EXPERIMENTAL STUDY ON SANDBARS EVOLUTION WITH BED EROSION GROWTH IN MIXED ALLUVIAL-BEDROCK UNIFORMLY CURVED CHANNEL

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ABSTRACT

Difficult to be monitored from the surface, the riverbed erosion may affect the stability and durability of structures placed in the river channel. The knowledge of the erosion process on riverbed would help to prevent such adversity. This study focused on erosion in mixed alluvial-bedrock uniformly curved channels, here relating the formation of sandbars and the evolution of the erosion. An experimental study was carried out within an annular flume, made of Plexiglas, to simulate the erosion in such channels; using gypsum as the bedrock and sand as the abrasive material. The rotation of the top lid, put on the water surface, induces the water to flow. The relative bed elevation was surveyed using laser beam, both for the bed configuration and for the erosion, after 10 min, 3h, 6h, 12h, 24h, and 48 h of cumulative duration of the experiment. At the early stage of the experiment, the sand formed along the inner wall a uniform transverse slope of 22°. Then gradually, it turned into migrating sandbars. The bars morphology progressively changed - smooth to rectangular-like shape. Furthermore, the number of bars increased - from 5 to 9. Simultaneously, bed erosion occurred and grew at the base of the transverse slope. The sandbar morphology is related with the bed erosion growth: the more developed the erosion is, the more sandbars is generated, and the faster is the erosion rate.

Keywords: Sandbar, erosion, uniformly curved channels, mixed alluvial bedrock

1. INTRODUCTION

Under natural conditions, river channels are rarely straight, they are rather meandering and curving. In such channels, the inherent secondary flow shifts the sediment towards the inner bank and forms the transverse slope.

Booij (1994) and Baar et al. (2018) obtained, from experiment, the appropriate ratio of the top lid and bottom floor rotation in order to build uniform transverse slope. They found slightly different ratio values, which were attributed to the bed roughness difference. However, many studies also showed that if the top lid is only used, the uniform transverse slope was also obtained, but only at the early stage of the experiment. Then it gradually turned into migrating sand bars or dunes, as a result of instability in the flume generated by small disturbances (Engelund, 1975; Kikkawa et al., 1976).

In addition to sediment transport, bed erosion monitoring is also considered. Several studies revealed different processes contributing to the riverbed erosion, and they can generally be classified as: chemical, and/or mechanical. Sklar and Dietrich (2004) has shown the importance of bed erosion by sediment saltation on alluvial bed channels, part of mechanical erosion process. In addition, Taguchi et al. (2017, 2018) performed experimental bed erosion study in annular flume, based on Sklar and Dietrich model (2004). They found that in curved channel, erosion occurs under moderately covered bed: deepest erosion was located along the center of the flume channel. Furthermore, it was also found that the number of bars gradually increased.

The fluid flow and the sediment characteristics and its mode of transport control the bed morphology. However, not much know is the relationship between the erosion growth and the bars formation. How are the sandbars formed and evolved? How they are related with the bed erosion?

In this study, we did experiments in annular flume using gypsum to simulate the bed and sand grains as abrasive materials. The gypsum has been used because not only it is easy to use, but also it provides quick results in term of erosion by saltation. The gypsum is cautiously prepared and installed in order to obtain a homogenous bed.

Bed morphology survey using laser beam was used to collect the relative bed height. One by one, sediment deposition and the bed erosion are surveyed. Herein after will be presented the materials used and the methods used, followed by the presentation of the results.

2. EXPERIMENTAL PROCEDURES

To investigate any interconnection between the erosion growth on the sandbar's evolution in uniformly curved channel, we conducted experiments in an annular flume made of Plexiglas, using sand as abrasive tools and gypsum to simulate the bedrock.

Annular flume has been used for many purposes: research on fluid dynamics (Krishnappan, 1993), on sediment transport (Ikeda, 1974; Kikkawa et al., 1976), and on erosion (Taguchi et al., 2018). One of its important features is that secondary flow can be generated inside the flume. Recently, Taguchi et al. (2017, 2018)conducted erosion experiments on a mixed alluvial bedrock with the same flume. A picture of the flume is presented in the following figure:

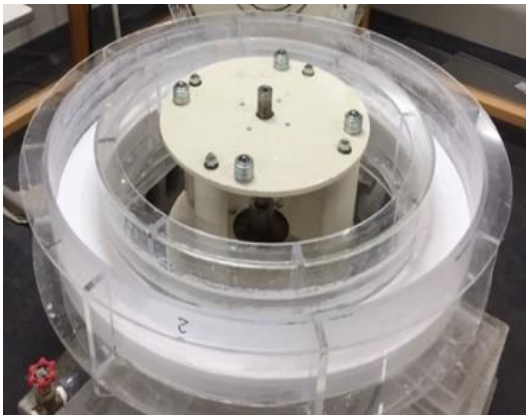

Figure 1. Plexiglas-made annular flume, with gypsum bedrock (white).

As opposed to the studies done by Taguchi et al. (2017, 2018), the present one was performed with different material (gypsum) and with longer experiment time. This permitted us not only to operate faster, but also to obtain fast- and detailed erosion footprint, and to visualize advanced erosion aspect.

The Plexiglas-made annular flume has a rectangular cross-section. It has 0.45m average radius, 10cm width and 18cm maximum depth. The flow is induced by the rotation of the Plexiglas plate top lid which is put on the water surface. The bed consisted of homogeneous gypsum, 6cm thick, laterally and circumferentially flat. Abrasive material is composed of 2.5kg sand, $0.52.10^{-4}$m diameter and 2620kg/m^3 density. The water depth is 5.10^{-2}m, obtained after adjustment and leveling of the top lid surface.

Throughout the experiment, the rotation of the top lid was about 4.2rad/s (40rpm). The experiment was subdivided specified time, and the cumulative time experiments are as following: 10 minutes, 3h, 6h, 12h, 24h, and finally 48h.

After each run, the top lid is removed, and the water is pumped out for the bed elevation survey. It is meant to monitor the spatial distribution and morphology of the sand grains and the bed erosion evolution using a laser beam. The survey is done circumferentially, starting at 5.10^{-2}m from the inner wall till $9.5.10^{-2}$m near the outer wall, and with an interval of 5.10^{-2}m radial interval.

3. RESULTS and DISCUSSION

At this early stage of the experiment, for 10 minutes, the sediment was shifted toward the inner wall due to the helical flow and formed a uniform transverse slope. The base of the transverse slope was located around the centerline of the channel and has a slope about 22°, which is in agreement with those found by Engelund (1975), between 21 – 27^o.

The instability in the flume led to a progressive formation of migrating sand bars (figure 3). The bars also varied throughout the experiment, these variations were observed in the bars' shape, dimension, and distribution inside the flume. Those characteristics are resumed in the table below:

Table 1 Bars characteristics

	Bars					Erosion		
Time	**Number of bars**	**lateral width – Min. (10^{-2}m)**	**Average width (10^{-2}m)**	**lateral width – Max. (10^{-2}m)**	**relative max. height (10^{-2}m)**	**width (10^{-2}m)**	**Max. depth (10^{-2}m)**	**Max. depth position** (10^{-2}m)**
10 min	Uniform (1)	4	5	6	7.9	No erosion	No erosion	No erosion
3h	5	3.5	2.82	7	8.2	1	0.2	5.6
6h	5	0.56	2.71	7.5	8.3	2.2	0.3	4.6
12h	6	1.51	3.85	5.84	8	2.6	0.54	5
24h	8	0.9	3.63	5.87	7.7	3.4	1.2	4.4
48h	9	0.8	3.55	5.81	7.4	4.2	1.6	4

*coverage above $0.1x10^{-2}$ m of sediment, ** distance from the inner wall

The number of bars increased with time, the shape and the dimensions of the bars also altered - smooth at the early stage of the experiment, then gradually turned into small rectangular-like shape. Simultaneously, the erosion progressed. With a constant amount of sediment, the more are the formed bars, the higher is the frequency of the passage of bars on the bedrock, and consequently increasing the probability of abrasion occurrence on the bedrock (Sklar and Dietrich, 2004). On the other hand, the development of the erosion seems to control also the formation of the bars as presented in the figure 2. The erosion width is non-dimensionalised by the flume width.

When erosion can contain less than 25% of the sediment amount, the number of bars is less than five. Above that ratio, the sediment bars increase slowly.

4. CONCLUSIONS

In uniformly curved channel, at equilibrium state, the sediment is shifted toward the inner wall, due to the helical flow, and forms the uniform transverse slope with an angle about 22°. The instability in the flume leads to the formation of migrating bars, with different shapes and dimensions. From the experiment, the development of the bedrock erosion is found to be one of the reasons of the bars' fluctuation.: the bigger becomes the erosion, the more becomes the number of the sand bars. Inversely, the bars formation also influences on the growth of the erosion.

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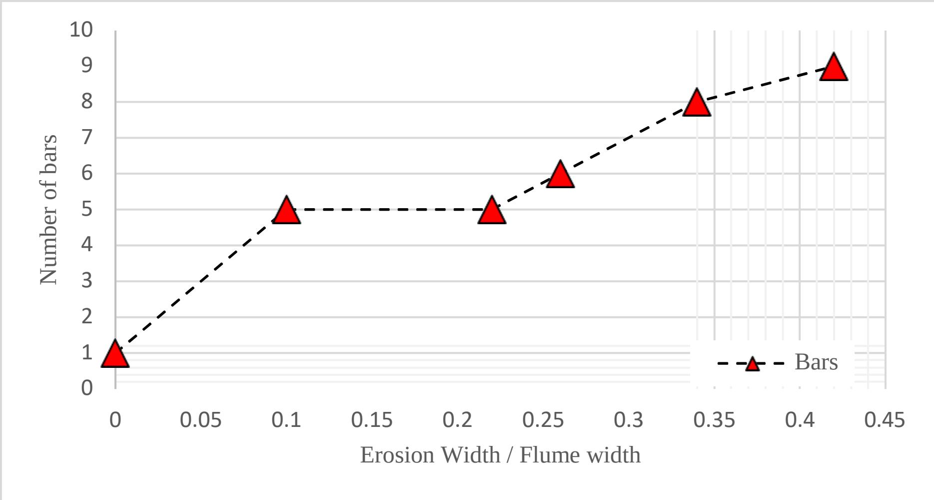

Figure 2 Number of bars vs. ratio of Erosion width / Flume width

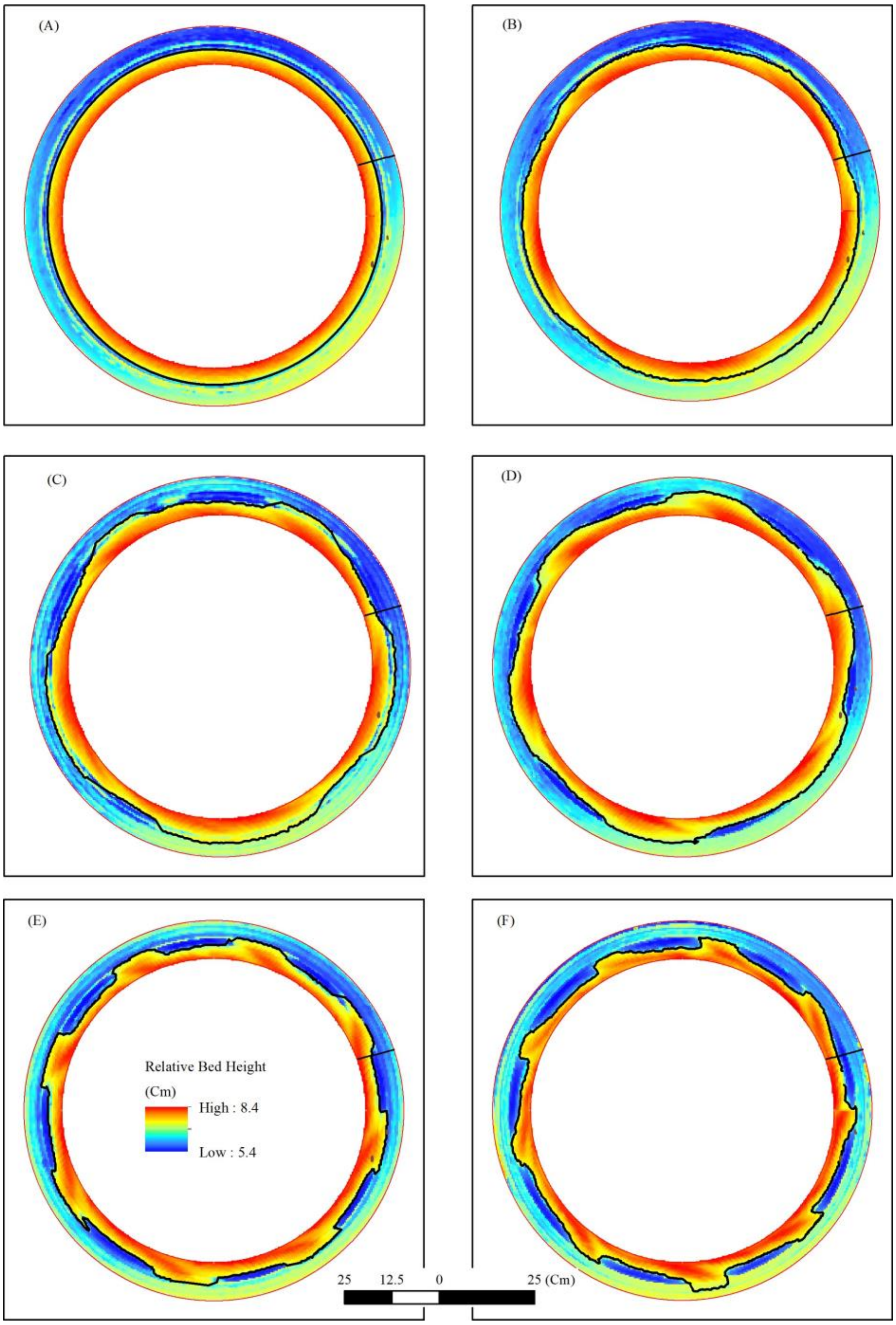

Figure 3. Sediment deposition pattern evolution: (A) - after 10 minutes of experiment run, (B) - after 3 hours, (C) - after 6 hours, (D) - after 12 hours, (E) - after 24 hours, (F) - after 48 hours.