PREDICTION OF URBAN INUNDATION AND FLOODING OF URBAN RIVERS CAUSED BY HEAVY RAINFALL AND STORM SURGE IN TOKYO 23 WARDS

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ABSTRACT

In recent years, damage caused by heavy rainfall and typhoons has frequently occurred in various parts of Japan due to climate change. Countermeasure to this climate change is necessary especially in the coastal area, and it is important to investigate the influence of storm surge and typhoon on urban inundation. In light of this situation, the Flood Control Law, revised in 2015, created a system for publicizing the inundation areas related to largest possible flood, inland water and storm surges. For each possible impact, it is demanded in future to take appropriate measures. In this study, using the sophisticated urban inundation prediction system S-uiPS developed by the first author, we assumed that both large-scale torrential rain and storm surge would occur at the same time, and the process of inundation occurring in the 23 wards of Tokyo is examined. In 23 wards of Tokyo, the rainwater exclusion system consisting of roads, drainage pipes and urban rivers has been maintained, and inundation is reduced by draining the water to urban rivers. When the sea level goes up at the time of storm surge, the water surface elevation of the urban river which flows down to Tokyo Bay become higher. In this case, the inundation will occur due to the reverse flow to the drainage system through the storm-water outfall. The objective is to elucidate the range of storm surge effects in urban rivers, and to make clear the inundation process and the local inundation risk in urban areas.

Keywords: urban inundation, torrential rain, storm surge, highly urbanize area, numerical prediction.

1. INTRODUCTION

In recent years, damage from large typhoons and localized torrential rain has been increasing in various parts of Japan due to extreme weather. Typhoon No.21 which occurred in September 2018 caused severe damage due to furious wind around Osaka Bay. Typhoon-triggered Storm surges and high waves causing massive inundation damage in Kansai International Airport and took a long time to recover. A ship colliding with the bridge which connecting the opposite bank and the airport. In addition, during the heavy rains in western Japan in July 2018, severe inundation damage occurred there. The Meteorological Agency announced an extraordinary heavy rain warning in Kyoto prefecture and other 10 prefectures. The number of casualties were over 200. Considering this current state, the importance of software countermeasures has been increasing more and more due to the frequent occurrence of inundation damage because the existing facilities or hardware countermeasures cannot work well to prevent from the damage due to extremely high natural impact. Sekine laboratory has clarified the risk of inundation occurring in highly urbanized areas such as the 23 wards of Tokyo using a sophisticated inundation prediction system S-uiPS (Sekine's urban inundation Prediction System). In this study, the prediction of urban inundation in 23 wards of Tokyo was performed on the assumption that both heavy rainfall and Storm surges caused by Typhoon would occurred simultaneously.

2. STUDY AREA AND ANALYSIS OVERVIEW

2.1 Features of the target area

The target area in this study is located in west of the Sumida River in the 23 wards of Tokyo as shown in Fig 1. This area is equivalent to more than 60% of the total area of the 23 wards and the total area is about 390 km^2. It is composed of 18 administrative districts including Chiyoda ward, where the central functions of politics and economy. Figure 1(left) is an elevation contour map of the roads in this area. As can be seen from the figure, the western area has an altitude of over 50m, but the altitude decreases as it approaches the coastal area.

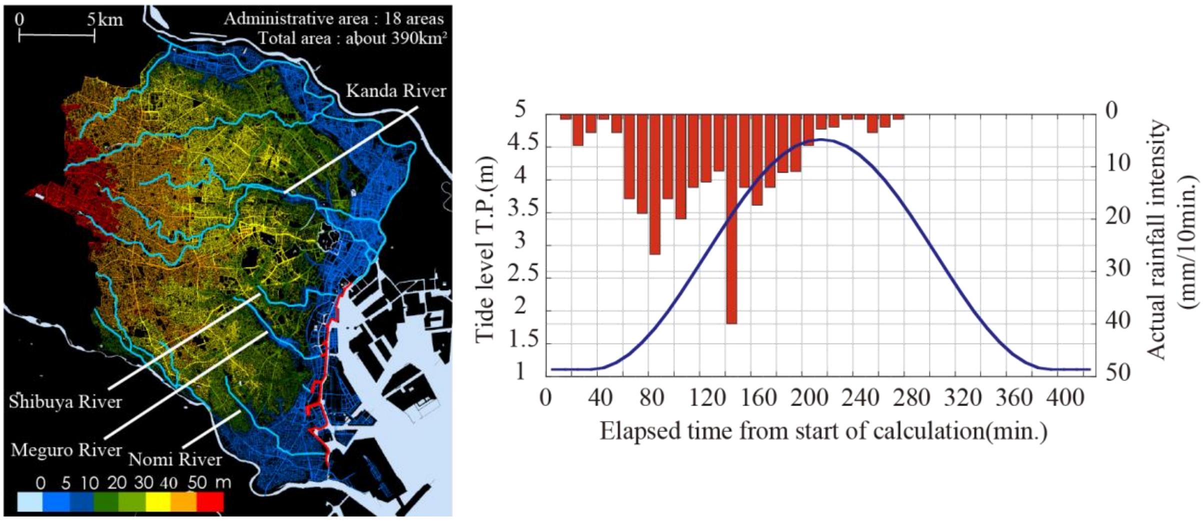

Figure 1. Elevation contour map (left), and temporal change of rainfall and tide level used in this study (right).

And it should be noted that lowland area with an altitude of 5m or less spread along the Sumida River and the area near the river mouths of some urban rivers including the Kanda River, the Shibuya River, the Meguro River and et al. In order to protect the embankment from the storm surge of Tokyo Bay, a seawall has been installed at the seafront from the mouth of the Sumida River to the mouth of the Nomi River and it is shown in Fig.1 (left) in a red solid line.

2.2 Summary of the prediction system

In highly urbanized areas, rainwater on roads flows into drainage system through street inlet tank. After that, rainwater flows down in the drainage network and is discharged into urban rivers or the sea from drainage facilities such as pump stations and water regeneration centers. In order to conduct accurate and reliable flow computation of rainwater, we created a database in which all information on current urban infrastructure facilities have been input faithfully. Based on this database, we performed prediction of urban inundation in Tokyo using the same sophisticated prediction method S-uiPS. This database contains information about (1) all road networks, (2) all drainage networks, (3) rainwater storage capacity of water reclamation centers and pump stations, (4) rainwater storage pipes, (5) urban rivers flowing in the area, (6) land use of the urban block, such as the building coverage ratio and etc. In addition, it is noted that any coefficients which should be calibrated are not included at all.

2.3 Target rainfall data and storm surge

In this study, we used the heavy rainfall of Suginami that occurred in a wide area around Suginami ward, Tokyo in September 2005 (Sekine, 2016). This was the largest scale of torrential rain which ever occurred in the 23 wards of Tokyo, and at that time we experienced the last flood damage that the river revetment was destroyed. As for the downstream boundary conditions of urban rivers, the temporal fluctuation of the tide shown in Fig.1 (right) was used. The probability that such storm surge occurs is 1/1,000 (Tokyo Metropolitan Government, 2018). The initial conditions for this computation were assuming that there was no rainfall until the start of the calculation, and that each river had a normal flow rate.

3. RESULT AND DISCUSSION

3.1 Inundation process of target area

First, at 120 minutes after the start of rainfall while the tide level is rising, the inundation occurs in a wide area in the target area. In particular, flooding of more than 80 cm occurred mainly in the coastal areas and lowlands along rivers. In addition, the water level of the river rises as the rise of the tide, and the effect of the high intensity rainfall indicates that the drainage pipe becomes full in most areas not only along the river. At 225 minutes after the start of computation, which is just after the peak of the tide level, it can be seen that the area where the inundation depth exceeds 80 cm has been expanded, mainly along the riverside and the coastal area. In addition, the high water level of river makes the reverse flow in drainage pipe from rivers and the situation becomes more complicated. It results in a significant number of pipe being left full. And water surface elevation in most urban rivers become close to the upper-edge of revetment wall. Finally, when the rainfall stops and the tide level begins to decrease, the inundation depth tends to decrease except for the lowlands along the river. This is because the drainage system is recovering from the full state, and as a result, it is presumed that the floodwater on the roads has been removed into the system.

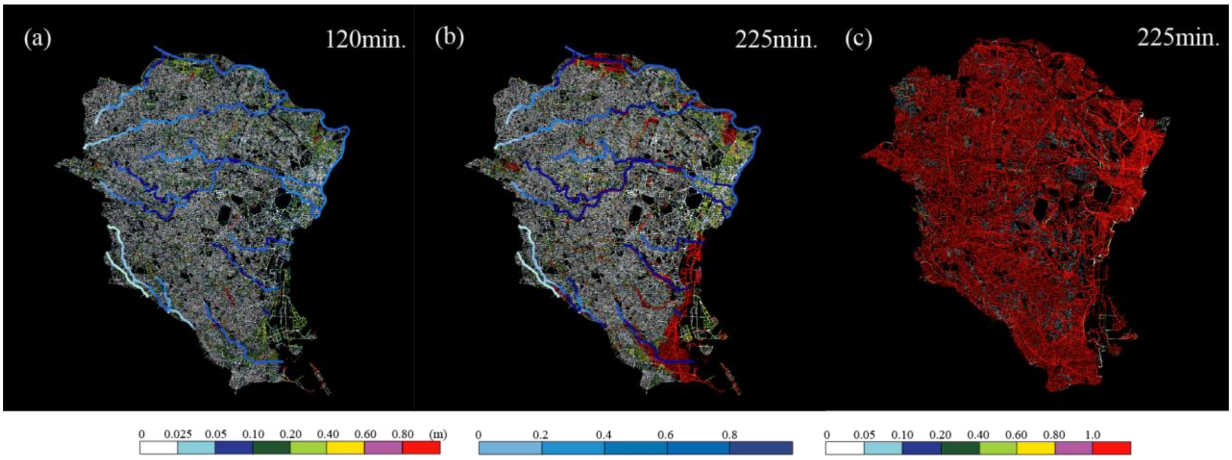

Figure 2. (a)(b) contour map of on road inundation depth at 120, 225 minutes from the beginning of rainfall, (c) contour map of drainage full rate at 225 minutes. Legend (from left): Road inundation depth, River relative water depth, Sewerage full rate.

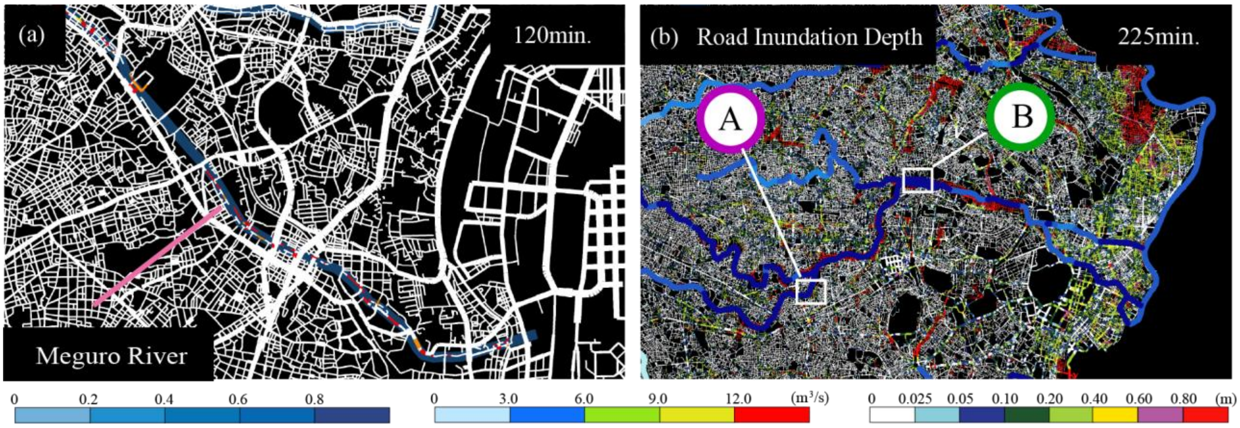

Figure 3. (a) Overflow discharge contour map along the river, (b) Inundation depth contour map along the Kanda River. Legend (from left): relative water depth from river, overflow discharge from river to road and inundation depth on roads.

3.2 Inundation in urban river basins

In the target area, there are many urban rivers extending from the west inland to the east coast. When the tide level of Tokyo Bay rises, rivers flowing directly into Tokyo Bay are affected by tidal fluctuations quickly, so the river water level will increase rapidly at a relatively early stage. In addition, a stream running up the river is generated. From Fig. 2, it can be seen that the relative water depth of the above rivers becomes large at the stage of 225 minutes from the beginning of this computation. Furthermore, as shown in Fig.3 (a), it can be seen that the overflow from river to urban area occurs along the Meguro River at 120 minutes after the time just before the rainfall peaked. Although points A and B indicated by circles in Fig.3 (b) are sufficiently far inland from the river and sea, inundation exceeding 0.8 m occurs at points along the river are shown in the figure.

Figure 4 shows the results at points A and B along the Kanda River. Fig.4 (a) and (b) show the temporal changes in the flow rate of water flowing from a road to a river or from a drainage pipe to the river at points A and B. When the value is negative, it means that there is flooding from the river over the revetment wall or reverse flow from the river to the drainage pipe. As the time goes on, the rainfall becomes severe, and the river water level rises due to the rise of the tide level. After that, reverse flow from the river to the drainage pipe has occurred. As can be seen from Fig. 4 (c) and (d), the drainage pipe leading to the river becomes full and the capacity of drainage is significantly reduced. Under such conditions, the tide level and the river water level rises, and the discharge from drainage pipe to the river became zero or negative. As mentioned above, the area where the inundation depth exceeds 0.8m spreads along the river, and in such area the overflow from the river occurred. It should be noted that the point A is about 15 km upstream from the river mouth of the Kanda River indicated by the circle in Fig.3 (b), and is the junction with the Zenpukuji River.

4. CONCLUSIONS

In this study, the largest possible heavy rainfall and storm surges were assumed, and the inundation prediction was performed under the condition of simultaneous occurrence. As a result, if a large amount of rainwater is discharged from the drainage pipe to the river due to the rainfall and/or the tide rises due to storm surge, the water surface elevation in upstream reach of the urban river flowing directly into Tokyo Bay also rises quickly. And the flow in river propagated in upstream direction, and the inundation in inland area faced urban river even

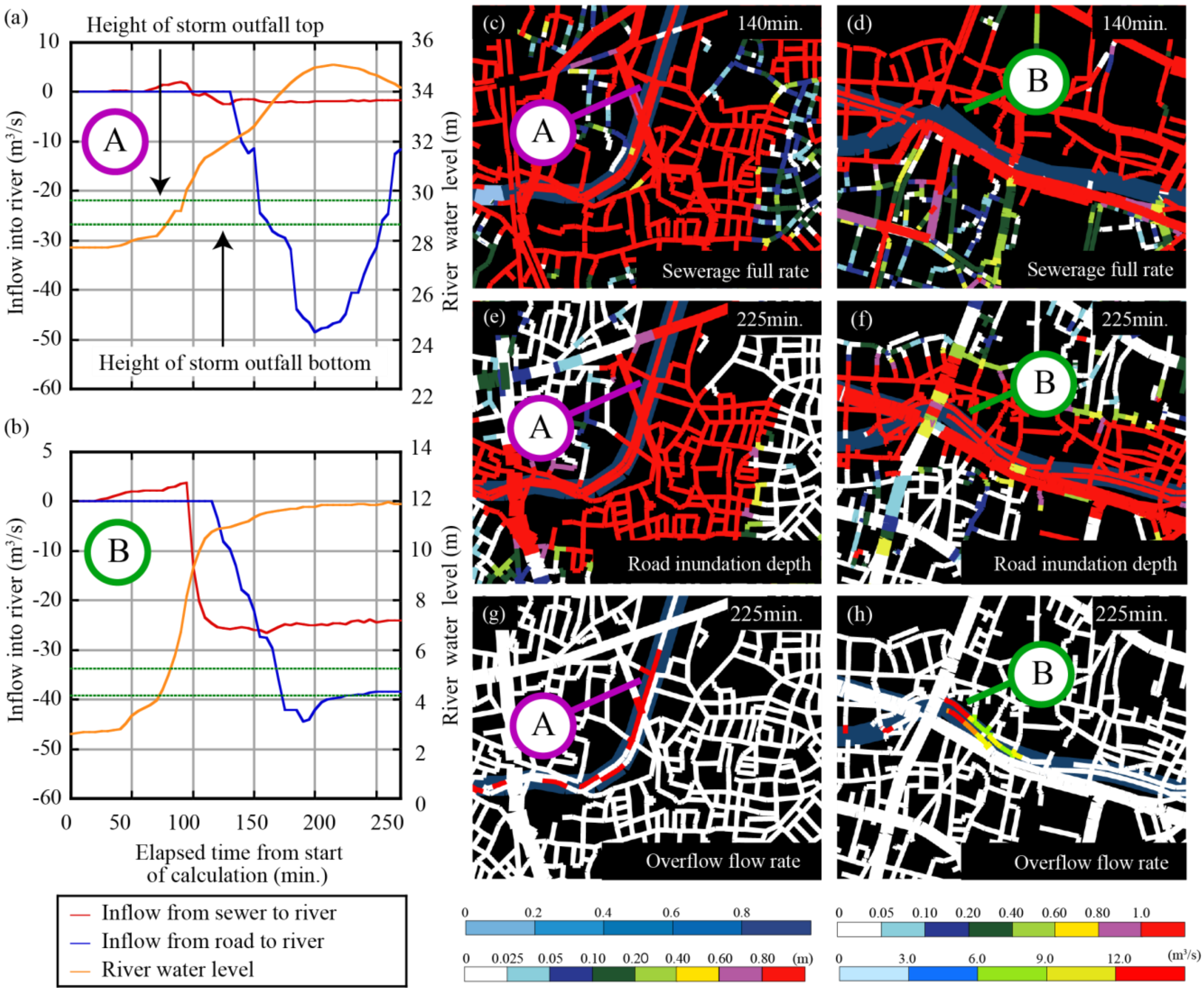

Figure 4. Results of computation at points A and B along the Kanda River: (a) and (b) Time change of inflow from road and sewer to river, (c) and (d) Contour map of drainage full rate at 140 minutes from the beginning of rainfall, (e) and (f) Contour map of road inundation depth at 225 minutes, (g) and (h) Contour map of overflow discharge from the river to the road at 225 minutes. Legend (from upper left to right): Relative water depth of river, drainage full rate, inundation depth on road and overflow discharge from river to road.

far from the river mouth becomes so severe. It is because the river water flows into a drainage pipe reversely and also flows over the revetment wall into inland area. The flooding from the Kanda River may cause enormous damage, if such storm surges and the torrential rain occur simultaneously.

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