MECHANISM OF VEGETATION DESTRUCTION DUE TO A LARGE FLOOD IN THE COMPOUND MEANDERING RIVER

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ABSTRACT

Two types of flow can be seen in compound meandering channels, which are simple meandering channel flow and compound meandering channel flow. The compound meandering channel flow has a characteristic that maximum velocity filament passes the inner bank side around the peak discharge of large floods. Therefore, large flood flows may destruct vegetations on sandbars formed near the inner bank. In the Ota River, flood discharge by typhoon 0514 was largest in the past 50 years. Vegetations on sandbars formed near the inner bank were destructed by this flood. On the other hand, vegetations on the outer bank side of the flood channel were remained. The authors observed temporal changes in water surface profiles during the flood, vegetations and bed scouring before and after flood. The objective of this study is to make clear the mechanism of vegetation destruction in compound meandering channels by 2-D flow analysis using the observed temporal changes in water surface profiles and field data.

Keywords: flood, vegetation destruction, temporal changes in water surface profiles, compound meandering channel, bed scouring

1. INTRODUCTION

Vegetations in rivers have important roles to make the good river environment. They supply habitats and corridors in aquatic life, and are essential elements composing river landscapes. On the other hand, vegetations give rise to serious problems with respect to the flood control such as water level increase due to their large resistance. So, it is required to establish a vegetation management in rivers. Fukuoka and Fujita (1992) had developed quasi-2D flow analysis method, in which effects of vegetations on flows are considered by no flux within vegetation clusters and shear stress exerted on the interface between the flow and vegetation. Maeno et al (2005) proposed unsteady 2D flow analysis method, in which effects of vegetations on flows are considered by drag force. Shimizu et al (2002) showed process of vegetation destructions based on the degradation of movable river-bed. Yagisawa and Tanaka et al (2008) indicated the relation between river beds conditions and vegetation destructions based on threshold drag moment of vegetations and calculated the threshold shear stress for vegetation destructed. They suggested that the investigation of local scouring around the vegetations is needed for understanding mechanism of vegetation destruction. But the important issues still remain, which include evaluation of effects of vegetation destruction on flood flow behavior and the depth of bed scouring causing vegetation destruction, although effects of bed scouring on vegetation destruction have been suggested. In this study, we attempt to solve above the issues by observation data of temporal changes in water surface profiles during the flood, vegetation conditions and river beds profiles before and after flood.

Compound meandering rivers which are generally adopted in the design of rivers in Japan have two types of flood flow: simple meandering channel flow and compound meandering channel flow (Okada and Fukuoka, 2004). Large floods assume to be compound meandering channel flow at the peak discharge and may destruct river vegetations on sandbars formed near the inner bank. The flood of the Ota River due to typhoon 0514 was the largest in the past 50 years. The flood flow destructed most of vegetations on sandbars formed near the inner bank side. The objective of this study is to make clear the mechanism and the cause of vegetation destructions on compound meandering channels by detailed investigation before and after the flood and unsteady 2-D flow analyses using the observed temporal changes in water surface profiles.

2. OBSERVATION OF VEGETATIONS AND THE FLOOD IN OTA RIVER

Temporal changes in water surface profiles were observed at 200m intervals of longitudinal distance by the water level gauges installed on either bank (see Figure 1).

Our gauges were not possible to measure water level beyond the design water level. Discharge hydrograph was measured using floats at Yaguchi-daiichi discharge observation station. In 2003, we investigated the situation of vegetations growing on flood channels and sandbars. The measurement items were positions, height, species and density of vegetations and measured data are stored in databank (see Figure 2).

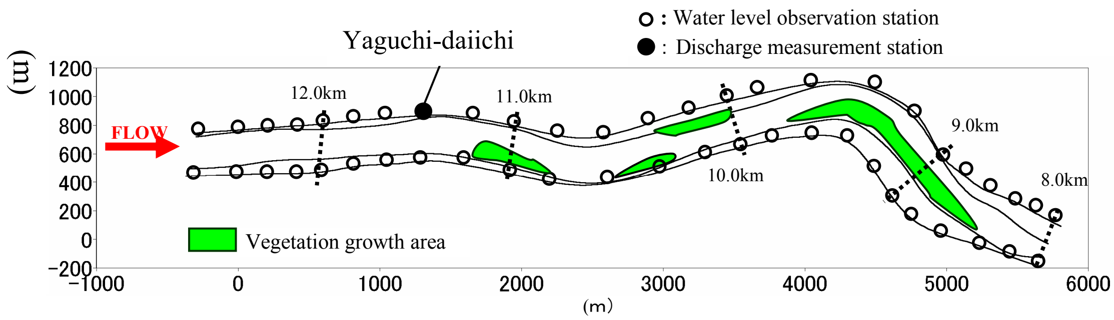

Figure 1. Channel conditions of section studied

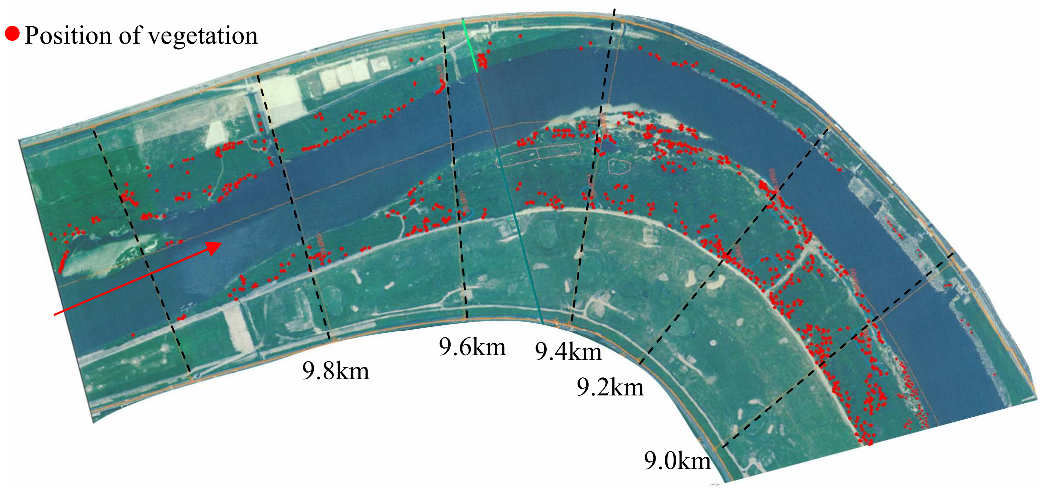

Figure 2. Situation of vegetation growth

Therefore, we can discuss positions and causes of vegetation destruction by surveying after the flood. Surveying demonstrated that Salix chaenomeloides grew in front of sandbar and Morus alba on sandbar of higher elevation to compared Salix chaenomeloides growth area.

3. CHANGES IN TEMPORAL WATER SURFACE PROFILES DUE TO VEGETATION DESTRUCTION

3.1 Situation of vegetation destruction

Okada and Fukuoka (2004)'s studies concerning compound meandering channel proved two types of flows: simple meandering channel flow and compound meandering channel flow. They proposed the diagram to judge flow regime of the compound meandering channel by the relation between sinuosity S (=meander length/meander wavelength) and relative depth Dr (=flood channel depth/main channel depth). The discharge of the Ota River flood by typhoon 0514 was largest in the past 50 years and water level of the flood reached near the design flood water level (see Figure 3). Figure 4 shows the diagram plotted by the sinuosity and the relative depth at the peak discharge of the Ota River. The flood flow around the peak discharge was considered as compound meandering channel flow.

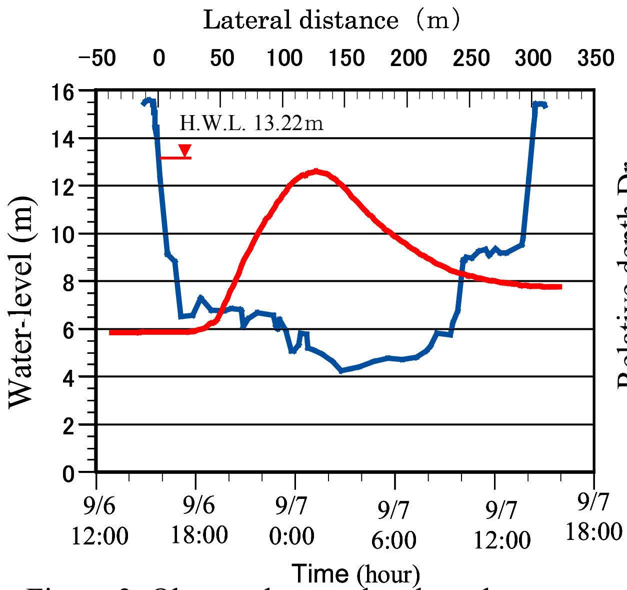

Figure 3. Observed water-levels and cross-section at discharge observation station

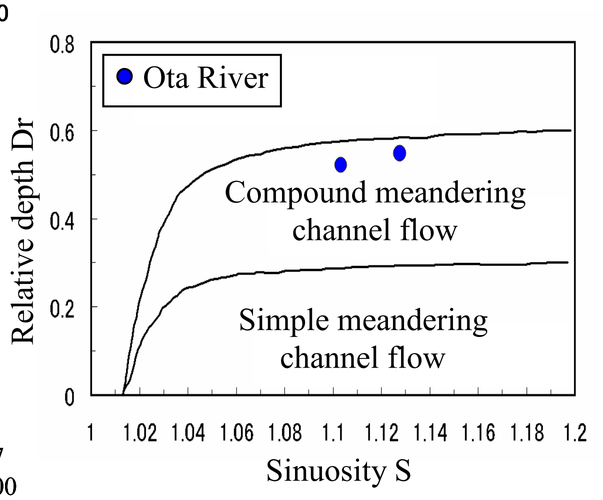

Figure 4. Flow classification diagram of compound meandering channels

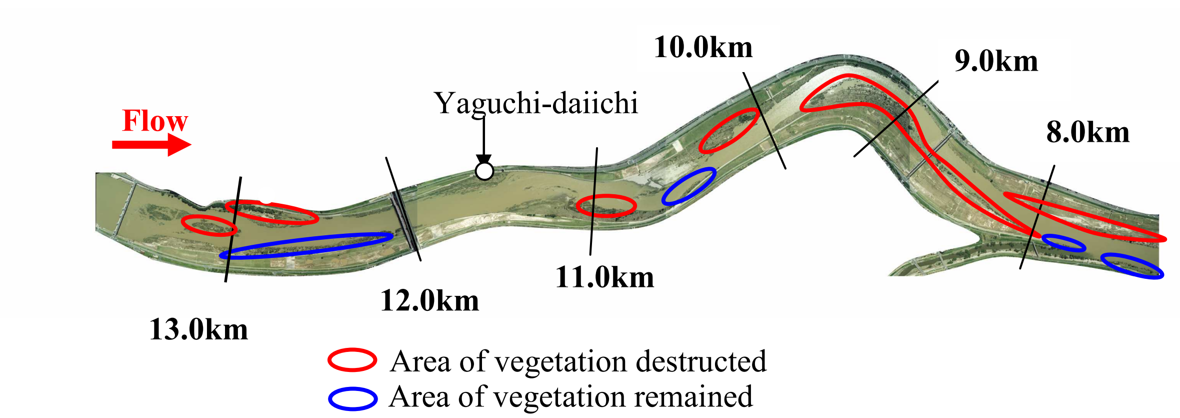

Figure 5. Location of vegetation destruction

Figure 6. Vegetation destruction on sandbar

The location of vegetation destructions in the Ota River is shown in Figure 5. The vegetation destructions by typhoon 0514 were largest in scale. The vegetation on sandbars formed near inner bank was destructed due to maximum velocity filament passing the inner bank side. On the other hand, the vegetation on flood channel near the outer bank remained. Okada and Fukuoka (2004) showed that the compound meandering channel flow gave rise to scouring of sandbars formed near the inner bank. Figure 6 shows the vegetation destructions due to bed scouring. Roots of vegetations are revealed due to bed scouring around vegetations.

3.2 Observed Temporal changes in water surface profiles

River characteristics such as channel shape, bed configurations, and vegetations appear in the observed temporal changes in water surface profiles of flood flows (Fukuoka, 2005). Figure 7 and Figure 8 show observed temporal changes in water surface profiles in the rising period and the receding period of the flood, respectively. The comparison of these figures shows when vegetations were destructed by the flood flow. In the flood rising period, effects of the vegetation clearly appear in water surface profiles, which have mild slope with vegetations and steep slope with no vegetation. On the other hand, in the flood receding period, effects of the vegetations do not appear in the water surface profiles in the flood receding period.

From the comparison between field inspection after the flood and the observed temporal changes in water surface profiles, vegetations on sandbars of the inner bank side seem to have been destructed between a.m. 2:00 and a.m. 3:00 around peak discharge, in which the water surface profile becomes irregular. In the following sections, detailed mechanism of vegetation destruction is discussed by the two-dimensional unsteady flow analysis (Fukuoka and Watanabe, 2004) using observed temporal changes in water surface profiles.

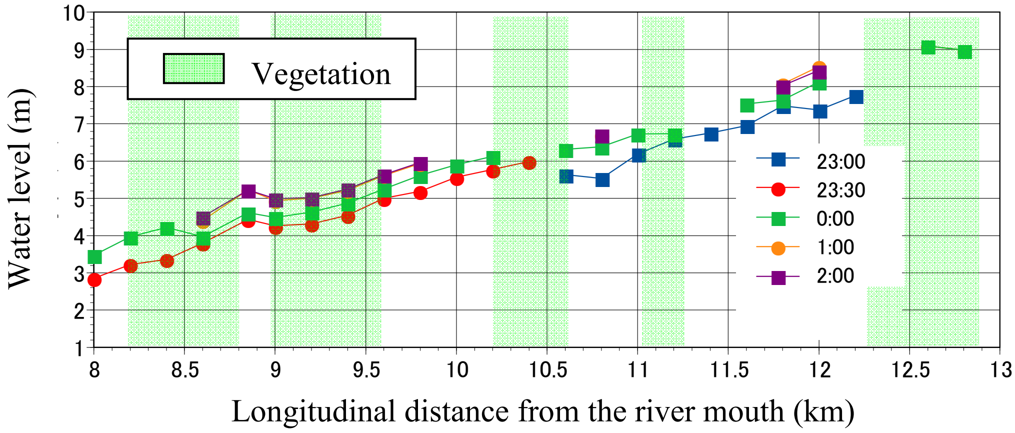

Figure 7. Observed water surface profiles in the flood rising period

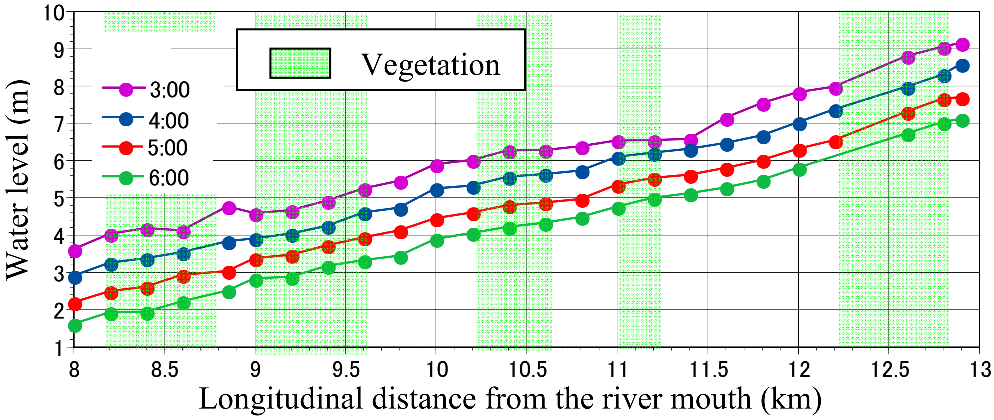

Figure 8. Observed water surface profiles in the flood receding period

3.3 Unsteady 2D flow analysis using observed water surface profiles

The calculation is conducted based on the method of Fukuoka and Watanabe et al (2004). Equations of motion (1), (2) and equation of continuity (3) are as follows. The effects of vegetations on flood flows are represented by vegetation permeability coefficient K of equation (4).

$$h\frac{\partial \tilde{U}}{\partial t}+\tilde{U}h\frac{\partial \tilde{U}}{\partial \tilde{\xi}}+\tilde{V}h\frac{\partial \tilde{U}}{\partial \tilde{\eta}}+\tilde{J}(\tilde{V}-\tilde{U}\cos\theta^{\eta\xi})(\tilde{U}h\frac{\partial \theta^{\xi}}{\partial \tilde{\xi}}+\tilde{V}h\frac{\partial \theta^{\xi}}{\partial \tilde{\eta}})=-gh(\frac{\partial \zeta}{\partial \tilde{\xi}}+\cos\theta^{\eta\xi}\frac{\partial \zeta}{\partial \tilde{\eta}})$$

$$-\tau_{0\xi}+\frac{1}{J}\left\{\frac{\partial}{\partial \xi}(\tilde{J}d\eta\cdot h\tilde{\tau}_{\xi\xi})+\frac{\partial}{\partial \eta}(\tilde{J}d\xi\cdot h\tilde{\tau}_{\xi\eta})\right\}-\tilde{J}h\left\{(-\tilde{\tau}_{\xi\xi}\cos\theta^{\eta\xi}+\tilde{\tau}_{\xi\eta})\frac{\partial \theta^{\xi}}{\partial \tilde{\xi}}+(-\tilde{\tau}_{\xi\eta}\cos\theta^{\eta\xi}+\tau_{\eta\eta})\frac{\partial \theta^{\xi}}{\partial \tilde{\eta}}\right\} \quad (1)$$

$$h\frac{\partial \tilde{V}}{\partial t}+\tilde{U}h\frac{\partial \tilde{V}}{\partial \tilde{\xi}}+\tilde{V}h\frac{\partial \tilde{V}}{\partial \tilde{\eta}}+\tilde{J}(\tilde{U}-\tilde{V}\cos\theta^{\eta\xi})(\tilde{U}h\frac{\partial \theta^{\eta}}{\partial \tilde{\xi}}+\tilde{V}h\frac{\partial \theta^{\eta}}{\partial \tilde{\eta}})=-gh(\cos\theta^{\eta\xi}\frac{\partial \zeta}{\partial \tilde{\xi}}+\frac{\partial \zeta}{\partial \tilde{\eta}})$$

$$-\tau_{0\eta}+\frac{1}{J}\left\{\frac{\partial}{\partial \xi}(\tilde{J}d\eta\cdot h\tilde{\tau}_{\eta\xi})+\frac{\partial}{\partial \eta}(\tilde{J}d\xi\cdot h\tilde{\tau}_{\eta\eta})\right\}-\tilde{J}h\left\{(-\tilde{\tau}_{\xi\xi}+\tilde{\tau}_{\xi\eta}\cos\theta^{\eta\xi})\frac{\partial \theta^{\eta}}{\partial \tilde{\xi}}+(-\tilde{\tau}_{\xi\eta}+\tilde{\tau}_{\eta\eta}\cos\theta^{\eta\xi})\frac{\partial \theta^{\eta}}{\partial \tilde{\eta}}\right\} \quad (2)$$

$$J\frac{\partial h}{\partial t}+\frac{\partial}{\partial \xi}\left(\tilde{J}d\eta\cdot\tilde{U}h\right)+\frac{\partial}{\partial \eta}\left(\tilde{J}d\xi\cdot\tilde{V}h\right)=0 \quad (3)$$

$$\frac{\partial}{\partial \tilde{\xi}}=\frac{\partial}{d\xi\partial\xi},\quad \frac{\partial}{\partial \tilde{\eta}}=\frac{\partial}{d\eta\partial\eta}$$

$$(\tau_{0\xi},\tau_{0\eta})=(\frac{gn^2}{h^{1/3}}+\frac{gh_a}{K^2})\sqrt{u^2+v^2}(\tilde{U},\tilde{V}) \quad (4)$$

$$h_a=\min(h,h_{tree})$$

$$u^2+v^2=\tilde{J}^2(\tilde{U}^2-2\tilde{U}\tilde{V}\cos\theta^{\eta\xi}+\tilde{V}^2)$$

Table 1. Vegetation permeability coefficients and Manning roughness coefficients

Vegetation permeability coefficent(m/s)		
Location	Flood rising period	Flood receding period
8.0~9.6km Right bank	40	60
10.4~10.8km Right bank	50	60
10.8~11.4km Right bank	40	60
8.0~8.8km Left bank	50	60
9.6~10.6km Left bank	50	60
Manning roughness coefficent ($m^{-1/3}\cdot s$)		
Main channel	0.025	
Flood channel	0.035	

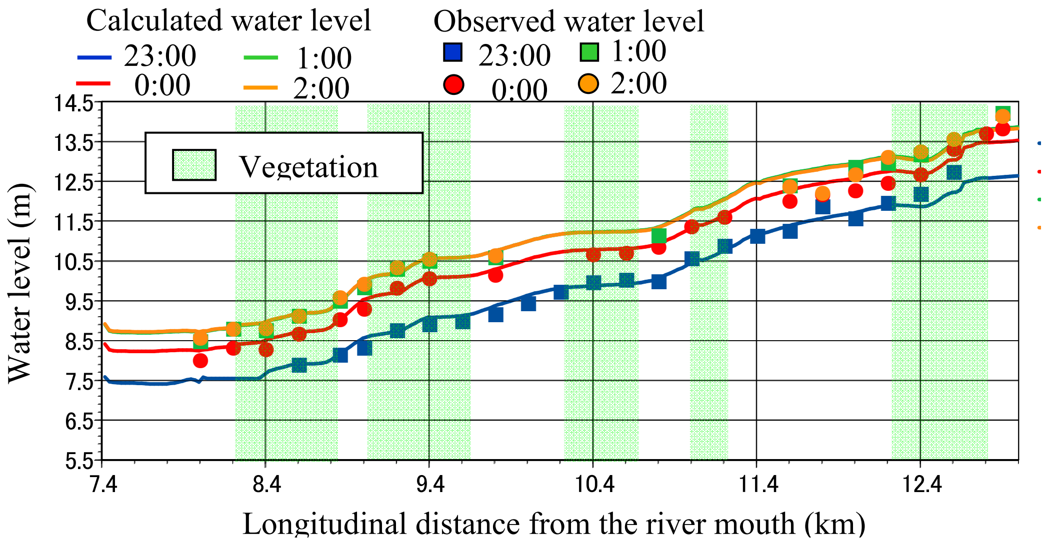

Figure 9. Observed and calculated water surface profiles in the flood rising and peak period

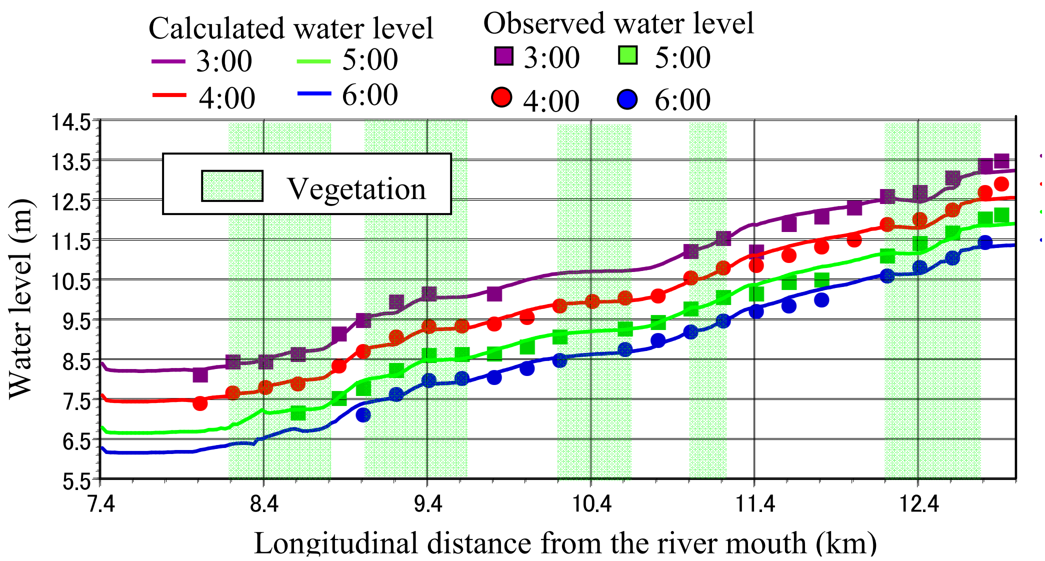

Figure 10. Observed and calculated water surface profiles in the flood receding period

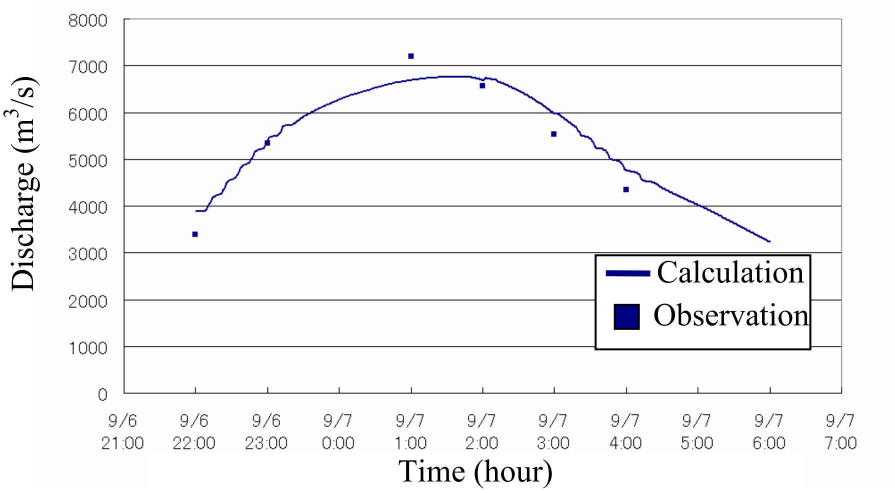

Figure 11. Observed and calculated discharge

Manning's roughness coefficient n is given by ordinary values of channel resistance to main channel and flood channel. And K is determined so as to agree with the observed water surface profiles. Characteristics of the water surface profiles in the flood receding period are different from these of the flood rising period. The difference arises mainly from the change in vegetation resistance associated with the large scale vegetation destructions. Therefore the vegetation permeability coefficients would change between a.m. 2:00 and a.m. 3:00 around the peak discharge. Table 1 shows the vegetation permeability coefficients and Manning's roughness coefficients used in the analysis.

The vegetation permeability coefficients in the flood receding period are large compared with these of the flood rising period. The analytical grid is divided longitudinally into 224 cells and divided laterally into 23 cells. The boundary conditions are observed water level hydrographs at 8.6km and 11.6km (Yaguchi-daiichi discharge observation station). Figure 9 and Figure 10 show observed and calculated water surface profiles in the rising period and the receding period of the flood, respectively. The calculation results show a good agreement with observed temporal changes in water surface profiles. Figure 11 compares with calculated discharge hydrograph observed and discharge hydrograph measured at the Yaguchi-daiichi discharge observation station. The above proves that the vegetation on the sandbar formed near inner bank were destructed between a.m. 2:00 and a.m. 3:00 around the peak discharge. We believe that the vegetation on sandbars formed near inner bank would be destructed in the flood of the design scale of the Ota River since the flood of the design scale slightly is lager than its by typhoon 0514.

4. MECHANISM OF VEGETATION DESTRUCTION

4.1 Vegetation destruction by bed scouring on sandbar formed inner bank side

The velocity distribution and maximum velocity filament by the calculation result at a.m. 2:00 is shown in Figure 12. Figure 13 shows cross-section at 9.4km point, and compares change in the cross-section before and after the flood. The spatial distribution of the bed variation before and after the flood is shown in Figure 14. Maximum velocity filament occurs on inner bank sandbar formed around 9.4km point where vegetation growth was denser and vegetation destruction was severe. Velocity has near 4.0(m/s) there. The maximum bed

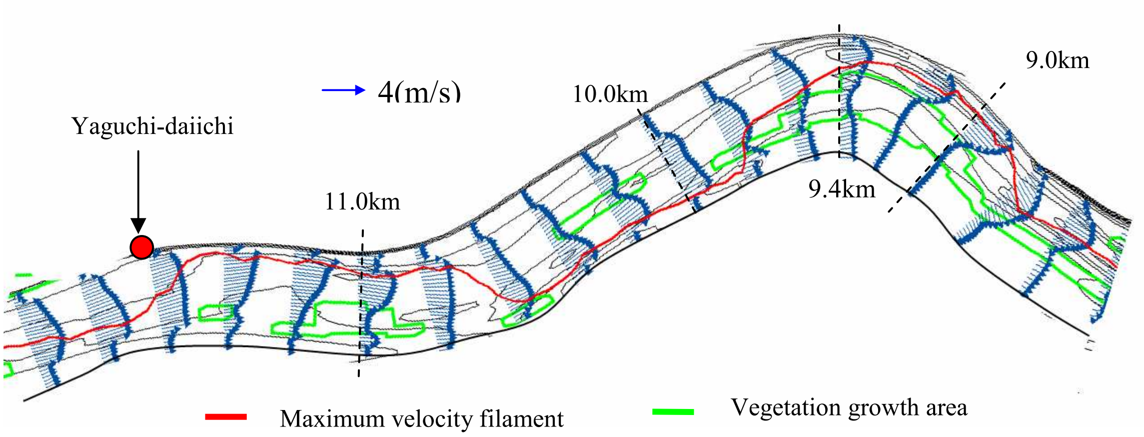

Figure 12. Velocity distribution and Maximum velocity filament

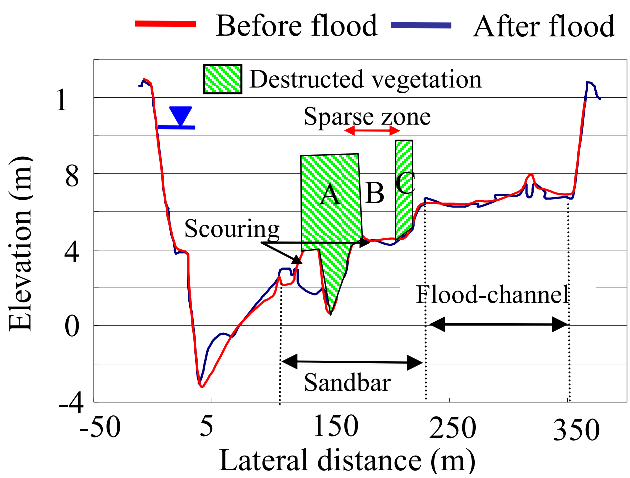

Figure 13. Cross section at 9.4km point

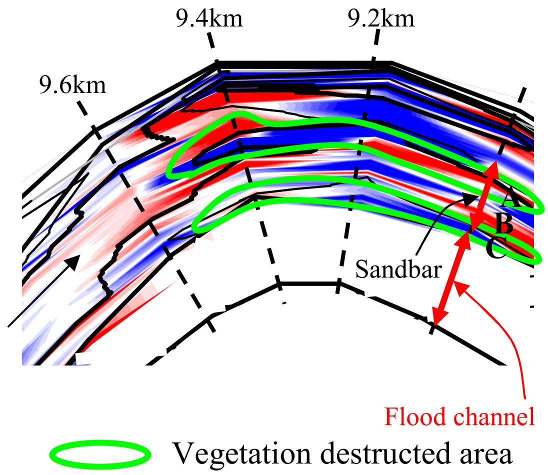

Figure 14. Change in bed profiles before and after the flood

scouring which reaches 2-meter in depth occurred around the vegetation A on sandbar at this section (see Figure 13). The longitudinal bed scouring occurs near the vegetations A on sandbar and vegetations C beside flood channel (see Figure 14). There is a sparse vegetation zone B in the middle of the sandbar around the 9.4km point (see Figure 13 and Figure 14). The bed scouring on sandbar was formed near the inner bank side due to the flood flowing there about peak discharge. Hence, it is concluded that the main mechanism of vegetation destruction is the bed scouring around the vegetations on the sandbar.

4.2. Difference of bed scouring by floods scale

Figure 15, Figure 16 and Figure 17 show aerial photographs in the neighborhood of 9.4km after 1972, 1993 and 2005 floods, respectively. In 1972, the vegetations on sandbar formed inner bank side have not grown yet (see Figure 15). The vegetations have grown densely on sandbar since 1990 (see Figure 16). The maximum flood discharge in 1972 was similar to 7200(m^3/s) of the 2005 flood and 6800(m^3/s). Scouring occurred on sandbar formed inner bank side (see Figure 15 and Figure 17). On the other hand, the flood scale in 1993 which maximum discharge was 3900(m^3/s) was smaller than 1972 and 2005 floods. Therefore scouring would not occur on sandbar formed the inner bank side. Three cases of floods show that vegetation destruction occurs only in large scale flood. Hence, we believe that the vegetation destruction on is seen due to the sandbar bed scouring around the vegetations, when the scale of design flood happen in the Ota river.

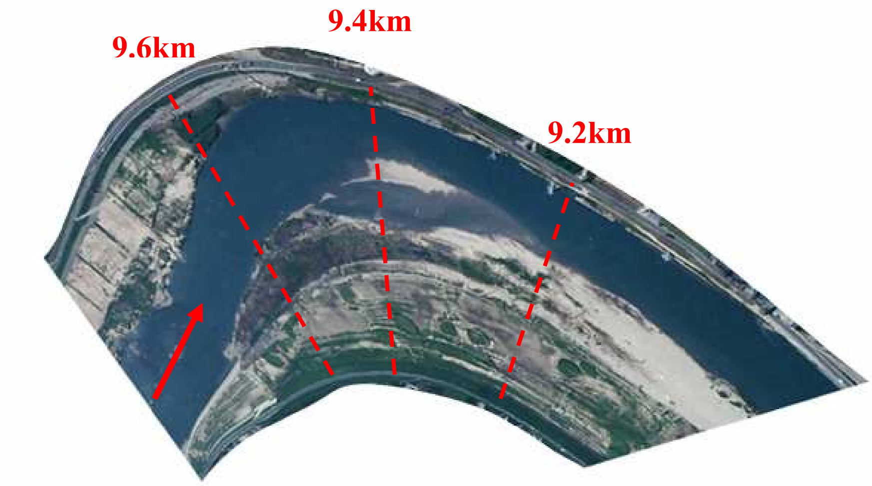

Figure 15. Sandbar bed scouring by 1972 flood

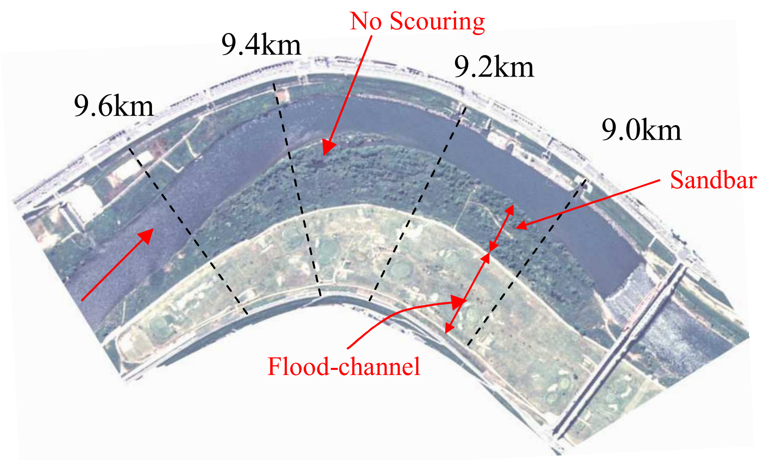

Figure 16. Sandbar bed scouring by 1993 flood

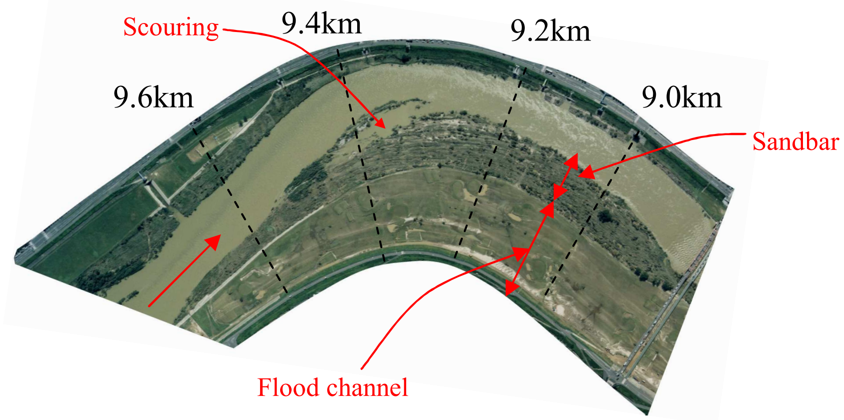

Figure 17. Sandbar bed scouring by 2005 flood

5. CONCLUSION

The following conclusions were drawn on vegetation destruction by flood.

(1) The effects of vegetation destruction appear in temporal changes in water surface profiles of flood flow. In flood rising period, water surface profiles were irregular in shape due to the presence of vegetations. But water surface profiles in flood receding period were relatively smooth for the vegetation destruction.

(2) Unsteady 2D flow analysis using measured temporal changes in water surface profiles gives an information that how much discharge destructs vegetations and when vegetations were destructed.

(3) Survey of bed scouring and the vegetations before and after the flood showed that the bed scouring around vegetation on the inner bank sandbar gave rise to vegetation destruction.

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