Urban inundation analysis considering the water behavior of subway

Daisuke SATO (Chubu University), Makoto TAKEDA(Chubu University), Masataka MURASE (PASCO Corporation), Naoki MATSUO(Chubu University)

Introduction

Recently, the serious water disaster occurred due to heavy rain with wide area and long period under the influence of the global warming. As the occurrence of further natural disasters are concerned by the progress of the global warming, the countermeasures for the large scale inundation are very important. In highly urbanized areas such as Tokyo, Osaka, and Nagoya in Japan, the underground space is developed as underground shopping mall and subway. It is easy to imagine that if a large scale inundation occurs in such area, flood water will flow into the underground area and cause serious damage to people, economy and traffic. In order to estimate such water disaster and examine the countermeasures, it is important to understand the inundation situation of the land and the underground space due to large scale inundation.

The urban inundation analysis model has been developed in Tokyo, Osaka and Nagoya in consideration of the water behavior of the underground space(Murase et al., 2018). In this study, the analysis model applied to the inundation situation of Fukuoka city and Kyoto city. The aim of this study is to examine the feature of the inundation situation, the effect of grid scale on inundation analysis results, and evaluate the risk of underground space in the case of Fukuoka city and Kyoto city.

Model

Inundation analysis model

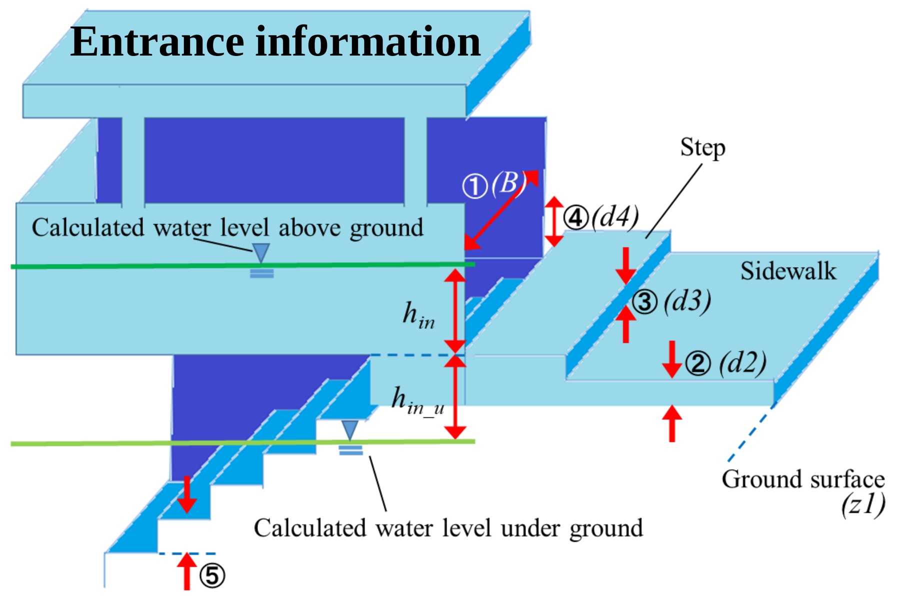
$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=-qo$$

$$\frac{\partial M}{\partial t}+\frac{\partial uM}{\partial x}+\frac{\partial vM}{\partial y}=-gh\frac{\partial (z_G+h)}{\partial x}+\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial M}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial M}{\partial y}\right)-\frac{\tau_{bx}}{\rho}$$

$$\frac{\partial N}{\partial t}+\frac{\partial uN}{\partial x}+\frac{\partial vN}{\partial y}=-gh\frac{\partial (z_G+h)}{\partial x}+\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial N}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial N}{\partial y}\right)-\frac{\tau_{by}}{\rho}$$

$$\tau_{bx}=\frac{\rho g n^2 M\sqrt{u^2+v^2}}{h^{4/3}}$$

$$\tau_{by}=\frac{\rho g n^2 N\sqrt{u^2+v^2}}{h^{4/3}}$$



Survey items
Check the location of entrance
Entrance width (B) : ①
Height from the ground surface to sidewalk (d2) : ②
Height from the sidewalk to step (d3) : ③
Water stop board height (d4) : ④
Height of one step the stairs from basement to the station yard : ⑤
Number of steps from basement to station yard
Height of one step the stairs from the station yard to the platform
Number of steps from the station yard to the platform

Figure 1 Measurement items of field survey

Analysis model of water behavior in underground space

$$A_u\frac{\partial h_u}{\partial t}=\Sigma Q_e-\Sigma Q_o$$

$$h_{in}=H-(z1+d2+d3)$$

$$h_{in\_u}=h_u+z_{bu}-(z1+d2+d3)$$

The large value is h_1 , the other is h_2.

$$h_2/h_1\leq\frac{2}{3} \qquad Qe=\mu Bh_1\sqrt{2gh_1}$$

$$h_2/h_1>\frac{2}{3} \qquad Qe=\mu' Bh_2\sqrt{2g(h_1-h_2)}$$

$$h_{s\_u}=h_s+z_{bs}-z_u$$

The value and h_{in_u} are lager in h_1 , the other is h_2.

$$h_2/h_1\leq\frac{2}{3} \qquad Qo=\mu Lh_1\sqrt{2gh_1}$$

$$h_2/h_1>\frac{2}{3} \qquad Qo=\mu' Lh_2\sqrt{2g(h_1-h_2)}$$

Analysis model on the water behavior of subway line

$$\frac{\partial A_s}{\partial t}+\frac{\partial Q_s}{\partial x}=qos$$

$$\frac{\partial Q_s}{\partial t}+\frac{\partial U_sQ_s}{\partial x}=-gAs\frac{\partial (h_s+z_{bs})}{\partial x}-\frac{gn_s{}^2Q_s|U_s|}{R_s{}^{4/3}}$$

u, v are the water velocity of the x, y coordinate respectively, h is the water depth, M, N are the flux (m²/s) of the x, y coordinate respectively($M=uh$, $N=vh$), q_o is the outflow discharge per unit area, $q_o=\Sigma Q_e/\Delta x\Delta y$ ($\Delta x\Delta y$: area of grid (m²)), z_G is the ground elevation, τ_{bx}, τ_{by} are bottom share stress (Pa) of the x, y coordinate respectively, ρ is water density, g is the gravity acceleration, ε_x, ε_y are the eddy viscosity coefficient of the x, y coordinate respectively (the value is zero in this study), n is Manning's roughness coefficient. A_u is the horizontal area of underground shopping mall and subway stations, h_u is the water depth, Q_e is the inflow discharge into underground shopping mall and subway station, Q_o is the inflow discharge into the subway line. h_{in} is the water depth at the entrance. h_{in_u} is the water depth of the underground shopping mall and subway station at the step of entrance. h_u is water depth of underground shopping moll and subway station, z_{bu} is the bottom elevation of underground shopping mall and subway station, μ is 0.35, μ' is 0.91, h_{s_u} is the water depth of subway line from bottom elevation of underground shopping mall and subway station. h_s is the water depth of subway line, z_{bs} is the bottom elevation of subway line. L is the circumferential length of the entrance of subway line. A_s is the cross sectional related the water flow of the subway line, Q_s is the discharge, q_o is the lateral discharge per unit length ($q_{os}=Qo/\Delta x_s$), U_s is the velocity, n_s is the roughness coefficient of Manning, R_s is the hydraulic radius. Slot width is calculated by gA_{ss}/C^2, A_{ss} is the cross section of subway line, C is the wave velocity(assumed 20m/s). x, y are coordinates and t is time.

Results

Difference due to the scale of the analysis grid size

(■ is boundary condition.)

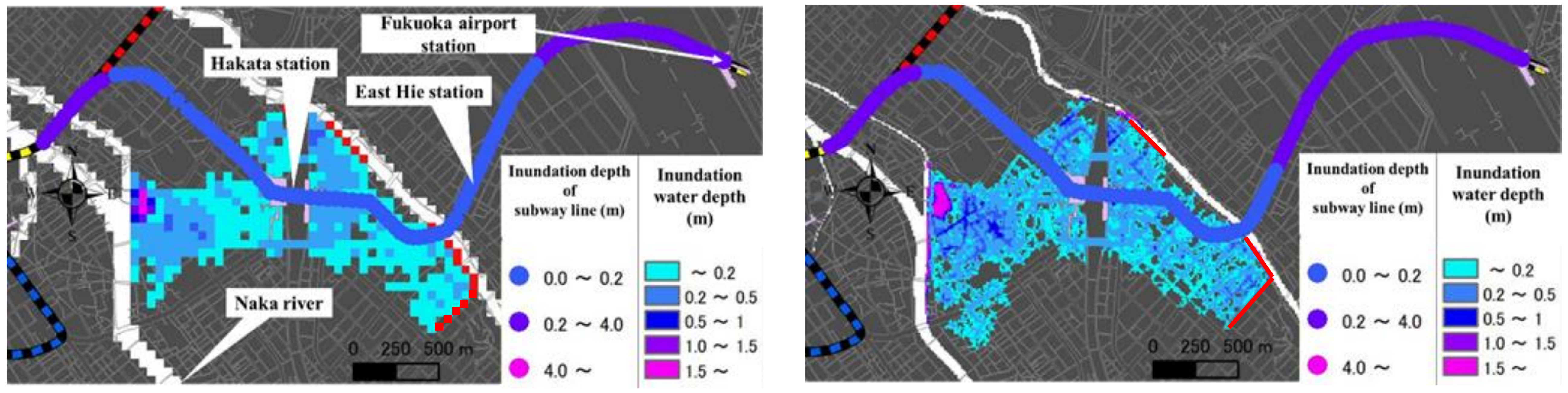


Figure 2 Maximum inundation water depth **in Fukuoka** (left : 50m grid, right : 10m grid)

Analysis results considering detailed information

(The point (✖) where constant inflow discharge (50m³/s) was given for 180 minutes.)

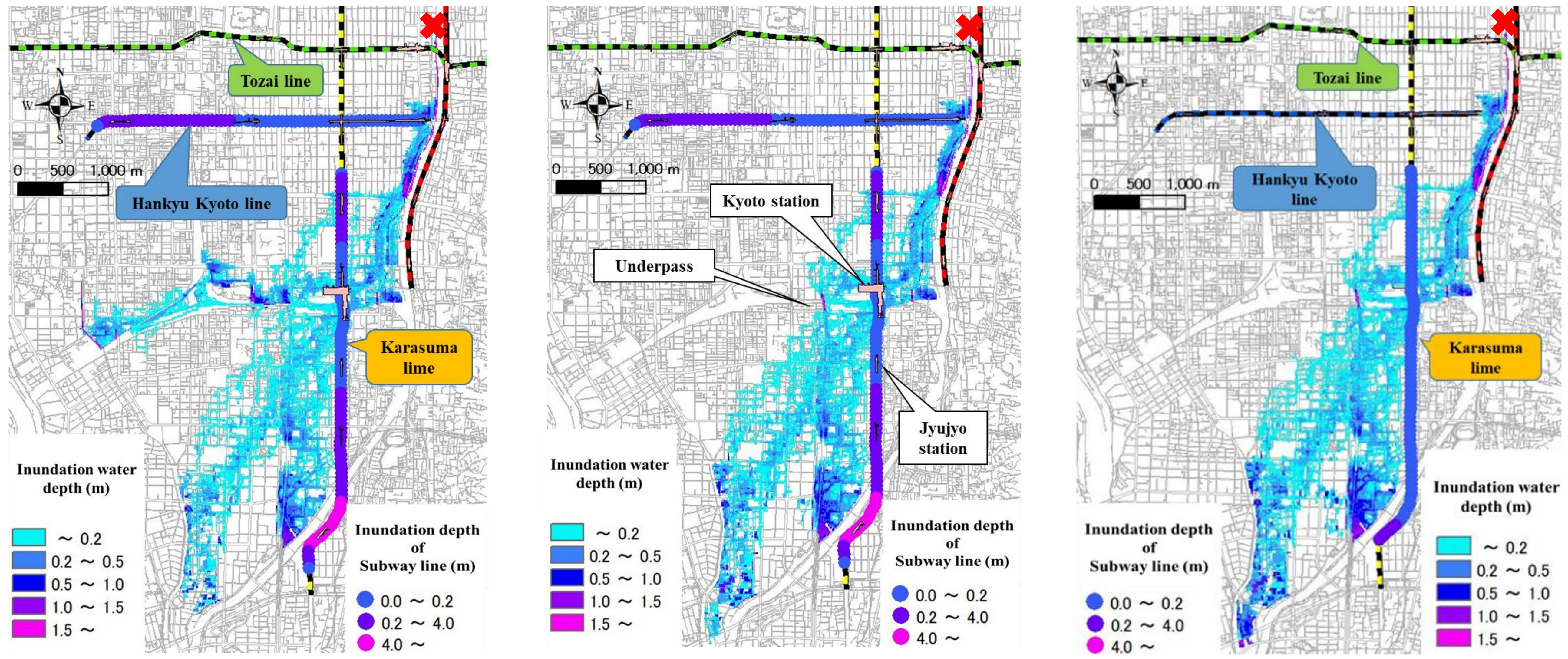


Figure 3 Maximum inundation water depth **in Kyoto**
(left : original , center : considering underpass , right : considering water stop board)

- The difference of analysis results were obtained by using 10m grid and 50m grid (Figure 2). The inundation area of 10m grid extends to the south part near the Naka River. Furthermore, in the case of 10m grid, the inundation water depth with 0.2m~4.0m is wider in subway line than the case of 50m grid.
- The behavior of the inundation water was changed by considering the underpass (Figure 3). The inundation area on the west side from Kyoto station decreased, and the inundation area and depth on the south side increased slightly. Further, by considering the water stop board, the inflow of flood water into the underground space was reduced to about 6.7%.

Conclusion

- By the numerical simulation on Fukuoka city and Kyoto city, the characteristics and danger of inundation situation on the land and underground space were clarified due to dike break in flood.
- It was shown that the inundation analysis using fine grid was effective, and the inundation analysis result changed depending on the consideration of micro topography such as underpass.
- It was shown that the water stop board was very effective for underground inundation under this analysis condition.

Reference
Murase et al.,2018, The inundation analysis the three major metropolitans areas by dike break of flood, Underground Space Symposium Papers and Reports, Vol.23,pp.97-102.