DETECTION METHOD FOR VULNERABLE POINTS OF RIVERBANK EROSION AGAINST LARGE FLOODS

FUMIYA YAGI

Graduate student, Department of Civil and Environmental Engineering, Hiroshima University, Higashi-Hiroshima, Japan, tonahuma77@gmail.com

TATSUHIKO UCHIDA

Associate professor, Department of Civil and Environmental Engineering, Hiroshima University, Higashi-Hiroshima, Japan, utida@hiroshima-u.ac.jp

YOSHIHISA KAWAHARA

Professor, Department of Civil and Environmental Engineering, Hiroshima University, Higashi-Hiroshima, Japan, kawahr@hiroshima-u.ac.jp

ABSTRACT

A river channel curves in various ways and generates a three-dimensional flow, which causes riverbank erosion at the bends and is a major cause of damage to river structures. To reduce the damage caused by riverbank erosion, it is essential to establish a method that can be used to calculate the risks of riverbank erosion. The purpose of this study is to develop such a method to clarify the three-dimensional flow in a two-dimensional framework and to establish a method for evaluating riverbank erosion. Turbulence energy was used as an indicator of the risk of riverbank erosion, and we clarified that it could be assessed using quasi-three-dimensional analysis. As a result, it was found that turbulent energy could be estimated at erosion danger points regardless of the erosion mode. In addition, the value of the turbulent energy $k^{1/2}$ at the location at which the riverbank erosion occurred exceeded 0.4–0.5 m/s.

Keywords: Bottom velocity computation (BVC) method, bank erosion, turbulence energy, Seno River, Misasa River

1. INTRODUCTION

Heavy rains in western Japan in July 2018 severely damaged the main roads along rivers due to riverbank erosion, especially in the rivers' upper reaches. To mitigate the risks of future damage, it is necessary to establish a means for predicting the risk of riverbank erosion during large-scale floods. Many studies have been conducted to uncover the mechanism of bank erosion, which occurs predominantly on the outer bank due to the increase in shear force and bed scour. It is well-known that the reason for this is the secondary flow caused by the vertical inhomogeneity of the centrifugal force in the curved segment of a river, and the large flow velocity biased toward the outer bank [Fukuoka et al. (1983), Blanckaert et al. (2009)].

Much research has been carried out on the risk of bank erosion using various methods in large-scale rivers. In some cases, rivers are divided by cells and the probability of riverbank erosion is estimated using an index that indicates the size of the flood scale [Graft et al. (1984), Sandra and David et al. (2000)]. Rosgen et al. (1995) used the bank erosion hazard index (BEHI) model to represent bank height, root depth, root density, river angle, and soil type, as well as the near-bank stress (NBS) model for vertical velocity distribution and shear force near riverbanks to quantify riverbank erosion rates.

The risk of riverbank erosion has also been evaluated using a six-level index. Beeson et al. (1995) showed that the erosion probability (in a case with vegetation in the curved reach) is reduced to approximately 1/5 of a case without vegetation in the curved reach. Bandyopadhway et al. (2014) showed that the index uses eight conditions (rainfall, bank slope, curvature radius, river slope, river soil characteristics, whether the riverbank is covered with vegetation, and human origin) to evaluate the risk of riverbank erosion over a wide area. The bank erosion risk was also explained using the BEHI-NBS model index. However, these are empirical qualitative indicators. In addition, the number of surveyed points is small, and many aspects remain unclear regarding the accuracy of the application.

Although a qualitatively-based evaluation for detecting riverbank erosion has been conducted, research on the risk prediction of large-scale floods on small- and medium-sized rivers is not sufficiently considered.

Table 1. Analysis conditions for the Misasa River and the Seno River

	Misasa River	Seno River
Calculation method	BVC	
Ground data	5mLP data(H26・Asia Navigation)	5mLP data(H28・Asia Navigation)
Downstream end condition	Constant water surface gradient	
Upstream end discharge	Runoff analysis	
Equivalent roughness	0.1(m)	0.01(m)

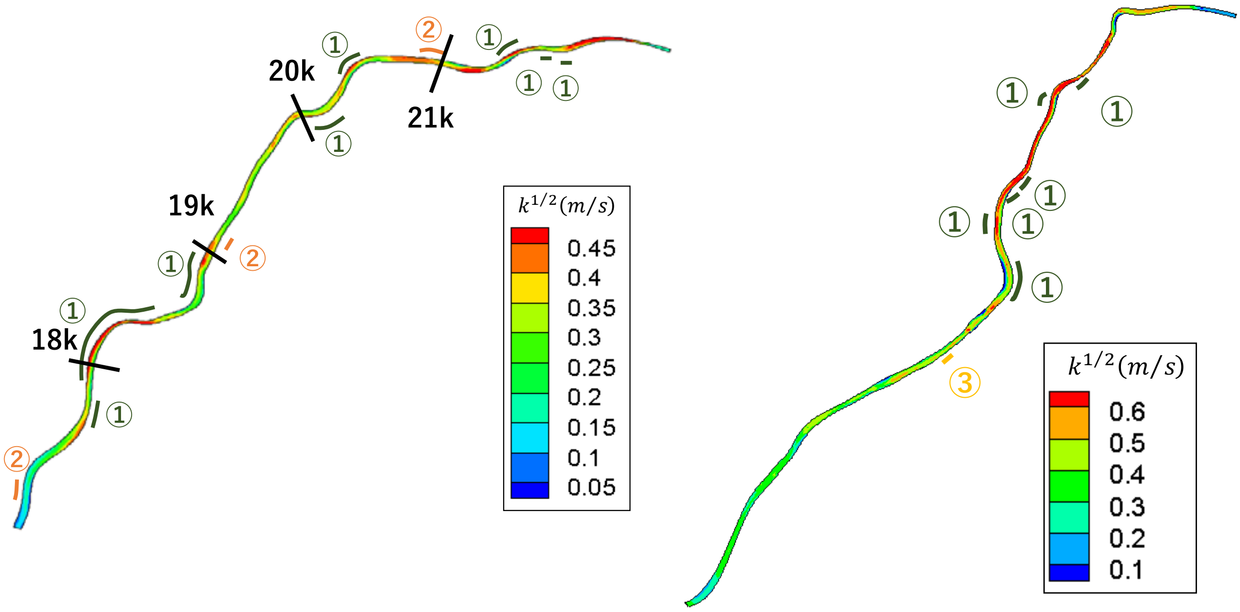

Fig. 1. Planar distribution of the maximum value of the turbulent energy $k^{1/2}$ in the Misasa River and the Seno River. (Left: Misasa River, Right: Seno River)

In this study, the risks of riverbank erosion over large areas, including upstream rivers and small rivers, with minimal data, are predicted based on a quasi-three-dimensional analysis of flood flows using the bottom velocity computation method [Uchida et al. (2014); (2016)]. The study examined a method for detecting the risks of riverbank erosion.

2. CALCULATION METHOD

In this study, three forms of riverbank erosion occur in places where the turbulence energy is large. First, turbulent energy is produced by the expansion, contraction, and rotation of the vortex by the secondary flow. Second, the depth average flow is increased by the effect of the weir, and turbulence is produced from the bottom shear force. Third, the horizontal vortex expands, contracts, and rotates under the influence of the structure, producing turbulence. These three factors produce turbulent energy and cause riverbank erosion.

In this study, the bottom velocity computation (BVC) method, which is a water depth integral model, was used to calculate the turbulence energy. The BVC method can calculate the flow velocity, pressure, and its vertical distribution on the bottom surface in a two-dimensional plane. It does this by solving the equations under the boundary conditions between the bottom and the water surface, assuming the vertical distribution of the flow velocity. The basic equations are solved in a general coordinate system. Table 1 shows the analysis conditions.

The upstream discharge hydrograph was calculated using the RRI (Rainfall-Runoff-Inundation) model ((Sayama et al. (2013)). With rainfall and topographical data, the RRI model analyzes the rainfall run-off and the river flood integrally.

3. CALCULATION RESULTS

Figure 1 shows the planar distribution of the maximum value of turbulent energy $k^{1/2}$ during a flood analyzed using the BVC method for the Misasa River and the Seno River. Erosion mode (1) shows riverbank erosion due to secondary flow, erosion mode (2) shows riverbank erosion due to an increase in water depth average velocity, and erosion mode (3) shows riverbank erosion due to the effects of structures.

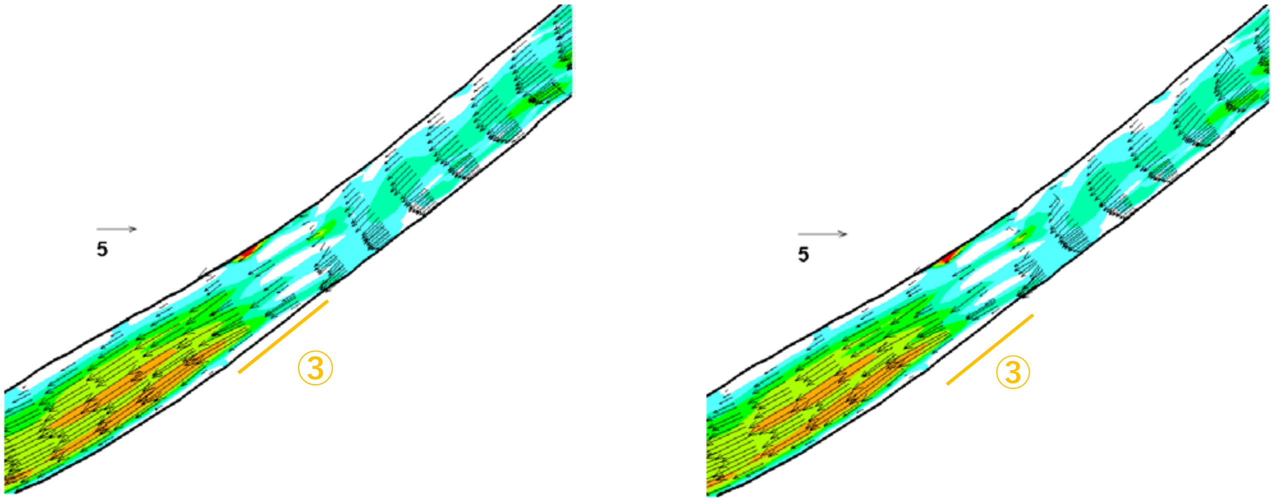

Fig. 2. Plane distribution of bank erosion on the left bank in the Seno River.
(Left : Water surface velocity, Right : Bottom velocity)

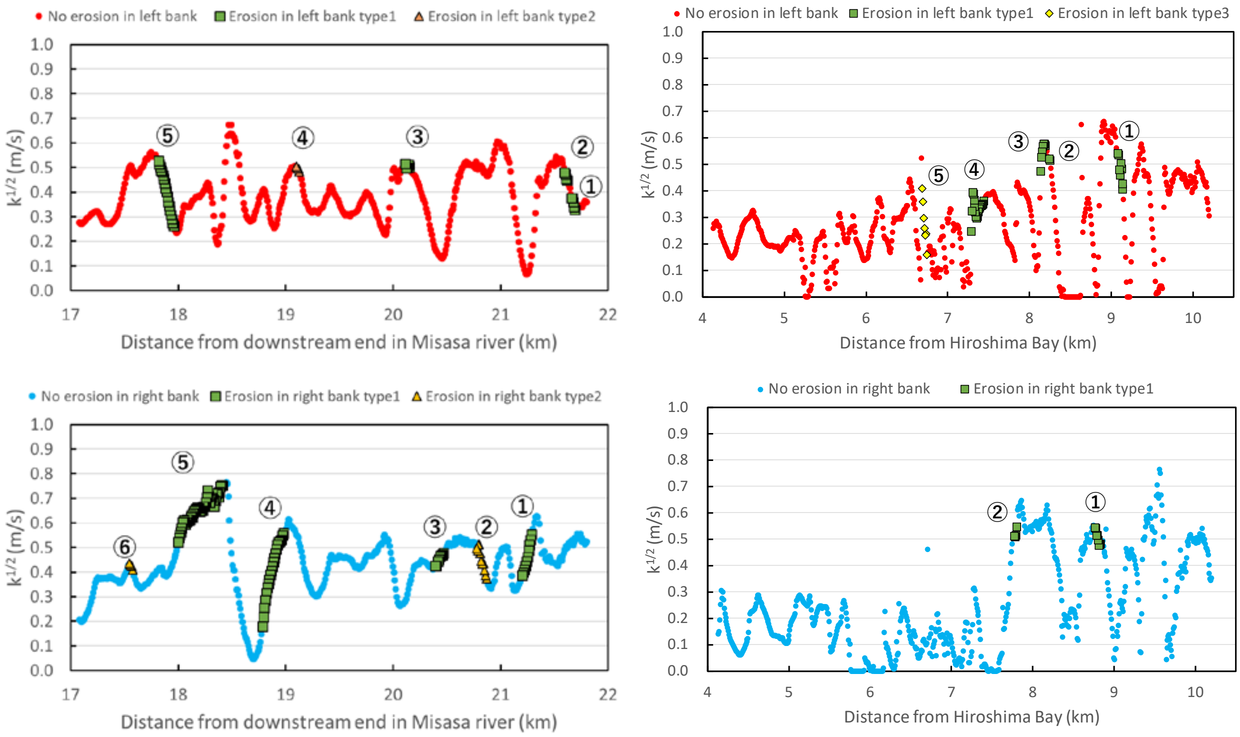

Fig. 3. Longitudinal distribution of the maximum value of turbulent energy $k^{1/2}$
in the Misasa River and the Seno River.
(Left: Left and right banks in the Misasa River, Right: Left and right banks in the Seno River)

Erosion mode (1) occurred at the curved segment of the Misasa River, and erosion from erosion mode (2) occurred in other locations. The contours are red at all erosion sites, and the erosion sites showed high turbulence energy. In the Seno River, erosion mode (2) occurred at the curved segment, and turbulence energy increased in erosion mode (3) within the straight segment.

Figure 2 shows the vector of the water surface and bottom velocity and the contour of the turbulent energy in erosion mode (3) of the Seno River. It can be seen that both the water surface velocity and the bottom velocity are distorted around the affected area. The pier is located upstream of the erosion, and it is thought that the expansion and contraction of eddies caused erosion.

Figure 3 shows the vertical distribution of the maximum value of turbulent energy in the Misasa River and Seno River. The turbulence energy is calculated by averaging the second and third values from the wall near both the left and right banks. The erosion sites on the banks of the Misasa River and the Seno River occur upstream and downstream of the local maximum of turbulent energy, regardless of the erosion mode.

Further study is needed on how to expand the erosion area, but the local maximum of the turbulence energy along the riverbank can be said to be an erosion hazard. In the Misasa River and the Seno River, riverbank erosion occurs when the local maximum value of the turbulent energy $k^{1/2}$ exceeds 0.4–0.5 m/s.

However, since riverbank erosion assessment is performed using only two rivers and using the same rainfall event, it is essential to study and evaluate different floods and rivers in the future. In addition, although the turbulence energy is high, there are some places where erosion is not considered because the side banks have trees in places where erosion has not occurred.

4. CONCLUSION

The main conclusions of this study are as follows:

1) – Regardless of the type of erosion, the maximum value of the turbulence energy calculated using the BVC method was in the upstream and downstream directions of the local maximum value of the location at which erosion occurred.

2) – The value of the turbulent energy $k^{1/2}$ in the location at which the riverbank erosion occurred exceeded 0.4–0.5 m/s.

REFERENCES

Beeson, C.E., and Doyle, P.F. (1995): Comparison of bank erosion at vegetated and non-vegetated channel bends. Water resources Bulletin., Vol. 31, No. 6, pp. 983–990.

Bandyopadhway, S., Ghosh, K., and Kumar, D.S. (2014): A proposed method of bank erosion vulnerability zonation and its application on the River Haora, Tripura, India. Geomorphology., Vol. 224, pp. 111–121.

Blanckaert, K. (2009): Saturation of curvature-induced secondary flow, energy losses, and turbulence in sharp open-channel bends. Laboratory experiments, analysis, and modeling. Journal of geophysical research., Vol. 114, F03015.

Fukuoka, S., Yamasaka, A., Takeuchi, S., Furuya, A., and Naganou, E. (1983): Bank erosion in a curved channel. Proceedings of the Japanese conference on hydraulics., No. 27, pp. 721–726.

Graft, W.L. (1984): A probabilistic approach to the spatial assessment of river channel instability. Water Resour. Res., Vol 20 (7), pp. 953–962.

Rosgen, D.L. (2001): A practical method of computing streambank erosion rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference. Vol 1.

Sandra, J.W., and David, J.G. (2000): A GIS-based approach to mapping probabilities of riverbank erosion: regulated River Tummel, Scotland. Regul. Rivers: Res. Mamt., Vol 16, pp. 127–140.

Sayama, T., Tatebe, Y., Fujioka, S., Ushiyama, T., Yorozuya, A., and Tanaka, S. (2013): An emergency response-type rainfall-runoff-inundation prediction for 2011 Thailand flood. J Hydraulic Eng., (JSCE) Vol. 69, No.1, pp. 14–29.

Uchida, T., Fukuoka, S., (2014): Numerical calculation for bed variation in compound-meandering channel using depth integrated model without assumption of shallow water flow. Advances in Water Resources., Vol 72, pp. 45–56.

Uchida, T., Fukuoka, S., Papanicolau, A.N., and Tsakiris, A.G. (2016): Nonhydrostatic Quasi-3D Model Coupled with the Dynamic Rough Wall Law for Simulating Flow over a Rough Bed with Submerged Boulders. J Hydraulic Eng., (ASCE), Vol. 142 (11), 04016054.