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URBAN FLOOD ANALYSIS CONSIDERING UNDERGROUND SPACE

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An integrated inundation flow model is developed which can treat both surface and underground urban inundation. We combine an inundation model on the surface with an underground inundation model. The surface inundation model is based on the horizontally two-dimensional unsteady flow model with unstructured meshes. The underground inundation model is based on the storage pond model, in which the underground mall is expressed as a combination of three-dimensional storage ponds. The drop flow formula is applied to the inflow at entrance to underground mall. This model is applied to Fukuoka City, Japan, and the inundation that occurred there in 1999 is simulated. The simulation results are in good agreement with the inundation records.

Key Words: *urban flood, inundation flow model, underground, Fukuoka flood*

1. INTRODUCTION

When flooding hits the central district of large cities, inundation occurs underground and damage can be serious, e.g., such as those in Fukuoka, Japan, in 1999 and in 2003 and that in Seoul, Korea, in 2001. This makes it very important to study inundations underground in terms of hydraulics and disaster prevention.

An inundation flow model is developed which can treat both surface and underground urban inundation. This model is applied to Fukuoka City, one of the large cities in Japan, and underground mall there.

2. SIMULATION MODEL

We combine an inundation model on the surface with an underground inundation model. The surface inundation model is based on the horizontally two-dimensional unsteady flow model with unstructured meshes[1)]. The basic equations are continuity and momentum equations.

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=r-r_d \tag{1}$$

$$\frac{\partial M}{\partial t}+\frac{\partial (uM)}{\partial x}+\frac{\partial (vM)}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{gn^2M\sqrt{u^2+v^2}}{h^{4/3}} \tag{2}$$

$$\frac{\partial N}{\partial t}+\frac{\partial (uN)}{\partial x}+\frac{\partial (vN)}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{gn^2N\sqrt{u^2+v^2}}{h^{4/3}} \tag{3}$$

where h is water depth, M and N are x and y directional discharge flux, respectively, r is rainfall intensity and r_d is drainage ability by sewer system. u and v are x and y directional velocity, respectively, H is water level from reference datum, g is gravity acceleration and n is Manning coefficient.

The underground inundation model is based on the storage pond model, in which the underground mall is expressed as a combination of three-dimensional storage ponds[2)]. Continuity and momentum equations are as follows:

(Continuity equation)

$$A\frac{dh}{dt}=\sum_{i=1}^{m}Q_i+Q_{in} \tag{4}$$

$$A = A_f : h < D, \quad A = A_s : h \geqslant D$$

where A is the effective storage pond base area, h is the water depth, Q_i is the inflow discharge from the i-th adjacent storage pond, and Q_{ins} is lateral inflow discharge from the ground surface. D is the ceiling height of storage pond, A_f is area related to storage pond shape and A_s is slot area.

(Momentum equation)

$$\frac{L}{gA_b}\frac{dQ}{dt}=\Delta H-\alpha LQ|Q| \tag{5}$$

where Q is discharge and L is the distance between base area centroids of adjacent storage ponds. A_b is the cross-sectional area of adjacent storage ponds, determined based on the water depths in adjacent ponds. ΔH is the water level difference between adjacent storage ponds and α is the loss coefficient associated with Manning coefficient.

At inflow from the ground surface to the underground space and dropping from upper to lower floors in multistory underground space, the following step flow formula is applied.

$$Q = B_e \mu h \sqrt{g h_e} \quad (6)$$

where, B_e is the effective width of entrance, μ is the discharge coefficient and h_e is water depth in the upper storage pond.

3. APPLICATION TO FUKUOKA CITY

(1) Studied area and computation conditions

Fig. 1 shows the studied area of about 2.8km^2. The ground elevation drops from the Mikasa River in the direction of JR Hakata station. **Fig. 2** shows the underground space under JR Hakata station. The subway track space was assumed to be a large storage pond. Total area and volume of underground except for subway space are about 5.2x10^4 m^2 and 16.9x10^4 m^3, respectively.

For the boundary condition, we used the overflow discharge from the Mikasa River obtained by Hashimoto et al.[3] The drainage by the sewer system of 36.4mm/hr, 70% of the designed value, was considered. Inflow into building basements and water stored in storage tanks of the underground mall were also considered. Steps of entrances to underground and pavement (30cm high in total) were also taken into account. The values of n were

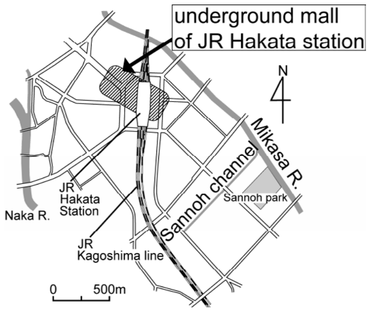

Fig.1 Studied area of Fukuoka City

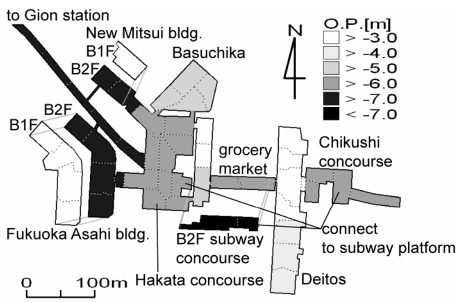

Fig.2 Studied underground mall under JR Hakata station

assumed 0.067 for ground and 0.03 for underground, and μ was set at 0.544.The non-linear convective terms in Eqs. (2)(3) were dropped here.

(2) Simulation results

Fig.3 compares the computed maximum water depth distribution and actual inundation records, both of which agree well. **Fig. 4** shows computed maximum water depth distribution and actual inundation records for underground areas studied. The computed result agrees well with actual records.

4. CONCLUDING REMARKS

Through the application of such an integrated model, the risk of underground inundation by heavy rainfall or overflow from the river can be discussed in more practical way.

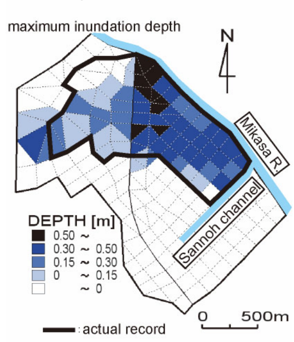

Fig.3 Maximum inundation depth on the ground

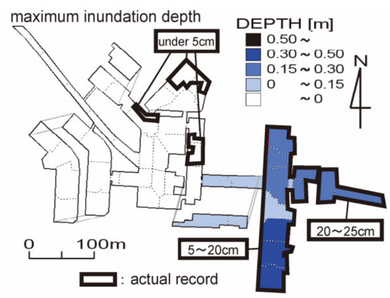

Fig.4 Maximum inundation depth of the underground

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