Coarse sediment movement around U-shaped vegetation zone on gravel bar with two meandering channels

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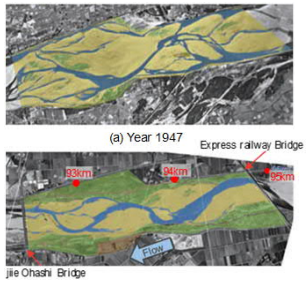
Introduction

In mid-upper regime of Kinugawa River, for example, the channel morphology was such as braided or two lane meandering more than seventy years ago. In these days, however, channel morphology is changing into single lane meandering, forming water colliding fronts which cause river disasters. Furthermore, habitats of alien species such as Eragrostis curvula is being enlarged and those of endemic species for gravel bed, such as Aster kantoensis Kitam, becomes almost extinct.

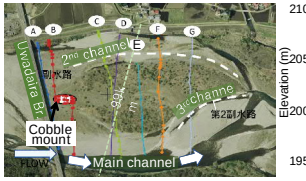
As a countermeasure against these issues, from about ten years ago, gravel bar restoration project started in Kinugawa River. This project intends to increase submergence frequency by cut down of the height of gravel bars, and to control flood flow by installing cobble mount at the upstream end of a gravel bar. However, partially because effective maintenance has not been performed after the restoration, gravel bars were covered with fine sand, and grassland of alien species and forest area were enlarged.

In the present study, vegetation transition on a gravel bar with two meandering channels was investigated over three years after implementation of gravel bar restoration. Subsequently, numerical analyses were performed to examine the influences of vegetation distribution pattern and its partial removal on the flow structure and coarse sediment behavior on gravel bars with two meandering channels.

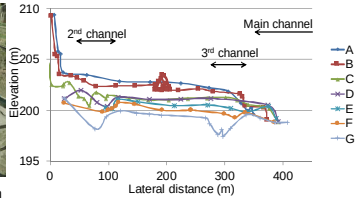


Transition of channel morphology in mid-upper regime of Kinugawa River

Field investigation



Aerial photograph of the field investigation site and traverse lines for topographic survey (A-G).



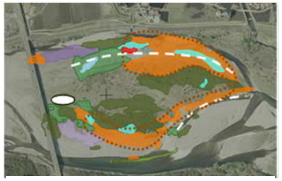
Elevation along the traverse lines (A-G)

The field investigation site is a gravel bar near the Uwadaira-Bashi Bridge in mid-upper regime of Kinugawa River, located at about 99km point from the confluence to Tonegawa River in Kanto Plain, Japan. This gravel bar was about 700m long and 400m wide, and the average bed slope was 1/200. This gravel bar was formed between the two meandering. The restoration project of this gravel bar was implemented in the year 2011, which cut down the bar height, covered the bar surface with cobble and installed cobble mount at the upstream end of this bar.

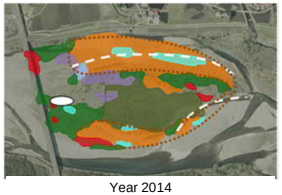
Vegetation distribution survey was executed every year from the year 2012 to 2014. During these three years, we had two floods, which made almost no change of gravel bars in mid-upper reach of Kinugawa River. As a whole, most of vegetation grew thickly in/around a U-shaped zone, open toward the upstream direction. This U-shaped zone is mainly composed of Poaceae, and formed within a certain range of relative height to water surface of the main channel and the second channel.

Communities of endemic (and mixed endemic) species for gravel bed were rare but recognized around outer edge of rather upstream part of the U-shaped zone, where gravel was deposited more than the other area. Alien species, which adapts to sandy bed, were distributed in very large area on the gravel bar, especially in the internal area of the U-shape, where fine sand was deposited. The difference of sediment size between the outer edge and the internal area is supposed to be due to velocity difference in flood flow, affected by the flow resistance of the U-shaped zone. Therefore, the U-shaped vegetation zone, established in initial stage immediately after the restoration, plays a very important role in vegetation transition on gravel bars.

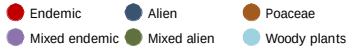
Year 2012



Year 2013



Year 2014

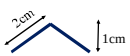


Transition of vegetation distribution from the year 2012 to 2014 (Brown dotted line indicates U-shaped vegetation zone of Poaceae)

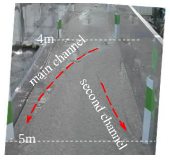
Laboratory experiment for Gravel bar topography

A laboratory experiment was performed on stable gravel bar topography with two meandering channels for numerical analyses. In the experiment, a straight flume of 8m length, 30cm width and 24cm height was used. In order to obtain stable bar topography, groynes were installed every 1m from the upstream end so that the channel width was narrowed periodically. The channel slope was set to 1/30, the bed material diameter was 0.9mm, and the flow rate was 430 cm³/s. Then, 2 hours after supplying water, bar topography was stably formed with two meandering channels where the difference between the main channel and the second channel was clear.

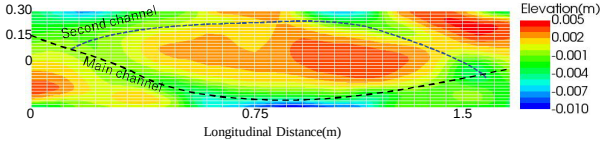
Installation of a groyne



Dimensions of a groyne.



Two meandering channels with groyne



Smoothed topography of a bar with two meandering channels.

Numerical analysis

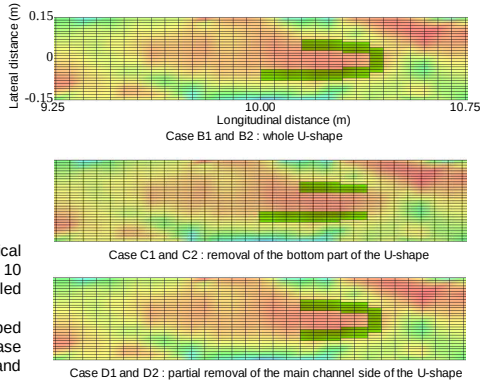
Numerical method and condition

Table 1. Numerical analysis conditions

Case	Vegetation pattern	Coarse material	Flow rate (m^3/s)	Bed slope	Bed roughness
Case A1	None	None	330×10^{-6}	1/30	0.028
Case A2		Casted (5mmϕ)			
Case B1	Whole U-shape	None			
Case B2		Casted (5mmϕ)			
Case C1	The bottom part removed	None			
Case C2		Casted (5mmϕ)			
Case D1	The main channel side partially removed	None			
Case D2		Casted (5mmϕ)			

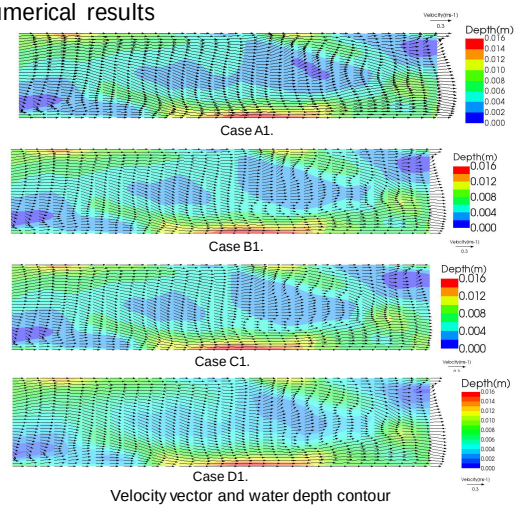
Nays-2DH solver of iRIC system (iRIC-UC, 2020) was used for numerical analyses of the two-dimensional flow and movable bed. In numerical analyses, 10 sets of the gravel bar topography obtained from laboratory experiment was installed periodically in a rectangular straight channel of 30cm .

Case A1 and A2 were with no vegetation. Case B1 and B2 were with U-shaped vegetation area. The U-shaped has longer side arm on the main channel side. Case C1 and C2 were cases for removal of the bottom part of the U-shape. Case D1 and D2 were cases for partial removal of the main channel side of the U-shape.

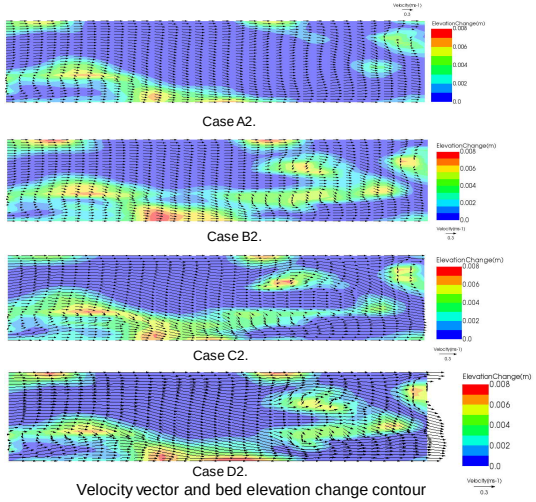


Vegetation pattern in numerical analyses

Numerical results



Velocity vector and water depth contour



Velocity vector and bed elevation change contour

Case A1: Meandering flow is observed along the main channel, and a flow along the second channel, divided from the main flow, is suggested.

Case A2: A large deposition area can be seen along the right edge of the main meandering flow.

Case B1: The flow is decelerated in/around the vegetation area itself and also the behind of the vegetation.

Case B2: Additional noticeable deposition area is spread over a wide area in/around the U-shape, which encourage the alien species.

Case C1 & C2: The effect of removal of the bottom part of the U-shape almost eliminates the low velocity region in the internal and the behind region, therefore, the deposition area around the vegetation is reduced. The influence of the main channel side of the vegetation still remains.

Case D1 & D2: The deposition area along the right bank side is a little reduced. However, the most serious deposition areas are not at all reduced because the low velocity areas in the internal and behind region of the U-shaped vegetation still remain.

Conclusion

On a large-gravel bar with two meandering channels, a U-shaped vegetation zone, open to the upstream side, was formed along the main channel and the second channel immediately after the gravel bar restoration. This U-shaped zone was mainly composed of Poaceae, and formed within a certain range of relative height to water surface of the main channel and the second channel.

Endemic species for gravel bed were mainly recognized around outer edge of the U-shaped zone, and alien species were distributed especially in the internal area of the U-shape where fine sand was deposited. It is suggested that flow resistance of the U-shaped zone affects the flood flow structure and sediment distribution, which influences vegetation segregation on the gravel bar.

In the present study, stable gravel bar topography with two meandering channels was successfully reproduced in a laboratory experiment with groynes. This topography was used in the present numerical analyses.

Numerical results show that low velocity regions are formed in the internal and behind area of the U-shape vegetation, where coarse sediment is deposited more than the other areas, and the deposition area in the main channel side arm of the U-shape is merged with that along the main channel.

Numerical results also show that removal of the bottom part of U-shape eliminates the low velocity regions, which is most effective on the whole area. And if the main channel side arm can be removed in addition, significant improvement is expected.