STUDY ON SEDIMENT TRANSPORT OF COMPOUND CHANNEL WITH NON-UNIFORM FLOWS

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ABSTRACT

The experimental study on sediment transport in a straight compound channel with overbank non-uniform flows has been carried out. The studies have shown that degradations and aggradations will occur in the channel for flows with under-loaded sediment and with over-loaded sediment correspondingly. Degradations or aggradations are generally developing firstly in the certain short distance of the entrance, and this process develops gradually downstream. The net scoured or deposited sediment from/on the channel beds is almost linearly related to the sand feeding rate, and it will increase as the increasing time. The change of sediment transport rate with time is varying at early stage, after a certain time it will reach a relative stable stage. This would be expected to reach a new (quasi-) equilibrium for the given conditions (flow and tailgate) via adjusting the bed form.

Keywords: Sediment, compound channel, non-uniform, overbank flow

1. INTRODUCTION

In a nature alluvial river, flowing water and sediment on the bed interacts each other and try to reach an equilibrium state, which is that the driving force of flowing water is well balanced by the corresponding amount of suspending sediment. Hence the river bed reaches a so-called relatively stable state of bed profile. If this balance between the capability of driving flow and the amount of sediment is broken for some reasons, e.g. due to change of sediment source, build of hydraulic structure on the river, etc., the revolution of river bed will occur either degradation or aggradation. Due to the complexity of interaction effect between flowing water and sediment, the understanding of alluvial hydraulics is still not well even for uniformly sand inbank flows.

Due to the complexity of the flow-sediment interaction, the majority of research on sediment movement was undertaken on a simple channel with inbank flows. Recently a couple of research works were undertaken on sediment transport in a compound channel with overbank flows (Ayyoubzadeh, 1997; Brown, 1997; Atabay & Knight, 1998; Knight et al, 1998, Tang & Knight, 2001a). This enhances the understanding of the interaction of the floodplain flow with the main channel and its impact on the flow resistance, sediment bed forms, transport rate and channel geomorphology etc. However those studies were carried for an equilibrium or quasi-equilibrium flow on the compound channels.

To explore the sediment transport with non-equilibrium flows and how the bed profile changes when the flow is sediment under- or over-loaded in a compound channel, a laboratory study was taken in order to enhance the understanding of interaction between flow and sediment in a non-uniform overbank flow in this paper.

2. EXPERIMENTAL PROCEDURES

The experiments were performed at the University of Birmingham in a non-tilting 22m long flume with a test length of 18m. The flume was 1213 mm wide and configured into a two-stage channel with a 398mm wide, 50mm deep sand (d_{50} = 0.88mm herein) main channel and two 407.3mm wide rigid floodplains, as show in Fig. 1. The flume had water supplied through a circulation system comprising of three pipelines, 50 mm, 100 mm and 150 mm in diameter, and discharges were measured by an electro-magnetic flow meter, a Venturi meter and a Dall tube respectively. The sand can be re-circulated in the flume via a slurry pump and the internal 50 mm pipeline, or can be conducted via the pipeline to be collected at the tank at the entrance of the flume. Water surface profiles were measured directly using pointer gauges. Firstly a preliminary development of bed was allowed, and a uniform flow is set up through the tailgate adjustment to make the mean water surface slope being equal to the valley slope of the floodplain, fixed at 2.204×10^{-3}, thus the flume is assumed to achieve a quasi-equilibrium status. Then, for each test of non-equilibrium flow it started immediately by operating the Solitec feeder with pre-setting feeding rate of sand.

During the experiments, sediment transport rates were measured by manually collecting samples over 10~15 minute intervals during each experiment, and the transported sediment from the flume were also measured, finally bed profiles were measured with an automatic HR touch sensitive bed profiler.

3. EXPERIMENTAL RESULTS

3.1 INTRODUCTION OF EXPERIMENTAL TESTS

In this study, for the simplicity of comparison the non-uniform flow tests were undertaken under a particular flow depth, e.g. Q_{total} ~ 16 *l*/s or Dr ~ 0.25. Four different sediment input loads (here termed as 0X, 1/2X,1X & 2X respectively) via the direct Solitec feeder (the flume switched to a non re-circulating mode) were carried out, where X is the sediment transport rate (265ppm) based on the uniform flow test (quasi-equilibrium experiment) for the particular depth. All the tests were run around 6~8 hours for each of them, among them the test of 0X-load was run extra long time of 4 days. As it would be expected, degradation and aggradation will occur in the channel when the sediment directing feed rate on the entrance of the flume is under-loaded and over-loaded respectively. It is the intent to investigate the sediment transport with non-equilibrium flows and how the channel bed profile change.

3.2 CHANGE OF SEDIMENT TRANSPORT RATE WITH TIME

When the flume was shifted to the flow with direct sand feeding mode immediately from the quasi-equilibrium status, despite of the same discharge of flow, the flow in the channel became non-equilibrium flow for whatever the direct under-loaded or over-loaded sand feeding cases. Consequently the bed of channel will be adjusted continuously to achieve a new equilibrium corresponding to the different sand feeding rates. The change of sand bed can be either longitudinal bed slope or bed forms alone but without change of width because the side-wall was fixed in the experiments. Due to the adjustment of channel bed, the sediment transport rate will change with time coordinately. The sampling sediment transport rate, in terms of both concentration (X_{ppm}) and sand weight rate (G_s), are shown in Fig. 2 and Fig.3 for 0X, 1/2X, 1X and 2X accordingly.

Those figures show that:

Generally the sediment transport rate is varying at the very early stage, after a period around 250 minutes, which is about the same traveling time of the dune (dune migrate rate Cs ~ 5.8cm/min) from the entrance to the tailgate of the flume with the total length of 15m, calculated based on the study by Tang & Knight (2001b), it reaches a relatively stable statue, which would be expected to be a new equilibrium or quasi-equilibrium corresponding to the adjusted bed slope for each particular feeding rate of sand. For the cases with under-loaded sand feeding rate (Case 0X & 1/2X), the channel bed would be expected to be degradation due to the more sand from the bed being transported downstream, in particular at certain short distance from the flume entrance. So the flow in the flume is non-uniform. On the other hand, for the over-loaded sand feeding rate (Case 2X) the channel bed would be expected to be aggradation due to more sand from the sand-loaded flows being deposited longitudinally, in particular at certain short distance from the flume entrance, thus the flow in the channel is also non-uniform. Due to the discharge of flow and the height of tailgate being fixed at constant, the sediment transport rate has the tendency of reaching a value of 255ppm or 4.0 g/s for all 4 cases (almost the same discharge Q~16 l/s), which corresponds to the condition of flow and sediment.

3.3 CHANGE OF BED PROFILES

As would be expected, degradations and aggradations occur to the channel bed when the flow is with under-loaded and over-loaded sediment respectively. This can be clearly shown in Fig.4, where for the case of 2X (V0012) the bed profile is higher and for the case of 0X (V0016) it is lower compared with the bed slope for the quasi-equilibrium flow case of X (V016). This result also shows that the adjustment of the bed slope for the non-equilibrium cases occurs in a large longitudinal range, and that the majority of adjustment (scour for under-loaded flows or deposit for over-loaded flows) occurs in certain short distance at the entrance. The process of adjustment would be expected to go further downstream gradually. To pursue how the bed profile changes in detail, a 4-day long series experiment for the case of 0X was undertaken. The bed profiles are compared in Fig.5, which clearly shows that the degradation of channel bed develops both gradually and longitudinally with the time, but most change quickly occurs in the certain short distance of the entrance.

It is very interesting that the sand volume collected from the flume shows a good linear relationship with the directing feeding rate of sand. The result is compared in Fig.6, where the negative and positive values of sand volume indicate the scoured and the deposited volume of sand for the degradation and the aggradations respectively. Fig.6 implies that the more degradation occurs for the lower under-loaded flows, and that the more aggradations occur for the higher over-loaded flows. This can be also shown in term of the bed profile, illustrated in Fig.7, where the bed slope increases from the case of 0X to 2X.

A further analysis about the change of bed profile of long-series experiment is shown in Fig.8, where the collected sand volume almost linearly increases with the developing time of the degradation, and the bed slope deceases accordingly. A good relationship about change of the bed slope with time exists, as shown as follows:

$$S = -5E\text{-}07\, t^2 - 0.0006\, t + 2.0595 \qquad R^2 = 0.9921$$

Where S = bed slope ($\times 10^{-3}$) and t = time (min).

For this long series test, the development of different section with time for an interval integration steps (Δx =1.5m) is illustrated in Fig. 9, where it confirms the earlier result that the major change of bed profile occurs in the upstream entrance quickly and largely, and gradually reduces along the channel downstream.

4. CONCLUSIONS

From this experimental study, the following preliminary points may be drawn:

- Degradations will occur in the channel when flows carry under-loaded sediment.
- Aggradations will occur in the channel when flows carry over-loaded sediment.
- Degradations or aggradations are generally developing from the certain short distance of the entrance, and this process develops gradually downstream.
- The net scoured or deposited sediment from/on the channel beds is almost linearly related to the sand feeding rate, and it will increase as the increasing time.
- The change of sediment transport rate with time is varying at early stage, after a certain time, it will reach a relative small stage. This would be expected to reach a new (quasi-) equilibrium for the given conditions (flow and tailgate) by adjusting the bed form.
- Further more data are needed for the detailed description and determine for the developing process of degradation or aggravation.

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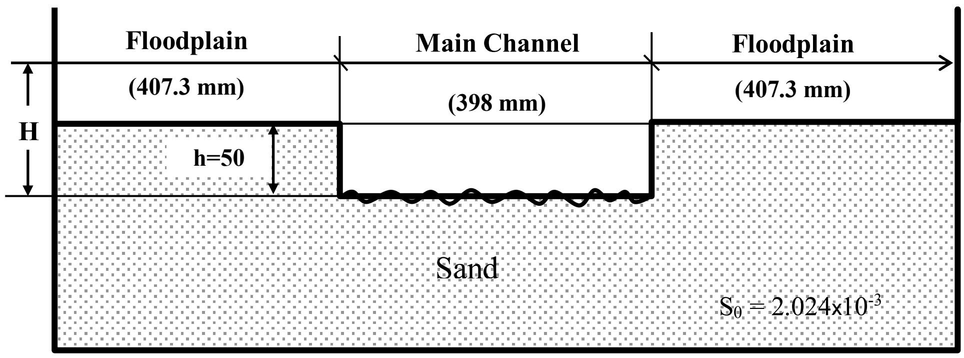

Fig.1 Schematic cross section of the flume at the University of Birmingham