THE SHAFLOW MODEL : APPLICATION FOR FLOOD MITIGATION PLANNING IN THE TSURUMI RIVER

by

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Abstract

A case study applications of the SHAFLOW model is presented. The model was applied to investigate the proposed plan for flood mitigation in a 1.5 km long reach of the Tsurumi river in Yokohama, Japan. The reach which consists of a confluence, floodplain and a bend has a complex bed topography and a bank geometry. The model generated the curvilinear grid and computed the two-dimensional flow pattern. The agreement of the computed results with the field observation corresponding to a past flood event is satisfactory. Then, the increase of flood risk due to over grown vegetation in the floodplain was investigated. Finally, the application of the SHAFLOW model under the proposed dredged bed topography for flood mitigation provides two-dimensional velocity and water surface elevation pattern in the reach for a flood of 100 year return period.

1.0 Introduction

The Tsurumi river is one of the five major rivers in the Greater Tokyo region of Japan. Despite the worldwide acknowledgement of its best practices in water resources management and

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environmental protection, the Greater Tokyo region is well known for its water stress and vulnerability to water related disasters including floods. The Tsurumi river which has a length of 43 km and a catchment area of 240 km2 flows through Shin-Yokohama district where the land value is very high due to the location of many industries. The river poses the risk of inundation in the event of high rainfall due to its highly urbanized catchment, as high as 80%, which causes massive influx of water at once into the river. Flood control and the river environment improvement in the Tsurumi river have been a major focus of river engineers.

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The Tsurumi river with its floodplain experiences a bend of about 90 degrees and a confluence of about 40 degrees with the Toriyama river at its concave right bank in Shin-Yokohama, where the area surrounding is densely populated and highly industrialized (Fig.1). It has been identified that the levees of the river at the confluence are at a high risk of breaching or being overtopped during seasonal floods.

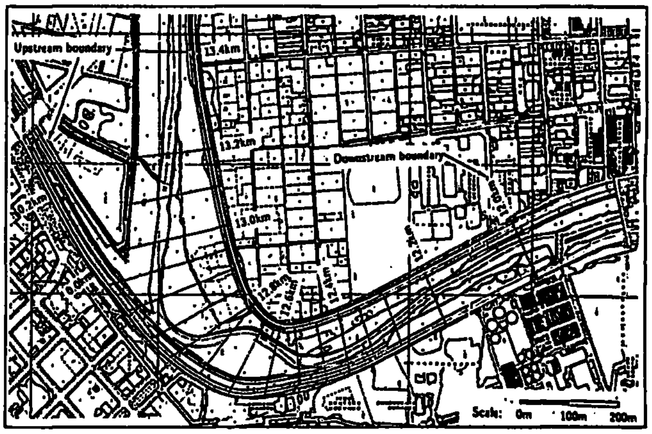

Figure 1: The tsurumi-Toriyama confluence in Yokohama

To protect the Shin-Yokohama city from a possible flood disaster, a decision has been taken to improve the river reach to convey safely a flood of a 100 year return period that corresponds to discharges of 1070 m^3/s and 130 m^3/s in the Tsurumi river and the Toriyama river respectively. Thus, various flood control measures have been proposed including the dredging of the river, construction of upstream flood retarding basins, raising of the levee, etc.. The first proposal is more attractive than the others as it does not necessitate acquiring additional land, which is very expensive in the area. The details of water elevation, velocity pattern at the confluence region due to the flood flow under the present condition and the proposed dredged river bed condition have become essential for the planning, appraisal and design of the flood control project.

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The SHAFLOW model described in the preceding paper of this issue is one of the models useful today for obtaining these details of flow pattern. Though sediment transport is not considered in the present version of the SHAFLOW model, the effect of sediment on the flow can be taken into account through the increased roughness coefficient. This paper summarizes the case study application of the SHAFLOW model to compute the flow in the Tsurumi river at the Tsurumi- Toriyama river confluence region. A river length of 1.4 km from chainages of 12.0 km to 13.4 km from the river mouth which includes the confluence region as shown in Fig.1 was selected for the model application.

2.1 Model calibration

The SHAFLOW Model was first calibrated for the given river reach by using flow data collected in the river during a past flood event. The data available consists of the upstream discharges of the main river and the tributary, and water surface elevations at every 200 m along the left bank and right bank. Upstream discharges during the flood were 667 m^3/s and 69 m^3/s in the Tsurumi river and the Toriyama river respectively. The bed topography contours over the region measured after the flood are shown in Fig. 2. The bed topography was complex with the existence of the scour hole common to the confluence flows as documented in Best (1988) and Weerakoon et al. (1990). The flow condition above, referred as Case CS below, was simulated by the SHAFLOW model. The application of the model starts with the generation of the curvilinear grid in the flow computation region. The grid module of the SHAFLOW model generated the 51x33 computational grid shown in Fig. 3. Streamlines generally follow the thalweg (the deepest line) and therefore, streamwise grid lines have been generated to follow the thalweg in order to minimize skewed flow with respect to grid lines (Wenka.et al., 1993, Wijbenga, 1985).

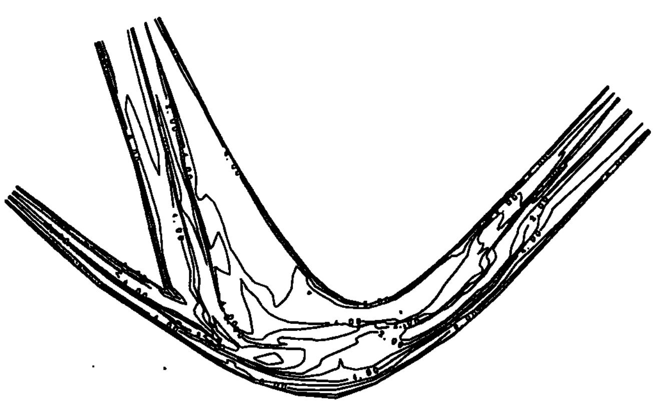

Figure 2: Bed topography in the tsurumi-toriyama river confluence;
(Contours are in metres)

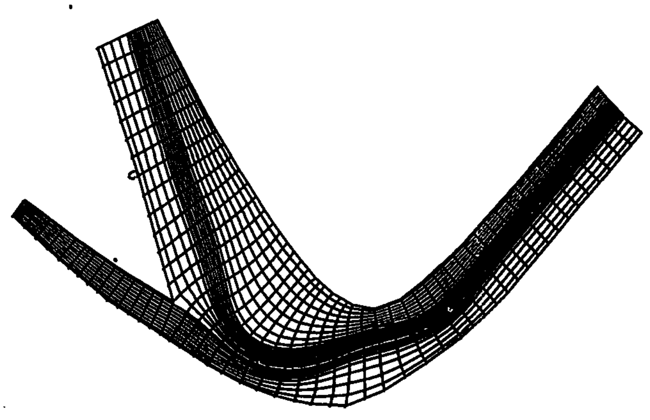

Figure 3: Computational grid for the tsurumi-Toriyama river confluence

The selection of the Manning coefficient n was done here paying much attention on the nonuniformity of the river geometry. The main channel bed is irregular with pools and riffles whereas the floodplain is vegetated with bushes and sparse trees. Therefore, two different values for *n* were imposed for the floodplain and the main channel. The sensitivity of *n* was tested by performing using six different sets of *n* values as given in Table 1. The effect of sediment on the mean flow is only indirectly taken into account by the coefficient *n*. The bed and banks are irregular with pools and humps, thus the value for ε was taken as 1 m^2/s which gives $\beta = 1$ (Fischer et al. 1979, Ogink 1985).

Case Tsurumi river confluence	*n* (SI units)	ε cm^2/s	$\beta=\varepsilon/u_*H$
CS1	0.04 r/c, 0.06 f/p	10^4	1
CS2	0.04 r/c, 0.055 f/p	10^4	1
CS3	0.035 r/c, 0.06 f/p	10^4	1
CS4	0.035 r/c, 0.05 f/p	10^4	1
CS5	0.040 r/c, 0.04 f/p	10^4	1
CS6	0.030 r/c, 0.03 f/p	10^4	1
CSM4	0.03 r/c, 0.03 f/p	10^4	1
CSM6	0.03 r/c, 0.05 f/p	10^4	1
d/s = at downstream, u/s = at upstream, r/c= river channel, f/p flood plain			

Table 1. Specification of Manning coefficient and eddy viscosity

The boundary conditions for the SHAFLOW model are discussed in Part I of the publication. Accordingly, unit discharge distribution is imposed at the upstream boundary. The down stream free surface elevation which was obtained from the field observation was imposed as the downstream condition. The free-slip condition was employed at the banks.

The computed mean water surface elevations along the main river for six different cases CS1 to CS6 given in Table 1 are compared with field observations in Fig. 4. It shows the rise of the free surface elevation with increasing *n*, and also shows the importance of the correct selection of *n* in representing the roughness. Case CS1 results show a better agreement with the observation. The n values in Case CS1 agree with the recommended values of n for one-dimensional analysis of similar river reaches (Ven Te Chow, 1988). Here, only the details of the flow pattern obtained from Case CS1 computations are discussed. Water surface elevations at banks are compared with observations in Fig. 5. Prediction shows similar trend with minor discrepancy. The prediction can be considered to be satisfactory because the field measurement has been done from the remains of debris after the flood, where the measured values can vary as much as (10 cm due to wind, eddies, etc.. Free surface elevations are also elaborated by contours in Fig.6. Contours show the free surface superelevation at the river bend in 12.4 km to 12.7 km section, commonly evident in stream bends due to the centrifugal force associated with the curving streamlines. The maximum free surface superelevation of about 0.2 m is shown at section 12.5 km. The river width reduces to half from 13.0 km to 12.7 km sections. The narrow river section beyond 12.7 km affects the upstream flow in this subcritical flow condition. This is evident from the increased free surface gradient shown by concentrated contours in the section of 12.5 km in the river. The small free surface gradient in the Toriyama river shows the backwater effect.

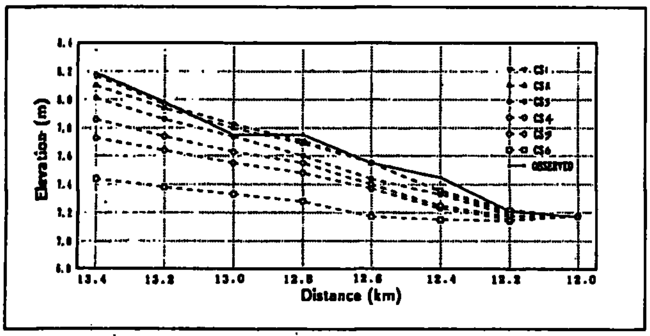

Figure 4: Mean water surface elevation along the Tsurumi river

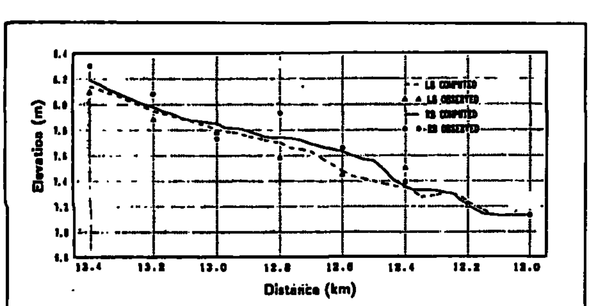

Figure 5: Water surface elevation at the banks of the Tsurumi river

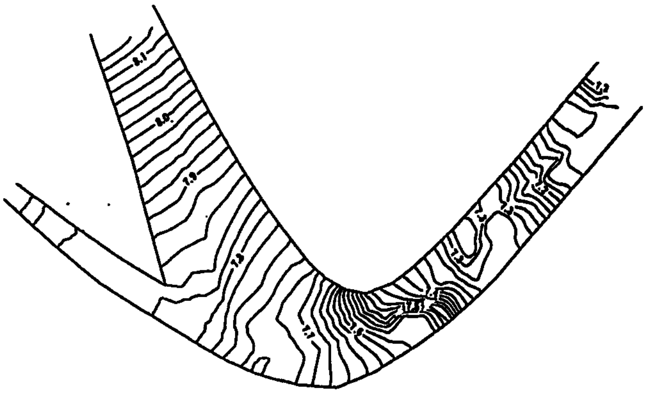

Figure 6: Free surface elevation contours of the confluence from Case CSI; (Contours are in meters)

Velocity vectors are shown in Fig. 7 and they follow the thalweg in most places. The mixing of two river flows is shown by the fact that the velocity distribution across the mixing layer becomes gradually even from 13.0 km to 12.8 km. The low velocities in the Toriyama river are due to the backwater effect caused by the confluence. The flow in floodplain with higher roughness compared to the main channel shows lower velocities than in the main channel. This feature is common in compound channels and it is the cause of the generation of intermittent large eddies to transfer momentum from the main channel to the flood plain (Fukuoka, 1997). A flow recirculation appears at the left bank floodplain near 12.2 km where the floodplain has a valley. The low velocities present in these types of recesses, called embayments, are useful for fish to survive during floods. The maximum velocity of about 4.0 m/s appears in the narrow river section 12.5 km to 12.2 km. The high velocity adjacent to the right bank in this section exerts a high erosive stress on the bank.

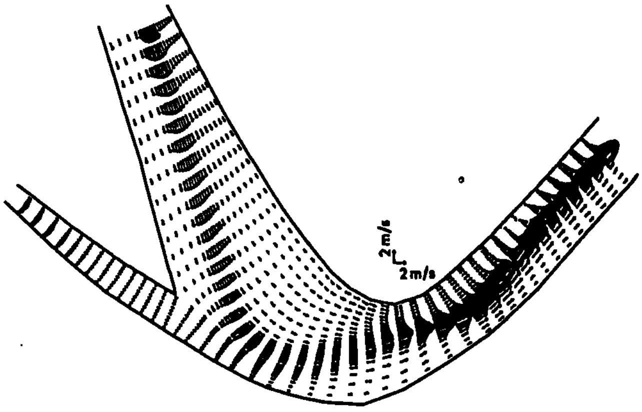

Figure 7: velocity vectors at the confluence for Case CS1

2.2 Effect of overgrown vegetation on flood flow

The Tsurumi river floodplain carries water only during seasonal flash floods as common in floodplains of Japanese rivers. Therefore the floodplains are used as play grounds, leisure or amusement parks, nature reserves, camping sites, etc., for enriching the social life of the people. Nevertheless, overgrown trees and thick vegetation in floodplains, especially in the parks and nature reserves, have a detrimental effect on flood conveyance which is the prime service of the floodplain. The SHAFLOW model can be used to simulate the effect of overgrown vegetation by increasing the roughness coefficient n in the grids lying in the respective regions.

Some sections of the floodplain of the Tsurumi river are covered with an extremely thick vegetation growth as indicated in Fig. 8. The SHAFLOW model is applied here to understand the flow if the same flood in Case CS (section 2.1) occurs at the present condition. The river bed topography and the bank profiles could be taken as the same in Fig.2 without causing serious error. This enables the use of the same computational grid shown in Fig.3. However, to simulate the overgrown vegetation condition, a larger roughness was introduced by using an n value of 0.18 for the grids that fall in the regions with overgrown vegetation (Case CSR). The rest of the grids were assigned the same n values as in Case CS1, i.e. 0.06 for the main channel and 0.04 for the floodplain.

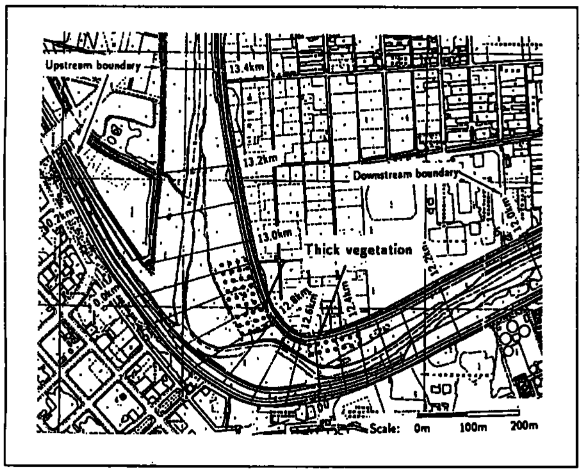

Figure 8: Regions of increased roughness in Case CSR

A marked increase of about 0.1 m in the water surface elevation along the left bank just upstream to the section 12.4 km is shown in Fig. 9. There shows an increase in the water levels by about 0.1 m in sections from 13.0 km to 13.4 km. This implies an increased flood risk due to overtopping or breaching the levee. The velocity vectors given in Fig.10 show low velocities in the left bank floodplain in sections 12.8 km to 13.0 km and 12.4 km 12.6 km due to vegetation growth. The retardation of flow due to vegetation results in the deposition of sediment in floodplains. Furthermore, vegetation in the left bank has caused to repel the flow towards the right bank. The lower conveyance in the left bank floodplain has caused increase velocity in the right bank floodplain resulting in larger erosive stresses on the right bank. The velocity in the river bend region has increased up to 4.5 m/s.

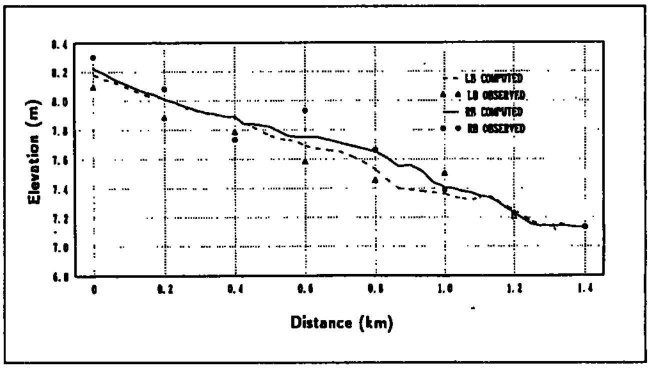

Figure 9: Water surface elevation at the banks of the Tsurumi river in Case CSR

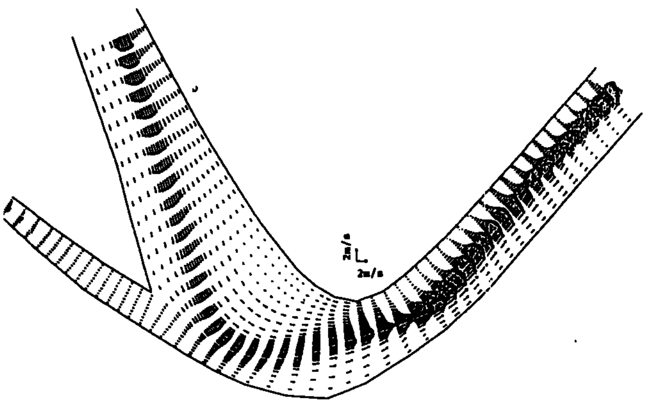

Figure 10: Velocity vectors at the confluence for Case CSR

The above investigation reveals the necessity of keeping the floodplain of the Tsurumi river reach free of thick vegetation for reducing the flood risk until a long term solution for flood control is provided. The vegetation in the floodplain reduces the flood conveyance in floodplain rivers but is useful to protect the river banks.

2.3 Flood control project proposal I - Dredging

Fig. 11 shows the proposed river bed topography for reducing flood risk in the river reach where the river bed is to be deepened by dredging. The main river channel is to be widened without changing the levees in the two sides. The widening of the river needs to acquire the adjacent lands, resettle people, relocate industries, pay compensation and rebuild the levees and this has been found to be not feasible. The floodplain becomes narrower as shown in the proposed section.

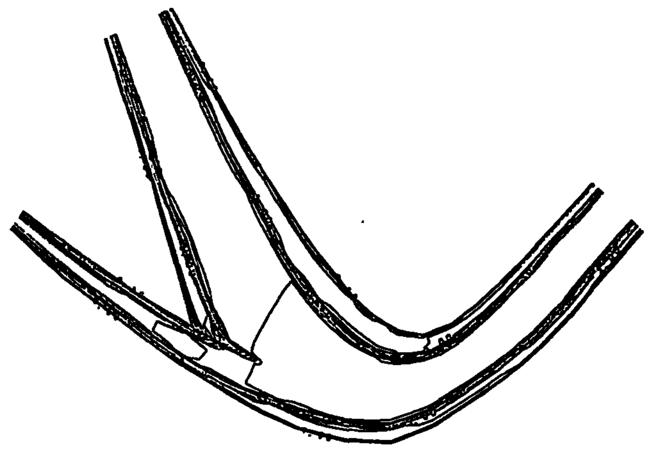

Figure 11: Proposed bed topography

The SHAFLOW model was employed to the reach under the proposed river geometry shown in Fig.12 to understand the flow pattern during a flood of 100 year return period that corresponds to discharges of 1070 m^3/s and 130 m^3/s in the Tsurumi river and the Toriyama river respectively. The existing river section is not sufficient to convey the flood discharge which is more than double the discharge considered in the previous cases in Sections 2.2 and 2.3. The SHAFLOW grid module was used to generate a new curvilinear grid of 51x33 to cover the region and is shown in Fig. 12. The downstream water level elevation required by the SHAFLOW model as a boundary condition was obtained from the results of the feasibility investigation carried out by the application of a one dimensional model by the Keihin river works of the Ministry of Construction of Japan . The case CSM4 represents the condition soon after dredging and the case CSM6 represents the condition after a few years. The model coefficients used in the computations are given in Table 1. The roughness of the bed is expected to change gradually with the development of the scour hole, pools, dunes etc. on the bed and the growth of vegetation in the floodplain and banks. This effect was investigated by selecting a Manning's roughness coefficient of 0.05 for Case CS6.

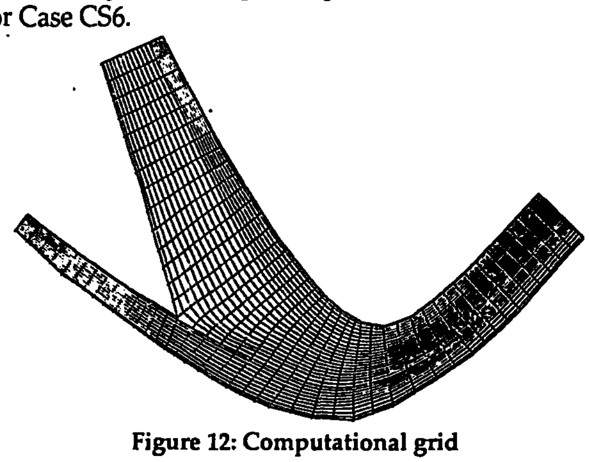

Figure 12: Computational grid

The predictions of water surface elevation under these two cases are shown in Fig. 13. The prediction of the one-dimensional model analysis and initially planned design levee top levels are also given. The one-dimensional model seems to grossly underestimate the water surface elevation at the upstream under the same boundary conditions. Computations were also done using different grids but the differences in predictions were negligible. The velocity vectors and free surface elevation contours are also shown in Fig. 14 and Fig. 15 for CSM4. The low conveyance in the narrow river beyond 12.5 km is shown to be the critical section which controls the water surface levels in upstream. The steep water surface gradient in sections from 12.8 km to 12.6 km shows the build up of the head required to realize the flow through the narrow section. The free surface superelevation in the bend is shown to be about 0.3 m at section 12.6 km. It is clear that backwater the effect due to the constriction at the bend is serious in all cases. Depths have been underestimated by the one-dimensional model under the same downstream boundary conditions. The maximum velocity in this region was about 2.5 m/s. However, it should be noted that the downstream condition imposed, such that the depth is from the one-dimensional model, is influential on the results.

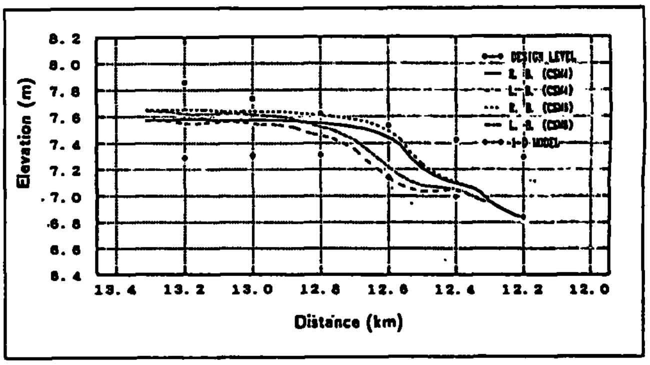

Figure 13: Water surface elevation at the banks of the Tsurumi river

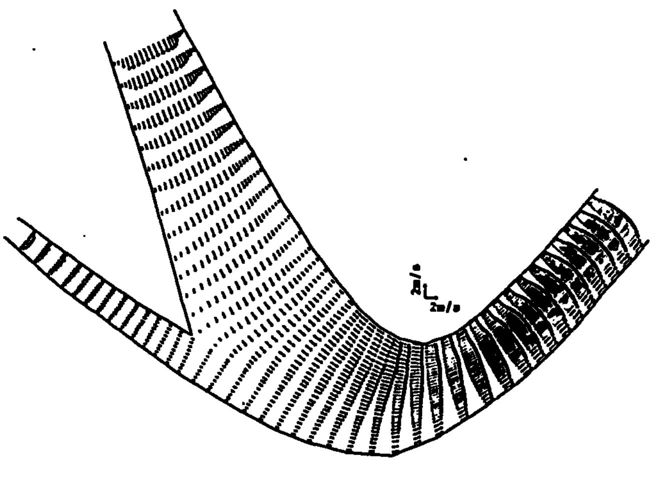

Figure 14: Velocity vectors at the confluence in Case CSM4

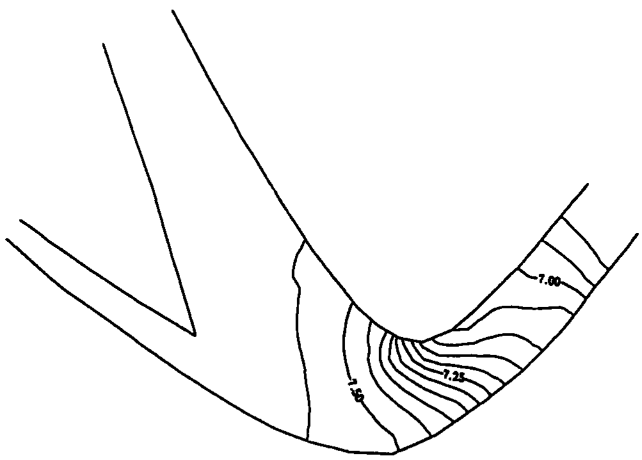

Figure 15: Free surface elevation contours of the confluence from Case CSM4;

(Contours are in metres)

The above model predictions of flow pattern and free surface elevation highlight many undesirable effects accompanied by the proposed development. The bottom shear stress τ is proportional to the free surface gradient, S as given by $\tau \propto hS$. Therefore, the steep free surface gradient from the 12.8km to 12.6km will exert a high erosive shear stress on the perimeter. Unless, the section is lined in this part of the river severe erosion may be expected. The elevated water levels upstream of the Tsurumi river is shown to be about 0.5m above the predictions of the one-dimensional model (e.g. at the section 13.4 km). Thus, the raising of the levees from preplanned levels becomes necessary. Furthermore, the low velocities in the left bank floodplain in sections from 13.2 km to 12.8 km implies possible rise in river bed due to sedimentation in the reach. The accompanied increased hydrostatic pressure force on the right bank levee together with high erosive forces due to larger velocity will require a strong levee and bank protection.

The investigation reveals that the proposed bed topography as in proposal I alone is not a suitable flood mitigation proposal though the cost of development could be the minimum. Alternative proposals such as the construction of the retarding basins in an upstream region where the acquisition of land area is feasible have to be combined with proposal I. The effect of a retarding basin would be the reduction the peak flood discharge, and the SHAFLOW model could be employed to investigate the flow behaviour with the new discharges.

5.0 CONCLUSIONS

- The overgrown vegetation in the floodplain of the investigated Tsurumi river reach leads to an increased flood risk. It is important that the floodplain in the reach is maintained free of overgrown vegetation until the flood mitigation work is completed.
- The SHAFLOW model predictions in the Tsurumi river reach under the proposed dredged bed topography reveal that the proposal is not satisfactory for reducing flood risk, and thus a revised proposal incorporating the construction of retarding basins in the upstream region will be necessary.
- A case study application of the SHAFLOW model for computing two-dimensional velocity and depth pattern in complex flow situations in a real river confirms the important features of accuracy, stability and convergence of the SHAFLOW model described in the preceding paper in the issue.

Acknowledgements

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