京都大学防災研究所年報 第43号 B-2 平成12年4月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 43 B-2, 2000

Velocity Measurements in a Rectangular Embayment Attached to a Straight Open Channel

Yasunori MUTO, Hirotake IMAMOTO and Taisuke ISHIGAKI

Synopsis

Velocity measurements were carried out in a straight open channel with a rectangular embayment. Two laser Doppler anemometers (LDA) and an electromagnetic current meter (EMC) were employed. Flow exchange between the main flow region and the dead zone, formed within the embayment, is investigated. Turbulent shear region induced at around the junction between the main flow and the dead zone is also studied. Rough sketch of the flow structure drawn from preliminary experiments indicates that large circulating flow is induced in the embayment for the inbank case, however such a circulation cannot be seen for the overbank case. In this case flow exchange between the embayment and its adjacent flood plain takes place in a quite complex manner. Aspect ratio of the embayment also affects the exchange process. For the tested cases a rectangular embayment, whose aspect ratio is 3, exchanges more effectively than the square embayment case due to instability of the dominant circulating flow formed in the embayment.

Keywords: embayment; velocity measurement; flow exchange; turbulence; shear region

1. Introduction

Rivers on an alluvial plain, usually the gradient is very gentle, tend to meander and widen. In such a river reach the water depth sometimes becomes very shallow and thus is not enough to ensure inland navigation. In order to maintain stable navigation course, some construction works for establishing deeper channel part along the centre of the river are commonly adopted. Such works includes spur dyke. In many Japanese major rivers spur dykes for maintaining navigation course were constructed from the middle to late 19^{th} century, just after Meiji revolution. These dykes were designed to extend perpendicular to the main stream of the river flow from the one side or both sides of the embankment, and several dykes were set to work as a group for one river reach. After several decades, as inland navigation declined, spur dykes become not so popular as river management works, however the dykes constructed in these ages still remain in several rivers and the spaces between these dykes show a new function for the rivers, mainly from the environmental point of view. That is, velocity is slow and water quality is stable generally in the space compared with those in the main channel, which provides preferable environment for natural lives. Owing to a dead zone formed in the space and rather slow velocity, sediment tends to be deposited in the space and it becomes shallower, which allows vegetation to flourish and creates new waterfronts. Nowadays these spaces, a sort of embayment, are recognised to possess a precious closed ecosystem within it, and should be preserved and passed onto the next generation in a good condition. The basic hydraulics in the embayment has recently been explored by several researchers (Yagi, 1984; Jali et al., 1993; Nakagawa et al., 1995; Kimura, 1997; Wallast et al., 1999), but its whole picture is still not clear.

In order to understand fundamental flow behaviour in an embayment attached to a river, a basic experiment was conducted in a relatively small laboratory flume. The model river is a straight channel with a rectangular embayment. The size of the embayment was changed from 1 to 3 in its aspect ratio (=length/width). The tested water depth includes both inbank and overbank conditions. Here considered overbank condition was Dr=0.15, where Dr is the relative depth (= main channel depth / flooding depth). Velocity measurements using laser Doppler anemometry (LDA) and an electromagnetic current meter (EMC) were carried out. In addition flow pattern on the water surface was visualised with the aid of small pieces of paper and a still camera.

2. Experimental Set-up

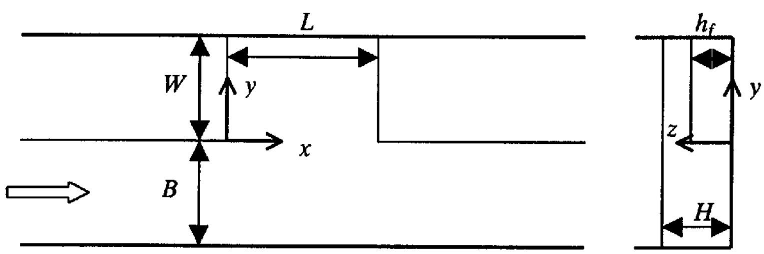
Two laboratory flumes were used in the experiments. The flume for LDA measurements is made of glass and has 8m long, 32cm wide, 25cm deep and its slope of 0.00125. The flume for ECM measurements and flow visualisation is made of mortar and has 23m long, 2m wide, 25cm deep and its slope of 0.00125. Model flood plain was set along the one side of the flumes and a model embayment attached to the main channel was formed in the middle of the flumes. Schematic view of channel geometry and definition of dimensions are shown in Fig.1.

Two depth conditions were investigated, i.e. inbank and overbank flow. The depth condition for the overbank flow is referred to with the relative depth, Dr, which is the ration between the main flow depth, H, and the flooding depth, H-h_f, and Dr=0.15 was adopted. Hydraulic conditions for the experiments are summarised in Table 1.

In the LDA measurements, two LDA systems were used in order to obtain simultaneous 3-components velocity. A 2-colour 3-beam Ar laser system was used for the streamwise and vertical components. And a 1-colour 2-beam He-Ne laser system was used for the lateral component. Measuring volumes of both systems were set at the desired point by eye. Sampling rate was 50Hz and 3000 data was collected for each point.

In the ECM measurements a 2-component electromagnetic current meter was used and the streamwise and lateral components of velocity were measured simultaneously. Sampling rate for one point was 20Hz and 1200 data was collected for each point.

Flow pattern on the water surface was visualised using 1cm×1cm pieces of paper as a tracer. Visualised flow patterns were captured by a 35mm still camera with various exposed time.



	W	L	L/W	B/W
LDA measurements (B=16cm, h_f=4cm)	16cm 16cm	16cm 48cm	1 3	1
ECM measurements (B=137cm, h_f=10cm)	63cm 63cm	63cm 189cm	1 3	≒2

Fig. 1 Channel geometry and definition of dimensions

Table 1 Hydraulic conditions

	Q (cm^3/s)	H (cm)	U_m (cm/s)	u_* (cm/s)	Re	Fr
LDA inbank	2,271	3.80	37.4	1.78	9,650	0.74
overbank	3,028	4.70	35.0	1.60	7,320	0.77
ECM inbank	32,529	5.60	42.4	2.52	22,000	0.60

3. Results and Discussions

3.1 Geometry effect - Aspect ratio of the embayment

The effect of aspect ratio of the embayment on the exchange process is firstly examined in the inbank case with two geometries, i.e. L/W=1 and 3.

Velocity distribution measured on the half water depth plan is shown in Fig. 2. A contour map indicating velocity magnitude is superimposed in the figure. For L/W=1, one large circulating flow is induced in the embayment. The embayment is occupied almost all by this circulation but its velocity is rather small, less than 10cm/s and about a quarter of that of the main flow, thus steep velocity gradient is seen in the junction region. The central part of the circulation is stagnant whose velocity is nearly zero. On the other hand, for L/W=3, a large circulating flow can be seen which occupies latter three fourths of the embayment and has an anticlockwise rotation. A stagnating area formed at around the centre of the circulation extends in the streamwise direction, but its extension in the lateral direction is narrower than the L/W=1 case. At the upper left corner a small clockwise eddy can also be seen, but it is very weak compared with the larger one and this area is almost stagnant. Even for the dominant circulation its velocity is small thus steep velocity gradient is also seen in this case.

Turbulence intensities in the streamwise and lateral directions are shown in Fig. 3 and 4 respectively. The figures show that for both cases an area containing large turbulence is formed at the junction between the main channel and the embayment. The area coincides well with the one showing the steep velocity gradient in Fig. 1. This means that vigorous interaction between the main flow and the circulation takes place in this area. This leads to large velocity fluctuation in both directions, and produces large turbulence. Such an area seems to widen as getting downstream, especially for the L/W=3 case. This could indicate that the main flow and the dead zone can exchange more effectively in this case than the square embayment case.

One of the evidence for the aforementioned conjecture exists in the distribution of Reynolds stress $\overline{uv}$ shown in Fig. 5. $\overline{uv}$ has a close relation with momentum transfer in the lateral direction. The figure shows that the shearing layer at the junction becomes thicker as getting downstream. This tendency is much clearer for the L/W=3 case than the other case, and resultant shearing layer for the case spreads fairly into both sides of the junction, from x/W=-0.3 to 0.3.

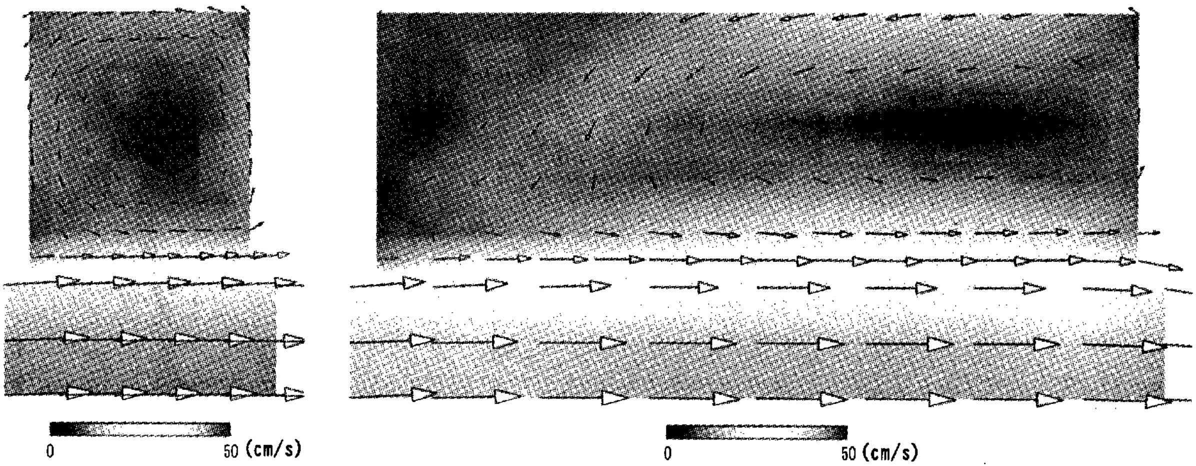
The other evidence can also be seen in the flow visualisation. The result is shown in Fig. 6. In the figure pictures taken in one sequence are shown for each case. The exposed time of the camera is 2sec. For L/W=1, left, the circulation in the embayment is quite stable and there seems no exchange between the main flow. However for L/W=3, right, the dominant circulation changes its shape and sometimes extends towards the main flow region. Vigorous exchange process can be seen with many tracers into and out of the embayment. Behaviour of the weak eddy, which sometimes enlarges and pushes against the dominant one, is also of interest.

3.2 Depth dependency

Here difference between inbank flow and overbank flow is studied. The aspect ratio of the embayment is L/W=1 for both cases.

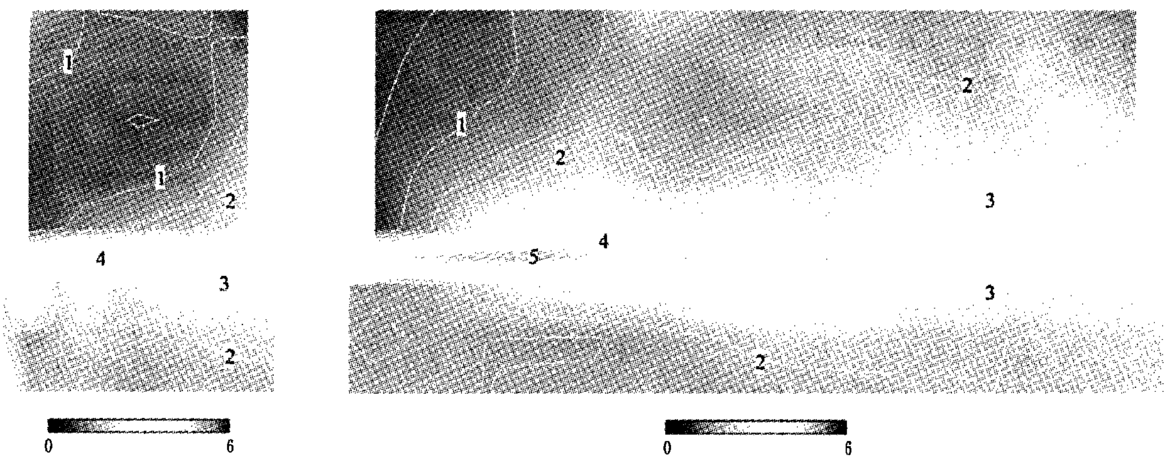
Figure 7 shows velocity distribution in a plan view. For the overbank case results on two plans, z/h_f=0.5 (half of the flood plain height) and 1.0 (the bankfull level), are shown. As is indicated by a contour map in (b-1), with dark blue colour fully covering up the embayment, almost all of the embayment below the bankfull level is a stagnating area. Velocity magnitude of this area is less than 4cm/s, which is under 10% of that of the main flow. As a result there seems no circulating flow which is clearly seen there for the inbank case, nor can clear flow pattern be seen. Sudden change of the map colour from the main flow region towards the embayment suggests that there exists very steep velocity gradient in between. On the other hand, as is seen in (b-2), flow at the bankfull level (and maybe over it) runs nearly along the streamwsie direction, being parallel to the main flow in the channel. It seems that the flow is not coming down into the stagnating area below the bankfull level, but just running over it. Velocity magnitude within the embayment is similar to that for the inbank case, but is still small compared with the main flow.

As examined in **3.1**, horizontal circulation is dominant for inbank cases, irrespective of the aspect ratio of the embayment. Whereas for overbank cases, some literature pointed out that vertical circulation is important. However such circulation cannot be seen in the tested overbank case here. This could be



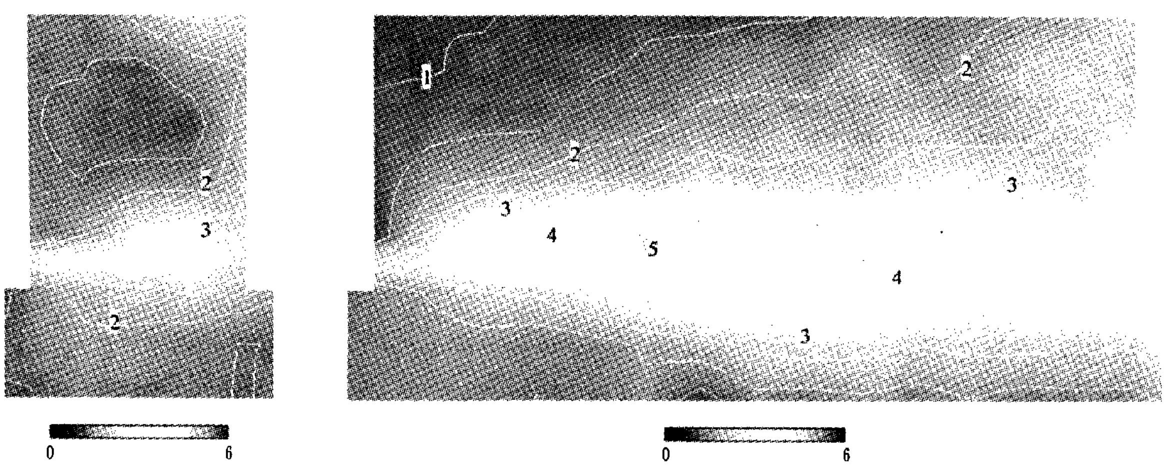
(a) L/W=1 (b) L/W=3

Fig. 2 Velocity distribution in a plan view (inbank, measured by ECM)



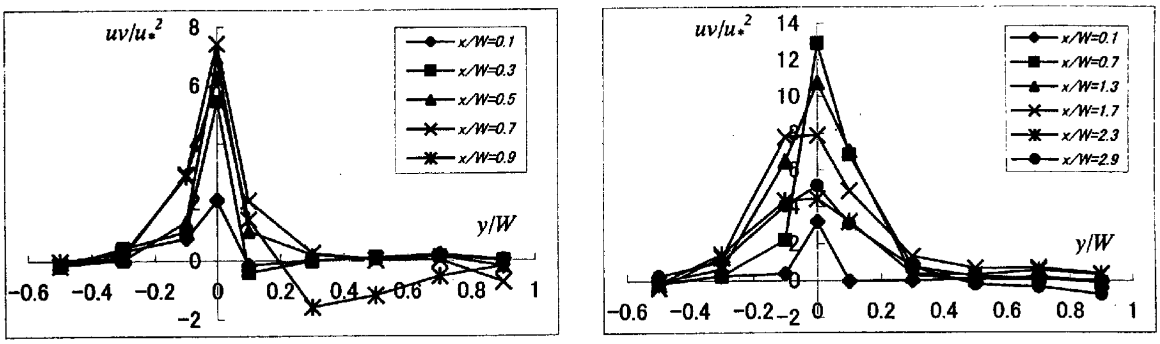
(a) L/W=1 (b) L/W=3

Fig. 3 Turbulence intensity u'/u_* (inbank, measured by LDA)



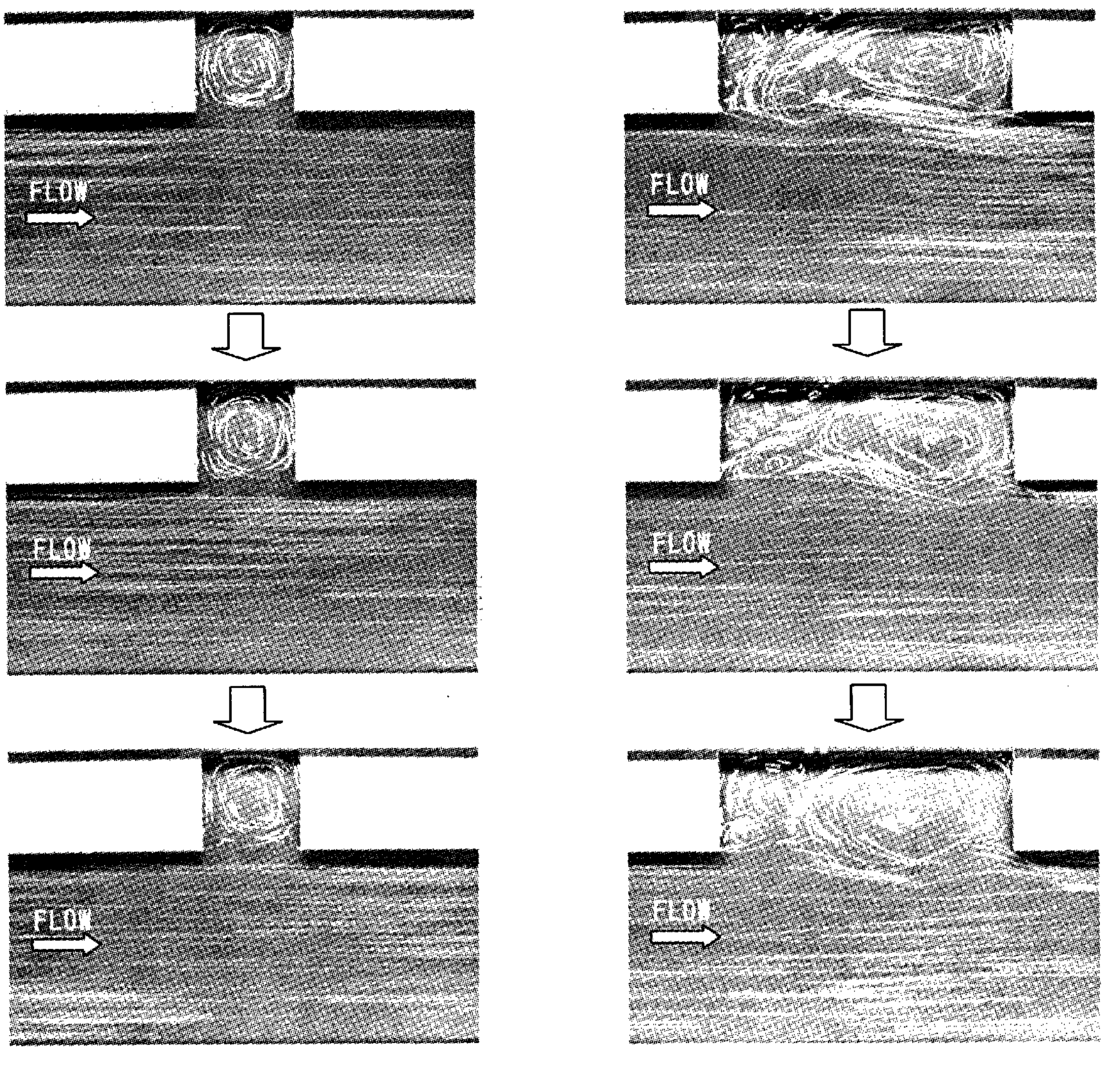
(a) L/W=1 (b) L/W=3

Fig. 4 Turbulence intensity v'/u_* (inbank, measured by LDA)



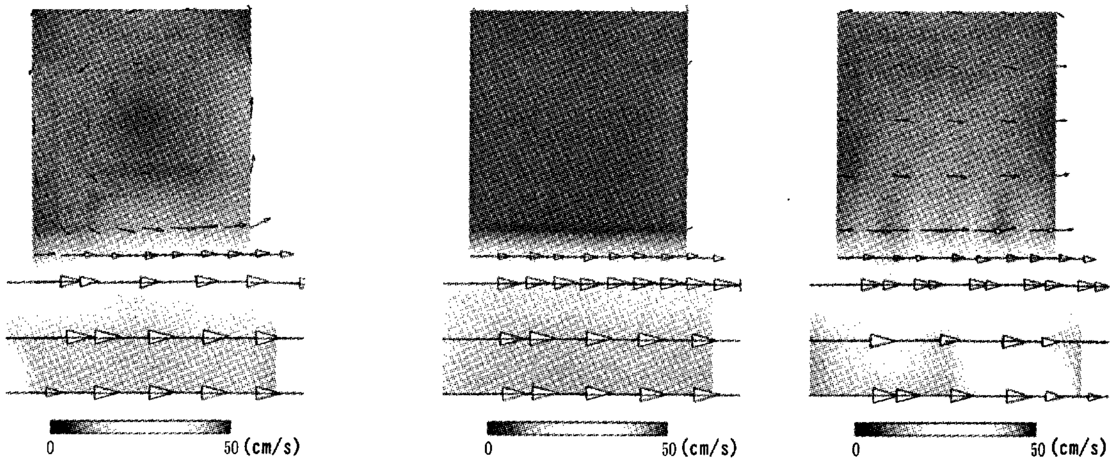
(a) L/W=1 (b) L/W=3

Fig. 5 Reynolds stress $\overline{uv}/u_*^{\,2}$ (inbank, measured by LDA)



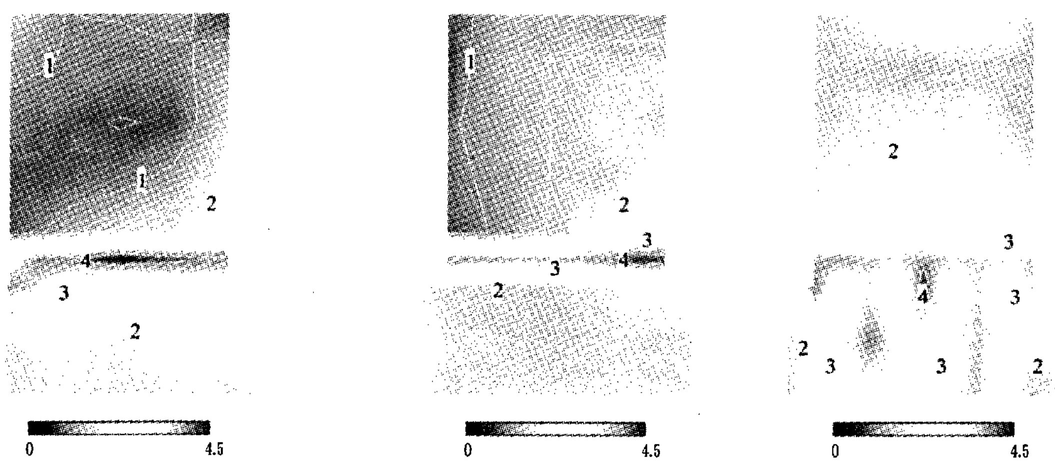
(a) L/W=1 (b) L/W=3

Fig. 6 Exchange process between the main channel and the embayment (inbank, $B/W \fallingdotseq 2$)



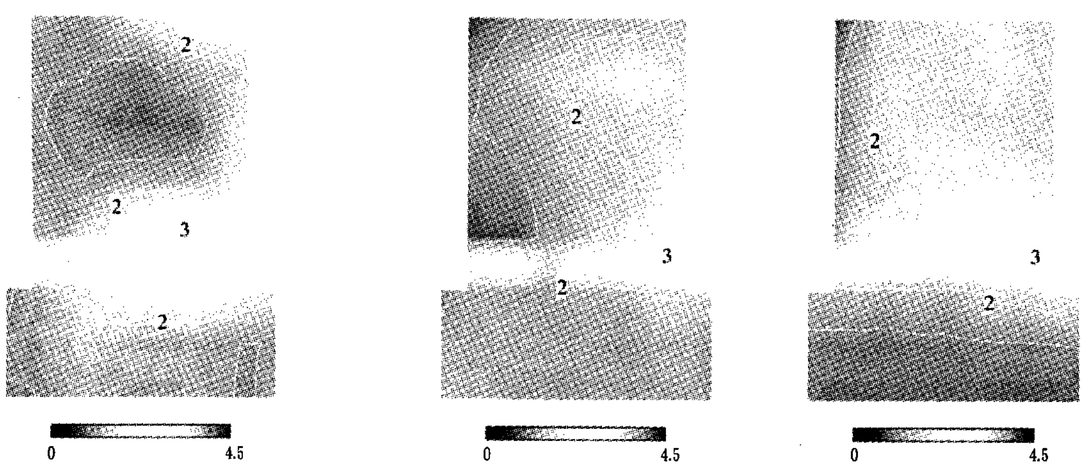
(a) inbank (b-1) overbank, z/h_f=0.5 (b-2) overbank, z/h_f=1.0

Fig. 7 Velocity distribution in a plan view (L/W=1, measured by LDA)



(a) inbank (b-1) overbank, z/h_f=0.5 (b-2) overbank, z/h_f=1.0

Fig. 8 Turbulence intensity u'/u_* (L/W=1, measured by LDA)



(a) inbank (b-1) overbank, z/h_f=0.5 (b-2) overbank, z/h_f=1.0

Fig. 9 Turbulence intensity v'/u_* (L/W=1, measured by LDA) attributed to the shallow flooding depth adopted here, Dr=0.15. When flooding depth becomes higher, vertical circulation resulting from the flow exchange between the upper (above the bankfull) and lower (below) layer flow, like flow expansion and contraction, can be observed more clearly.

Turbulence intensities are shown in Fig. 8 and 9. For the lower layer (b-1), z/h_f=0.5, turbulence intensities distribute similar to those of the inbank case. Only the difference is that large intensity values can just be seen within a rather narrow, restricted area. This well coincides with the fact of steeper velocity gradient mentioned above. At the bankfull level (b-2), z/h_f=1.0, both maps show differences from those of z/h_f=0.5. For u', an area containing large intensity spreads from the junction toward the main flow region. Whereas for v', such an area extends toward the embayment. For both layers the lateral turbulence intensity v' is generally small. This could imply that lateral exchange does not take place so strongly for overbank cases.

3.3 Effect of successive embayments

As is explained in **Introduction**, usually several dykes are set to work as a group for one river reach in practice. Consequently a sequence of embayments is seen in real rivers. As a basic model for such a sequence three successive embayments are formed in the experimental flume and preliminary measurements were carried out. Aspect ratio of each embayment is 1. The results are shown in Fig. 10 and 11. It can be seen in Fig. 10 that one large circulation is induced in each embayment, and velocity in the 2nd and 3rd rooms is faster than in the 1st one. It is also seen in the flow visualisation, Fig. 11 that many tracers come from the main flow into the embayments and vice versa. This clearly shows that exchange between the main flow and the embayments takes place much effectively.

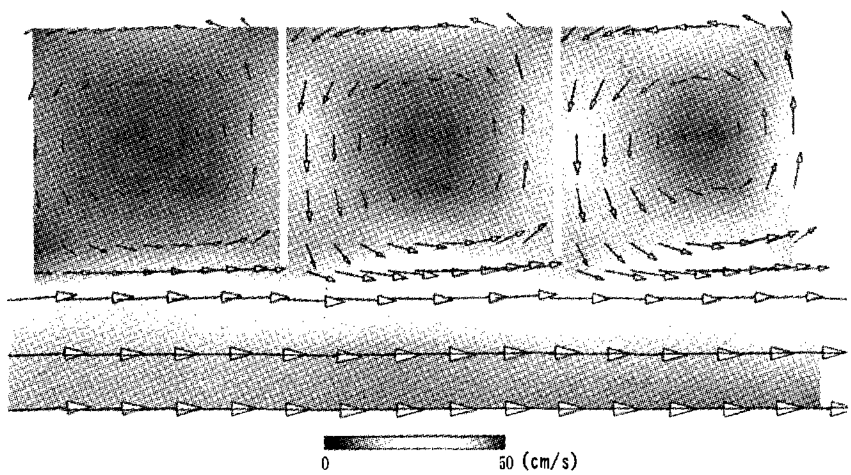


Fig. 10 Velocity distribution in a plan view (inbank, measured by ECM)

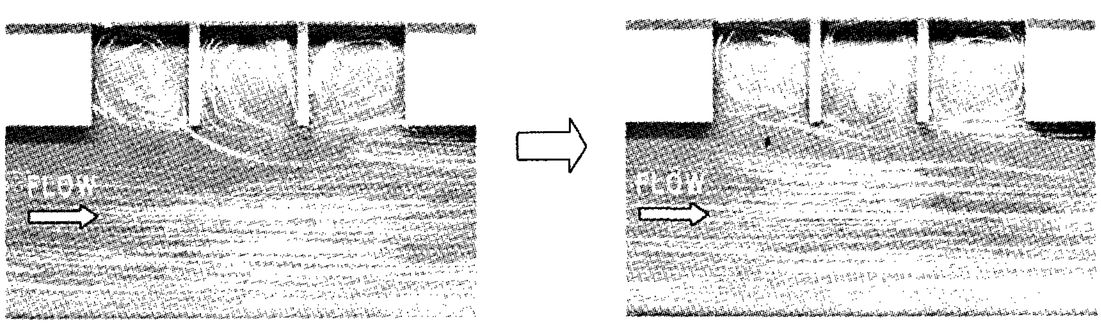


Fig. 11 Exchange process between the main channel and the embayment (inbank, $B/W \fallingdotseq 2$)

4. Concluding Remarks

Velocity measurements were carried out in a straight open channel with a rectangular embayment. Circulation flow induced in the embayment and flow exchange between the main flow region and the dead zone are of main interest. Both geometry condition and hydraulic condition were changed in order to examine their influences on the mechanisms concerning the aforementioned features. The results can be summarised as follows:

- Aspect ratio of the embayment determines the shape and stability of circulating flow induced there, and this as a results influences the exchange process.
- Horizontal exchange is dominant for inbank cases, but mechanism is more complex for overbank cases.
- The number of embayment, whether single or its sequence, also affects the exchange process. The picture drawn for single embayment, which is most the case in the experiments to-date, could not be extrapolated into natural rivers, where embayment is usually in sequence.

For overbank conditions one of the key elements determining the flow structure such as the exchange process is flooding depth. Nevertheless only one depth condition was explored here. Additional measurements are currently being carried on covering wider range of depth conditions.

Further investigation is also necessary in sediment movement and bed deformation in the embayment. This will give us some information on how the embayment has been formed in the past and how it to be in the future.

References

Jali, MA, Kawahara, Y, Tamai, N and Kan, K (1993): Proc. Hydr. Eng., Vol.37, pp.503-510.

Kimura, I (1997): Doctoral Thesis, Kyoto University.

Nakagawa, K, Kawahara, Y and Tamai, N (1995): Annual J of Hydr. Eng., Vol.39, pp.595-600.

Wallast, I, Uijttewaal, WSJ and van Mazijk, A (1999): Proc. 28th IAHR Cong., p.232.

Yagi, S (1984): Doctoral Thesis, Osaka University.

要　旨

わんど内の流れおよびわんど・主流部間の交換を検討するための基礎的実験として，長方形凸部を有する直線開水路流れにおいて速度計測を行った．その結果，凸部の開口幅を大きくすることにより交換が促進されること，水深の条件によって交換機構が全く異なることが明らかにされた他，凸部が連続した場合には個々の凸部形状が合同であっても交換現象は同一ではなく，単一の凸部における現象が代表値とはなり得ないことが示唆された．

キーワード：わんど，速度計測，流体交換，乱れ，せん断層