roughness

Series No.	Height of the roughness Z_O(cm)	Base length of single triangle L_O(cm)	Length of the full roughness L_R(cm)
1	2	4	152.4
2	4	8	152.4
3	6	12	152.4
4	6	12	128.4
5	6	12	12.0
6	6	18	18.0
7	8	16	16.0

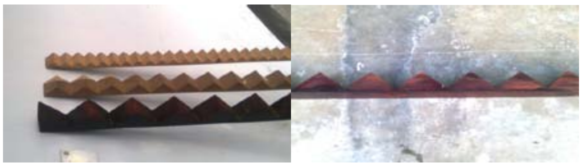

Fig. 1: Triangular roughness of different heights.

2.2 Laboratory tests

The tests were done in the laboratory tilting flume. Changing the following parameter the tests were done.

i) Different size of roughness

ii) Different slopes

iii) Different discharges

Fig. 2: Pictorial view of laboratory tilting flume.

Fig. 3: Pictorial view of point gauge.

Figure 2 shows the pictorial view of laboratory tilting flume in which experiments were performed to determine the water surface profile. Figure 3 shows the point gauge which is used to measure the depth of water of different point of the roughness.

3. RESULT AND DISSCUSSION

For the different heights and base lengths of the triangular roughness, experimental investigations on the changes of water surface profile in an open rectangular channel were performed. In this chapter the results are performed for different cases and discussions are made based on the comparison of the results.

3.1 Flow profile for series 1(Triangular roughness of 1 nos×8cm×16cm)

In series 1, four different tests were performed for different Froude number 0.160, 0.162, 0.169, and 0.176. These are discussed below.

a) Case 1 (Q= 0.00154 m^3/s, V= 0.168m/s, F_r= 0.160)

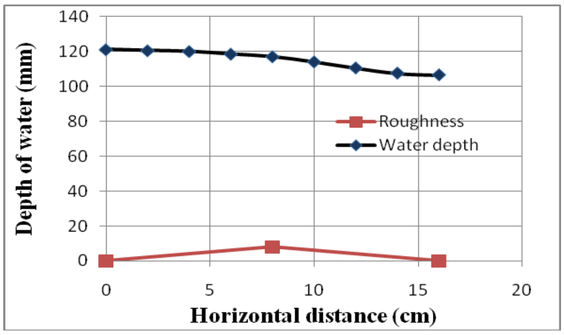

Fig. 4: Water surface profile over triangular rough channel (Case 1, triangle 8cm ×16cm, L_R= 16cm, F_r=—0.160).

Figure 4 shows that the upstream water depth is high at the trough of the roughness though at the next trough the water depth is low. The water depth is decreasing gradually towards the downstream. The difference between highest and lowest depth of the water is 1.5 cm.

b) Case2 (Q= 0.00164m^3/s, V= 0.172m/s, F_r= 0.162)

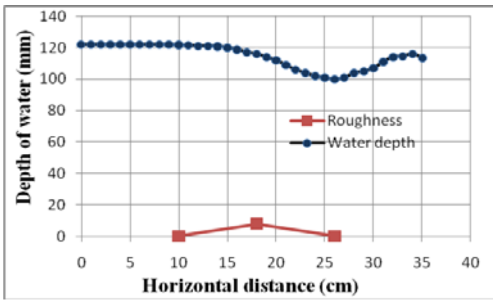

Fig. 5: Water surface profile over triangular rough channel (Case 2, triangle 8cm ×16cm, L_R= 16, F_r= 0.162).

Figure 5 shows that the water depth at the upstream of roughness is about constant but it is decreasing gradually from the middle of the roughness. Near the trough of the roughness the water depth is the lowest. The water depth is increasing gradually towards the downstream after the roughness. The difference between highest and lowest depth of the water is 0.85 cm.

c) Case3 (Q= 0.00179m³/s, V= 0.183m/s, F_r= 0.169)

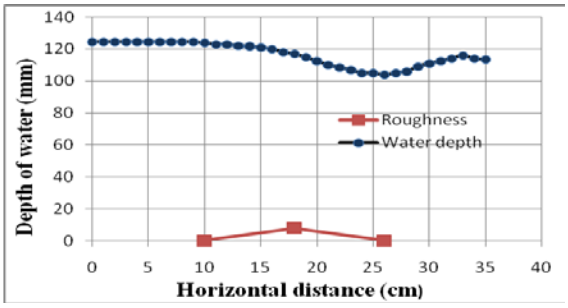

Fig. 6: Water surface profile over triangular rough channel (Case 3, triangle 8cm ×16cm, L_R= 16cm, F_r= 0.169).

Figure 6 shows that the water depth at the upstream of roughness about constant but it is decreasing gradually from the middle of the roughness. Near the trough of the roughness the water depth is the lowest. The water depth is increasing gradually towards the downstream after the roughness. The difference between highest and lowest depth of the water is 1 cm.

d) Case4 (Q= 0.002m³/s, V= 0.195m/s, F_r= 0.176)

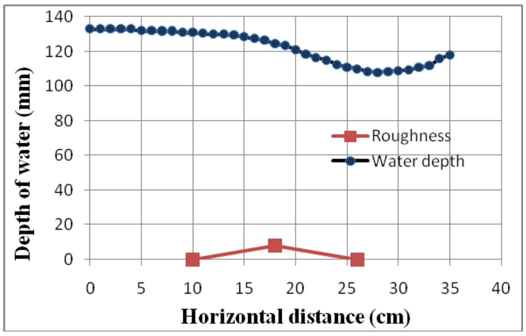

Fig. 7: Water surface profile over triangular rough channel (Case 4, triangle 8cm ×16cm, L_R= 16cm, F_r= 0.176).

Figure 7 shows that the water depth at the upstream of roughness is about constant but it is decreasing gradually from the middle of the roughness. Near the trough of the roughness the water depth is the lowest. The water depth is increasing gradually towards the downstream after the roughness. The difference between highest and lowest depth of the water is 1.4 cm.

e) Comparison of water surface profile among different cases of series 1:

Figure 8 shows that in the entire cases the water surface abruptly fall down near the crest of the roughness. The water depth and the maximum fluctuation are increasing with the increase of Froude number.

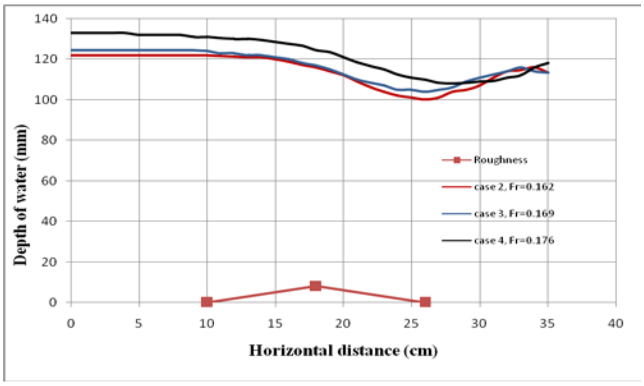

Fig. 8: Water surface profile for different cases over triangular rough channel (triangle 8cm ×16cm, L_R= 16cm).

3.2 Flow profile for series 2 (Triangular roughness of 1nos×6cm×18cm)

In series 2, four different tests were performed for different Froude number of 0.150, 0.155, 0.159, and 0.191. These are discussed below.

a) Case1 (Q= 0.00152m³/s, V= 0.160m/s, F_r= 0.150)

Figure 9 shows that the upstream water depth is high at the trough of the roughness though at the next trough the water depth is low. The water depth is decreasing gradually towards the downstream of the roughness. The difference between highest and lowest depth of the water is 0.75 cm.

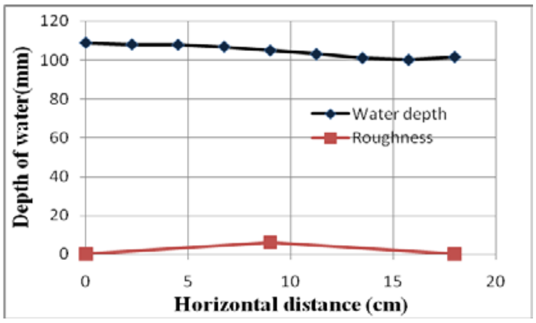

Fig. 9: Water surface profile over triangular rough channel (Case 1, triangle 6cm ×18cm, L_R= 18, F_r= 0.150).

b) Case 2 (Q= 0.00155m³/s, V= 0.164m/s, F_r= 0.155)

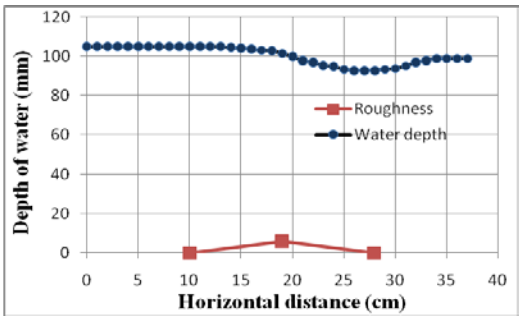

Fig. 10: Water surface profile over triangular rough channel (case 2, triangle 6cm ×18cm, L_R= 18cm, F_r= 0.155).

Figure 10 shows that the water depth at the upstream of the roughness is about constant but it is decreasing gradually from the middle of the roughness. Near the trough of the roughness the water depth is the lowest. The water depth is increasing gradually towards the downstream after the roughness. The difference between highest and lowest depth of the water is 0.6 cm.

c) Case 3 (Q= 0.00163m^3/s, V= 0.170m/s, F_r= 0.159)

Figure 11 shows that the water depth at the upstream of the roughness is about constant but it is decreasing gradually from the middle of the roughness. Near the trough of the roughness the water depth is the lowest. The water depth is increasing gradually towards the downstream after the roughness. The difference between highest and lowest depth of the water is 0.8 cm.

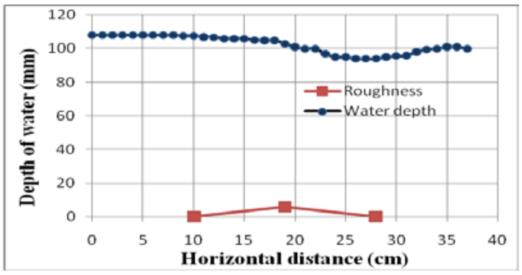

Fig. 11: Water surface profile over triangular rough channel (Case 3, triangle 6cm ×18cm, L_R= 18cm, F_r= 0.159).

d) Case 4 (Q= 0.00222m^3/s, V=0.213m/s, F_r= 0.191)

Figure 12 shows that the water depth at the upstream of the roughness is about constant but it is decreasing gradually from the middle of the roughness. Near the trough of the roughness the water depth is the lowest. The water depth is increasing gradually towards the downstream after the roughness. The difference between highest and lowest depth of the water is 1 cm.

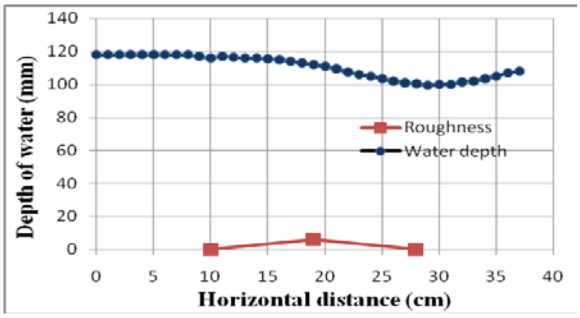

Fig. 12: Water surface profile over triangular rough channel (Case 4, triangle 6cm ×18cm, L_R= 18, F_r= 0.191).

Figure 12 shows that the water depth at the upstream of the roughness is about constant but it is decreasing gradually from the middle of the roughness. Near the trough of the roughness the water depth is the lowest. The water depth is increasing gradually towards the downstream after the roughness. The difference between highest and lowest depth of the water is 1 cm.

e) Comparison of water surface profile among different cases of series 2:

Figure 13 shows that in the entire cases water surface abruptly fall down near the crest of the roughness. The water depth and maximum fluctuation is increasing with the increase of Froude number.

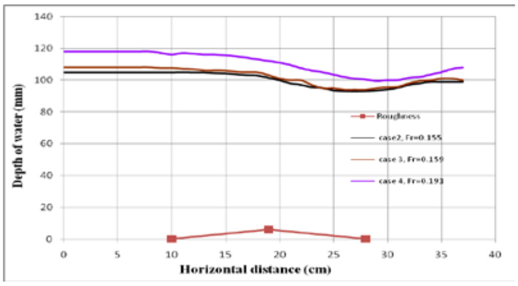

Fig. 13: Water surface profile for different cases over triangular rough channel (triangle 6cm ×18cm, L_R= 18).

3.3 Flow profile for series 3 (Triangular roughness of 2nos× 6cm×12cm)

In series 3, four different tests were performed for different Froude number of 0.160, 0.155, 0.177 and 0.180. These are discussed below.

a) Case 1 (Q= 0.00153m^3/s, V=0.167m/s, F_r= 0.160)

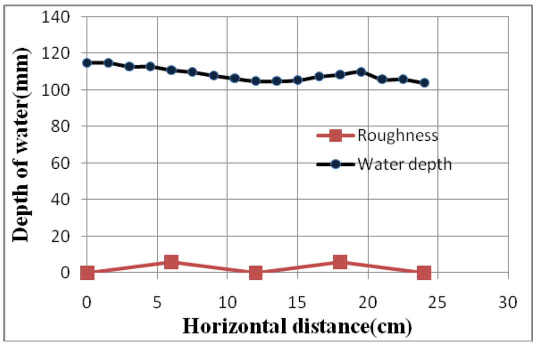

Fig. 14: Water surface profile over triangular rough channel (Case 1, triangle 6cm ×12cm, L_R= 24cm, F_r= 0.160).

Figure 14 shows that the water depth is high at the crest of the roughness and at trough the water depth is low. It is also seen that at upstream water depth is high and at downstream water depth is reducing gradually. The difference between highest and lowest point of the water is 1.1cm.

b) Case 2 (Q= 0.00155m^3/s, V= 0.164m/s, F_r= 0.155)

Figure 15 shows that the water depth at the upstream of the roughness is about constant. The water surface is gradually decreased starting from the 1st triangular roughness. The water depth is the lowest just before the second crest. Again the water surface is generally increased and shows the peak at the end of the roughness. The difference between highest and lowest point of the water is 2.8cm.

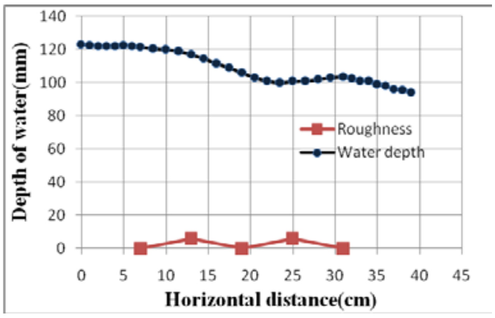

Fig. 15: Water surface profile over triangular rough channel (Case 2, triangle 6cm ×12cm, L_R= 24cm, F_r= 0.155).

c) Case 3 (Q= 0.00198m^3/s, V=0.195m/s, F_r= 0.177)

Figure 16 shows that the water depth at the upstream of the roughness is about constant. The water surface is gradually decreased starting from the 1st triangular roughness. The water depth is the lowest just before the second crest. Again the water surface is generally increased and shows the peak at the end of the roughness. The difference between highest and lowest point of the water is 2.7cm.

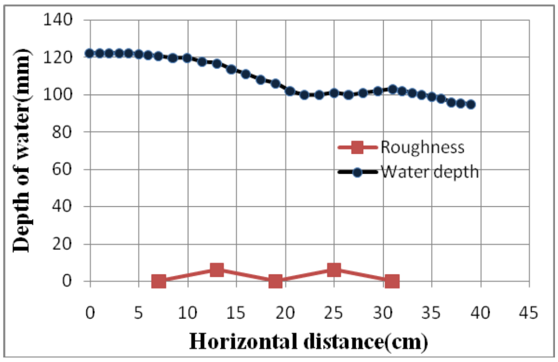

Fig. 16: Water surface profile over triangular rough channel (Case 3, triangle 6cm ×12cm, L_R= 24cm, F_r= 0.177).

d) Case 4 (Q= 0.00202m^3/s, V= 0.199m/s, F_r= 0.180)

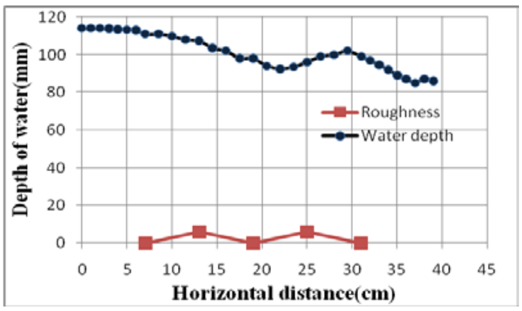

Fig. 17: Water surface profile over triangular rough channel (Case 4, triangle 6cm ×12cm, L_R= 24cm, F_r= 0.180).

Figure 17 shows that the water depth at the upstream of the roughness is about constant. The water surface is gradually decreased starting from the 1st triangular roughness. The water depth is the lowest just before the second crest. Again the water surface is generally increased and shows the peak at the end of the roughness. The difference between highest and lowest point of the water is 3.4cm.

e) Comparison of water surface profile among different cases of series 3:

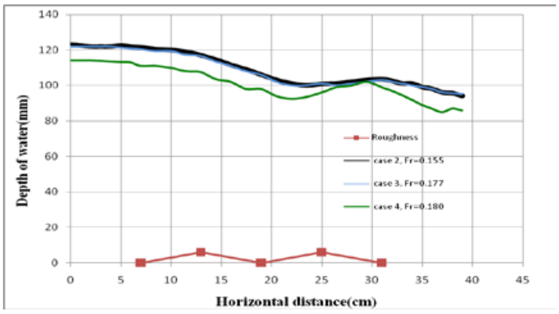

Fig. 18: Water surface profile for different cases over triangular rough channel (triangle 6cm ×12cm, L_R= 24cm).

Figure 18 shows that the water surface is gradually decreased starting from the 1st triangular roughness. It reaches to its lowest point just before the 2nd peak of the roughness. The water depth and maximum fluctuation are increasing with the increase of Froude number.

3.4 Flow profile for series 4 (Triangular roughness of 6×152.4 and 6×128.4)

In series 4, three different tests were performed for different frude number of 0.166, 0.190, and 0.380. These are discussed below.

a) Case 1 (Q= 0.00158m^3/s, V= 0.174m/s, F_r= 0.166)

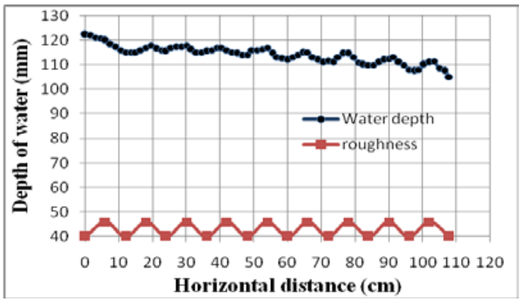

Fig. 19: Water surface profile over triangular rough channel (Case 1, triangle 6cm ×12cm, L_R= 128.4cm, F_r= 0.166).

Figure 19 shows that the water depth is high at the crest of the roughness and at trough the water depth is low. It is also seen that at upstream water depth is high and at downstream water depth is reduced gradually. The difference between highest and lowest point of the water is 2cm.

b) Case 2 (Q= 0.00164m^3/s, V=0.162m/s, F_r= 0.190)

Figure 20 shows that the water depth is high at the crest of the roughness and at trough the water depth is low. It is also observed that at upstream water depth is high and at downstream water depth is reducing gradually. The difference between highest and lowest point of the water is 2cm.

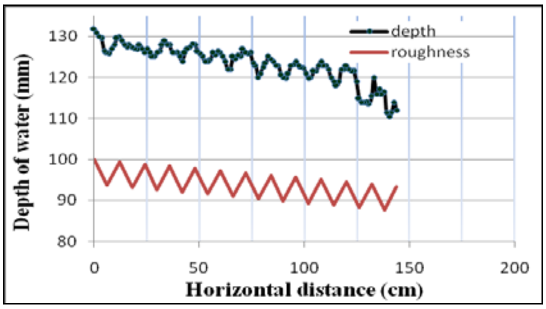

Fig. 20: Water surface profile over triangular rough channel (Case 2, triangle 6cm ×12cm, L_R= 152.4cm, F_r= 0.190).

c) Case 3 (Q= 0.00160m^3/s, V= 0.175m/s, F_r= 0.380)

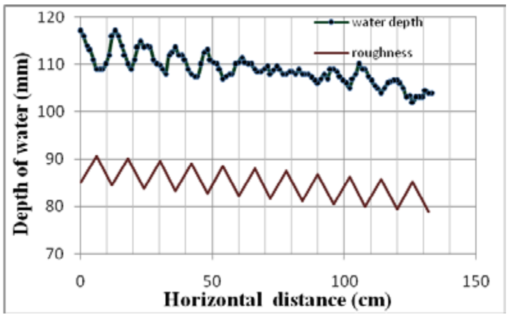

Fig. 21: Water surface profile over triangular rough channel (Case 3, triangle 6cm ×12cm, L_R= 152.4cm, F_r= 0.380).

Figure 21 shows that the water surface reaches at peak near the trough and the lowest point of water surface is found at crest of the roughness. At the middle portion of the roughness the fluctuation of the water is mild. The difference between highest and lowest depth of the water is 1.3 cm.

3.5 Flow profile for series 5 (Triangular roughness of 4×152.4 and 2×152.4)

These two roughness are catagorised in same serise because no undulation was found in the water surface for the reported flow condition.

4. CONCLUSION

In this study, experiments were conducted to investigate the fluctuation of water surface profile in an open channel with different types of triangular roughness. Based on the results, the following conditions are made:

- For single triangular roughness, the water surface was found to be abruptly falling down near the peak of the roughness and the water depth was found to be the lowest just before the second trough.
- For double triangular roughness, the water depth is the lowest just before the second crest of the triangular roughness and the water surface is peak at the end of the roughness.
- The maximum fluctuation of the water surface was found to be increased with the increase of Froude number.
- For series of triangular roughness (11 triangles), the pattern of wavy surface profile was found to be varied with flow conditions. For some cases, the low peak and high peak points are observed at the crest and trough of the triangular roughness. On the other hand, for some cases the reverse pattern of wavy water surface was observed.

5. RECOMMENDATION

In this study, based on the experiment, the following recommendations are made:

- Due to narrow width of the channel, there is strong side boundary effect on the flow. Therefore, the present results need to be verified with the experiments in a wider channel.
- The channel is very old and not capable of generating uniform flow. Therefore, the further study is recommended to compare the results with that of normal slope.

6. REFERENCES

[1] A. M. Nabi, "A 3D model of detailed hydrodynamics with sediment transport for simulation of subaqueous dunes", in 2nd *International Symposium on Shallow flows*, HKUST, Hong Kong, 2008, pp. 83.

7. NOMENCLATURE

Symbol	Meaning	Unit
Q	Discharge	(m^3/s)
V	velocity	(m/s)
F_r	Froude Number	Dimension less