

Integrated design of levees and river channels based on spatio-temporal three-dimensional energy distribution of excess flood flow

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Introduction

In recent years, large-scale floods have been occurring where the water level exceeds the planned high water level or is equal to the height of the top of the embankment. For this purpose, it is important to clarify the spatio-temporal variation of the distribution of the total energy head of a flood, which is the sum of the velocity head and the nonhydrostatic pressure head, over the riverbed height during a flood (Fukuoka 2023, Fukuoka et.al. 2024).

The total energy head of a flood, $H_{all}(x, y, t)$, is evaluated by Equation (2), integrating the three-dimensional energy head $H(x, y, z, t)$ from the bottom to the water surface, since the three-dimensional energy head of a flood $H(x, y, z, t)$ is defined as Equation (1)

$$H(x, y, z, t) = \frac{u^2(x, y, z, t) + v^2(x, y, z, t) + w^2(x, y, z, t)}{2g} + \frac{p(x, y, z, t)}{\rho g} + \hat{z} + z_b(x, y, t) \quad (1)$$

$$H_{all}(x, y, t) = \frac{1}{h(x, y, t)} \int_{z_b}^{z_s} H(x, y, z, t) dz \quad (2)$$

where u , v , w and p are the flow velocities of the x , y , z components and pressure in three-dimensional space, and these values are obtained from non-hydrostatic quasi-3D flood flow analysis by Takemura et.al.(2019), ρ is the water density, g is the gravity acceleration, h is the water depth, z_b is the riverbed height, and $\hat{z}$ is the height with respect to the riverbed height z_b .

Methods

Three-dimensional energy distribution analysis was conducted for the flood flow exceeding the planned scale in the middle reaches of the Tama River during the East Japan Typhoon in July 2019, and compared with the scour damage areas of the river channel and levees. In this process, a two-dimensional riverbed variation analysis is also performed in an integrated manner. Figure 1 shows the contours of the total energy head at the peak of flooding in the middle reach of the Tama River obtained by substituting the three dimensional analysis results of Q3D-FEBS (Takemura et.al. 2019.) into Equation (2). Figure2 shows the longitudinal relationship of levee height to the maximum value of total energy for each of the cross sections shown in Figure1. By drawing such contours and the relationship of total energy to levee height, we can see where the total energy head is higher in the river channel, where the energy gradient is greater, and where there may be problems in relation to the levee height. In particular, the total energy is high near flow concentrated points due to meandering of low water channel and near river crossing structures such as bridges, which is an issue to be considered. Furthermore, the study examines how the increased energy deforms the cross-sectional shape of the channel, which has a compound cross-sectional shape consisting of a low water channel and flood channel, in space and time, and discusses the desirable channel shape formed by the energy distribution

possessed by the flood flow.

Results

It can be seen that the flood energy is concentrated along deeper route of low water channel. When the maximum total energy head exceeds H.W.L., a large change occurs in the three-dimensional energy distribution of the flow in relation to the low water channel alignment. Especially in the vicinity of water concentrated flow against levee and around bridge piers, large changes occur. It also indicates that the risk of overflow from the levee increases at this time. The areas near the flood channel and levees where disasters have actually occurred correspond to the areas considered to be at risk in this energy analysis. In addition, the isopleth of the total energy head extends downstream, and the total energy is large at the points where the distribution of the total energy head is steep. In response to this large energy and its distribution, the longitudinal and cross-sectional shapes of the river channel change to a ship bottom shape with low resistance in order to reduce the scour and erosion to the river channel.

Conclusions

Three-dimensional energy behavior of excess flood flow in the Tama River was clarified. Estimation of hazardous areas based on the energy analysis method was shown to correspond almost exactly to the hazardous areas in the high water bed and levees of the Tama River. It was shown that a channel design method based on the energy distribution of flood flow is necessary for excess flood flow. Finally, the basic concept of the design of compound meandering channels is the ship-bottom shape channel, in which the width of the low channel can be freely changed according to the three-dimensional energy distribution of the flood flow.

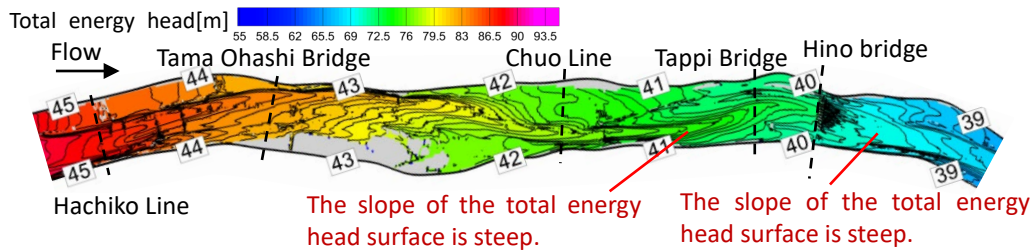


Fig.1. Contours of the total energy head surface at the peak discharge of the July 2019's flood in the middle reach of the Tama River.

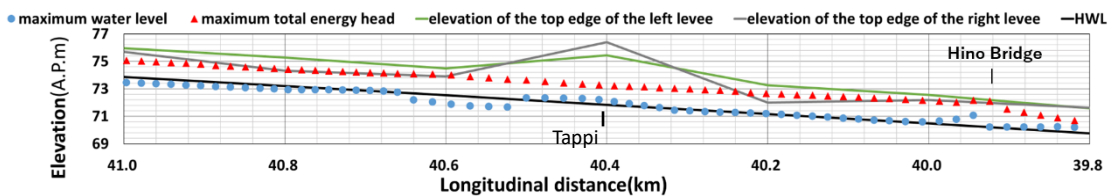


Fig.2. Longitudinal relationship of levee height to the maximum value of total energy for each of the cross sections.

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