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Local Scour Induced By 3D Flow Around Attracting And Deflecting Groins

LOCAL SCOUR INDUCED BY 3D FLOW AROUND ATTRACTING AND DEFLECTING GROINS

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In recent years, groins are set perpendicular to a riverbank, which is called a deflecting groin. However, many old groins in Japan were set at angles to a bank. This type of groin is called an attracting groin of which head is shifted toward downstream. Such groin is not usually used in a submerged situation, because a flow over the groin attacks a bank and erodes it. In this paper, local scour and flow structure around these two kinds of groin are investigated experimentally in non-submerged and submerged situations. By comparing the results in the two groin cases, the local scour induced by a three dimensional flow is discussed. It is found that scouring position is changing on the depth of overtopping flow in both cases and that a strong downward flow produces deep scour holes near the head or root of groin.

1 Introduction

Recently, groins are set not only for the protection of bank erosion but also for the environmental preservation in Japan. The main functions of groin are to deflect a flow and to reduce velocity near the riverbank. The secondary function is to form a varied bed configuration, and it is useful to preserve the river environment. There are many types of groin, however, impermeable groins are discussed in this paper. The recent groins are set perpendicular to a riverbank, which is called a deflecting groin. On the other hand, many old groins in Japan were set at angles to a bank. This is an attracting groin of which head is shifted toward downstream. Such groin is not usually used in a submerged situation, because a flow over the groin attacks a bank and erodes it. As there is an old attracting groin that was built for bank protection about 400 years ago in Kyoto Prefecture, hydraulic aspects of the groin have been investigated experimentally (Ishigaki et al 2004). In this paper, local scour and flow structure around attracting and deflecting groins are compared experimentally under same hydraulic conditions.

Many researchers have studied the hydraulics of groins, and three topics have been recently investigated. These are local scour (Kuhnle et al 1999, Ohmoto and Hirakawa 2000, Elawady et al 2001, 2002), the flow structure (Tominaga et al 1997, Uittewaal and Berg 2002), and the mass exchange in the groin fields (Uittewaal et al 2001, Kurzke et al 2002). They have dealt with the groins of angle –30 to 30 degrees. The attracting groin in this paper is out of consideration, because it has large angle of 65 degrees. Thus scour and flow structure around the attracting groin is investigated here, and these features are compared with results in case of a deflecting groin under the same hydraulic condition.

2 Experimental Methods

Figure 1 shows two kinds of groin. Width of both groins on the y-axis and cross section shape are same as shown in the figure. The groin models were set on the right hand side bank in a straight channel with a flat bed. The channel was 10m long, 1.0m wide and 0.3m deep installed with a discharge control system. The middle part of the channel was made of movable bed filled with fine sand of which the mean diameter was 0.26mm. The movable bed section was 1.8m long and 0.2m deep. The channel width was 0.9 m in the case of attracting groin as shown in Table 1.

Bed form, velocity, water level and flow were measured under clear water scour conditions in five cases of different water depths, which included four submerged and one non-submerged cases, as shown in Table 1. H/h is the relative depth, where H is the flow depth and h is the height of groin. The ratio between the friction velocity and the critical friction velocity of the bed material was kept from 0.78 to 0.91 by setting the same discharge velocity, 0.2 m/s, in all cases.

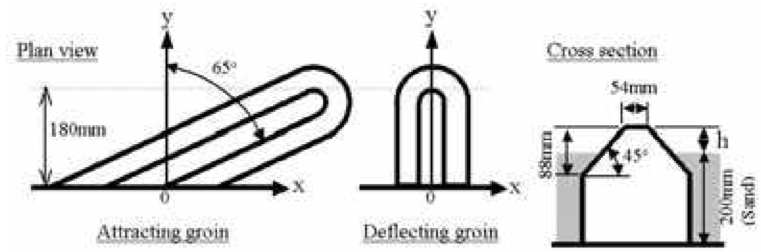

Figure 1. Plan view and cross section of attracting and deflecting groin used in the experiments.

Table 1. Hydraulic conditions for attracting and deflecting groin cases.

Case	H/h	H (cm)	Q (l/s)	u_*/u_{*c}	Groin
A1	0.82	4.08	7.27	0.91	non-submerged
A2	1.22	6.06	10.78	0.86	submerged
A3	1.41	7.00	12.60	0.85	submerged
A4	1.62	8.00	14.40	0.83	submerged
A5	1.92	9.48	17.38	0.83	submerged

H: depth, h: groin-height=4.95cm, Q: discharge, Channel width=90cm,
Sand: dm=0.26mm, Critical friction velocity of sand: u_{*c}=1.523cm/s

Case	H/h	H (cm)	Q (l/s)	u_*/u_{*c}	Groin
D1	0.82	4.51	9.02	0.88	non-submerged
D2	1.22	6.71	13.42	0.82	submerged
D3	1.41	7.76	15.52	0.81	submerged
D4	1.62	8.91	17.82	0.80	submerged
D5	1.92	10.56	21.12	0.78	submerged

H: depth, h: groin-height=5.5cm, Q: discharge, Channel width=100cm,
Sand: dm=0.26mm, Critical friction velocity of sand: u_{*c}=1.523cm/s

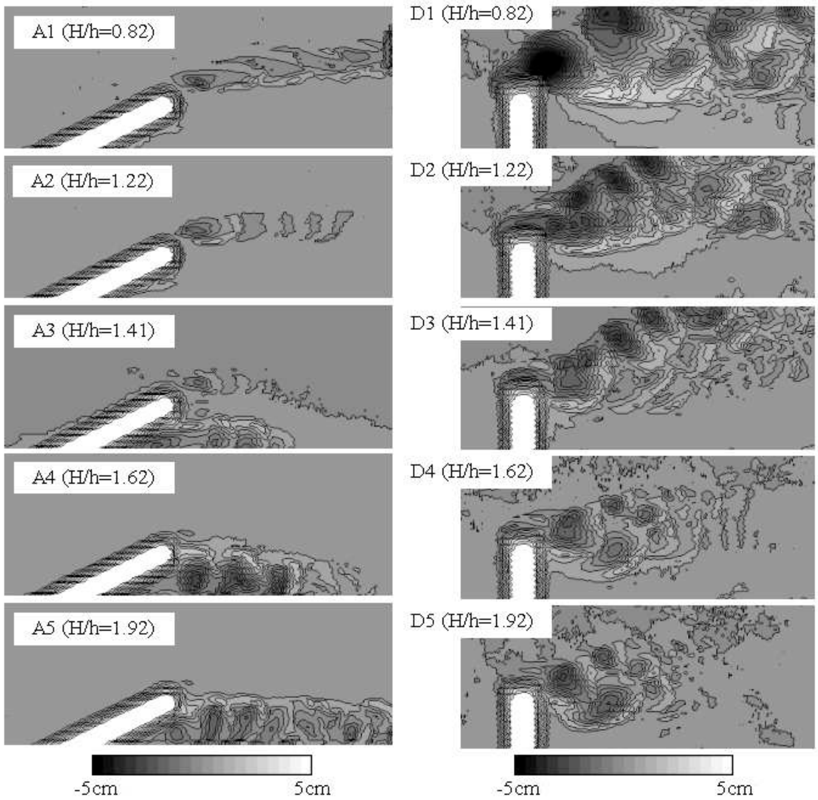

Figure 2. Bed forms around attracting and deflecting groins in the range of y=1 to 50 cm.

A laser level meter, an ultra-sonic level meter and an electro-magnetic velocimeter were the equipments used for the measurements of bed form, water level and velocity, respectively. Flow patterns were observed on the water surface and in a cross section of flow by using normal and submergible video cameras.

3 Local Scour around Groins

Figure 2 shows bed forms measured in the cases of attracting and deflecting groins. Bed forms were measured at each 4.25 mm in x-axis and 1 cm in y-axis by using a laser level meter. The measurements were done after one hour from the beginning of experiment in all the cases. Contour lines are shown in the difference from the original bed level in y=1 to 50 cm. Dark color shows scouring parts and bright color depositing parts. The friction velocity was almost same in all cases.

The formation of scour and deposition is different according to the relative depth, H/h, in both cases. In the case of attracting groin, scouring positions in submerged

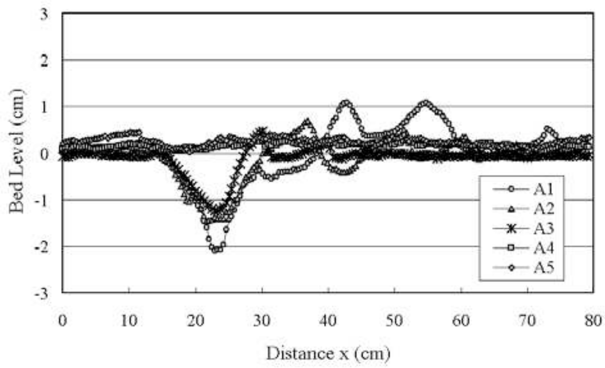

Figure 3. Longitudinal bed profiles in attracting groin cases at y=24 cm.

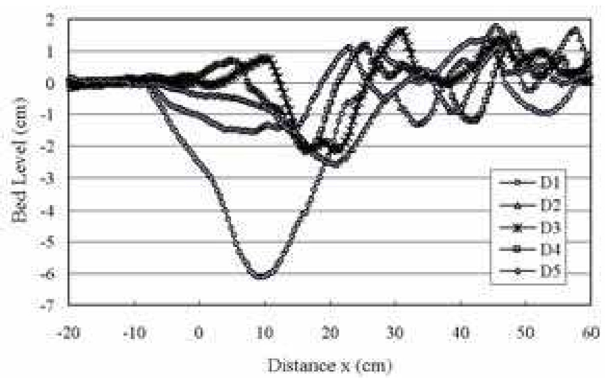

Figure 4. Longitudinal bed profiles in deflecting groin cases at y=29 cm.

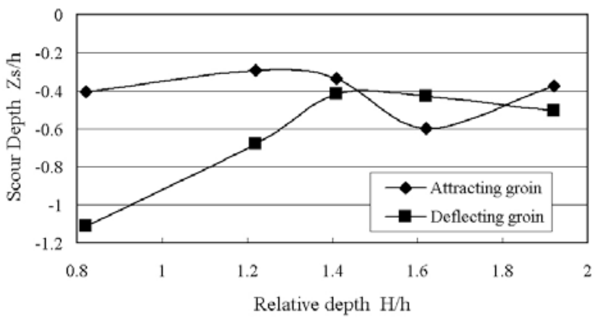

Figure 5. Relations between normalize scour depth, Zs/h, and relative depth, H/h.

situations are quite different from those in the non-submerged case. The position of deepest hole moves from the downstream side of groin head to the root side. The result in case of H/h=1.41 shows scour holes on both sides. The deepest points are near the root of groin in cases A3 to A5, H/h>1.4, and those are near the head in cases A1 and A2. The

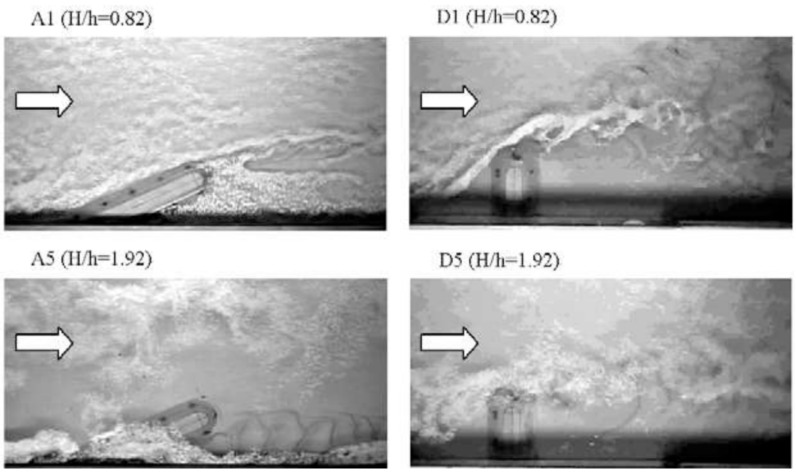

Photo 1. Flow patterns on the water surface visualized by a tracer method using sawdust.

position of scour holes in deflecting groin case also moves slightly to the root side, but the holes do not reach to the bank. No scour can be observed near the bank. The result in case D3 (H/h=1.41) also shows the both aspects of non-submerged and submerged cases.

The longitudinal profiles of bed form near the head of groin are shown in Figure 3 and 4. Lateral distance from the bank is 24 cm and 29 cm in the case of attracting and deflecting groins respectively. The sections in both cases cross the deepest points in non-submerged situation, H/h=0.82. It indicates that scour hole appears apart from the head of groin. Scour hole can't be observed in the deeper cases, A4 and A5, of attracting groin, however, it can be observed in all cases of deflecting groin.

Figure 5 shows the relations between the deepest scour depth and relative depth in both cases. The depth presented here is not the maximum value, because the running time of experiment was one hour. However, the result shows qualitative features. Scour depth does not vary widely in the attracting groin cases, but the depth around deflecting groin decreases in the shallow cases, D1 and D2, and becomes almost constant in the deeper cases, D3 to D5. The constant value is around Zs/h=0.5. It is found that the scour depth around an attracting groin is shallower than the depth around a deflecting groin in case of H/h<1.4.

4 3D Flow Structure around Groins

4.1. *Flow Patterns on the Water Surface*

Photo 1 shows flow patterns on the water surface for attracting and deflecting groins. Upper photographs are in non-submerged cases, A1 and D1, and lower ones are in submerged cases, A5 and D5. The flow patterns were visualized by sawdust as a tracer.

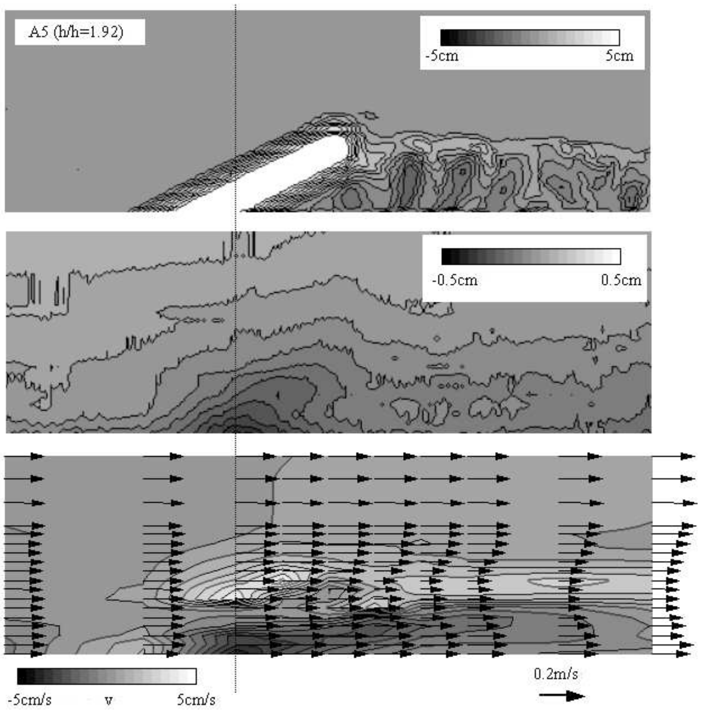

Figure 6. Bed form, surface profile and velocity components, u and v in attracting groin case.

Approach flows were deflected to the channel center by the groins in the non-submerged cases and the dead zone was produced behind the each groin. Deflection is stronger in deflecting groin case than in attracting groin case. The lower photographs of the submerged cases show different aspects respectively. In attracting groin case, the approach flow was not obviously deflected, and most part of the flow ran over the groin along the bank. It is easily anticipated that this overtopping flow causes local scour and bank erosion behind the groin. On the other hand, the approach flow was strongly deflected and the dead zone was produced on the downstream side in deflecting groin case. Velocity in the wake zones are small in both cases, however, the effect of velocity reduction is more conspicuous in deflecting groin case because reverse flow can be observed in the wake zone.

4.2. *Local Scour and Flow Structure*

To investigate the relation between flow structure and bed form around the groin, profiles of water surface, velocity distributions and bed from were measured for H/h=1.92. Figure 6 and 7 are the results in the range of y=2 to 45 cm and x=-50 to 90 cm. The measurements of surface profile and velocity were conducted after fixing the bed form by using mortar. The surface profile is shown in the difference from the mean flow

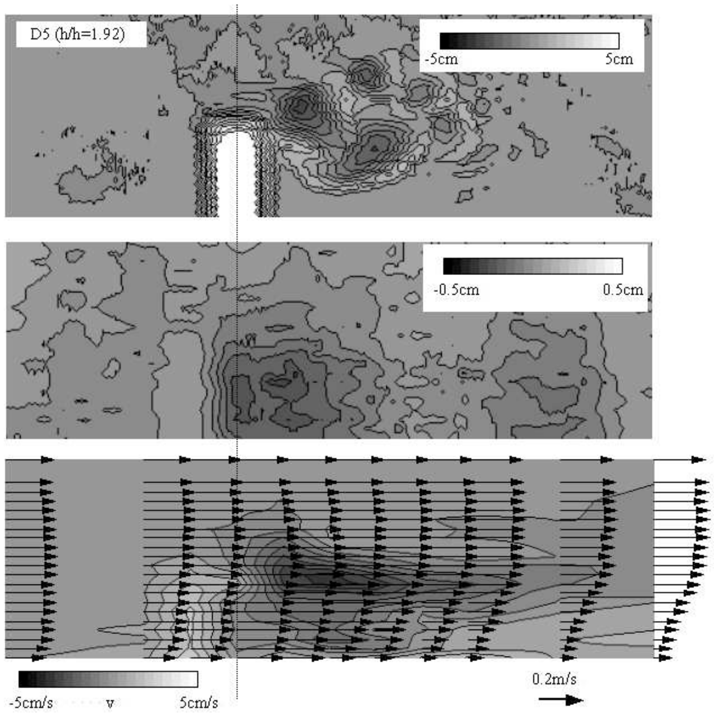

Figure 7. Bed form, surface profile and velocity components, u and v in deflecting groin case.

depth. The two velocity components were measured at 1 cm above the groin top by using an electro-magnetic velocimeter. Arrows in the velocity distribution are the longitudinal component of velocity u, and the contour lines show the distribution of vertical component of velocity, v. The dark color shows down-welling part and the bright color up-welling part. Notation of the bed form is identical as in Figure 2.

The water level over the groin is lower than the surrounding. Lowest point is near the root of groin in attracting groin case and near the head in deflecting groin case. It means that the flow is accelerated there. From the velocity distribution, it is found that the accelerated flow goes downward and intrudes into the wake region of groin, and then scours the bed in case A5. There are rapid flow regions near the channel center and along the bank. Low speed region is between them and deposition is observed there. As shown in Photo 1, velocity in the wake zone is small in case D5. It means that a deflecting groin is effective for bank protection. As a similar and important aspect in both cases, it can be confirmed that the regions of strong downward flow are coincident with scour regions in both cases. This means that overtopping flow with high speed goes to the bed and erodes there. This flow was also observed in a cross section by using a submergible video camera in both cases. It is found that local scour around attracting and deflecting groins is closely related to the three-dimensional flow structure.

5 Conclusions

Local scour and flow structure around two types of groin have been investigated experimentally. The main conclusions are as follows. 1) Scour holes are observed near the head of deflecting groin and near the root of attracting one in submerged situation with deep conditions as mentioned in the previous studies. However, the formation of scour and deposition is gradually changing with the relative depth, H/h, in both cases. 2) There is a hydraulic condition in which bed form in non-submerged and submerged situations can be observed simultaneously. 3) A deflecting groin is effective in protecting bank erosion. When an attracting groin would be used for bank protection, the magnitude of local scour along riverbank should be considered. 4) A strong downward flow overtopping the groin induces local scour and the local scour around groin is closely related to three-dimensional flow structure. It is important that hydraulic engineers have to recognize the relation between local scour and flow structure in planning the groins.

References

Elawady, E., M. Michiue and Hinokidani, O. (2001). "Characteristics of scour around repelling spur-dikes", Proc. of 29th Con-gress of IAHR, Beijing: Theme D, II, 343-349.

Elawady, E., M. Michiue and Hinokidani, O. (2002). "An investigation of scour around attracting spur-dikes", Advances in Fluid Modelling and Turbulence Measurements, Proc. of 8th Intr. Symp. on Flow Modelling and Turbulence Measurements, Tokyo: 111-118, World Scientific.

Ishigaki, T., Ueno, Y., M.M. Rahman and Khaleduzzaman, A.T.M. (2004). "Scouring of flow structure around an attracting groin", River Flow 2004, in printing.

Kuhnle, R.A., C.V. Alonso and Shields Jr., F.D. (1999). "Geometry of scour holes associated with 90 spur dikes", Journal of Hydraulic Engineering, ASCE: 25, (9), 972-978.

Kurzke, M., V. Weitbrecht and Jirka G.H. (2002). "Laboratory concentration measurements for determination of mass ex-change between groin field and main stream", River Flow 2002, Bousmar & Zech (eds.): 1, 369-376.

Ohmoto, T and Hirakawa, R. (2000). "Secondary current structure in open-channel flow with a series of submerged groyns", Proc. of 12th Congress of APD-IAHR, Bangkok: 1, 189-199.

Tominaga, A., M. Nagao and Nezu, I. (1997). "Flow structure and mixing processes around porous and submerged dikes", Proc. of 27th Congress of IAHR, San Francisco: Theme B, 1, 251-256.

Uittewaal, W.S.J and Berg, M.H. (2002). "Experiments on physical scale models for submerged and non-submerged groynes of various types", River Flow 2002, Bousmar & Zech (eds.): 1, 377-383.

Uittewaal, W.S.J., D. Lehmann and Mazijk, A. (2001). "Exchange processes between a river and its groyn field: model experiments", Journal of Hydraulic Engineering, ASCE: 127, (11), 928-936.