Experimental Study on Sediment Deposition Using Bandal Like Structure with Different Ratio of Permeable and Impermeable Part

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Spur dikes of the impermeable type have been found to demonstrate a significant effect in controlling sediment deposition when compared to those of the permeable type. However, instances of local erosion have been observed in impermeable spur dikes leading to numerous problems. On the other hand, a number of spur dikes comprising Bandal like structures have been successfully employed and observed to have performed effectively. The Bandal comprises two parts; the upper part is of the impermeable type while the lower part is permeable. When a high-velocity fluid stream impinges on the upper (impermeable) part, the water-splash effect guides the flow towards the mainstream direction. The low-velocity stream around a riverbed with high concentration suspended load flows through the lower (permeable) part, thereby causing deposition. Owing to significantly different flow characteristics existing in the permeable and impermeable parts under the same landform or hydraulic conditions, the ratio of sizes of the permeable and impermeable parts tends to influence the controlling function. However, such effects are solely qualitative and influence of the above size ratio on sediment deposition has not been considered in previous studies. In this study, channel experiments were performed to examine changes in the deposition function of the Bandal at different size ratios of the permeable and impermeable parts under similar hydraulic conditions. Results demonstrate that the suspended load volume passing through the permeable part and that moving from the main stream towards the Bandal installation section affects the total sediment-deposition volume. The most upstream Bandal was found to control the moving sediment volume. At different size ratios of the upper and lower parts, the suspended flow discharge changed. Discharge through the permeable part demonstrated change owing to low flow velocity downstream of the structure while that from the main-stream direction towards the Bandal demonstrated change owing to the splash effect.

Key words: riverbed deformation, suspended load, channel experiment, Bandal like structure, deposition function

1. INTRODUCTION

Recently occurrences of heavy rainfall have been on the rise owing to extreme climatic changes. Consequently, instances of flood damage—caused by overflowing rivers—and riverbank erosion have become frequent worldwide. To exercise better control over river flows and prevent flood damage, attention must be focused on riverbed variations sediment deposition and erosion because such phenomena greatly influence river-flow behaviors.

To prevent erosion on the outer banks of curved or meandering rivers, deployment of various types of spur dikes have been proposed and implemented (Fukuoka et al., 1992; Ghodsian and Vaghefi, 2009; Dehghani et al., 2013). Typically, in comparison to the permeable type, impermeable spur dikes play a significant role in controlling sediment deposition. However, impermeable spur dikes are prone to erosion, which in turn leads to several problems. Interestingly, many spur dikes comprising Bandal like structures (hereafter, described as Bandal) have been employed in Bangladesh and have been observed to perform effectively (Rahman et al., 2003; Alauddin et al., 2011; Nakagawa et al., 2011).

A Bandal typically comprises two parts; the upper part is made of the impermeable type while lower part remains permeable. When flow surface with high velocity hit the Bandal impermeable part, water splash effect lead the flow to main-stream direction. Flow around riverbed with high concentration of suspended flow pass the Bandal permeable part and deposition occur due to the slow velocity at Bandal downstream. Because the flow characteristics are different in permeable part and impermeable part even with in same landform or hydraulic condition, the ratio of permeable and impermeable part seems to influence on the controlling function. However, Bandal effects are considered only qualitatively and how deposition effect change due to different ratio of permeable and impermeable part is even not considered (Nakagawa et al., 2013; Nishio et al., 2016).

In this study, we conducted channel experiment to examine the deposition function of Bandal with different ratio of permeable and impermeable part on same hydraulic condition.

2. EXPERIMENT CONDITIONS

Experiments were performed using a rectangular channel measuring 2,000 cm in length, 30 cm in height, and 100 cm in width. The slope was set as 1/1,000 with a fixed bed condition. Water, at a flow rate of 31.6 l/s, was supplied under steady state (Froude number 0.55). A 0.6-cm dam-up was employed at the downstream end, and steady-state flow conditions were confirmed.

In the strict sense, fixed-bed conditions are significantly different from actual river conditions, wherein local scouring and complicated flow behaviors usually occur. Different flow characteristics were observed in the permeable and impermeable parts of the Bandal under similar hydraulic condition, and the ratio of the sizes of the two parts was found to significantly influence the sediment controlling function. Recent studies on Bandals were performed considering a fixed value of the permeable/impermeable size ratio. Thus, in this study, we performed fixed-bed experiments employing different Bandal size ratios to reveal the velocity and spatial distributions of the suspended load around the Bandal to obtain clarity regarding the deposition function.

Uniform sediments measuring 0.093 mm in diameter and density with 2.65 g/cm^3 were employed. The diameter 0.093 mm seems to be rather small, but in this experiment, we confirmed that exchanging with riverbed especially deposition have occurred. During experiments, the ratio u_*/w_0 (u_*: friction velocity, w_0: settling velocity) was set as 4.1 to represent the suspended load condition. Sediments were supplied at the rate of 1.92 cm^3/s under steady state using a sand feeder. Ripples were generated in this condition; however, it was ensured that sediment deposition didn't exceed the number of ripples appeared in results without setting dikes from preliminary experiment.

A non-overflow type Bandal model measuring 15 cm in height was used. The permeable part comprised 0.7 cm diameter brass columns placed 1.2 cm apart. The upper impermeable part of the model comprised a stainless steel plate. Height of the permeable part could be adjusted to 1.5, 3.5, or 5.5 cm. The length of Bandals and spur dikes were set to 15.2 cm with reference to the previous studies (Akikusa et al., 1960). Four Bandal models were placed at 30 cm intervals between 1,000-1,090 cm downstream of the left bank. An outline of experimental channel and relevant conditions are depicted in **Fig.1** and **Fig.2**. **Table 1** shows the experimental cases hydraulic and Bandal model conditions.

The flow depth was measured using an ultrasonic sensor in time series, and the deposition and surface flow velocity were measured approximately 4.5 hours after attainment of the equilibrium condition.

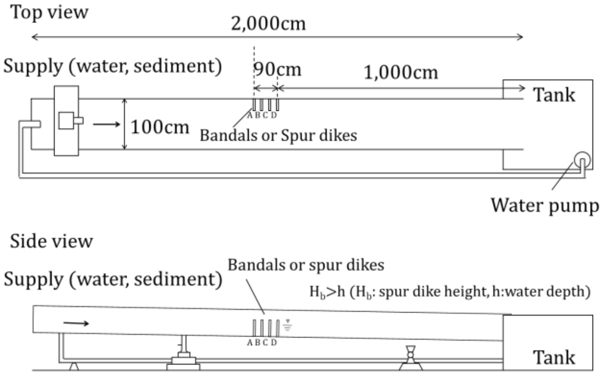

Fig. 1 Outline of experiment channel and Bandal conditions

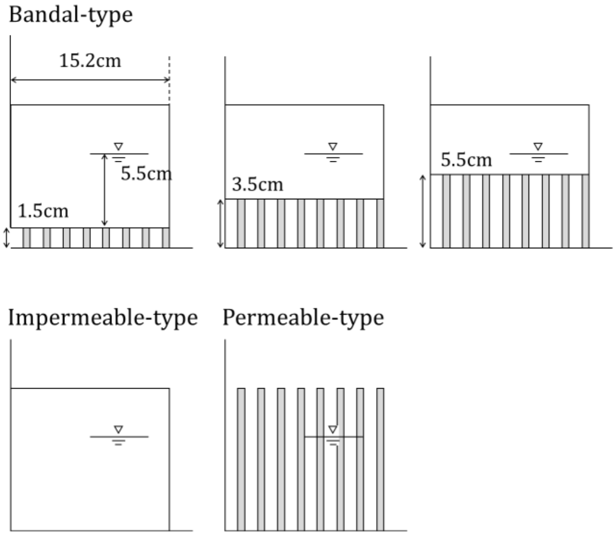

Fig. 2 Outline of Bandal models

Table 1 Experimental cases

Case	Discharge (l/s)	Channel width(cm)	Slope	Sediment diameter(mm)	Permeable height /Water depth
1	31.6	100	1/1,000	0.093	0.22
2					0.51
3					0.80
4					1.00
5					- (Impermeable type)

When measuring the surface flow velocity using PIV software, we used PCV powder (average diameter 0.113 mm, density 0.59 g/cm^3). A laser-displacement sensor was used to measure sediment thickness before and after the experiment.

3. RESULTS AND DISCUSSION

3.1 Results obtained using bed-level contour

Experimental results obtained using the bed-level contour are depicted in **Fig.3**. Ripple formation was observed in all cases considered during experiments. When setting spur dikes, stripe-shaped ripples were observed across the channel proceeding from the left bank towards the right remarkably formed in Case 2. This was attributed to the water-splash due to spur dikes. In Cases 1 and 5, the size of the impermeable part of the structure was rather large. Consequently, separated flow was observed due to water splashing. This separated flow demonstrated an effect on the main flow section by causing an increase in flow velocity. **Fig.4** depicts results of the surface flow velocity distribution along the longitudinal direction. A major difference between the types of spur dikes was observed—closed- and Bandal-type spur dikes led to formation of horizontal vortices; this, however, was not true in the case of open-type dikes. In the absence of spur dikes, the ripples had an average height 0.35 cm. When using spur dikes, sediment deposition was observed to be higher compared to the ripples at locations upstream of spur dike A. This was attributed to the dam-up effect caused during spur-dike setting. **Fig.5** depicts results of the water-surface profile. The broken line indicates steady-flow depth. In Case 5, the flow depth demonstrated a change upstream as well as downstream of spur dike A. In Cases 1-3, identical Bandal setting conditions and flow depth were maintained on the frontal side of spur dike A. However, the flow depth on the back side was altered in proportion to the height of the permeable part. In Case 4, the flow depth on the frontal side of the spur dike was observed to be slightly larger compared to its steady-state value; however, its value on the back side remained unaltered. When setting spur dikes, left-bank side between coordinates x = 1,100-1,150 cm, y = 0-10 cm demonstrated deposition; describing from larger cases, Case 5 with 0.8 cm, Case 1 with 0.78 cm, Case 3 with 0.56 cm, Case 2 with 0.55 cm and Case 4 with 0.31 cm. Similarly, the right-bank side bounded by coordinates x = 1,100-1,150 cm, y = 90-100 cm demonstrated a deposition height of approximately around 0.3-0.4 cm, which was comparable to that observed along the left bank. The deposition height was observed to almost identical to that observed in cases void of spur dikes.

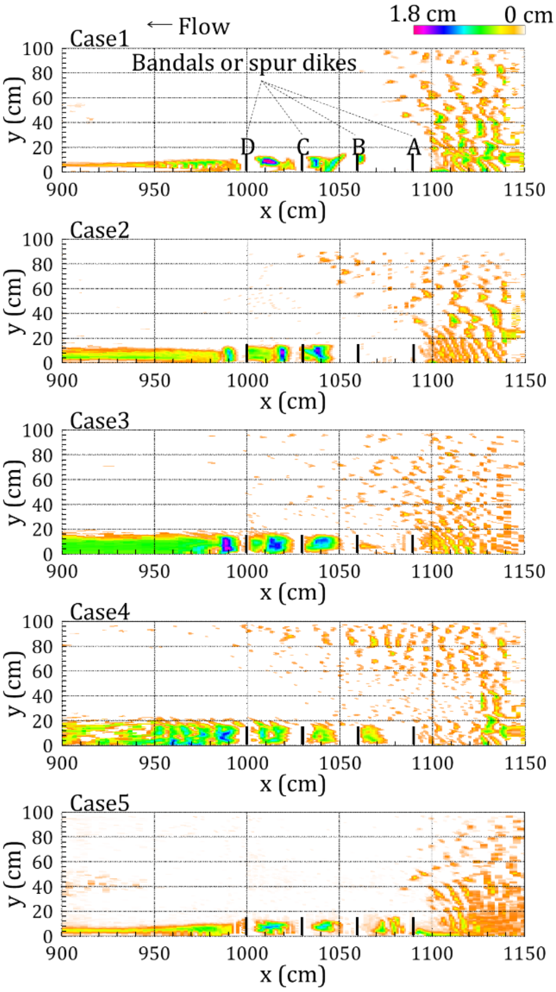

Fig.3 Bed-level contour

Furthermore, downstream right bank side from spur dikes installation, ripples didn't form. This was attributed to the increase in main-flow velocity due to the water-splash effect and changes in hydraulic conditions. The former trend was found to be significant in the impermeable part in Case 5. In other cases (Case 1-3), the effect was observed to be rather small and proportional to the height of the permeable part.

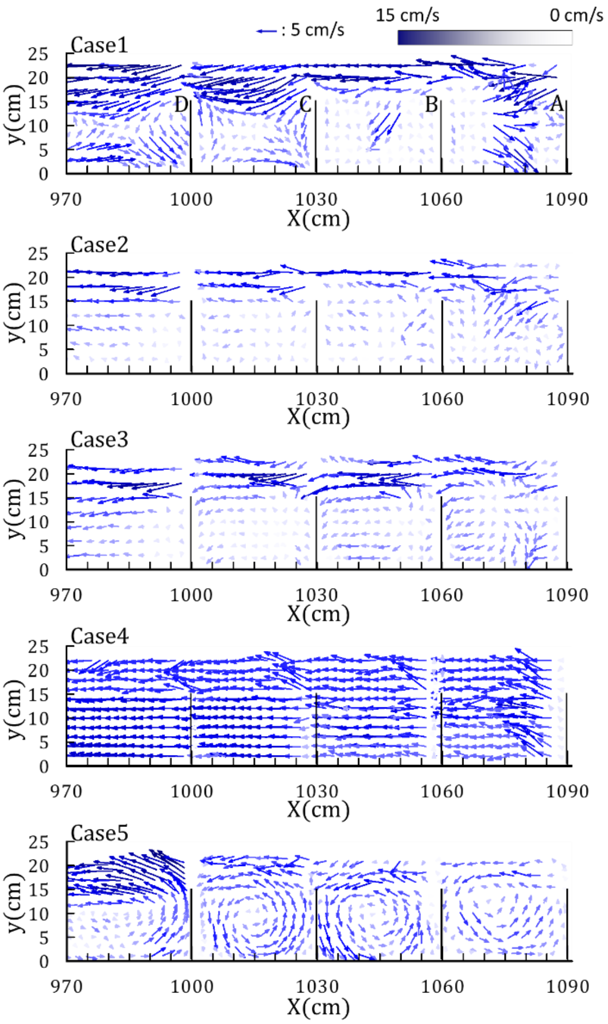

Fig.4 Water surface flow velocity distribution

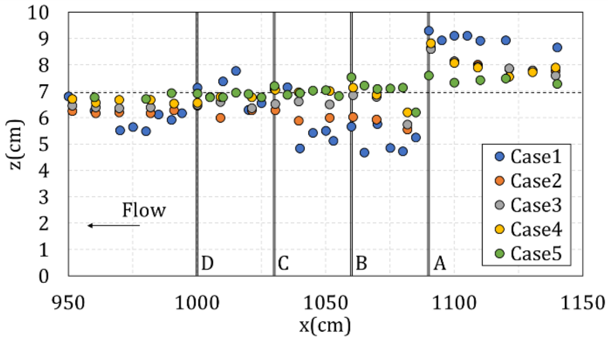

Fig.5 Water-surface profile（y=8 cm）

3.2 Comparison of sediment-deposition volume

Experimental results based on the sediment-deposition volume are summarized in **Table 2**. Here, the volume of sediments deposited between spur dikes were considered, because downstream of spur dike D showed different deposition process to that observed in sections between spur dikes. Furthermore, to compare the deposition process downstream of the spur dikes, attributes of the affected area of spur-dike installation were required to be understand. As observed in **Table 2**, the highest sediment deposition was observed between dikes C and D except for Case 1. Spur dikes set downstream seemed demonstrated smaller flow velocities compared to those set upstream, therefore prospected deposition enhanced on the downstream side. Comparing the volume of deposition between spur dikes A–D, the highest deposition was observed in Case 3 followed by Cases 2, 4, 5, and 1. Recent studies have reported that the Bandal-type structure demonstrates a larger deposition function compared to a purely impermeable type spur dike. However, Case 1 corresponding to the smallest permeable/impermeable size ratio of 0.27 demonstrated least deposition function. On the other hand, at an upstream section between spur dikes A and B, the largest deposition was observed in Case 4 followed by cases 5, 3, 2, and 1. The results demonstrate that the deposition function of the Bandal type was smaller compared to both impermeable and permeable type spur dikes.

3.3 Velocity distribution at sharp end of spur dike along x-y direction

From the experiments, it was observed that the most upstream spur dike A had the greatest influence on flow characteristics in all cases. This was especially true for impermeable type and Bandal type case, water splash occurred at spur dike frontal part and enlarge the main flow velocity due to the flow toward the right bank side. Downstream spur dikes (B, C, and D) didn't demonstrate the water-splash effect, thereby causing flow pulling into the section between successive spur dikes.

Tabel 2 Sediment-deposition volume

	Dikes A-B	Dikes B-C	Dikes C-D	Total
Case1	12.39	85.90	81.10	179.39
Case2	1.98	127.57	146.02	275.57
Case3	14.15	143.79	205.68	363.61
Case4	54.04	64.61	118.72	237.37
Case5	50.37	55.41	90.52	196.29

Unit: cm^3

In Case 5, the section between spur dikes A and B demonstrated presence of a vertical vortex due to shearing of fast flows separated from the frontal part of spur dike A (around y = 15 cm). This could lead to scouring and cause structural damage. Observing the flow direction between spur dikes, horizontal vortices occurred and seemed to expect deposition due to sediment settling. However, sediments must exist at spur dike intervals for deposition. Therefore, sediment inflow is expected. In cases corresponding to impermeable-type spur dikes, sediment inflow doesn’t occur through the spur dike. Therefore, sediment inflow must be provided from the main flow section. **Fig.6** depicts velocity distribution at the upstream spur dike (y=15 cm) along the x–y direction at several sections.

Upstream of spur dikes A and B, no vertical sections demonstrated fluid flow into the spur-dike interval owing to the water splash effect at spur dike A. Downstream of spur dikes A and B, low-velocity flow was observed and due to shearing of the main flow section, the flow direction was altered towards the left bank of the channel. Subsequently, the flow collapsed in the frontal part of spur dike B and moved into the interval section between spur dikes A and B. Although flow velocities were observed to be different, all cases demonstrated the same trend along the vertical direction. Downstream of the interval between spur dikes B and C and that between C and D, the flow direction showed toward right bank side at the back of spur dike B and C. Then at downstream of the dike, flow toward left bank side occurred and sediment flow into the spur dikes interval. It happened remarkably at downstream C-D interval which appeared at the deposition volume results.

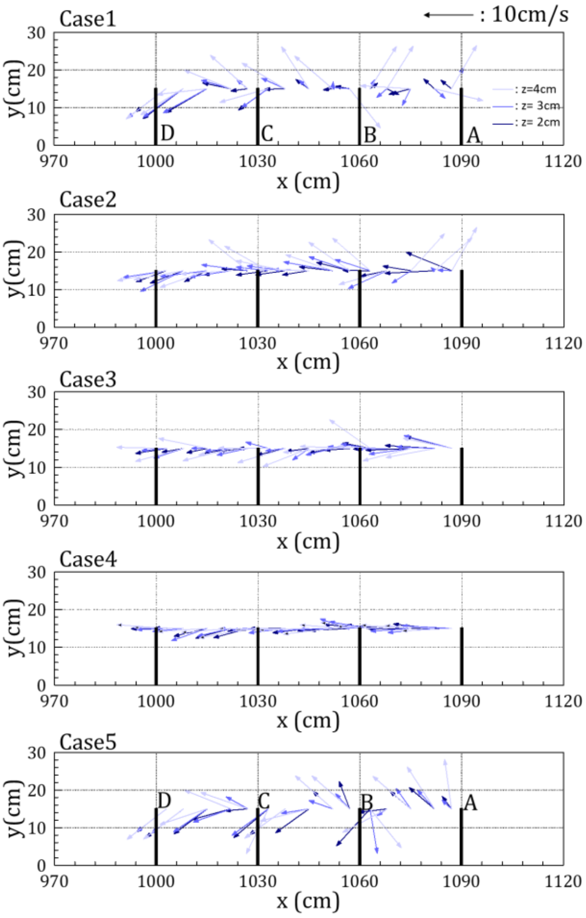

Fig.6 Velocity distribution (y = 15 cm) along the x–y direction

In Case 1, flow towards the right bank of the channel occurred due to water-splash effect of spur dike A similar to that in Case 5. However, flow toward preamble part around river bed caused flow toward upstream side at back of the spur dike A. Therefore, it became difficult to cause the fluid to flow into the interval between spur dikes A and B. In the interval between spur dikes B and C, flow velocity around the river bed was observed to be small, and the flow coming into the interval didn’t appear so much, and in the interval between spur dikes C and D, the flow entered the interval in a manner similar to that observed in Case 5. In Cases 2 and 3, effect of flow toward the permeable part of Bandal became large, and flow separation caused by the splash effect was negligible in comparison to that observed in Cases 1 and 5. In Case 4, the former trend was observed more significantly. Flow moving into the spur-dike interval was hardly noticeable. In view of these results, it may be inferred that the flow entering the spur-dike intervals served to transport suspended sediments and promoted their deposition.

3.4 Velocity distribution along x–z direction around spur dikes

Fig.7 depicts results of the velocity distribution along the x–z direction around spur dikes. The center point of the four spur dikes was determined at y = 8 cm. For the impermeable-type spur dikes in Case 5, the flow velocity was found to have reduced because the flow was inhibited even without passing through the spur dikes. Therefore, flow velocity had reduced, and upward flow was found to predominate. The Bandal-type cases (Cases 1–3) demonstrated different water levels around spur dike A as a boundary, and the flow velocity through the transmission section was observed to be large, thereby indicating downward flow. All three cases demonstrated similar flow characteristics, such as flow rising at downstream of spur dike A. However, the cause of this phenomenon was different in Case 1 from that in Cases 2 and 3. In Case 1, the phenomenon was caused by shearing with rapid

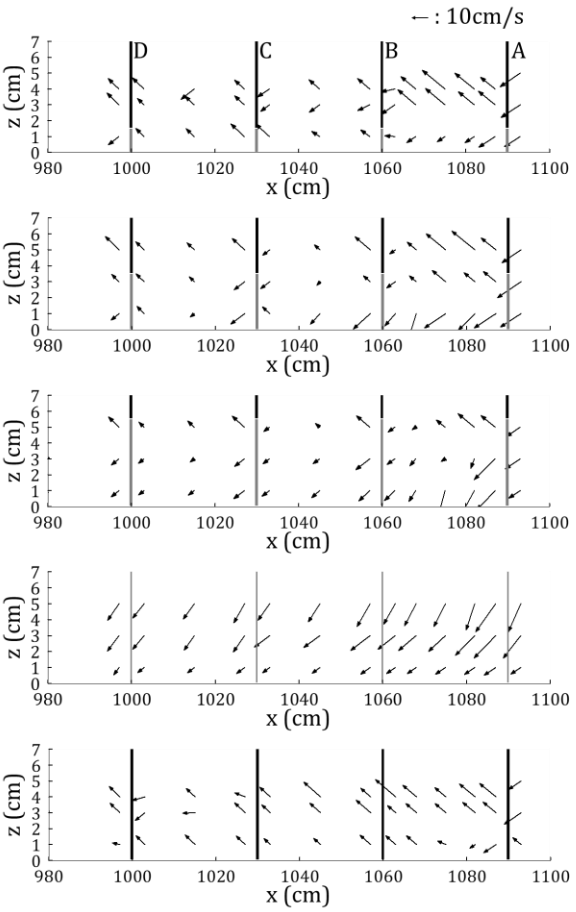

Fig.7 Velocity distribution along the x–z direction

separated flow. In Case 4 with transmission type, the flow becomes downward, and there wasn't mixing flow with upward and downward flow.

4. Consideration of sediment-deposition function around spur dikes

Fig.8 depicts shapes of sediment deposition corresponding each type of spur dikes. Corresponding to the impermeable type spur dike, the deposited sediments were settled from a horizontal vortex. Permeable-type spur dikes offered resistance to the flow passing through the permeable part; therefore, part of the sediment deposition demonstrated a convex form. Deposition shape for Bandal type spur dikes could best be described as a combination of sediments settled from the horizontal vortex generated in the impermeable part and those deposited owing to inhibited fluid flow against the permeable part. The proposed study reveals the sediment-deposition effect of Bandal type spur dikes. The maximum size ratio of the permeable/impermeable parts was 0.2 during experiments, and the results were observed to be strongly influenced by the presence of the impermeable part serving to promote sediment deposition. Therefore, reducing the size of impermeable part would make it difficult to cause sediment deposition owing to changes in flow characteristics.

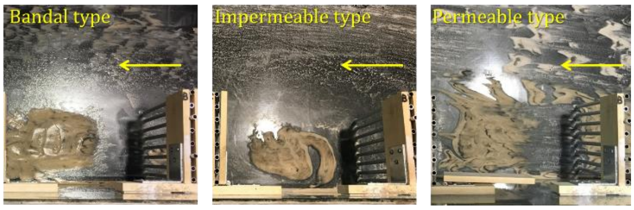

Fig.8 Shapes of sediment deposition corresponding each type of spur dikes

5. CONCLUSIONS

In this study, we conducted channel experiments to examine the suspended-load-deposition function of Bandal-type spur dikes with different size ratios of permeable and impermeable parts. Results of the study demonstrate two characteristics of the Bandal deposition function. It was observed that the suspended load volume passing through the permeable part strongly affects the deposition function. This may be attributed to low flow velocity downstream of the Bandal. Secondly, the suspended load volume moving from the main stream towards the Bandal-installation section also affects the deposition function. This effect is caused by the water-splash effect resulting from flow impingement on the impermeable part of the Bandal, thereby causing three-dimensional flow. Furthermore, it was observed that the most upstream Bandal—with the greatest splashing effect—controls the moving sediment volume. Because the deposition volume was the largest at the section between the first and second Bandal installations, the sediment volume flowing into the section affect. When the size ratio of permeable/impermeable parts is large, a large sediment volume tends to flow into the Bandal; however, attainment of three-dimensional flow becomes difficult. The study demonstrates that by setting a Bandal comprising a large permeable part leads to greater flow impingement on the impermeable part, thereby promoting sediment deposition.

In future studies, we intend to conduct experiments under movable-bed conditions to consider the effects of local scouring and planning to demonstrate effective deployment of Bandals along actual rivers as countermeasures against river-bank erosion.

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REFERENCES

Akikusa, I., Kikkawa, H., Sakagami, Y., Asida, K. and Tsutiya, A. (1960): Study on spur dikes, Research report of Public Works Research Institute, Vol. 107, pp. 61-153. (in Japanese with English abstract).

Alauddin M., Tashiro T, and Tsujimoto T. (2011): Design of groynes modified with both alignment and permeability for lowland river problems. Journal of Applied Mechanics, JSCE, 2(67), pp. 645-652.

Dehghani, A.A., Azamathulla, Md. H., Hashemi Najafi, S.A. and Ayyoubzadeh, S.A. (2013): Local scouring around L-head groynes, Journal of Hydrology, Vol. 504, pp. 125-131.

Fukuoka, S., Watanabe, A. and Nishimura T. (1992): On the groin arrangement in meandering rivers, Journal of Hydraulic, Coastal and Environmental Engineering, JSCE443/II-18, pp.27-36. (in Japanese with English abstract).

Ghodsian, M. and Vaghefi, M. (2009): Experimental study on scour and flow field in a scour hole around a T-shape spur dike in a 90° bend, Internationaxl Journal of Sediment Research, Vol. 24, Issue 2, pp. 145-158.

Nakagawa, H., Teraguchi, H., Kawaike, K., Baba, Y. and Zhang, H. (2011): Analysis of Bed Variation around Bandal-like Structures, Annuals of Disaster Prevention Research Institute, Kyoto University, No.54B, pp. 497-510.

Nakagawa, H., Zhang, H., Baba, Y., Kawaike, K. and H. Teraguchi (2013): Hydraulic characteristics of typical bank pro-tection works along the Brahmaputra/Jamuna River, Bangladesh, Journal of Flood Risk Management, Wiley, Vol.6, No.4, pp. 345-359.

Nishio, K., Nakagawa, H., Kawaike, K. and Zhang, H. (2016): Experimental study on flow field around Bandal-like structures under suspended load transport condition, Annual Journal of Hydraulic Engineering, JSCE, Vol.60, pp. I_841-I_846. (in Japanese with English abstract).

Rahman, M.M., Nakagawa, H., Ishigaki, T. and Khaleduzzaman, A. (2003): Channel stabilization using Bandalling, An-nuals of Disaster Prevention Research Institute, Kyoto University, No.46B, pp. 613-618.