Effect of overloading sediment supply on the bed topography in a compound meandering channel

S. Okada
Graduate Student, Graduate School of Engineering, Hiroshima University
(1-4-1, kagamiyama, Higashi-Hiroshima, 739-8527 Japan)

S. Fukuoka
Professor, Department of Civil and Environmental Engineering, Hiroshima University (ditto)

ABSTRACT:
This paper presents experimental results of the characteristics of bed topography in a compound meandering channel. We investigated the mechanism of bed level change due to overloading sediment supply. The flow parameters on bed level fluctuation include overloading sediment supply, planform of the channel and changes of relative depth. Experimental results show large scouring and deposition due to interaction of moving sandbars and velocity distribution due to planform. Furthermore, effects of scouring and deposition bring about sediment discharge variation in time and space.

1 INTRODUCTION

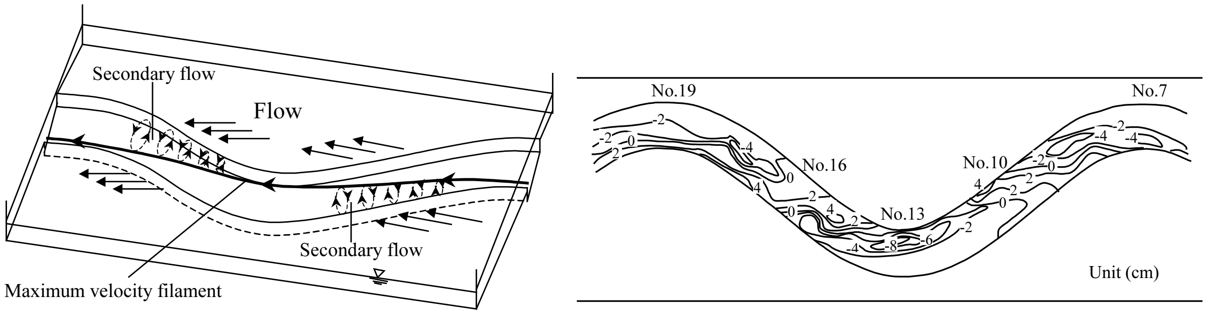
A lot of population and properties are mainly concentrated in alluvial plains in Japan. Considering this aspect, it has become a customary to improve rivers to compound sections by levees and to ensure safe flow during flood and to achieve stable channel under normal conditions. Considerable studies and research were carried out on compound meandering channel flows. Characteristics of flood flow and bed topography in compound meandering channel were investigated from hydraulic and bed topography data of laboratory experiments and several natural rivers.

On the flow and bed formation in a compound meandering channel, Ashida and Egashira indicated the difference of compound meandering channel flow and single meandering channel flow by comparing underbank flow, bankfull flow and overbank flow.

From the velocity distribution of compound meandering channel flow of the laboratory and natural streams, the flood flow was classified into two categories; the compound meandering channel flow and single meandering channel flow. The relative depth Dr (flood plain depth/main channel depth) of 30% above and below demarcates compound and single meandering channel flow respectively, when the sinuosity of the meandering compound channel flow is above 1.015 (Fukuoka et al. 1997, 1999). Fukuoka et al. (1999) also performed numerical computations to verify the above results.

It has also been observed from the investigation that the flow structure in the main channel changes significantly and sediment transport rate decreases for compound meandering flow compared to single meandering flow (Fukuoka et al. 1997).

It is important to investigate the influence of sediment overloading on flow and bed topography for the purpose of river improvement and river environment, because overloading sediment in the channel might cause large bed level fluctuation.



(a) Illustrations of maximum velocity filament and secondary current

(b) Contour lines of bed level change after 9hours from flat bed (sinuosity=1.17,Dr=0.37)

Figure 1: Flow structure and bed topography of a compound meandering channel flow

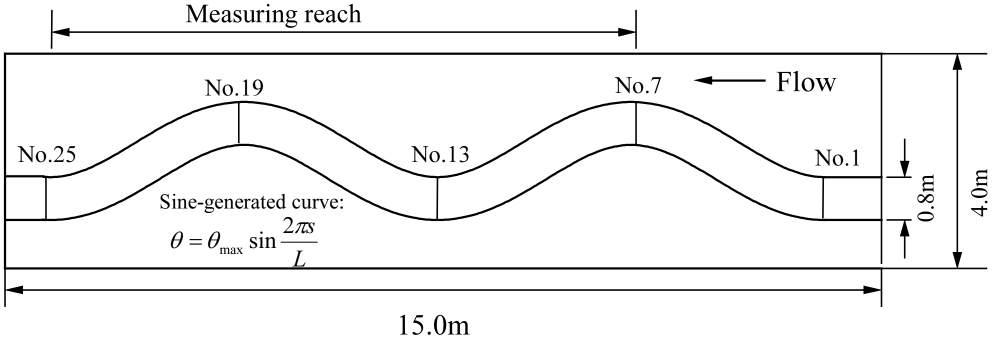


Figure 2: Experimental channel plan-form

In this paper, the mechanisms of bed level change for compound meandering channels are investigated by overloading sediment supply experiments. The variables of bed level fluctuation in compound meandering channel flows include over loading sediment supply, planform of the channel and changes of relative depth.

2 EQUILIBRIUM CONDITION OF BED TOPOGRAPHY IN MEANDERING COMPOUND CHANNEL FLOW

2-1 Flow structure and bed topography of compound meandering channel flow

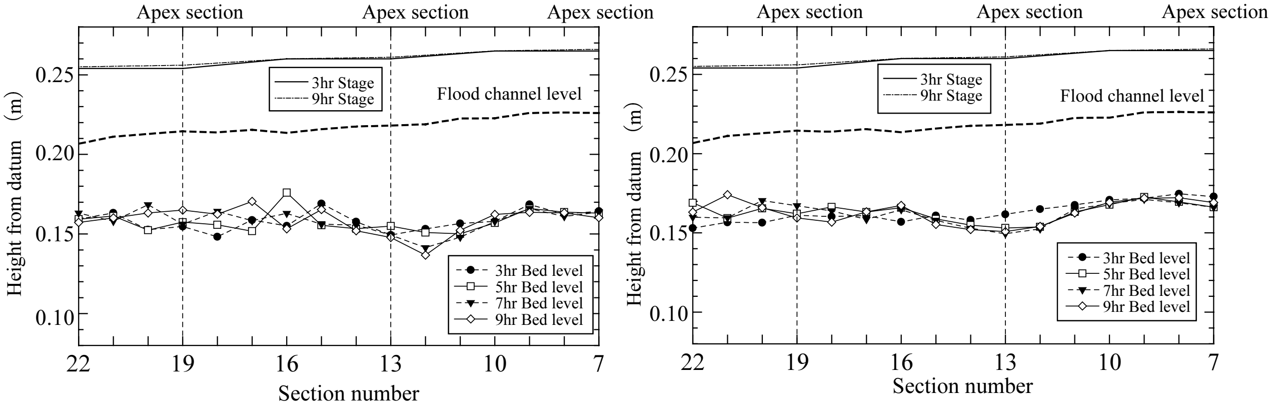
The studies by Fukuoka et al. (1997,1999) showed different flow characteristics for compound meandering channel and single meandering channel flow. The shear stresses at the imaginary horizontal interface across the

Table 1: Experimental channel condition

Wave length, L	7.5 m
θ max	35°
Initial bed slope	1/600
Sinuosity	1.10
Height of flood channel	5.5cm
Diameter of bed material (uniform graded sand)	0.8 mm

Table 2: Experimental condition (Experiment 1)

Experimental case	**1-1-1** **1-1-2**	**1-2-1** **1-2-2**	**1-3-1** **1-3-2**
Discharge (l/sec)	35.6	54.1	63.9
Relative depth Dr	0.31	0.44	0.49



(a) Case1-2-1 (Dr=0.44)

(b) Case1-2-2 (Dr=0.44)

Figure 3: Average bed level variation with time (Case1-2)

main channel at the same level as the flood channel are caused by interaction between main channel and flood channel flow. These horizontal shear stresses in the main channel produce secondary flow with the opposite rotation to the single meandering channel flow.

Flow interaction between main channel and flood channel varies in longitudinal direction, causing variation of intensity of secondary flow in that direction. As a result of flow interaction, sediment transport rate decreases with the relative depth (Fukuoka et al.1997).

These flow and bed topography in a compound meandering channel are illustrated in Figure 1 (after Fukuoka et al., 1999). Figure 1 (a) shows the maximum velocity filament and secondary currents. Figure 1 (b) shows the contour lines of bed level changes from initial flat bed after 9 hours flow for the condition of sinuosity 1.17 and relative depth Dr=0.37.

Changes in such flow structures and bed topography occur mainly along the maximum velocity filament due to longitudinal velocity change. The apex cross section has relatively high scouring depth compared to adjacent sections as shown in Figure 1 (b).

2-2 Experimental description

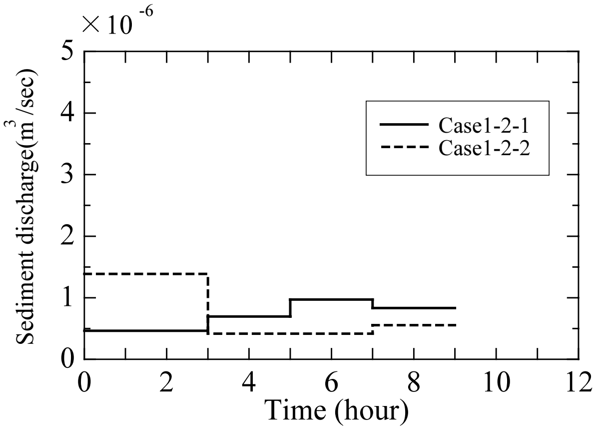
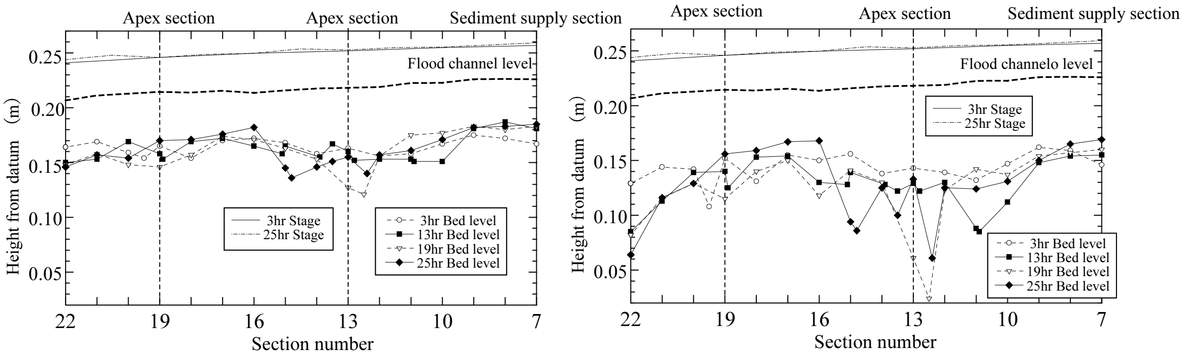


Figure 4: Sediment discharge variation with time (Case1-2-1, Case1-2-2)

Table 3: Experimental condition (Experiment 2)

Experimental case	2-1	2-2	2-3	2-4
Discharge (l/sec)	54.1		14.4	25.0
Relative depth Dr	0.44		0	0.26
Sediment supply discharge Q_{bin} (cm^3/min)	100	200	100	
Time (hour)	25			

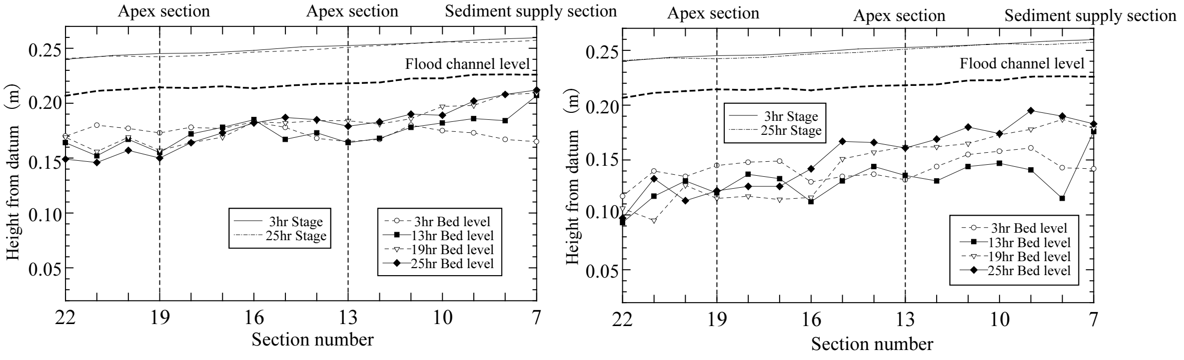
Experiment 1 was performed to investigate reproducibility of an equilibrium bedform in a compound meandering channel. The experiments were conducted in a compound meandering channel with plan geometry indicated in Table 1 and Figure 2. The channel was 15m long and 4m wide, the main channel



(a) Average bed level

(b) Maximum scouring depth

Figure 5: Case2-1 (Dr=0.44, Q_{bin}=100cm^3/min)



(a) Average bed level

(b) Maximum scouring depth

Figure 6: Case2-2 (Dr=0.44, Q_{bin}=200cm^3/min)

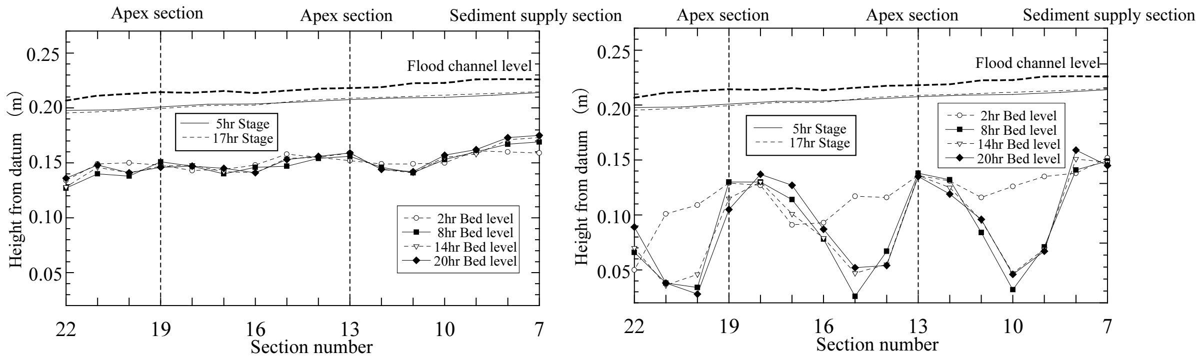
had width 0.8m and sinuosity 1.10. Experimental conditions are indicated in Table 2.

Measuring reach of the flume was located downstream from section No.7 as shown in Figure 2. In the Case1 experiment no sediment was supplied, sediment corresponding to the given flow conditions was transported in the channel.

2-3 Equilibrium condition of bed topography in meandering compound channel flow

Average bed level variation with time for Case1-2-1 and Case1-2-2 are shown in Figure 3. For the above two cases, comparison of average bed level with time indicates no significant difference. Figure 4 displays sediment discharge measured at the downstream end of the channel. Within 3 hours from the start of the experiment, the sediment discharge had a considerable difference between Case1-2-1 and Case1-2-2, as can be seen in Figure 4. The bed shape was adjusting to given flow conditions within that flow. The difference of sediment discharge for the two cases became negligible after 3 hours of flow, and no further variation of that occurred after 9 hours of flow. The flow after 9 hours implies that the condition of sediment transportation was in equilibrium condition. Similar results were obtained with Case1-1 and Case1-3 experiments.

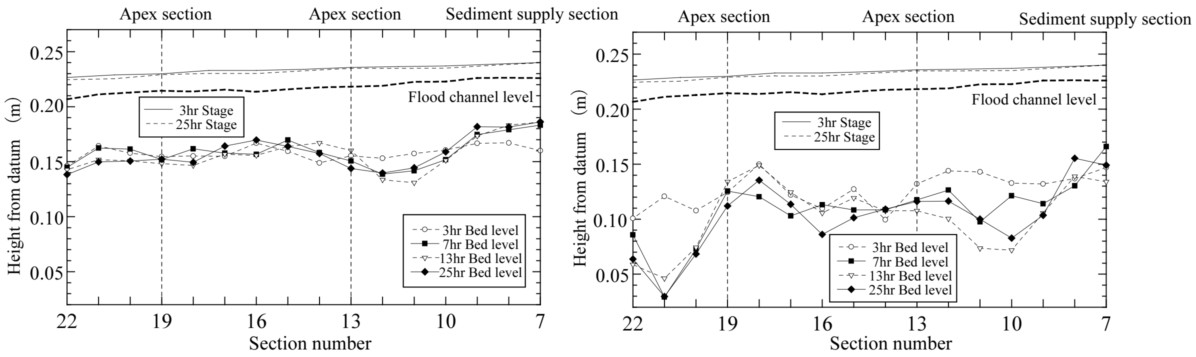
These experimental results showed that the sediment transportation corresponding to the flow, planform and cross sectional shape of the



(a) Average bed level

(b) Maximum scouring depth

Figure 7: Case2-3 (Dr=0, Q_{bin}=100cm^3/min)



(a) Average bed level

(b) Maximum scouring depth

Figure 8: Case2-4 (Dr=0.26, Q_{bin}=100cm^3/min)

channel made bed formations in an equilibrium condition in compound meandering channel flows.

3 EFFECT OF THE OVERLOADING SEDIMENT SUPPLY ON A COMPOUND MEANDERING CHANNEL FLOW

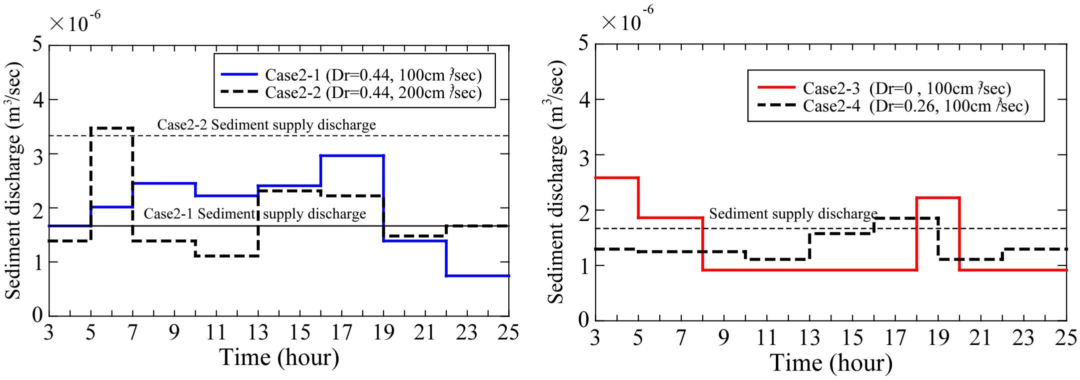
3-1 Description of Experiment 2

The plan geometry of the experimental channel for Experiment 2 was the same as in Experiment 1. Conditions for the experiment and the rate of overloading sediment supply are shown in Table 3. Results of Experiment 1 were used as a guide to this experiment.

The results of Experiment 1 showed that the sediment discharge was 60cm^3/min for the hydraulic conditions of Case1-2 at an equilibrium bed condition. Therefore, we decided sediment supply for Case2-1 and Case2-2 having rate of 100cm^3/min and 200cm^3/min; about twice and three times of Experiment 1 respectively.

In order to compare the results, the experiments were performed under the conditions of the same sediment supply rate for different relative depths, Dr=0(Case2-3) and Dr=0.26(Case2-4). The experiments of Case2-1, 2-2, 2-3 and Case2-4 started with flat bed without sediment supply into the channel for first 2 hours. After that time, sediment supply was made at 0.5m upstream of section No.7.

We then measured water stage, bed level and sediment discharge in the measuring reach indicated in Figure 2.



(a) Sediment discharge of Case2-1, Case2-2

(b) Sediment discharge of Case2-3, Case2-4

Figure 9: Variation of sediment discharge with time

3-2 Bed deformation in the overloading sediment condition

Results of bed deformation in the overloading sediment condition are shown in Figures 5,6,7 and 8. Figure (a) of each of the above figures shows the average bed level on different sections and Figure(b) of those show the maximum scouring depth variation with time. It was observed from the experiments that sandbars generated by overloading advanced downstream with time. And the local bed gradient ahead of sandbars was increased.

It was also observed that maximum local scouring occurred at high velocity sections (e.g. section No.13). These sections are the apices of the meandering channel, where maximum velocity and increment of bed gradient due to overloading sediment supply occur.

At the downstream section the deposition occurs and scouring depth decreases little by little.

For Case2-2 with about three times overloading sediment supply, deposition of the sediment occurred throughout the channel. Nearby the sediment supplying section, bed deposition in the inner side became larger and flow area of the main channel decreased gradually with time. Even though the bed level was rising in the main channel, the water stage hardly changed. This shows that the flow was spread to the flood channel, which was wider than the main channel.

Case2-3, which was a bankfull flow, maximum scouring depth of this experiment remained unchanged after 8 hours of flow.

Regarding Case2-4 with the relative depth of Dr=0.26, its maximum scouring depth became small compared to Case2-3. The maximum scouring depth of both the cases Case2-4 and Case2-3 occurred at the same locations of the channel. This indicates that Case2-4 has the flow and bed characteristics of single meandering channel flow.

For the case of overloading sediment supply, single meandering channel flow has a capability of transporting sediment to a certain extent, but in the compound meandering channel flow, sediment discharge decrease significantly and local scouring and deposition occurred. The bed elevation changes are influenced in upstream and downstream of the local scouring and deposition of the channel.

3-3 Rate of sediment supply and sediment discharge

Results of measured sediment discharge are displayed in Figure 9. It was deduced that sediment discharge measured at the downstream end has a close relationship with nearby bed level deformation.

For Case2-1 and Case2-2 in Figure 9(a), the sediment discharge decreased after 19 hours. This implies that sediment deposition at the upper section of downstream end occurred.

Figure 9(b) shows the results for Case2-3 and Case2-4. It is seen that sediment discharge variation with time of this cases became smaller than case 2-1 and case 2-2, because bed topography in these cases became in equilibrium as illustrated in Figures 7 and 8.

In the compound meandering channel flow, sediment discharge in time and space changed as a consequence of considerable non-equilibrium sediment transportation.

4 CONCLUSION

The following can be concluded from the laboratory experiments of bed deformation in compound meandering channels.

(1) Reproducibility of bed formation and equilibrium condition exists in the compound meandering flow when rate of sediment transport corresponding to the flow, planform and cross sectional shape of the channel are produced in the channel.

(2) In the case of compound meandering channel flow with over loading sediment supply condition, interaction of moving sandbars and velocity distribution due to planform of the channel causes large scouring and deposition. These effects of scouring and deposition cause sediment discharge variation in time and space.

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