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Review:

Urban Flooding and Measures

Keiichi Toda

Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto 611-0011, Japan
E-mail: toda@taisui5.dpri.kyoto-u.ac.jp

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Urban flood disasters occur often worldwide, and Japan is no exception, as indicated by the 1999 Fukuoka flood. Urban floods result from changes in the urban environment influenced by the specific features of the city involved. We review recent urban floods, their causes and characteristics, together with the results of recent studies. Focusing on two mathematical models – the integrated urban flood model of urban river basins and the underground inundation model – we discuss their simulation results. To demonstrate the dangers of underground inundations, we introduce evacuation experiments conducted using full-scale staircase and door models. Based on these studies, we propose comprehensive measures against urban floods, including underground inundations.

Keywords: urban flood, inundation simulation, underground space, evacuation, measures

1. Introduction

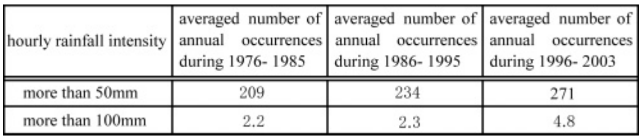
Flood disasters occur often in urban areas worldwide. The same is true of Japan, where urban floods occur almost yearly, e.g., the 1999 Fukuoka flood and the 2000 Tokai flood, and other East Asian countries such as South Korea, China, and Taiwan. In Europe, floods caused great damage in Prague, Czech Republic, and Dresden, Germany, along the Elbe River in August 2002.

Urban floods are closely related to changes in the urban environment. They also are influenced by urban area characteristics. Here, we review urban floods from the viewpoint of river basins, flood causes, and features, through recent studies on urban floods. Based on these studies, measures against urban floods are discussed. Note that this paper focuses on urban inundations caused by heavy rainfall, and does not deal with inundation by storm surges or Tsunamis.

2. Recent Urban Floods

Examples of recent urban floods include the June 1999 Fukuoka flood and the Tokyo flood in September 2005. The Fukuoka flood is of particular interest.

Table 1. Increase of heavy rainfall for a short time.



hourly rainfall intensity	averaged number of annual occurrences during 1976- 1985	averaged number of annual occurrences during 1986- 1995	averaged number of annual occurrences during 1996- 2003
more than 50mm	209	234	271
more than 100mm	2.2	2.3	4.8

2.1. Fukuoka Flood

Heavy rainfall in Fukuoka Prefecture on the morning of June 29, 1999, grew more intense in Fukuoka City, from 07:00, reaching an hourly 34 mm from 07:00 to 08:00 and 77 mm from 08:00 to 09:00. The 12-total from midnight to noon was 148 mm.

This and the consequent overflow from the Mikasa River flooded wide areas of the city. Inundation water flowed through the streets and reached Japan Railways (JR) Hakata station where the ground level was the lowest. The flow entered building basements, a subway station, and an underground shopping mall, causing heavy damage and drowning one woman in an underground restaurant about 400 m away from the station. Similar inundation occurred due to overflow from the Mikasa River in July 2003.

2.2. Tokyo Flood

On September 4, 2005, hourly rainfall exceeding 100 mm was observed at seven Tokyo area weather observatories and flooding from rivers and the sewer system damaged about 5,000 houses, especially in Nakano and Suginami Wards, inundating partially underground parking lots and basements. As the Kanda River basin's underground flood control storage system was completely filled with rainwater, another storage system then under construction was used in the emergency [1].

3. Urban Flood Causes

Main causes of recent urban floods involve (1) changes in rainfall attributed to climate change, (2) changes in runoff influenced by urbanization, and (3) features of urban areas suffering flood damage.

Table 1 shows the change in the frequency of local heavy rainfall nationwide based on the country's Automated Meteorological Data Acquisition System

(AMeDAS) data [2], comparing recent trends in the increase of short heavy rainfall to the situation 20-30 years ago. Rainfall tends to concentrate in comparatively narrow areas, as in Fukui in 2004, when over 200 mm of rainfall occurred during 4-5 hours in the Asuwa River Basin. Heavy rainfall is also likely recently when typhoons and weather fronts overlap.

Regarding changes in runoff, rainwater retention in an urban river basin is reduced as land becomes urbanized, with peak river water stages and discharge increasing and the duration from rises to peaks decreasing. These hydrographic changes raise the possibility of inundation due to river overflows and bank breaching much higher than before.

Land newly urbanized or developed is closely related to recent urban floods because it is potentially vulnerable to flooding or suffered from floods in the past. With increased runoff due to suburban development, fields developed into residential areas in the downstream river basin reduce rainwater retention, necessitating pump drainage where natural drainage no long functions well. Insufficient pump drainage capacity leads to flooding after heavy rains, especially, in low-lying areas in large cities and suburbs.

4. Urban Flood Features

Recent urban flooding in Japan is classified into (1) frequent inundation caused by drainage failure due to urbanization and (2) inundation due to urban rivers and channels overflowing due to heavy rainfall, with (2) carrying a potential for greater damage than (1). The sections that follow therefore focus on (2).

4.1. Sudden Short Inundations

As stated, discharge increases and quick peaks in urban rivers cause sudden flooding by overflow that expands quickly in urban areas. The inundation flows down streets between buildings forming a channel and may expand more quickly than in the countryside.

4.2. Inundation Expansion

Such water causes damage to both houses and buildings also to vehicles, which may drift and complicate the flow. Water may stagnate at underpasses, where cars may be submerged. Water also enters underground spaces such as malls and subways, many of which are multistoried, constituting complex three-dimensional networks as water flows to lower floors.

4.3. Complex Damage

Population, property, and information tend to be highly concentrated in city centers, where flooding may cause deaths by drowning or paralyze urban functions.

The water velocity is likely to be high along streets between buildings, possibly carrying away people trying to evacuate or trapping them in ditches or manholes. Water penetrating underground areas through staircases, rises rapidly, making evacuation very dangerous if not impossible, and presenting the most serious situation for evacuees.

If lifeline infrastructures such as electricity, gas, and water supplies are inundated, urban functions are paralyzed. Traffic is disrupted if streets are submerged. Emergency medical care at hospitals is also disrupted, along with regular civic life. Inundation impacts heavily on information and communication facilities and thus on economic activities.

4.4. Long-Term Recovery and Restoration

Lifeline infrastructure damage takes a long time to recover, disrupting civic life. Submerged enterprises must suspend business, especially in underground areas that cannot be drained quickly or easily. Underground areas also require much work to clean up, e.g., garbage disposal, and take more time to restore completely.

5. Simulation of Urban Flooding Due to Heavy Rainfall

It is very important to determine whether flooding will occur when rivers or sewers overflow their confines due to heavy rainfall and if it occurs, where and to what extent it will cause a dangerous situation. This information will help residents to keep safe and local governments to make measures against flooding. Simulation models to predict urban flooding based on mathematical models have been developed, some of which are in practical use. A simulation model for urban flood prediction introduced below is developed considering the entire river basin, including urban areas.

5.1. Simulation Model

A mathematical model is developed that expresses flood occurrence by heavy rainfall in urban areas, inundation flow behavior by overflow from rivers and drainage process by a sewer system comprehensively and in detail. The model is applied to Kyoto City, the old capital in Japan, and the applicability of this model is studied through comparison with inundation records.

The model consists of three sub-models:

(1) Runoff model for mountainous areas surrounding urban areas (mountainous area model);

(2) Inundation flow model for a studied city area (city area model);

(3) Sewer model demonstrating drainage by a sewer system (sewerage model).

The model concept is shown in **Fig. 1**. Sub-models are detailed below.

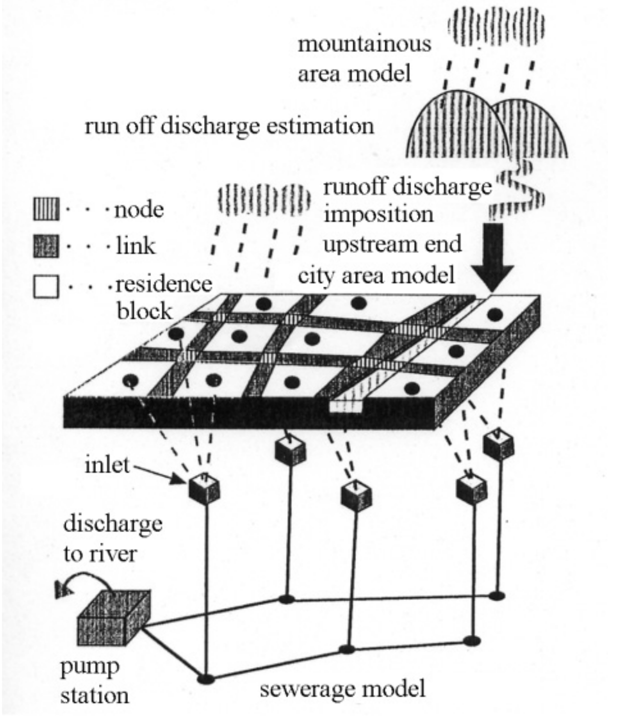


Fig. 1. Framework of total model.

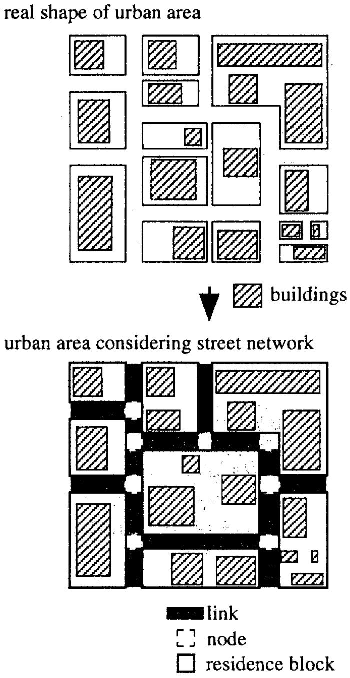


Fig. 2. Modeling of street network.

5.1.1. Mountainous Area Model

The mountainous area model is a slope runoff model based on the kinematic wave model. Once rainfall distribution is imposed on the river basin studied, runoff discharge at the downstream boundary in the mountainous area model, i.e., discharge at the upstream boundary in the city area model is obtained.

5.1.2. City Area Model

In inundation analysis in a built-up urban area, inundation flow must be taken into account, meaning the blockage of inundation flow by buildings or its spread along streets must be well expressed. So, we use a street network model in which a network consists of street links, cross point nodes, and residence blocks comprising buildings and vacant grounds [3] (**Fig. 2**).

Urban rivers and channels are regarded as streets whose elevation is low and are incorporated into the street network. River discharges obtained by the mountainous area model are imposed as the upstream boundary conditions. By these techniques, the inundation process by overflow from rivers and channels to streets and surfaces along them can be expressed in a creative way. Rainfall onto the city is taken into account as a lateral inflow. Surface elevation at the node where a street and a river (channel) intersect is replaced by river (channel) bed elevation.

Basic equations in links are expressed as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}=\frac{q_{in}}{B}+q_{rain}$$

$$\frac{\partial M}{\partial t}+\frac{\partial (uM)}{\partial x}=-gh\frac{\partial H}{\partial x}-\frac{gn^2|M|M}{h^{7/3}}$$

where u and M are velocity and mass flux in the longitudinal direction, respectively, h is water depth, H is water level from a reference datum, g is gravity acceleration, n is Manning roughness coefficient, q_{in} is lateral inflow (inflow discharge from residence block to link per unit distance), B is link width, and q_{rain} is rainfall per unit time.

The continuity equation at the node and residence block is treated based on discharge in and out as follows:

$$\frac{\partial h}{\partial t}=\frac{1}{A_m}\sum_{k=1}^{K_m}Q_k+q_{rain}$$

where A_m is area of the node or residence block, K_m is the total number of sides comprising the node or residence block, and Q_k is inflow discharge from the k-th side. In the connections of link, residence block and node, the momentum equation is expressed by neglecting the nonlinear convective term:

$$\frac{\partial M}{\partial t}=-gh\frac{\partial H}{\partial x}-\frac{gn^2|M|M}{h^{7/3}}$$

h and $M(Q)$ are solved from the continuity equation and momentum equation alternately by the leap frog method, and variables in both links and nodes (residence blocks) are solved together.

5.1.3. Sewerage Model

In a real urban area, sewer network systems both combined and separate spread in a complex way. Some of them flow out rainwater to rivers in a city directly and others discharge it to sewer plants and pump it out to rivers outside. Here, only modeling of the latter type by main sewer network is developed.

The model is a simple drainage type, considering only

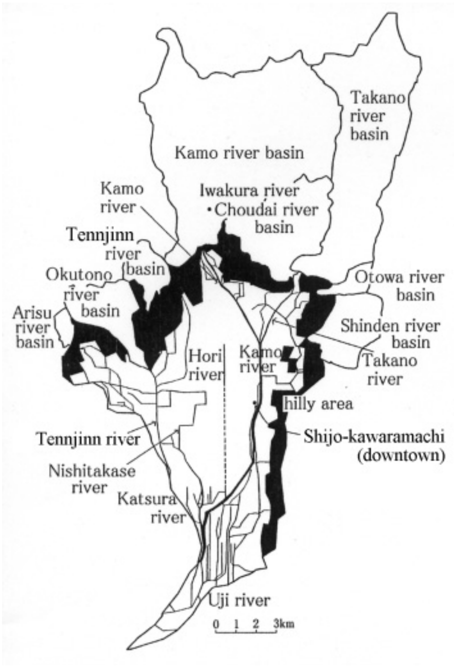


Fig. 3. Area of Kyoto City studied.

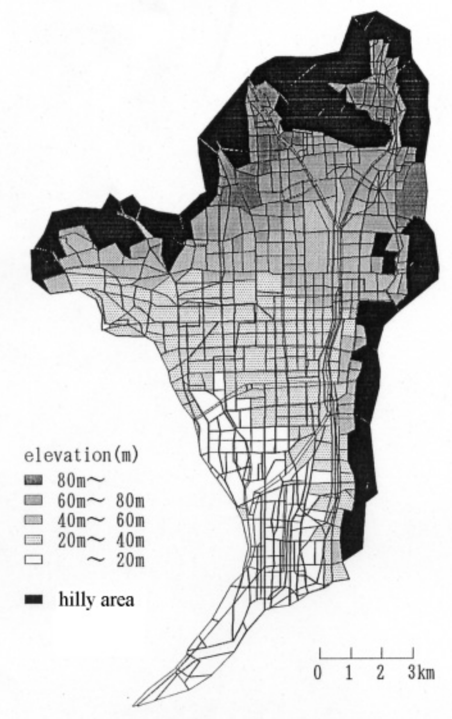


Fig. 4. Ground elevation and network.

the traveling time of water in a sewer system. First, the total catchment area is divided into sub-catchment areas. Next, the maximum drainage discharge for each sub-catchment is allocated based on the proportional distribution of sub-catchment areas from the maximum drainage discharge of the pump station at downstream end. Then, the drainage discharge, less than the allocated maximum discharge of each sub-catchment, is imposed at each sewer network node. So, discharge flowing down the sewer system does not exceed the assumed maximum drainage discharge. It flows down at a constant velocity and finally flows from the downstream pump station to rivers outside.

5.2. Studied Area and Remarks on Model Treatment

The above model was applied to Kyoto City area. The studied area is the central area of Kyoto City (**Fig. 3**). Kyoto City is surrounded by mountains to the north, east, and west. The Kamo River runs through the city center, the Katsura River on the west side and the Uji River on the south side. The studied area of "city area model" is that surrounded by the left bank of the Katsura River and the right bank of the Uji River. The ground surface elevation distribution is shown in **Fig. 4**. In Kyoto City, slopes are fairly steep north-south and the east side is higher than the west. The studied area of "mountainous area model" involves the eight river basins in **Fig. 3**. A hilly area between the mountainous area and the city area was treated as the residence blocks with high elevation in the city area model, where inflow from other link or node is not taken into account. **Fig. 4** also shows the city area network comprising nodes and links (streets, rivers and channels) and residence blocks.

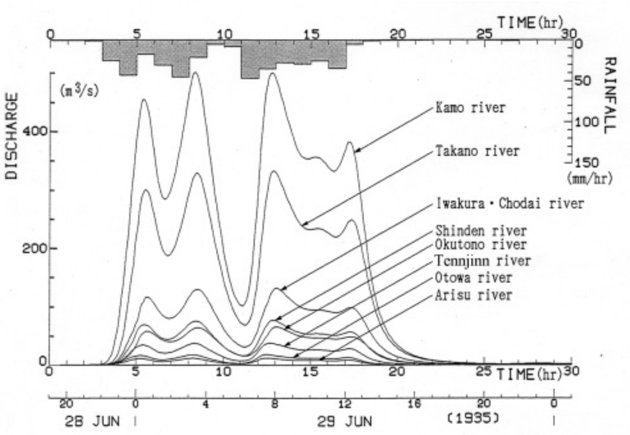


Fig. 5. Rainfall and runoff discharge.

The city has culvert type rivers. They were treated as open channels and expressed by a river link without lateral inflow. Ditch depth from the surface elevation to the riverbed was divided into four classes by river scale and set as a constant. The sewer model considered three main sewer networks that have pumping stations downstream. Pump drainage capacity is 190 m^3/s in total.

Rainfall conditions were taken from heavy rainfall records in Kyoto City from June 28 to 30, 1935. The hyetograph used is shown in the upper part of **Fig. 5**. Computation started at 19:00 June 28, 1935, defined as 0.0 hr. It was assumed that the same rainfall occurred in both mountainous and city areas. Initially, the city area including rivers and channels was assumed to be dry. Rainfall infiltration on the city area surface was not considered. In runoff analysis, runoff rate f was assumed to be 0.7.

In the city area model, Manning roughness coefficient

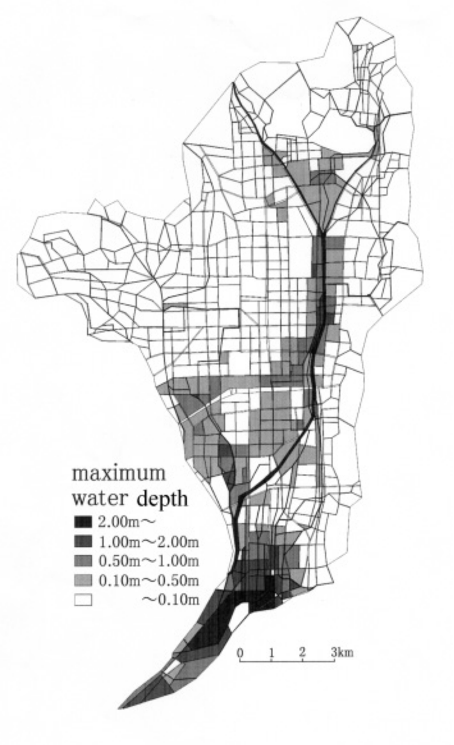


Fig. 6. Distribution of maximum inundation depth (computed).

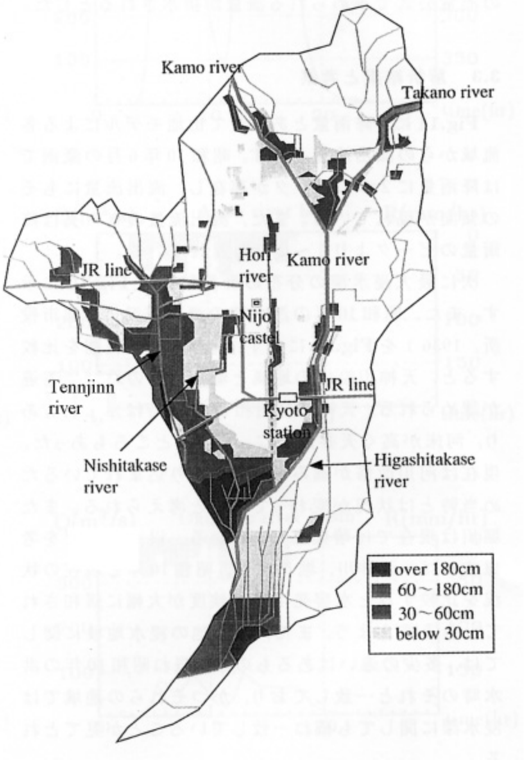


Fig. 7. Distribution of maximum inundation depth (record in 1935).

n was determined so that $n = 0.067$ at residence blocks, $n = 0.043$ at links and nodes and $n = 0.02$ at rivers and channels. The sewer pipe network flow velocity was set at a constant 2.0 m/s. For the other data, the present topographical data and the hydraulic data were used.

5.3. Computation Results and Discussion

Runoff discharge hydrographs are shown in the lower part of **Fig. 5**. The hyetograph shows two peaks and the hydrograph pattern corresponds to this. Peak runoff discharge is delayed 1 to 2 hours from the hyetograph peak.

Figure 6 shows the computation results for the maximum inundation flow depth distribution. **Fig. 7** shows the inundation depth distribution record in 1935. A comparison shows differences in both the western (Tennjinn River) and central (Hori River) areas. In 1935, the Tennjinn River was not improved and the riverbed was high. Later river improvement work lowered the riverbed. The Hori River has been changed to a culvert. The above results show that the flood risk in Kyoto City now is much less than in 1935. The other inundation area now mostly accords with that in 1935. The inundation depth distributions in 1935 and now are almost similar.

Figure 8 shows the temporal change of inundation depth at Shijo-Kawaramachi, in a downtown area (**Fig. 3**). By the overflow from the Kamo River, the maximum depth reached almost 1 m in 9 hours, and about 50 cm inundation depth continued for 11 hours. This is in the central commercial area of Kyoto City, which has an underground shopping mall and subway station. If such inundation occurs, it would heavily damage both surface and underground areas.

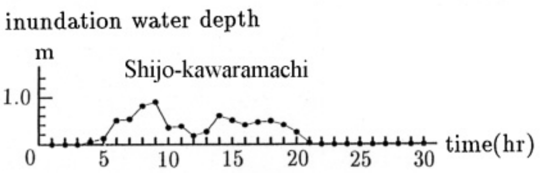


Fig. 8. Temporal change of inundation depth.

6. Simulation of Underground Urban Flooding

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 simulation model based on a storage pond model [4] is developed which can treat both surface and underground urban inundation. Continuity and momentum equations and a step flow formula are used as basic equations in the model. The inundation model on the ground surface here differs from that described in the preceding section and does not consider drainage by sewers for simplicity.

This model was applied to Fukuoka City, Japan, and the 1999 Fukuoka inundation was simulated in both on surface and in underground areas.

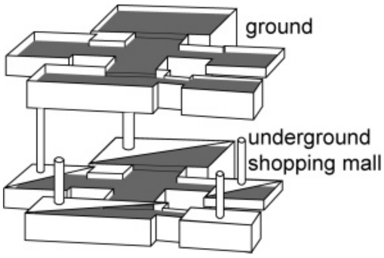


Fig. 9. Storage pond model.

6.1. Simulation Model

Underground spaces such as shopping malls are generally composed of stores, open spaces, subway entrances, and basements of adjacent buildings. An underground mall may be very complex, but can be divided into parts, assumed to be storage ponds with their own volume. And it can be expressed as a combination of three-dimensional storage ponds (**Fig. 9**). Slots expressing small areas of ceiling such as stairwells are incorporated in each pond, taking into account both open channel flow and pressurized flow conditions. Inundation dispersion is expressed by obtaining the discharge flowing between adjacent ponds. Ground surface inundation is calculated similarly, without slots.

Continuity and momentum equations are as follows:

(Continuity equation)

$$A\frac{dH}{dt} = \sum Q_i + Q_{ins}; \quad A = A_f : h < D, A = A_s : h \geq D$$

where A is the effective storage pond base area, H is the water stage, Q_i is the inflow discharge from the i-th adjacent storage pond, and Q_{ins} is lateral inflow discharge from the ground surface. h is water depth and 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)

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

where Q is discharge, g is gravity acceleration, 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.

$$Q = B_e \mu_0 h_e \sqrt{gh_e}$$

where, B_e is the effective width of entrance, μ_0 is the discharge coefficient and h_e is water depth in the upper storage pond. If the lower storage pond is pressurized, the above momentum equation is applied.

Fig. 10. Studied area of Fukuoka City.

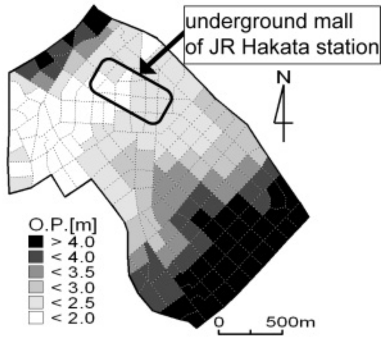


Fig. 11. Fukuoka City ground elevation.

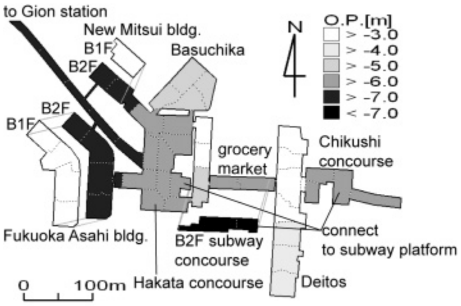


Fig. 12. Studied area of JR Hakata station underground mall.

6.2. Application to Fukuoka City

6.2.1. Studied Area and Computation Conditions

Figure 10 shows the studied area of about 2.8 km^2 and **Fig. 11** shows the ground elevation distribution. Ground elevation drops from the Mikasa River in the direction of JR Hakata station. **Fig. 12** 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 5.2×10^4 m^2 and 16.9×10^4 m^3, respectively.

For the boundary condition, the overflow discharge from the Mikasa River obtained by Hashimoto et al. [5] was used. **Fig. 13** shows the discharge hydrographs and **Fig. 14** shows the storage ponds to which overflow discharges are allocated as lateral inflows. Computation starts at 09:00 on June 29, 1999, when overflow began

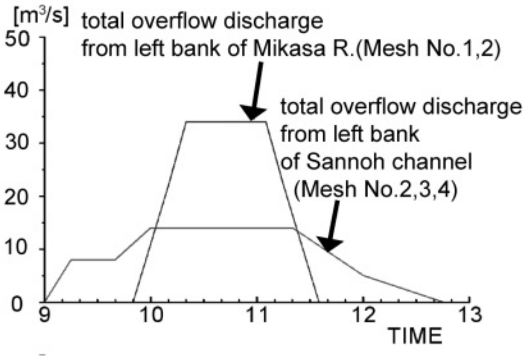


Fig. 13. Inflow discharge hydrographs.

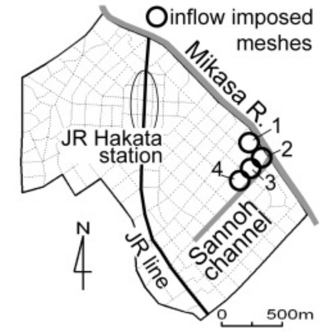


Fig. 14. Inflow Imposed meshes.

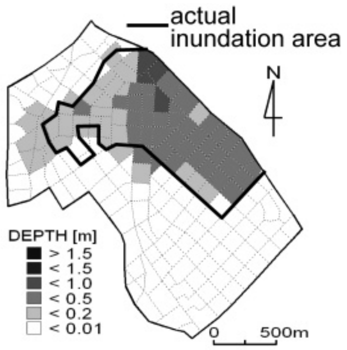


Fig. 15. Maximum inundation depth on the ground.

from the Sannoh channel.

The drainage by the sewer system of 36.4 mm/hr, 70% of the designed value, was considered. Inflow into building basements and water stored in storage tanks of the underground mall were considered. Steps of entrances to underground spaces and pavement (30 cm high in total) were also taken into account. The values of Manning coefficient n were assumed to be 0.067 for ground and 0.03 for underground, respectively, and the discharge coefficient of the step flow formula was set at 0.544.

6.2.2. Computation Results

Figure 15 compares the computed maximum water depth distribution and actual inundation records, both of which agree well. The inflow water volume into basements of buildings and water volume stored in storage tank of the underground mall amount to 6.0×10^4 m^3 and 1.3×10^4 m^3, respectively.

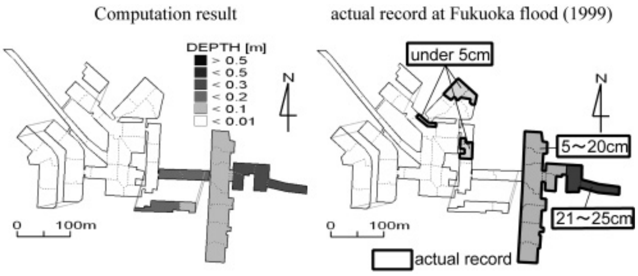


Fig. 16. Maximum inundation depth of the underground.

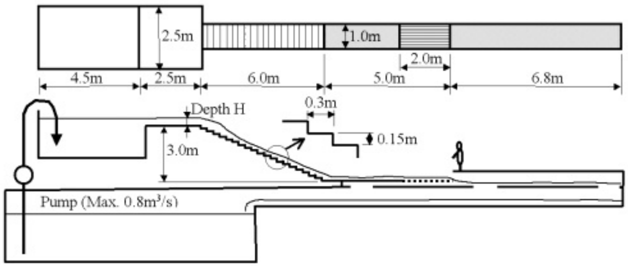


Fig. 17. Real size model of staircase.

Figure 16 shows computed maximum water depth distribution and actual inundation records for underground areas studied. The computed result agrees well with actual records. The computed water volume flowing into the subway track space is about 5,000 m^3 at 13:00, while the actual water volume is assumed to be 1,000-2,000 m^3. This difference may be due to the estimation accuracy of the water volume stored in the storage tank and the step height of entrances to the underground mall.

Such an application of the model indicates practically what actual inundations may do.

7. Evacuation in Underground Inundations

Underground inundations make it necessary that people evacuate immediately via staircase against a swift inflow. Underground areas are much smaller than surface areas, so water rises rapidly. People caught in basements must attempt to evacuate from doors held shut by hydrostatic pressure. When we consider a suitable evacuation way from underground space in flooding, it is very important to understand the critical condition of evacuation via staircase or by opening a door. Evacuation experiments using real-sized models are introduced below.

7.1. Evacuation via Staircase

To simulate real flow in a staircase, an actual-sized model was installed (**Fig. 17**). It has 20 steps with 0.3 m treads and 0.15 m risers for a total height of 3 m and width

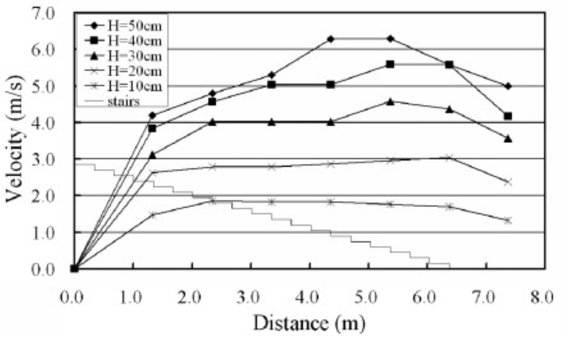


Fig. 18. Velocity distribution.

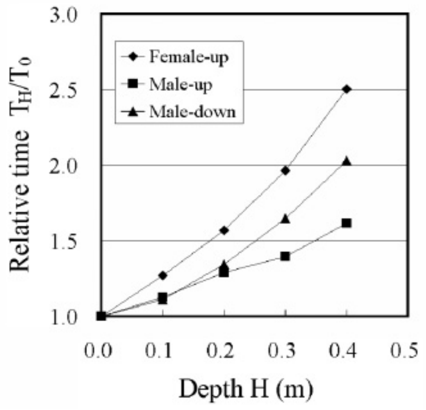


Fig. 20. Evacuation time.

Fig. 19. Evacuation experiment by use of staircase model.

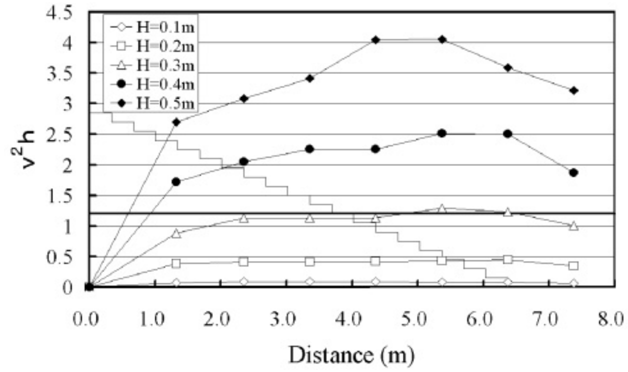


Fig. 21. Distribution of momentum.

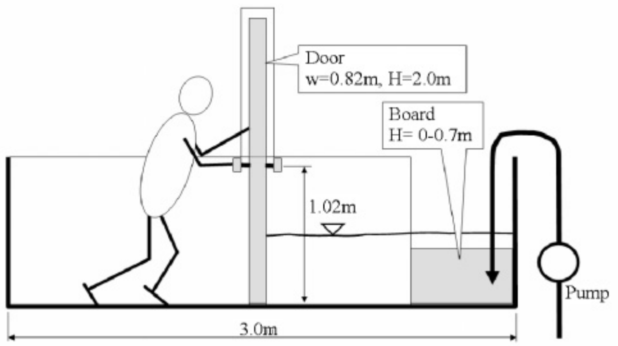


Fig. 22. Real size model of door.

of 1 m. Flow discharge is supplied up to 0.8 m^3/s. Evacuation tests were conducted by 49 subjects and water depth and flow velocity were measured. Flow velocity near the water surface was measured by a visualization method. Fluorescent tennis balls were used as tracers and illuminated by ultraviolet lamps and the location and time of each ball was calculated. **Fig. 18** shows the distribution of flow velocity along the staircase. Flow velocity is high, exceeding 4 m/s when water depth on the ground (H in **Fig. 17**) exceeds 0.3 m.

Subjects were 16 women and 33 men. Evacuation time required to walk across a 5 m landing and up a 20-step staircase was measured at four water depths from 0.1 m to 0.4 m. A lifeline was used for safety at 0.3 m and 0.4 m (**Fig. 19**). **Fig. 20** shows the relationship of evacuation time T_H to water depth H. Evacuation time is normalized by walking time without water flow T_o. The figure shows the time required to descend the staircase for reference. Evacuation time increases with water depth on the ground and the gradient of curve changes between 0.2 m and 0.3 m for women, and between 0.3 m and 0.4 m for men, respectively. And 70% of subjects found it difficult to evacuate at water depths exceeding 0.3 m.

Another criterion of evacuation was shown by Takedomi et al. [6]. Using momentum expressed by velocity (v) and water depth (h) of flow over a staircase, they found that $v^2h = 1.5$ m^3/s^2 is the evacuation limit. **Fig. 21** shows the momentum distributions obtained from the experiment. Given **Fig. 20** results and subjects' comment of limit of $H = 0.3$ m, the critical condition for evacuation of $v^2h = 1.5$ is reasonable and, in fact, $v^2h = 1.2$ may be the critical condition.

7.2. Evacuation Through Door

To investigate the critical water depth in front of a door, a real-sized door model was used (**Fig. 22**) and 59 subjects – 47 men and 12 women – attempted to open the door at several water depths (**Fig. 23**). Experiments showed the critical water depth in front of the door to average 0.4 m for men and 0.35 m for women. The critical depth for children to evacuate, determined by 10-year-olds in experiments, was about 0.30 m.

Fig. 23. Evacuation experiment by use of door model.

8. Measures Against Urban Flooding

8.1. Prevention and Reduction of Inundation

Measures to prevent or reduce flooding and inundation damage on the ground are as follows:

(1) For structural measures, it is required to review urban river discharge capacity and to promote river improvement works if necessary. In urbanized river basins, runoff discharge tends to increase. Once river embankments overflow or are breached, severe inundation damage is inevitable. The water volume brought in such cases is much greater than water brought by rainfall in flood-prone areas. It is very important to examine runoff discharge through runoff analysis considering changes in land use and land covering condition, and to clarify the current flood-baring capacity of rivers through hydraulic analysis. If safety against river flooding is low, it should be improved from the viewpoint of total river basin management.

In sewer drainage plan, it is assumed that rainfall water can be drained through sewer systems into rivers unconditionally. But when the river water level is high, drainage capacity is greatly reduced, and in some cases, drainage itself may be limited by the danger of the river. This makes it important to review net sewer drainage capacity and to improve both natural drainage and pump drainage capacity. Large and small rainwater storage facilities are considered effective in developed urban areas.

(2) For nonstructural measures, it is required to draw up urban flood hazard maps and inform residents of inundation risks and emergency evacuation information. Given the “facelessness” of urban neighborhoods and the lack of communication between residents, newcomers may be ignorant of the flood risks. Educational activities are important especially to urban residents, which may lead to flood damage prevention or reduction.

8.2. Measures Against Underground Inundation

Measures for preventing or reducing underground inundation damage are as follows:

(1) Typical structural measures include setting of flash-boards or steps at entrances. This could greatly reduce underground inundation and, in large-scale river flooding, could do much to slow underground inundation. As for steps, some devices such as mild slope-like shape are required from the barrier-free aspect.

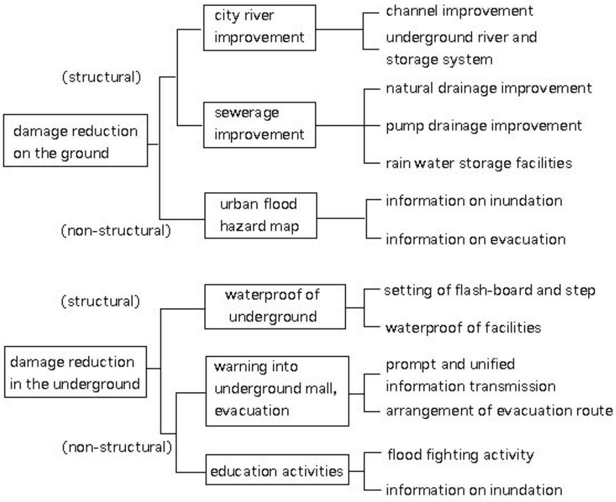


Fig. 24. Measures against urban flood.

Many underground drainage pumps are set for spring water or some rainwater intrusion. But they have such limited capacity that they cannot deal with inflows of water caused by heavy rainfall concentrations or river flooding. The large scale pump facilities that would actually be required could not be fit into most underground areas, nor could the places required for discharging high water volumes.

(2) Typical nonstructural measures are suitable information transmission and evacuation systems. In many cases, people underground do not know what happens aboveground, and information is not transmitted well in underground areas.

It is very important to develop information transmission that informs people underground of meteorological, riparian, and aboveground conditions promptly. Information should be condensed by related agencies and suitably transmitted to avoid panics. Given the large, miscellaneous crowds that flock to underground areas, the need for good evacuation route maps and simple, plain evacuation signage, together with emergency electricity in power failures become especially important.

In addition, citizen awareness is indispensable in flood disaster prevention underground. People working in underground business districts and shopping mall are rarely aware of the danger underground flooding can bring. It is important for them to recognize such danger and to consider initial disaster prevention in daily life. If people are realistically aware of the need for quick evacuation and are informed of what to do, worst-case scenarios could be avoided.

The above measures are summarized in **Fig. 24**.

9. Concluding Remarks

Urban inundations tend to trigger excessive damage due to the complexity of urban structures and the large concentrations of people and property. It is thus urgent that urban flood risks should be reviewed, predicted in detail, and followed up by concrete suitable flood measures involving structural and nonstructural aspects.

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Name:
Keiichi Toda, Ph.D.

Affiliation:
Professor, Disaster Prevention Research Institute, Kyoto University

Address:
Gokasho, Uji, Kyoto 611-0011, Japan

Brief Career:

1986- Postdoctoral Associate, Iowa Institute of Hydraulic Research, University of Iowa, U.S.A.
1986-1994 Newjec Co. Ltd., Osaka, Japan
1995- Disaster Prevention Research Institute, Kyoto University, Japan

Selected Publications:

- "Hydraulic Design of Intake Structures of Deeply Located Underground Tunnel System," Water Science and Technology, Vol.39, No.9, pp. 137-144, 1999.
- "Hydraulic Model Test of Inundation Water Intrusion into Complicated Underground Space," Journal of Hydroscience and Hydraulic Engineering, Vol.23, No.2, pp. 13-25, 2005.

Academic Societies & Scientific Organizations:

- International Association of Hydraulic Engineering and Research (IAHR)
- Japan Society of Civil Engineers (JSCE)
- Japan Society for Natural Disaster Science (JSNDS)