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Investigation of Suspended Sediment Transport and Bed Deposition around Bandal-like Structures

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ABSTRACT

This paper describes the flow structure, suspended load concentration and bed deposition characteristics around a group of Bandal-like structures with experimental methods. The experiments demonstrate that the local flow around Bandal-like structures are complex due to the flow separation, the upward flow, the flow circulation and the interaction between the mainstream and the bay area. In particular, the upward flow passing through the lower part of the Bandal-like structures plays an important role in supplying sediment to as well as promoting sediment deposition in the bay area.

KEY WORDS: Suspended sediment; Bandalling, Bandal-like structure; sediment concentration; indigenous knowledge.

INTRODUCTION

Bandalling is an indigenous method of river training in the India subcontinent for maintaining navigable channels of alluvial rivers during low water season. A Bandalling structure physically appears as a vertical screen mounted on a frame. In general, the screen is made of bamboo mats and the frame consists of a series of bamboo sticks. As bamboos are locally available and inexpensive labors are easily employable on site, Bandalling structures have achieved a wide use in some large continental rivers such as the Ganges River and the Brahmaputra River. According to the physical appearance, a Bandalling structure can be described as a combined structure of an impermeable groyne in the upper part and a permeable groyne in the lower part (Zhang et al., 2010). When the sediment-laden flow approaches a Bandalling structure, the low sediment-concentrated flow of the upper layer is diverted to the mainstream and is accelerated, resulting in mainstream bed degradation and increase of water depth. It is the mechanism for the navigability enhancement. On the other hand, the high sediment-concentrated flow of the lower layer passes through the Bandalling structure and sediment deposition occurs behind it due to the velocity reduction there (Rahman et al., 2004). As sediment deposits along the river bank, the risk of bank erosion is reduced and a new agricultural land is created. In other words, Bandalling is not only effective for the improvement of domestic navigation but also promising in farmland protection and disaster mitigation. Unfortunately, the performance of Bandalling is not always as efficient as desired according to analyses of field data obtained in major Bangladeshi Rivers (Rahman et al., 2003). In order to take full use of this indigenous method, there is a crucial need to combine updated

insight of river dynamics with local indigenous knowledge and experiences. The structure having the similar functions as Bandalling structures is defined as Bandal-like structure herein despite its construction materials, shape and layout. In the past decade, several groups have conducted research on the flow and the bed morphology around Bandal-like structures, e.g. Rahman et al. (2004), Zhang et al. (2010), Uddin (2010), Nakagawa et al. (2013) and Rahman and Osman (2015). These research revealed the complex flow structure around Bandal-like structures and some of the advantages of Bandal-like structures over other traditional river training works. Nevertheless, one of the most important parameters, the suspended load around Bandal-like structures, is yet unknown. In this paper, detailed measurements and analyses are conducted for the local flow, suspended load concentration and bed deposition around Bandal-like structures.

EXPERIMENT METHOLDS

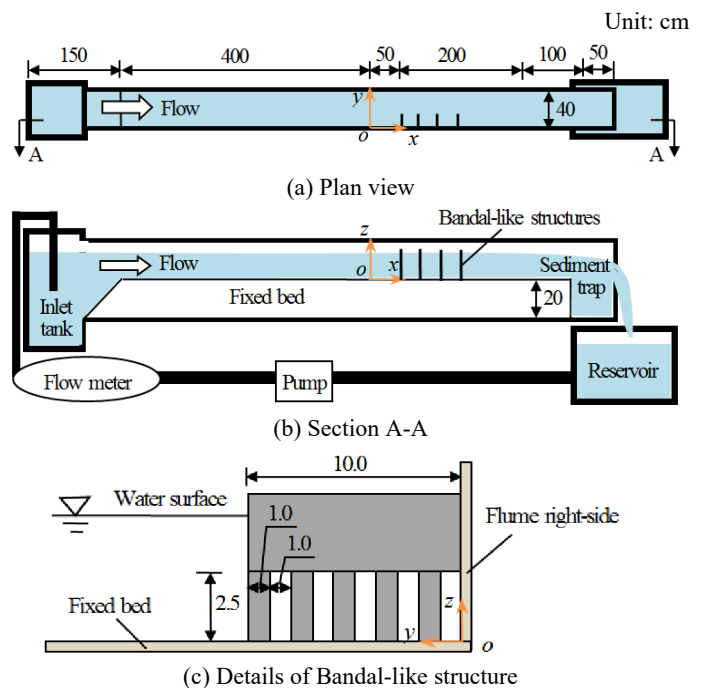


Fig. 1 Experiment setup (not to scale).

Experiment Setup

Experiments were conducted in a straight tilting flume at the Ujigawa Open Laboratory of Kyoto University (Japan). The flume was 8m-long, 40cm-wide and 30cm-deep as shown in Fig.1. In the experiment, a 7m-long and 20cm-thick wooden deck was set at the bottom of the flume so that a sediment trap was formed at the most downstream part of the flume. The longitudinal slope of the flume, as well as the wooden deck was 1/1,280. Four Bandal-like structures were installed on the wooden deck along the right side of the flume, labelled as structure A, B, C and D from the upstream to the downstream hereafter. The distance between two consecutive Bandal-like structures was 20cm. Each Bandal-like structure consisted of 5 piles and an impermeable upper layer as shown in Fig.1(c). The Bandal-like structure was 10cm long and 1cm thick, perpendicular to the right side of the flume and being high enough to maintain non-submerged in the experiment.

Table 1. Hydraulic conditions in the experiment

Flow discharge (l/s)	5.70
Channel slope	1/1280
Uniform flow depth (cm)	4.43
Uniform flow velocity (cm/s)	32.17
Near-bed friction velocity (cm/s)	1.67
Sediment density (g/cm ³)	2.65
Sediment mean diameter (μm)	92.9
Sediment settling velocity (cm/s)	0.57
Reynolds number Re	10,894
Froude number Fr	0.49

Experiment Measurements

The hydraulic conditions in the experiment was described in Table1, which were determined based on the results of several trial experiments to ensure active suspended sediment transport in the approach flow area. The model sediment was a kind of silica sand. The sediment was almost uniform with a mean diameter of 92.9μm and a specific gravity of 2.65. The sediment was continuously supplied from the most upstream of the wooden deck. The amount of sediment supplied was decided based on the examination of the propagation of the bed forms in the approach flow area. With the sediment supply, the properties of the bed forms in terms of ripples in the approach flow area almost maintained throughout the experiment. During the experiment, the flow discharge was kept constant. A quasi-equilibrium condition was reached when the bed forms in the approach flow area and the deposition patterns in the bay areas formed by two consecutive Bandal-like structures showed insignificant changes. It took 3 hours. The water levels, three-dimensional velocity distributions, suspended sediment concentrations and bed deposition depths were measured at the final stage of the experiment. The water levels and the bed deposition were measured with an ultrasonic displacement meter and a Laser displacement meter, respectively. The flow velocities in the water column and on the water surface were measured with an electromagnetic velocimetry and a PIV (particle image velocimetry) analysis method, respectively. Water with suspended sediment was sampled at the height of 40% of the water depth at several representative points with a syphon-type sampling system. After that, the samples were analyzed and the sediment concentrations were obtained.

RESULTS AND DISCUSSIONS

Flow Velocity

The authors have previously investigated the flow structure around an individual Bandal-like structure under scoured bed conditions (Zhang et al., 2010 and Zhang et al., 2013). According to the results, the flow velocity around a Bandal-like structure was quite complex and strongly three-dimensional. As the flow velocity played a crucial role in the transport of suspended sediment, detailed flow velocity measurements were conducted in this study.

Flow velocity on water surface. The longitudinal and transverse velocity vectors (u , v) on the water surface were plotted in Fig.2. It was well recognized from the figure that the diversity of the flow field was significantly enhanced in the proximity of the Bandal-like structures. The velocity in the mainstream was much larger than that in the bay areas between two consecutive Bandal-like structures. In the mainstream, the flow almost maintained parallel to the side of the flume. While in the bay areas, the flow structures were quite sophisticated and exhibited evident spatial changes from the upstream to the downstream. For clarity, the sketches of typical flow patterns in the bay areas were drawn in Fig.2 based on the measured velocity vectors.

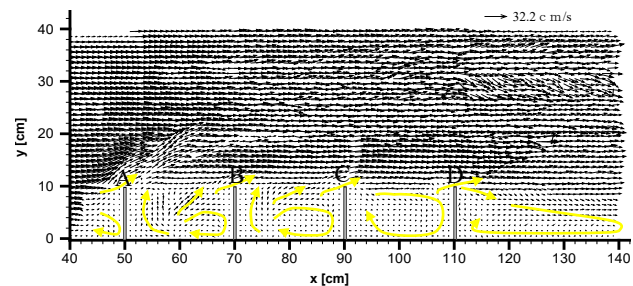


Fig. 2 Flow velocity vectors (u , v) on the water surface.

According to Fig.2, the flow separation was observed at the head of each structure, being the most significant around structure A. The circulation flow was one of the most typical flow patterns in front of each structure. The size of the circulation cell in the bay area became larger and larger from the upstream to the downstream. In bay AB, the circulation was confined at the corner in front of structure B due to the strong flow passing through the lower part of structure A. The existence of this flow resulted in an obvious surface-oriented upward flow in bay areas and influenced the circulation cells in the bay area. This flow has significant implications for the transport of suspended sediment, which distinguished Bandal-like structures from other types of groynes. Due to the velocity reduction, the influence of this flow turned weaker and weaker towards downstream. In bay CD, the circulation cell almost occupied the whole bay area and the center of the circulation almost coincided with the geometrical center of the bay. Behind structure D, a wake circulation was easily recognizable, somewhat similar to that formed behind a group of impermeable groynes (Zhang et al., 2015).

Flow velocity along transverse cross-sections. The flow velocities along typical transverse cross-sections were plotted in Fig.3, which provided more detailed information on the complexity of the local flow. At $x=45$ cm (in front of structure A) as shown in Fig.3(a), the flow was partially toward the right side of the flume and partially diverted to the mainstream. The former was due to the existence of a small circulation

near the upstream corner of structure A, while the latter was attributed to the flow separation at the head of structure A as shown in Fig.4. In the bay areas AB ($x=55\text{cm}$ and 65cm) and BC ($x=75\text{cm}$ and 85cm), the upward flow was evidently observed. The flow structure in the vertical plane of bay AB was quite complex due to the existence of various flow patterns, corresponding to the complex flow on the water surface (Fig.2). On the other hand, there was an interesting finding on the flow in bay BC according to Fig.3 (d) and Fig.3 (e). The flow was toward the mainstream in the upstream (i.e. $x=75\text{cm}$) and was toward the bay area in the downstream (i.e. $x=85\text{cm}$). It indicated that flow exchanges took place between the mainstream and the bay area.

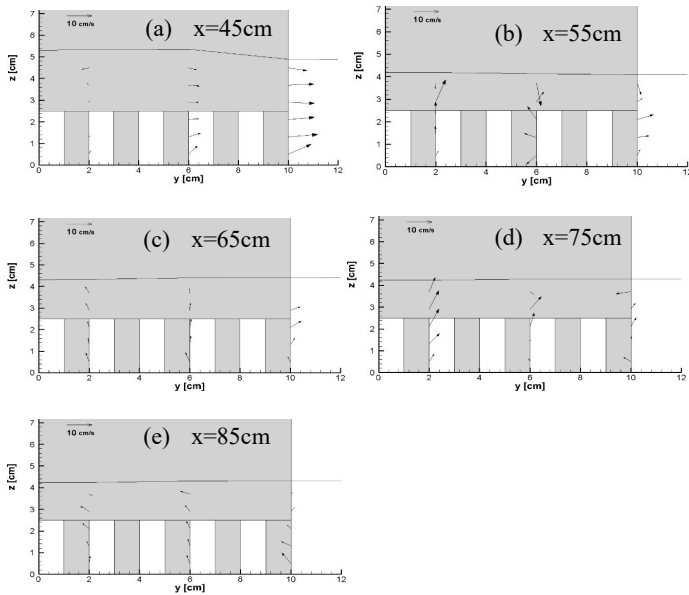


Fig.3 Flow velocity vectors (v, w) at different locations.

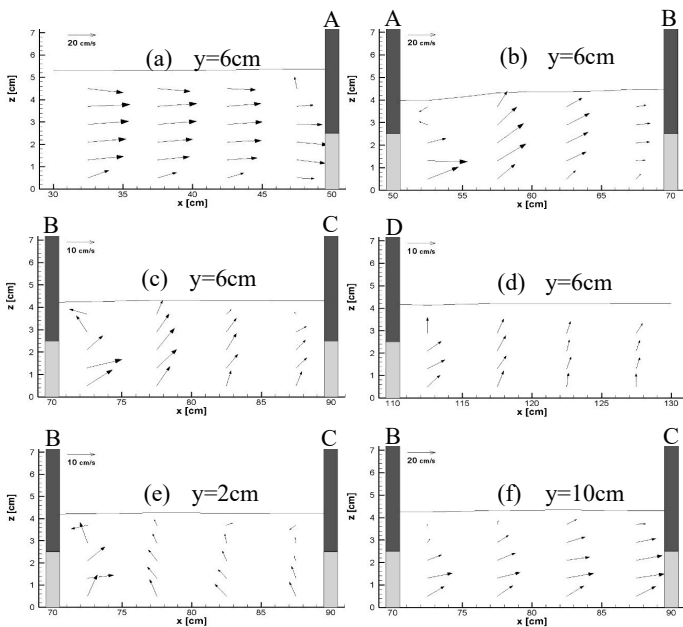


Fig.4 Flow velocity vectors (u, w) at different locations.

Flow velocity along longitudinal cross-sections. The longitudinal change of the flow velocity at $y=6\text{cm}$ in the vertical plane was shown in Fig.4 (a-d). The approach flow was partially blocked in front of structure A. As a result, the velocity gradually became smaller when the flow approached structure A. After passing each Bandal-like structure, the flow gained an upward velocity and at the same time, the longitudinal velocity was significantly reduced. The upward velocity maintained in all of the bay areas. Fig.4 (e) and Fig.4 (f) drew an image on the flow along the right side of the flume ($y=2\text{cm}$) and near to the mainstream ($y=10\text{cm}$) in bay BC. It was found that the flow was toward upstream near the flume side and was toward downstream near to the mainstream. It was consistent with the observation in Fig.2. Moreover, the upward flow velocity along the flume side was found to be larger than that near to the mainstream.

Bed Deposition Patterns

The change of the bed level from the initial flatbed to the final bed and the photo of the bed deposition patterns were shown in Fig.5. Due to sediment deposition, bed forms in terms of ripples took place on the bed in the approach flow area. In the reach with Bandal-like structures, sediment deposition was mainly observed in the bay area and the wake zone behind structure D. There was almost no sediment deposition in the mainstream. As the flow velocity was accelerated, the mainstream bed had a potential to be continuously eroded. In this area, most of the sediment coming from the upstream was transported by water to the downstream directly and a very small amount exchanged with the adjacent bay areas.

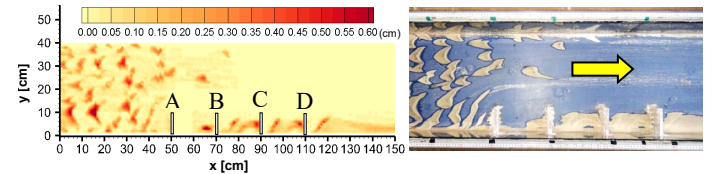


Fig.5 Bed deformation from the initial flatbed.

The deposition patterns in the bay areas varied from the upstream to the downstream. Although a large amount of sediment was carried by the flow passing through the lower part of structure A, the deposition area in bay AB was very small and the area was consistent with the circulation cell where the flow velocity was relatively small (Fig.2). The reason was that the strong surface-oriented flow in bay AB prevented most of the sediment from deposition there. On the other hand, the deposition patterns in bay BC and bay CD were similar. The deposition covered most of the bay area and two ridges were evidently distinguishable in each bay. The upstream ridge was related to the upward flow, while the downstream ridge was associated with the circulation flow as shown in Fig.2. The sediment carried by the upward flow or trapped by the circulation flow settled down in the bay areas where the flow velocity was small enough. Behind structure D, a long distance of sediment deposition occurred due to the velocity reduction in the wake circulation zone.

Sediment concentrations

The distributions of sediment concentrations in the mainstream ($y=25\text{cm}$) and near the Bandal-like structures ($y=2\text{cm}$, 6cm and 10cm) were plotted in Fig.6 and Fig.7, respectively. In the mainstream, the concentrations exhibited insignificant changes from the upstream to the

downstream according to Fig.6. The averaged concentration was 128ppm. It was much lower than 187ppm which was the concentration in the same flume without any hydraulic structures, and was close to 133ppm which was the concentration in case of the installation of impermeable groynes (Zhang et al., 2015). Due to backwater effect, the flow velocity in this experiment at the upstream inlet was slightly smaller than that without any hydraulic structure. As a result, the amount of sediment supplied in this experiment was a little smaller than that without hydraulic structures in order to maintain the suitable bed forms. The concentrations near the Bandal-like structures, however, varied depending on the locations. In front of structure A, the mean concentration was 134ppm, slightly higher than that in the mainstream. The highest concentration was found along the side of the flume due to sediment accumulation by the small circulating flow there (Fig.2). The averaged sediment concentration decreased gradually from the upstream bay AB to the downstream bay CD according to Fig.7 (b), (c) and (d), coinciding with the reduction trend of the flow velocity in the bay areas. The concentrations in the bay areas were closely related to the local flow field and showed complex distributions. In the wake zone behind structure D, concentrations were generally low along the side of the flume due to the large area of low velocity.

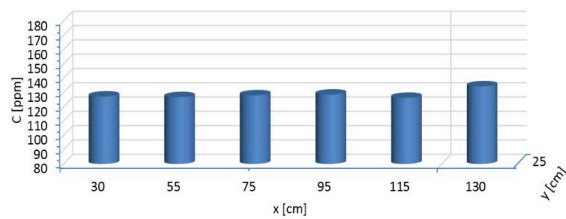


Fig.6 Sediment concentration in the mainstream.

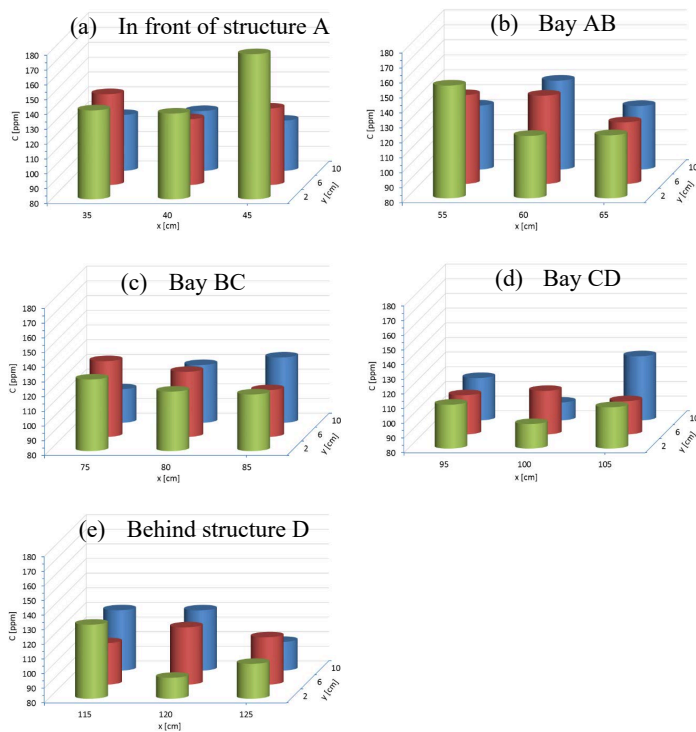


Fig. 7 Sediment concentrations near Bandal-like structures.

CONCLUSIONS

The laboratory experiments revealed the detailed local flow structure and suspended load distribution and deposition properties around Bandal-like structures. The Bandal-like structure soundly enhances the flow diversity in their vicinity. In general, the local flow is strongly three-dimensional due to the existence of flow separation at the head, the upward flow passing through the lower part, the circulating flow in front of and behind Bandal-like structures, and the interaction between the mainstream and the bay area. The suspended sediment concentrations in the bay area are closely related to the flow field, which decreases from the upstream bay to the downstream bay. In the mainstream, sediment concentration is constant and maintains at a low level, possessing an erosive potential. Sediment deposition was evident in the bay area and the geometry of the deposition is governed by both the upward flow and the circulating flow. The experiments were conducted under fixed bed conditions, while local scouring and bed degradation took place in actual rivers, which would influence the flow field and the sediment transport. Further research considering the movable bed dynamics is planned in the future.

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