HYDRAULIC CHARACTERISTICS OF UNSTEADY FLOWS IN MEANDERING COMPOUND CHANNELS

Akihide Watanabe
Associate Professor, Department of Civil and Environmental Engineering,
E-mail: awata@hiroshima-u.ac.jp

Shoji Fukuoka
Professor, Department of Civil and Environmental Engineering, Hiroshima
University, 1-4-1 Kagamiyama, Higashi-hiroshima City, 739-8527, Japan, telephone
081-824-24-7821, fax number 0824-24-7821, E-mail: sfuku@hiroshima-u.ac.jp

Abstract: Hydraulic effects of unsteadiness, plan and cross-sectional shapes of channel on flood flow were investigated in meandering compound and single channels.

In the case of an unsteady meandering compound channel flow, the discharge and velocity had two values for the same depth on rising and receding water periods. Comparing stage hydrographs for meandering compound and single channels, it was observed that compound meandering channel had early response giving high values during rising water period and delayed response giving high values during receding water period. Also, greater unsteadiness and sinuosity are accompanied by earlier peaking of velocity and a greater rate of depth increase in the rising water period.

Keywords: flood flow, hydrograph, unsteadiness, meandering compound channel, channel plan-form, depth-discharge curve

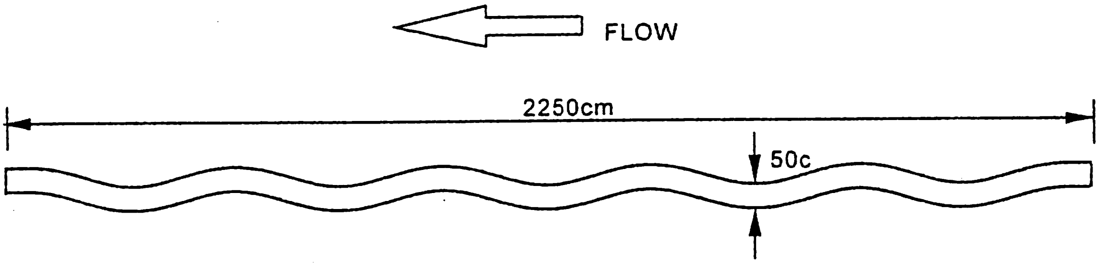
1 INTRODUCTION

For reasons of flood control and river environment, cross-sectional form seen most often in the middle and lower reaches of Japan's large rivers is a compound section which comprises a main channel and flood channels. Furthermore, because flood flows are often treated as quasi-steady flows in the one-dimensional analysis, water level and velocity are determined on the basis of non-uniform flow calculations.

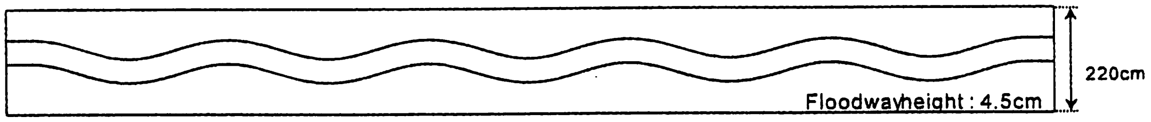
It has been shown that in a compound meandering channel, mixing of the flows in the main channel and flood channel produces resistance that differs greatly from that of simple meandering channels (Ervine et al 1993, Fukuoka et al 1997). Studies of flood flows have also shown that the effects of flow unsteadiness manifested far more markedly in a compound channel than in a simple channel (Fukuoka et al 2000) and that bed evolution can be considered approximately as that in steady flow corresponding to each relative depth (Fukuoka, 1999, Okada et al 2000). In this paper, temporal changes in depth, velocity and discharge were measured under given hydraulic and geometrical conditions comparable to those in actual rivers, determining the effects of unsteadiness, channel's planform, and cross-sectional form on hydraulic characteristics of a compound meandering channel.

2 EXPERIMENTAL CONDITIONS AND METHOD OF MEASUREMENT

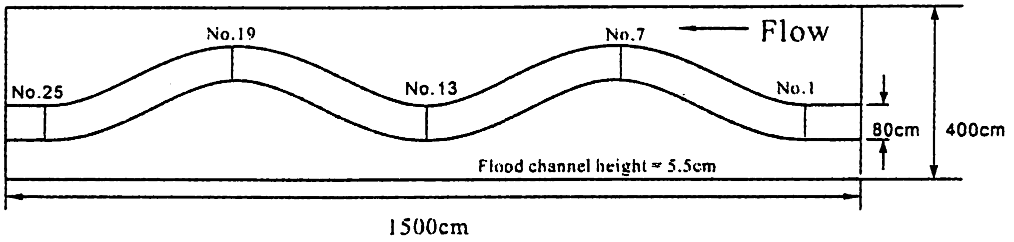
First, experiments were carried out with the simple meandering channel shown in Fig. 1 (a) to clarify the basic characteristics of the discharge hydrograph of flood flows, particularly the effects of unsteadiness. By comparing these results with those for a compound meandering channel in Fig.1 (b), the authors considered the effects of compound section on flood flow hydraulics. Then using the movable bed compound meandering channel in Fig.1(c), the authors performed experiment under conditions of different sinuosity, main channel conditions, and flood channel roughness coefficient to determine the effects of each.



(a) Fixed-bed simple meandering channel



(b) Fixed-bed compound meandering channel



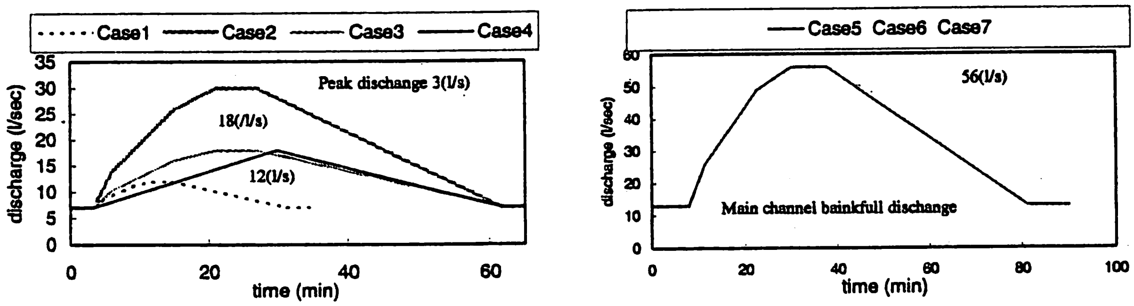
(c) Movable-bed compound meandering channel

Fig. 1 Channels used for experiments

Table 1 shows the experimental cases: one case of a simple meandering channel and six cases of a compound meandering channel. Case1 was a simple meandering channel; Cases 2, 3, and 4, a fixed-bed compound meandering channel; and Cases 5, 6, and 7, a movable-bed compound meandering channel. The given hydrographs are shown in Fig. 2 (a) and (b), in which the hydrograph is superimposed over main channel bankfull discharge, which is defined as the steady-flow discharge. Table 2 lists flood data from the Tonegawa river, whereas Table 3 lists the actual flood equivalents of experimental channel (a) assuming a 200: 1 scale. The results show that the hydrograph given for the channel correlates well to the flood hydrograph of an actual river.

Table 1 Experimental conditions

	Main channel bankfull discharge (l/sec)	Peak discharge (l/sec)	Maximum relative depth	Main channel bed conditions	Flood channel roughness coefficient	Channel type (sinuosity)	Notes
Case1	7.0	12.0	0	Flat rigid-bed	0.02	A (1.02)	Simple meandering
Case2		30.0	0.51			B (1.02)	Compound meandering
Case3		18.0	0.41				
Case4		18.0	0.40				Compound meandering, isosceles triangle-shaped hydrograph
Case5	13.0	56.0	0.38	Flat movable bed	0.014	C (1.10)	Compound meandering, small n_{fp}
Case6				Movable bed after 3 hrs of bankfull discharge			Compound meandering, historic bed
Case7			0.40	Flat movable bed	0.019		Compound meandering, large n_{fp}



(a) Fixed bed compound channel (b) Movable bed compound channel

Fig. 2 Discharge hydrograph

Table 2 Flood flows in Japanese rivers

River name (Observation station)	Maximum relative depth	Maximum discharge	Duration of flood channel inundation
Tone river, August 1981 (Kawamata)	0.53	7,800 (m^3/sec)	47 (hrs)
(Kurihashi)	0.56	8,100 (m^3/sec)	64 (hrs)

Table 3 Actual flood equivalents of experimental channel flood

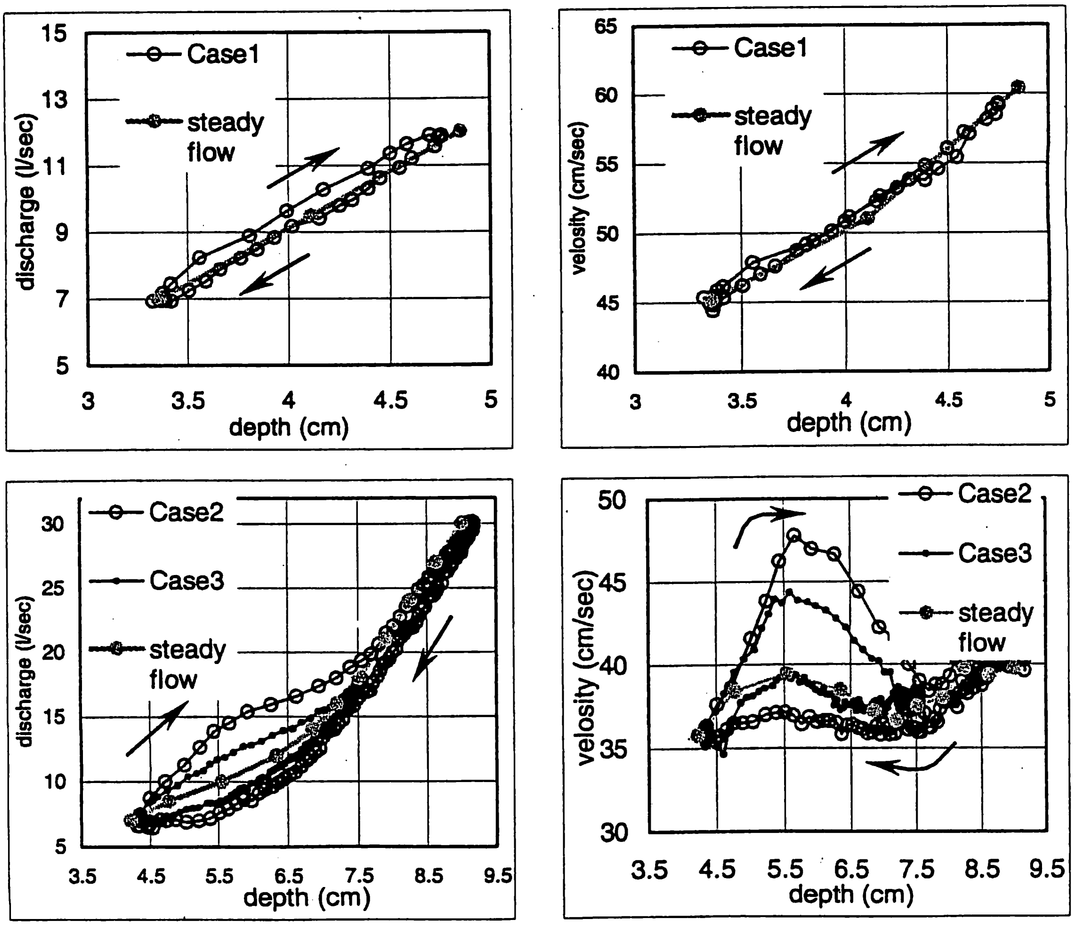
	Maximum relative depth	Maximum discharge	Duration of flood channel inundation
Case2	0.51	17,000 (m^3/sec)	13.3 (hrs)
Case3	0.41	10,200 (m^3/sec)	13.2 (hrs)

The discharge hydrograph was given by an electromagnetic flowmeter equipped with a discharge control device. Water level was measured with a capacity-type wave height meter and servo-type wave height meter; velocity with I type electro magnetic velocimeter. Measurements were made at the channel's central cross-section. Depth was measured in the center of the main channel; velocity, at one-second intervals at roughly 60% of depth in the main channel (three points) and the flood channel (three to five points).

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Effects of unsteadiness

The relationship of depth to discharge and depth to main channel average velocity in each case is shown in Fig.3 (a) and (b). For depth, the value from the channel's center was used; for velocity, the average for three points in the main channel was used. Arrows in the graphs indicate the passage of time. Both the simple and compound sections resulted in a loop. In the case of the simple section, although discharge in the rising water period was slightly higher for a given depth than in the receding water period, the relationship between discharge and depth was a generally linear one. In the case of the compound section, in contrast, this discharge/depth relationship was far different than in the case of the simple section, suggesting the marked effects of unsteadiness and the compound section. With a larger loop

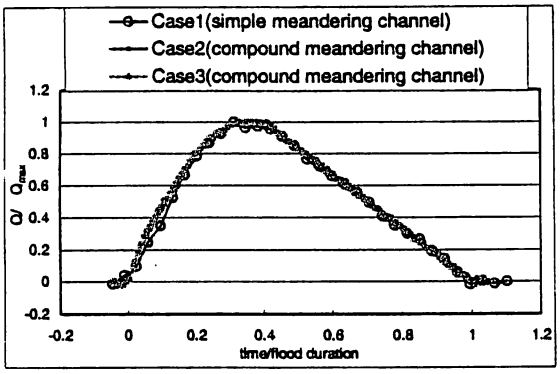


(a) Depth-discharge relationship (b) Depth-main channel velocity relationship

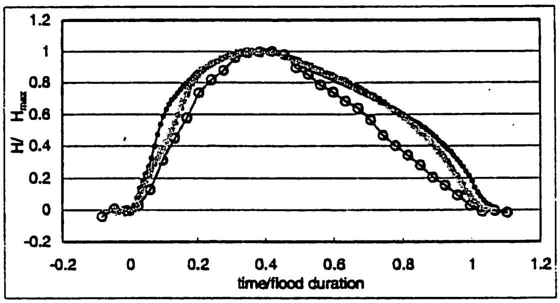
Fig. 3 Depth-discharge and depth-velocity curves than in the case of the simple section, the compound section resulted in large differences in discharge at a given depth between the rising water and receding water periods. As for the depth/ main channel velocity relationship, in the simple meandering channel, the peak in depth corresponded to the peak in main channel velocity, with almost no change in this relationship between the rising water and receding water periods. In the compound meandering channel, however, main channel velocity with a steady flow reached its first peak at a depth (5.5 cm) slightly greater than main channel bankfull depth. After decreasing, velocity increased again with depth to reach a second peak at maximum depth. With an unsteady flow, velocity at a given depth was even greater than at the same depth in the steady flow. In addition, the unsteady compound meandering channel resulted in a characteristically large loop.

3.2 Effects of channel planform

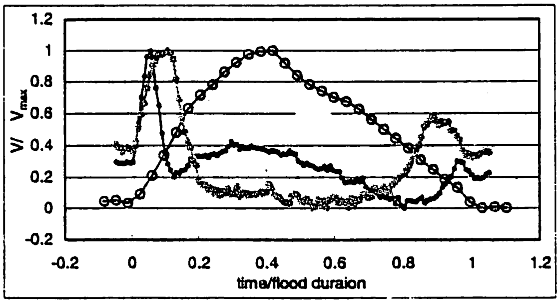
Fig. 4 is a comparison of dimensionless discharge, depth, and velocity in the simple meandering channel (Case 1) and the compound meandering channel (Cases 2 and 3).



(a) Dimensionless discharge

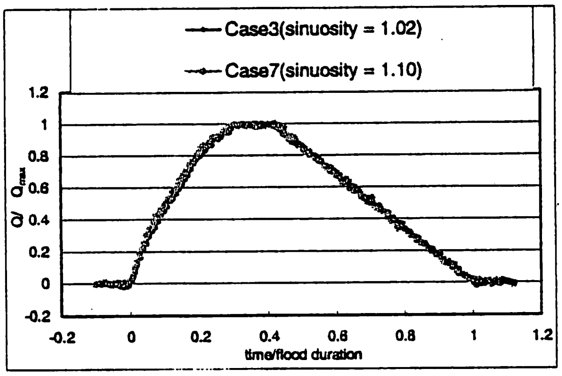


(b) Dimensionless depth

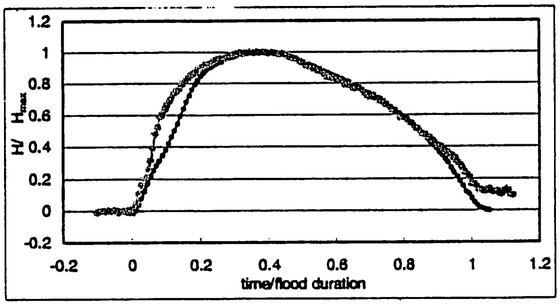


(c) Dimensionless velocity

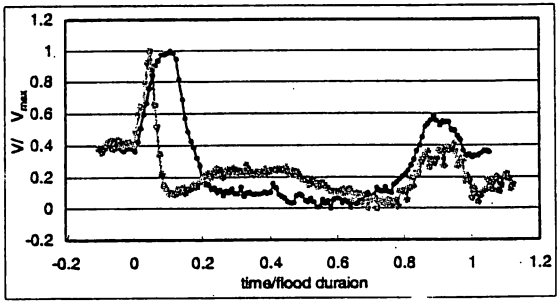
Fig. 4 Effect of channel planform on flood flow propagation



(a) Dimensionless discharge



(b) Dimensionless depth



(c) Dimensionless velocity

Fig. 5 Effect of channel sinuosity on flood flow propagation

These data were nondimensionalized by flood duration, which was defined as the time required for the flood to return to main channel bankfull discharge The time at which flooding began to increase from the main channel bankfull discharge was defined as the starting point (i .e., a time of zero). Discharge, depth, and velocity were nondimensionalized by the ratio of each value to the maximum relative to the value of main channel bankfull discharge defined as zero. Discharge exhibits almost similar shapes in each case whereas the temporal change characteristics of depth and velocity differ greatly between the simple and compound channels: In the latter, the increase in depth in the rising water period is quicker, and the decrease in depth in the receding water period slower, than in the case of the simple channel. Behind this difference is the fact that a compound meandering channel maintains a greater depth over the duration of a flood.

Although the peak in velocity in the simple meandering channel roughly corresponds with the peaks in discharge and depth, discharge in the compound meandering channel exhibits a sharp peak at the point in time corresponding to the early inundation stage in the flood channel. This phenomenon occurs because of the increase in surface slope caused by the greater effect of flood channel roughness as inundation of the flood channel begins in the upstream reaches of the channel during this time period. Furthermore, a comparison of Cases 2 and 3 (which concern the compound meandering channel) shows that velocity peaked earlier in Case 2, in which the rate of discharge increase was higher, indicating that greater unsteadiness translates into earlier peaking. In addition, in the late inundation stage in the flood channel, the compound channel exhibits a second, smaller peak, which is more pronounced in Case 3, in which flooding conditions were less severe.

3.3 Effects of channel sinuosity

To determine the effects of channel planform, the authors nondimensionalized, in the same manner described above, discharge, depth, and main channel velocity for Case 3 (sinuosity = 1.02) and Case 7 (sinuosity = 1.10) (Fig. 5). Nondimensional discharge in each case is roughly similar but shows different depth increase characteristics: In the rising period, depth increases more quickly in high-sinuosity Case 7 than in Case 3. Similarly, discharge clearly peaks more quickly in Case 7 than in Case 3. This suggests that, in a compound meandering channel, a main channel with a large sinuosity results in the pronounced exchange of flows between the main channel and flood channel, i. e., the effects of the compound meandering section are greater.

3.4 Dimensionless depth/discharge curve

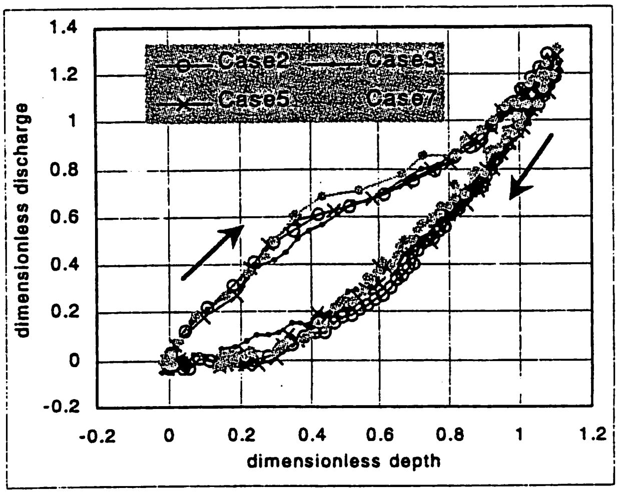


Fig. 6 Dimensionless depth-discharge curve

Fig. 6 facilitates a comparison of the shapes of the loops formed when discharge and depth in the various cases are nondimensionalized at the point where the loop of the depth/discharge curve closes. It can be seen that higher-sinuosity Case 7 exhibits a somewhat larger loop than does Case 3. Thus, the effects of sinuosity (i.e., its tendency to engender active mixing between main channel and flood channel) are also evident in this graph. Furthermore, the various cases exhibit comparatively similar forms and, in particular, suggest a roughly constant relationship in the receding water period.

4 CONCLUSIONS

The principal conclusions are as follows.

(1) For an unsteady flow in a simple meandering channel, the difference in depth/discharge curve between the rising water and receding water periods is small, and the relationship is essentially a linear one. Further, maximum velocity generally corresponds to the respective peaks of discharge and depth. In an unsteady compound meandering channel, however, discharge at a given depth differs between the rising water and receding water periods, with the graph exhibiting a loop. Furthermore, depth rises earlier in the rising water period and declines more slowly in the receding water period. The maximum value for average velocity in the main channel and in the overall cross-section occurs immediately after water enters the flood channel and is larger at a given depth than in the case of a steady flow.

(2) In an unsteady, compound meandering channel, greater unsteadiness and sinuosity are accompanied by earlier peaking of velocity and a greater rate of depth increase in the rising water period.

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