VEGETATION EFFECTS ON THE LATERAL CHANNEL MIGRATION DURING 2016 AUGUST FLOODS IN THE OTOFUKE RIVER

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ABSTRACT

Floodplain vegetation is one of the key factors to determine the channel planform dynamics in alluvial systems. In this study, we focused on the range of vegetation variety, especially vegetation disappearance during flood event due to scouring and bank erosion by means of computational analysis targeted on the Otofuke River and subsequent experimental test. The results showed that if vegetation is young and relatively easily flushed away by scouring and bank erosion during flood, it leads to weak points (gaps) of bank strength along main flow channel, resulting in the flow concentration into the gaps, leading to active local bank erosion and lateral channel migration for a short-term more than that of cohesionless, no-vegetated case.

Keywords: Otofuke River, record breaking rainfall, vegetation, bank erosion

1. INTRODUCTION

Alluvial rivers have a complex interaction between bars-channels-floodplain formation (Kleinhans and Berg, 2011). In particular, the strength of river banks is one of the crucial physical factors to control the bar accretion and bank erosion rates (e.g. Gurnell et all., 2012; Gran and Paola 2011), dominating the channel planform evolution that is theoretically estimated according to width to depth ratio (Kishi and Kuroki, 1984; Parker, 1976). In a meandering channel, the rate of bank erosion and floodplain formation are almost simultaneously and develop channel amplitude with maintaining the constant width (Parker et al., 2011). In contrast, in a braided and a transition channel (characterized with weakly braided and chute bars and chute channels), the low bank stability leads easily bank erosion, resulting in channel widening and multi-thread bars with shallow water flow. In earlier researches focused on the interaction between river morphodynamics and bank strength (using cohesive material or vegetation), they showed the strong impact of vegetation to reproduce channel transformation from braided to meandering in experiments (Van Dijk et al., 2013; Tal and Paola, 2010; Braudrick et al., 2009), and computational approaches (Jang and Shimizu, 2007). However, most of early researches deal with the fully vegetated conditions on floodplain so that the effects of the range of vegetation varieties such as their age, distribution, and survival or removal rates on channel morphological dynamics remain unclear.

In 2016 August, the record-breaking rainfall due to the typhoon (No. 10) attacked the Tokachi River basin of Hokkaido, Japan and numerous areas of tributaries of the Tokachi River were faced severe bank erosions and levee breaches caused by the channel migration in a short term (Furuichi et al., 2018). Especially, upstream area of the Otofuke River which is one of the tributaries having steep gradient (1/120) and course bed materials (mean diameter is 55mm) was experienced levee breaches at seven locations alternately left and right banks at one-night (Figure 1, Figure 2). As illustrated by Figure 1, before the disaster in this area, flood plain vegetation was well flourished on floodplain areas along both banks of the low-flow channel, leading to channel form changes from the original multi-thread channel system (in the Otofuke River) to the weakly sinuous, single-thread channel as a meander. However, after a series of floods, the weakly sinuous channel of the Otofuke River faced active channel migration in the path of the channel. This also led to damage of bank embankments and

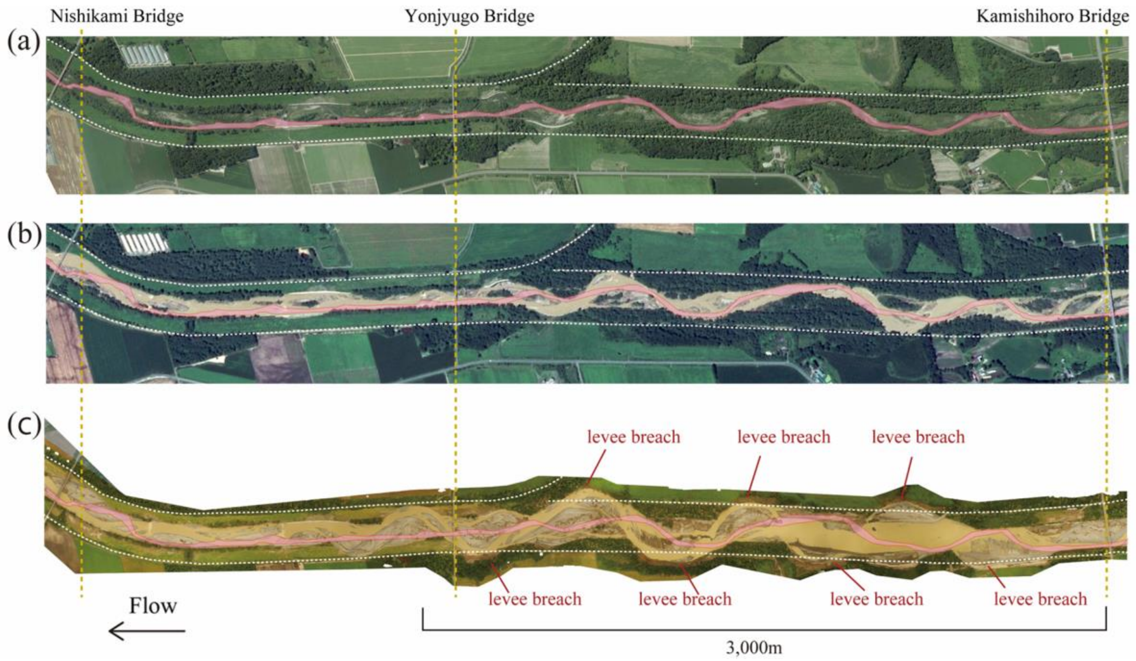

Figure 1. Aerial orthogonal photograph of the Otofuke River before and after the record-breaking flood. White dotted lines indicate the levee positions. Pink-colored area represents the channel flow path before the disaster. Photographs were taken 7th August 2016 by Google earth (a); 24th August 2016 by Landsat 8 (b); 15th September 2016 by UAV (c).

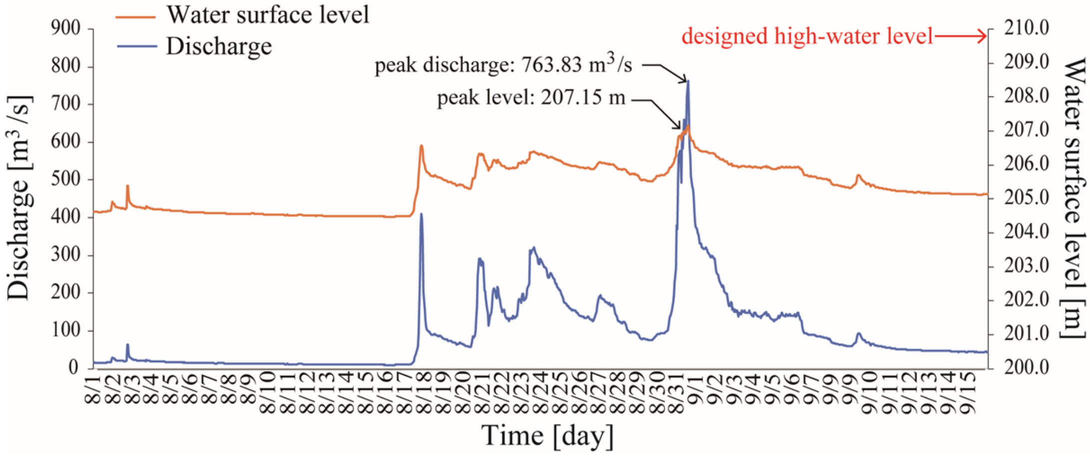

Figure 2. Time series of water surface level and estimated discharge at the gauging station located few kilometers downstream of the damaged area illustrated in Figure 1. The maximum water level and peak discharge during a series of flood events occurred at 31st August 2016 (No.10 Typhoon). The maximum water surface level did not over the designed high-water level of levees.

total seven locations on the left and right banks alternated breaks as shown in Figure 1-c. Here, we focused on this channel planform changes in the Otofuke River where excessive flourished vegetation was flushed in space and time and the weak sinuous single-thread channel was significantly migrated in laterally, to understand the underlying processes of the interaction between channel patterns and the diversity of vegetation variety.

Several early researches focused on the vegetation survival and removal rate on meandering channel dynamics by two-dimensional computational approach (Van Oorschot et al., 2016). According to their reports, in the case with high mortality of vegetation during flood, the lateral migration rate of the meandering flow path was larger than that of low mortality and of no vegetation. In the case with low mortality, channel migration less developed in lateral direction but higher skewed. Hence, it is very important to know as a question related to channel migration, how the spatiotemporally disappearance of vegetation affects channel morphological changes. The point to note is a gap in bank strength along the main channel, causing a weak point for bank erosion at the high-water stage during floods. Therefore, in this research, following the previous study focused on the reproduction of the channel deformation and consideration of the process of rapid channel meandering by means of numerical approach (Okabe et al., 2017), we investigated the effects of floodplain vegetation, which was flashed away in space and time during flood, on channel lateral migration by means of both computational approach and laboratory experiments.

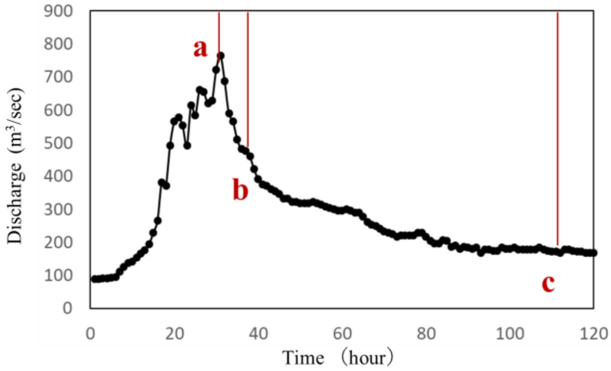

Figure 3. Hydrograph in the computational analysis

Figure 4. Short willow root system in the Otofuke River

2. COMPUTATIONAL ANALYSIS

2.1 Hydraulic settings in the numerical simulation (with and without floodplain vegetation)

In this study, two-dimensional numerical model of Nays 2D, which is provided the International River Interface Cooperative (iRIC) project (http://i-ric.org/en/, Nelson et al., 2016), was used to comparison with the channel patterns with and without consideration of floodplain vegetation in the simulation which targeted on the flooding disaster of the Otofuke River (Figure 1). Governing equations are based on the unsteady 2D continuity equation and momentum conservation equations which are summarized in the document (Jang and Shimizu, 2005). The total distance of the targeted area was around 7.3 km. The calculation grid size was determined as the simulated results did not change if it was made smaller, the length in the streamline direction of d_x = 7.0m, the length in the transverse direction of d_y = 4.0 m, and time step of d_t = 0.2 second. Hydrograph for this simulation (Figure 3) was estimated by water surface elevation which was recorded by the gauging station at the several kilometers downstream from the research area. The peak discharge of estimated hydrograph by the No.10 typhoon was around 763.83 m^3/sec. The mean diameter of uniform sediment material was set as 55mm based on the field survey data conducted by the Hokkaido Regional Development Bureau. The roughness value was set as Manning roughness coefficient of 0.03. The areas of growing vegetation were determined by using the aerial photograph as shown in Figure 1-a, and the density of vegetation was set as 0.03 based on the references (Nagata et al. 2016). In the simulation, vegetation effect is considered as flow resistance (drag force) in the momentum equations. To consider the vegetation disappearance due to bed scour and bank erosion, we set a threshold scouring and erosion depth as 20 cm (Figure 4) based on the references (Nagata et al. 2016). Initial topography data was determined using 2m Digital Elevation Model measured in 2013.

2.2 Results in the numerical simulation

Figure 5 shows contour maps of the simulated bed elevation changes with and without floodplain vegetation in the simulation. Figure 6 shows the time series changes of simulated cross-sectional bed elevation (location is

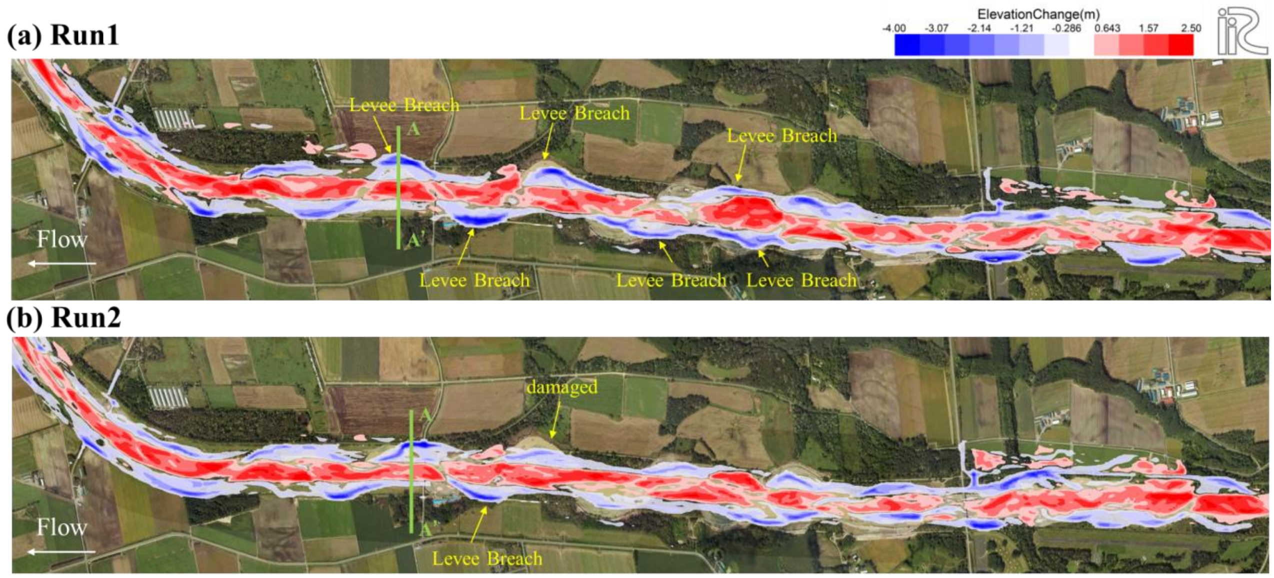

Figure 5. Simulated bed elevation changes in the Otofuke River with floodplain vegetation (a); without floodplain vegetation (b). Back ground image was taken on 22th Sep. 2016.

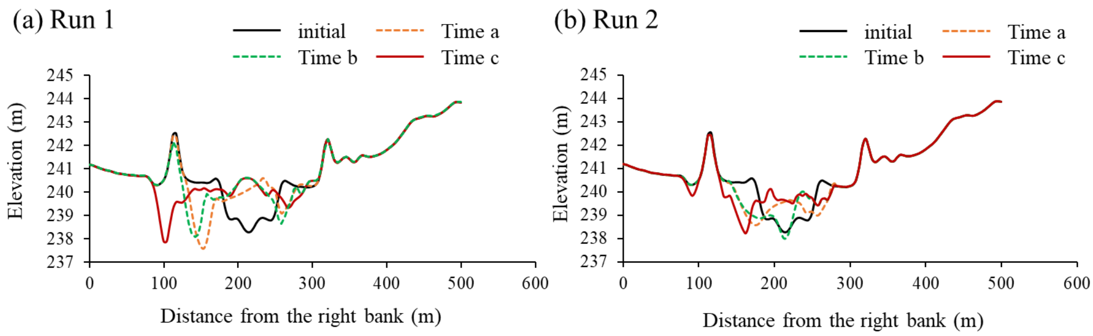

Figure 6. Time series changes of cross-sectional bed topography (cross-line A-A') with floodplain vegetation (a): without floodplain vegetation (b). The number of a to c indicates the designated time on the hydrograph in Figure 3.

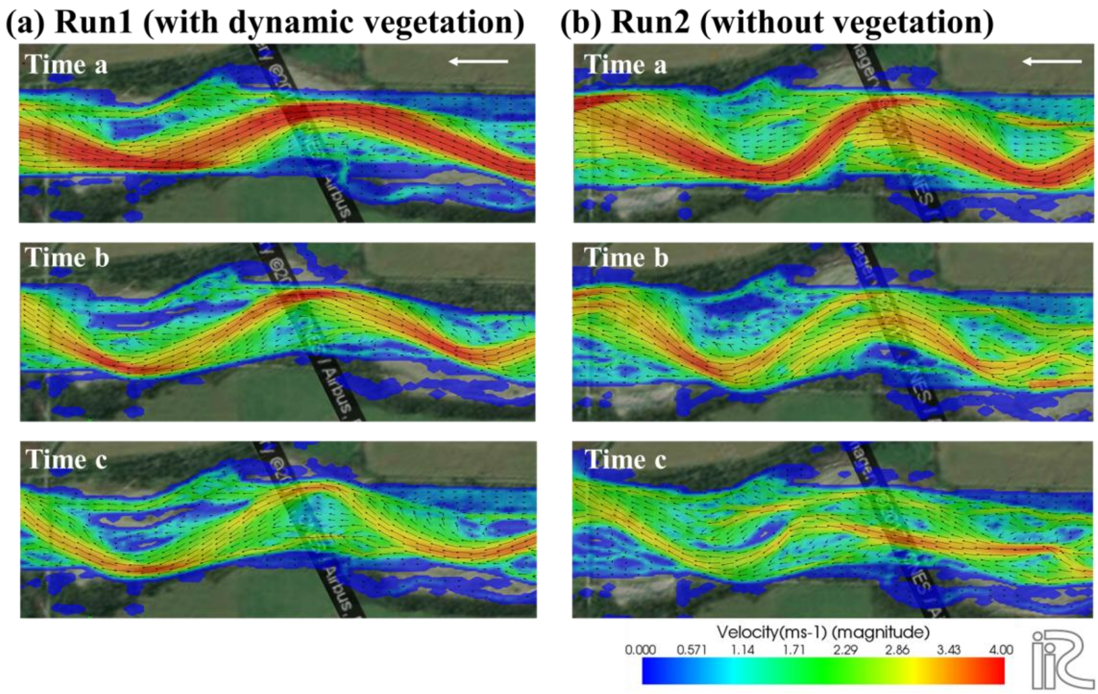

Figure 7. Contour maps of calculated depth average velocity and velocity vector map with floodplain vegetation (a); without floodplain vegetation (b). The case without vegetation, chute channel appears faster. Time a to c indicate the discharge timing illustrated in Figure 3.

illustrated in Figure 5). The results of numerical simulation with floodplain vegetation match well with the results of field observation (Okabe et al., 2017): six locations of levee breaches could be reproduced (Figure 5a), simulated maximum water level did not exceed the crest of embankments (no figures here), and the distance of channel widening in cross-section A-A' was reproduced well almost the same as the measured value in the field (Figure 6a). Comparison the results with and without vegetation (Run 1 and Run 2, respectively), it is surprisingly that lateral migration rate in the case with floodplain vegetation (Figure 5a) was much larger than that of without floodplain vegetation (Figure 5b). Unlike the case with vegetation, levee breaches related to bank erosion were not significant observed in the case without vegetation (Figure 5b, Figure 6b).

To comparison with the flow configuration in two computational cases, Figure 7 shows the time series of depth averaged velocity. Comparing the two cases, channel curvature increased in both cases until the peak flow discharge. Thereafter, the channel planform was changed by different way. In the case with vegetation (Figure 7a), channel curvature continuity increased even in the latter half of the flood. While, in the case without vegetation (Figure 7b), chute channels appeared on floodplain and subsequent channel straightened. Due to the channel bifurcation, less levee breaches and bank erosion was reproduced (Figure 5b).

To consider the vegetation (survival and removed) effects on the channel migration pattern, Figure 8 showed the time series of channel evolution, bed topography, distribution of vegetation patches, and bed load vectors in the case with vegetation. Results showed several suggestions as followings: (1) The maximum elevation changes were gradually increased and formed mid-channel bars in the latter half of the flood (Figure 8, left). (2) Subsequently, the flow direction was deflected toward river banks in the latter half of the flood (Figure 8, left). (3) In addition, at the bend apex, floodplain vegetation patches disappeared due to bank erosion at the high-water stage (just after the peak discharge in this simulation) (Figure 8, right). The latter result implies that the

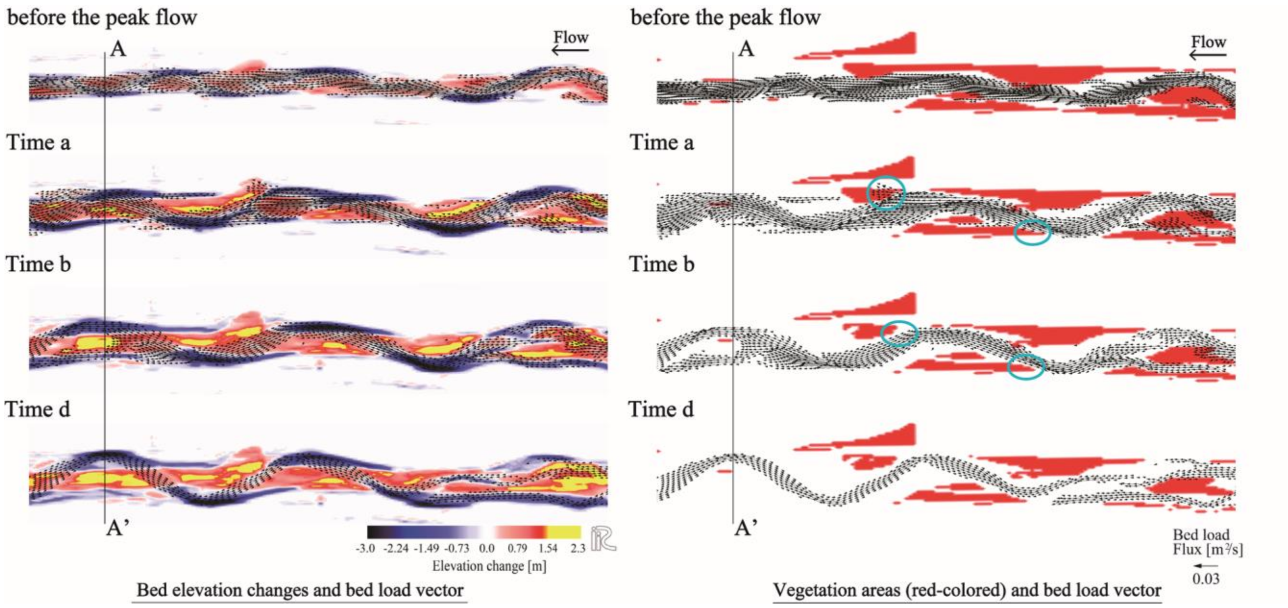

Figure 8. Time series changes of bed elevation and bed load vector (left); vegetation areas (red color) and bed load vectors (right) in the case with floodplain vegetation. Blue circle represents the location where strong flow resistance occurs by vegetation patches.

vegetation removal during the flood significantly affects the bank stability, leading to the acceleration of local bank erosion. Subsequently it allows quick channel migration in laterally.

3. LABORATORY EXPERIMENTS

3.1 Experimental Setup

Experiments were performed to confirm that the vegetation disappearance during floods promotes channel widening due to local lateral migration more quickly than that of no-vegetation, as in the numerical calculation described above Experiments were conducted in a 25.0-m-long and 3.0-m-wide rectangular flume having a bed slope of 1/100, located at the Civil Engineering Research Institute for Cold Region, JAPAN (Figure 9). The flume bed consisted of uniform grain size material (the mean grain size dm = 0.765). As an initial channel shape, 0.45-m-wide by 0.02-height of a straight channel were formed at the center part of the flume. At the inlet and outlet sections of the flume, mortar and plywood board were installed to maintain a constant bed height during the experiments, and the volume of the supplied sediment was determined not to arrow both bed aggradation and degradation at the just downstream part of the inlet section of the flume. Constant water discharge of Q = 0.00276 m3/s were supplied for 10 hours.

Three experimental cases are summarized below: floodplain was covered with no vegetation (Case 1), with alfalfa (Case 2), and with bentgrass (Case 3). In latter two cases, vegetation seeds were sprayed on left and right floodplain in a range of 0.5 width (Figure 9) by hands as possible as uniformly. After germination, averaged density was 4-6 individuals/ cm2. Alfalfa grew fast and had an averaged root length of 2.3 cm. In contrast, bentgrass grew slowly and had an averaged root length of 0.9 cm. In the experimental scale, bank stabilization

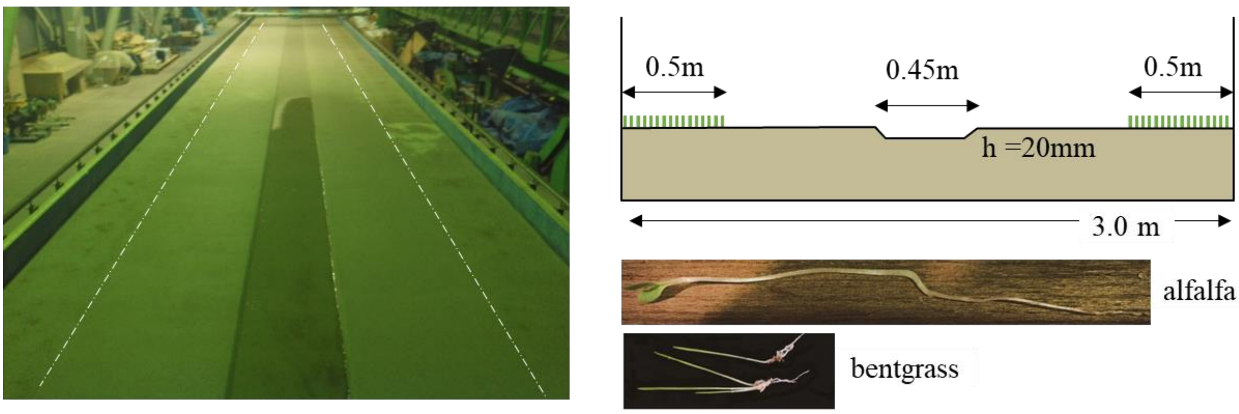

Figure 9. Experimental flume and model vegetation in the experiment (alfalfa and bentgrass).

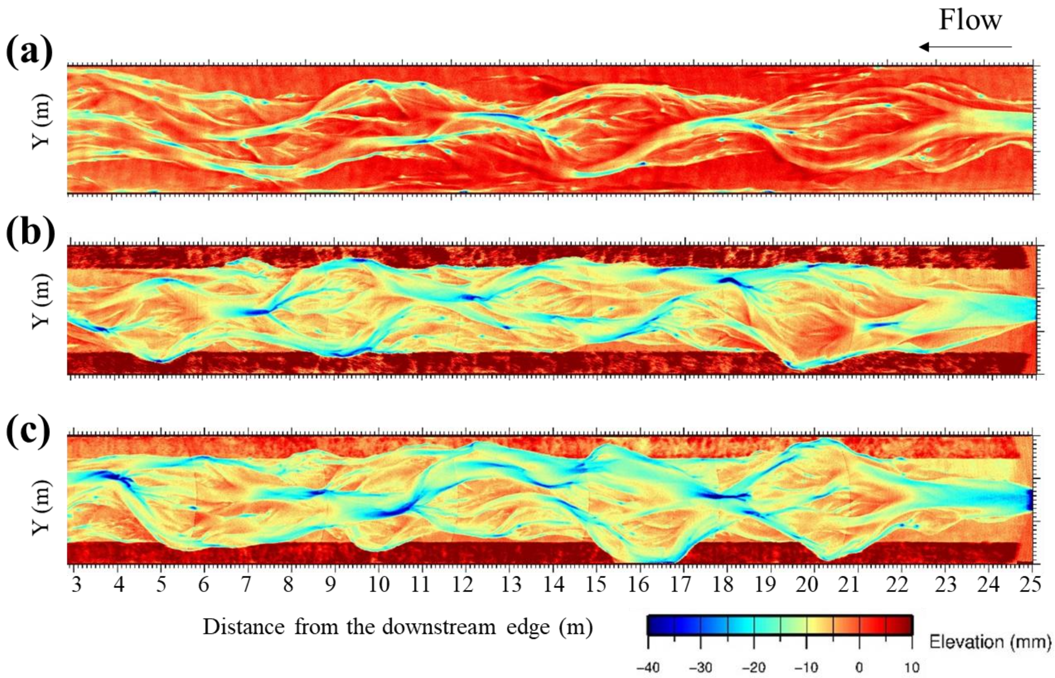

Figure 10. Bed topography in each case with no-vegetated floodplain (a); with alfalfa (b); with bentgrass (c). The strength of the riverbank is higher in the order of alfalfa, bentgrass, no vegetation.

by alfalfa is greater than that of bentgrass. Here, we examined the effects of vegetation disappearance on channel widening due to lateral migration during flood by using three different conditions.

3.2 Results in experimental tests

Figure 10 shows the results of channel deformation in each case. In the case with no-vegetated floodplain, initial straight channel transformed channel planform to shallow, multi-thread channel (Figure 10a). In contrast, the other two cases, added bank strength by vegetation, showed deeper channels compared to the no-vegetation case. Moreover, in the case with bentgrass (easily uprooted and flushed away), local lateral migration rate was clearly increased (Figure 10c). The results implied that if the vegetation intensity is enough to strengthen the river banks, local lateral channel migration due to bank erosion was highly suppressed compared to the cohesionless, no-vegetated floodplain case. However, if vegetation is young and relatively easily flushed away during flood, it leads to a local weak point (gap) along river banks, resulting in the flow concentration into the gap, leading to active local lateral channel migration for a short-term more than that of cohesionless, no-vegetated case. This study suggests that channel morphological patterns caused by the range of vegetation variety gives very important knowledge for river management in steep gradient rivers.

4. CONCLUSIONS

This study conducted to computational analysis and experimental tests to understand the vegetation effects on meandering channel planform. The results showed that the opposite effects of vegetation on meandering channel morphodynamics. When the vegetation intensity is enough to strengthen river banks, local lateral channel migration due to bank erosion was highly suppressed compared to the cohesionless, no-vegetated floodplain case. On the other hand, when vegetation is young (easily flushed away due to scouring or bank erosion at high-water level), it led to active lateral channel migration more than that of the non-vegetated floodplain case.

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