HORIZONTAL STRUCTURE OF FLOOD FLOW WITH DENSE VEGETATION CLUSTERS ALONG MAIN CHANNEL BANKS

SHOJI FUKUOKA
AKIHIDE WATANABE
Hiroshima University, Higashi-Hiroshima 739, JAPAN

ABSTRACT: Distinctive whiskerlike lines observed in an aerial photography clearly appeared in the experimental channel, evincing the type of horizontal flow mixing that arises from large-scale horizontal eddies due to vegetation, and thus proving that considerable horizontal mixing occurs in flood flows in actual rivers where vegetation exists. Application of the authors' analytical method for horizontal two-dimensional flows accurately duplicated actual horizontal flow conditions during flooding in the Tone river demonstrating that it is possible to calculate the general development of horizontal mixing in longitudinal areas with vegetation.

1. INTRODUCTION

The resistance characteristics of flood flows in channels with vegetation have been revealed1)2) and applied to flood analysis and the administration of channel vegetation3)4). The horizontal eddies arising from horizontal mixing between vegetation through flow and the main flow have been examined to reveal physically the resistance characteristics of these eddies. In addition, detailed measurement has been performed with experimental channels, and experimentation and analysis have clarified the structure of horizontal eddies5)6).

In this paper, the authors will apply their analytical method to the flood flow of an actual river in which vegetation along the bank of the main channel generates large-scale horizontal eddies. Then, the horizontal two-dimensional flow structure and the vegetation's resistance characteristics will be compared with the results of on-site observations.

2. CHARACTERISTICS OF THE SHINKAWA CHANNEL, TONE RIVER

The subject of this analysis is a section of the Tone river between its 133 and 139-km points, known as the Shinkawa channel (Fig. 1). This channel is nearly straight channel of around 6km long. The channel is a compound channel with a flood channel on both sides and dense vegetation (consisting of both trees and herbaceous plants) along the banks of the main channel. Distance between levees is roughly 600m, and the main channel is 300m to 400m wide and 4 to 5m deep. The bed

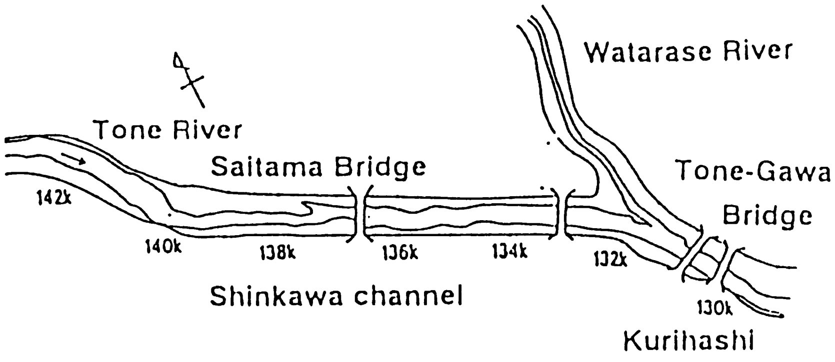

Fig. 1 The Shinkawa Channel, Tone River

material is sand mixed with gravel and 60% particle diameter is 0.3 to 0.6mm. Fig. 2 shows the distribution of the width and height of the vegetation along the banks of the main channel at normal discharge on May 23, 1980. Vegetation is sparse in the upstream section (near the Saitama Bridge, at the 137-km point), but forms unbroken strips in the downstream. Vegetation width is not consistent but rather changes longitudinally. It is wider along the left bank (40 to 60m) than the right bank (only 10 to 20m). The vegetation includes herbaceous plants are also there on the both banks. Trees range in height from 4 to 5m, while herbaceous plants are roughly 2 m high.

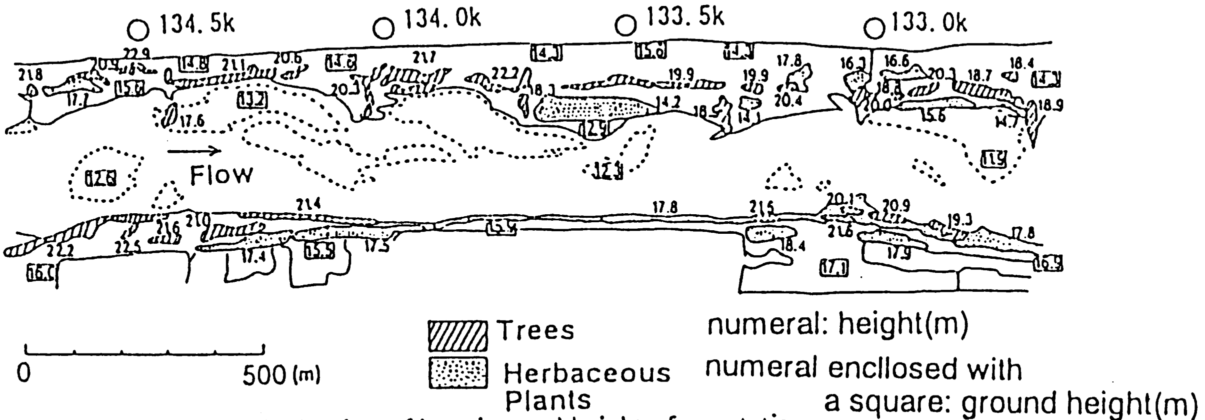

Fig. 2 Distribution of location and height of vegetation

3. COMPARISON OF THE RESULTS OF FLOOD FLOW OBSERVATION AND HORIZONTAL TWO-DIMENSIONAL CALCULATIONS

Photo 1, aerial photographs shown by taken at the Tone river's Shinkawa channel during August 1981 flooding clearly reveal horizontal mixing between the main flow and vegetation through-flow.

The horizontal two-dimensional flow analysis method[5)6)] assumes that vegetation, channel cross-section and other conditions are longitudinally constant, and is used to determine the flow field under such circumstances.

In order to compare results of analysis with aerial photographs and vector diagrams derived therefrom, we will use the channel's cross-sectional quantities and the hydraulic quantities of flooding at the time these photographs were taken. The lateral profile and hydraulic conditions used in the calculation are shown in Fig. 3 and Table 1.

Observed peak discharge was 7,800m^3/s at Kawamata upstream (150km, roughly 2:

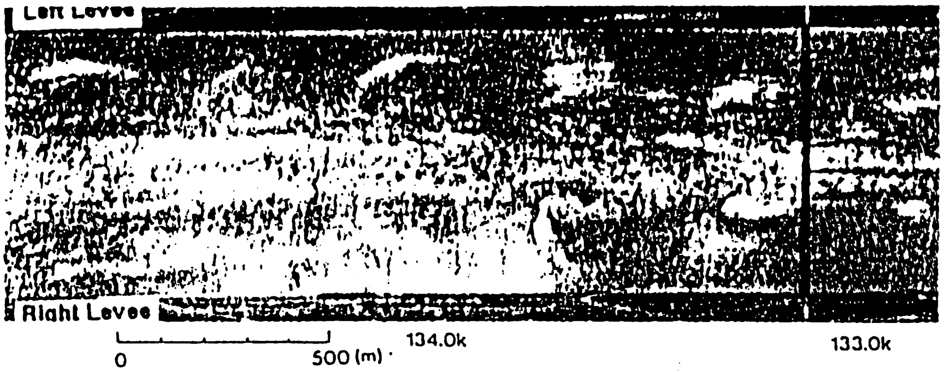

Photo. 1 Flood condition in the section where Vegetation grows densely (133.0-135.0km)

Table. 1 Hydraulic Condition used in the calculation

Discharge	Water surface gradient	Permeability coefficient	Manning's Roughness Coefficient	
Q(m³/s)	I	K(m/s)	Main Channel	Flood Channel
7,800	1/3,700	18	0.020-0.025	0.035(Left side), 0.030(Right side)

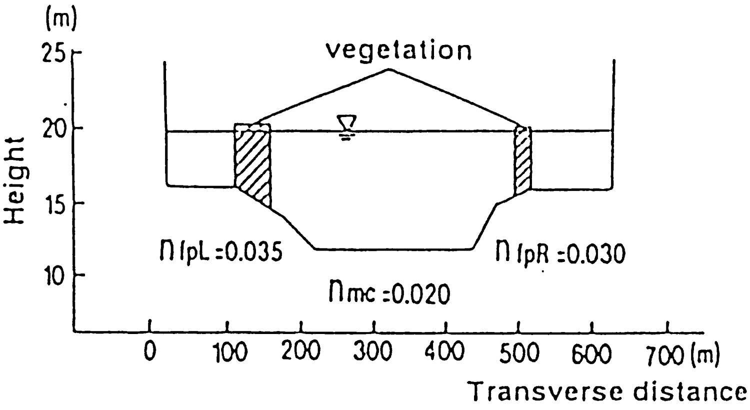

Fig. 3 Cross-section and vegetation used in the calculation

00 p.m.). The water surface gradient at peak discharge is roughly 1/3700. Depth is 7 to 8 m in the main channel and 3 to 4 m in the flood channel; at this time the water level was high enough to submerge the vegetation.

The vegetation's permeability coefficient (K) was calculated by the equation $K = U_w/I^{1/2}$ where U_w is the transverse average velocity in vegetation areas as determined from the vector distribution obtained from aerial photographs.

Photos 1 is an aerial photo taken in this section during flooding at 2:30 p.m. on August 23, 1981 in a section (133.0 to 135.0km) downstream from the Saitama Bridge where vegetation is dense. The horizontal flow structure caused by the vegetation is evinced by gradations in suspended sediment concentration. Whiskerlike lines can be seen extending into the flood channel from the vegetation zone. These lines, which occur at both banks of the main channel, appear to have a slight phase difference each other. These whiskerlike lines correspond to the flow structure observed in an experimental compound channel with vegetation5)6).

The surface velocity vector in Fig. 4 was calculated from the aerial photographs by dividing the distances by which the sediment and its patterns moved in two consecutive photographs by the interval between photographs. The results reveal meandering in the velocity vector with respect to the shape and position of the whiskerlike lines. This reveals that a large-scale horizontal vortical structure near the vegetation that has been observed in the laboratory experimental channel5)6) also exists in natural rivers.

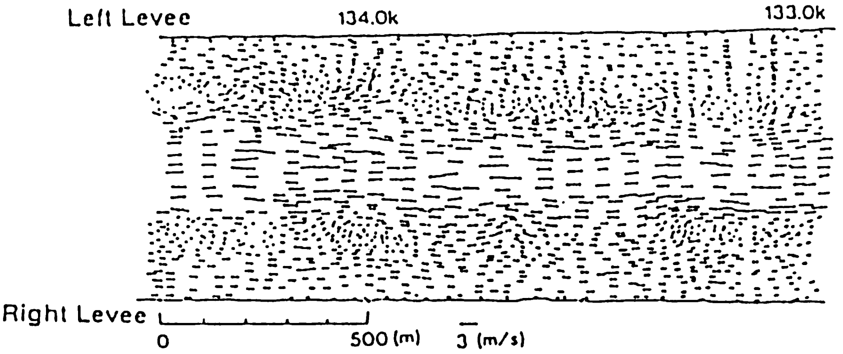

Fig. 4 Velocity vectors determined by Aerial Photograph

The intervals between eddies are not always constant, but differ slightly from one pair of consecutive eddies to the next. The size of a single vortical structure is between 350 and 450m.

Figs. 5 shows the velocity vector calculated with wavelength of 400m, which corresponds well to the actual measurements in Fig. 4. From the comparison of flood flow fields calculated with different wavelengths, the flow in the main channel begins to meander at a wavelength of 400m corresponding to the observed wavelength of 350 to 450m, at which point eddies on opposite banks begin interfering with each other.

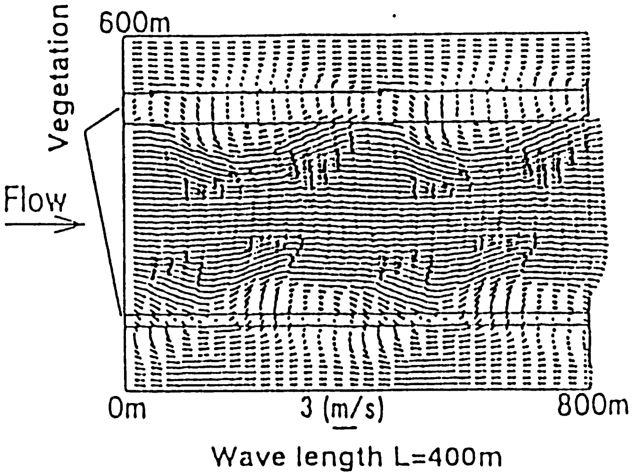

Fig. 5 Velocity Vectors (Results of calculation)

Fig. 6 is a visual representation of the flow pattern determined from the hypothetical release of markers in a velocity vector calculated with a wavelength (L) of 400m in order to facilitate comparison with the surface flow regime observed in the aerial photographs. The periodic lines is seen in actual rivers like those in Photo 1. Results of calculations agree with the aerial photographs in that they show whiskerlike lines extending into the flood channel from areas with vegetation. Comparing Photo 1 and

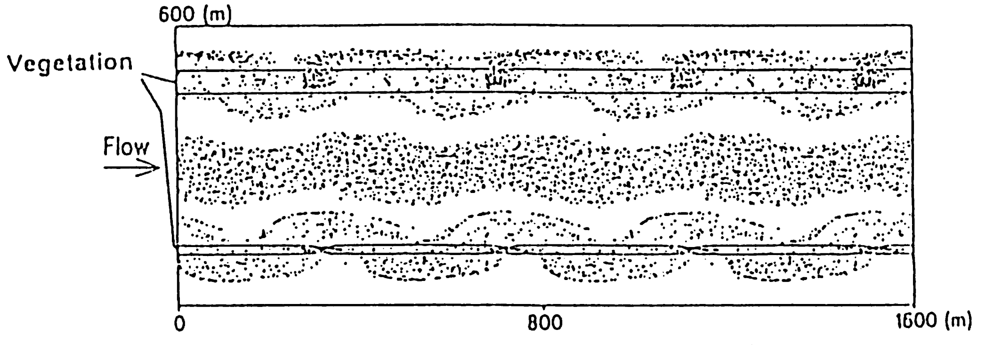

Fig. 6 Surface flow condition obtained when markers are introduced on theoretical velocity vectors

Fig. 6, which are similar in scale, clearly shows the shape of these whiskerlike lines to be nearly identical. While the photographs show a slight phase difference between opposite banks, in the calculations this phase difference is roughly $1/2\pi$.

Fig. 7 is the pattern of the downstream development of horizontal eddies calculated in the following way[5] : The initial water level is assigned a slight disturbance at both banks. With a phase difference between disturbance at opposite banks of 0.06π ($\tan\theta = 0.2$), the state of eddy development is determined for each wavelength, and the wavelength of eddy which is prominent at each point is selected, after which wave velocity is used to convert times to distances of downstream progression. When the value of X is near 2,500 m, at which the wavelength is 400 m, the phase difference between opposite banks increases, and at L = 500 m (X = 4,000 m), a state of equilibrium, the phase difference is nearly equal to π and horizontal eddies line up in an alternate position. Thus, a longitudinal distance on the order of several kilometers, or nearly ten times the width of the main channel, is needed for horizontal eddies at opposite sides to interfere with each other and take on such alternating pattern.

The flow in the downstream section in Fig. 7 where the wavelength is between 400 and 500 m agrees with the horizontal eddies in the aerial photographs, which has a longitudinal distance of 3 to 4 km to develop. The reach of dense vegetation in the Shinkawa channel is roughly 4km long.

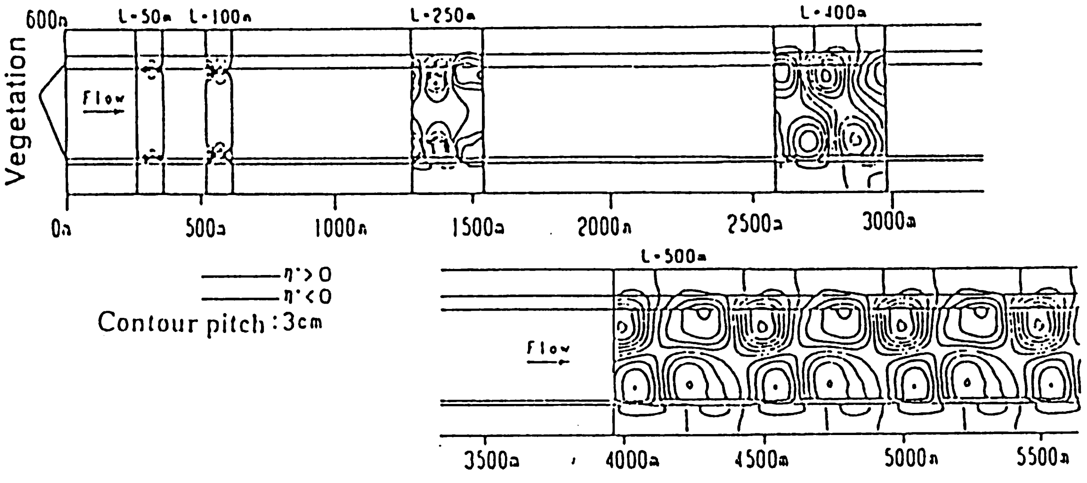

Fig. 7 Development process of two-dimensional horizontal eddies

Fig. 8, the transverse distribution of surface velocity at a cross-section by analysis of aerial photographs, shows that the presence of nearly continuous vegetation along the main channel results in prominent areas of low velocity. These low-

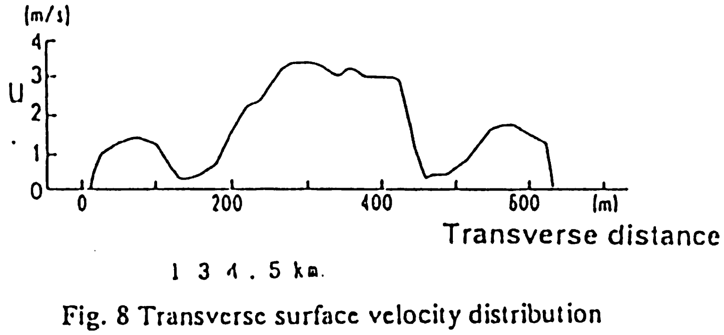

Fig. 8 Transverse surface velocity distribution determined by analysis of airial photograph

velocity areas, which also evince large horizontal vortical mixing, are large even in comparison with channel width. Comparison of calculated velocity distribution (Fig. 9) and observed one (Fig. 8) reveals that calculated velocity distribution at a wavelength of 400m agrees with observations to a considerable degree.

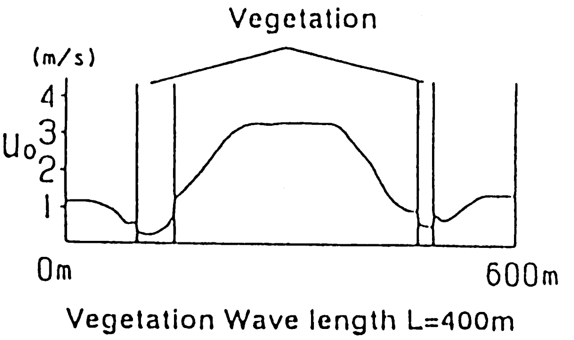

Fig. 9 Transverse velocity distribution (calculation)

4. CONCLUSION

The primary conclusions of this paper are as follows.

1)Velocity vectors from aerial photograph analysis and horizontal two-dimensional analysis confirmed that the whiskerlike lines visible in aerial photographs were actually large-scale horizontal eddies ranging in wavelength from 350 to 450 m, and that these eddies caused meandering near the vegetation.

2)Upon applying the authors' analytical method for horizontal two-dimensional flows to the Shinkawa channel, it was revealed, using visual representation, etc., that this method can be used generally to determine flood flow conditions in an actual river. Comparisons with calculated results showed that a wavelength of nearly 400m would result in the same flow field as that of the Shinkawa channel.

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