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HYDRAULIC MODEL TEST OF INUNDATION WATER INTRUSION
INTO COMPLICATED UNDERGROUND SPACE

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SYNOPSIS

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A hydraulic model test of water intrusion in underground space is conducted by means of the undistorted hydraulic model with 1/30 scale. The studied underground space is complex and comprises a shopping mall, parking lots and a subway station. Inundation processes are studied in detail and a means of evacuation from underground space is examined based on the depth and velocity of inundation flow through stairs. Experimental results show that if the inundation flow penetrates the studied underground space, the inundation area expands rapidly and the water depth rises very quickly. As for the stairs, the possibility of evacuation is influenced by the discharge to stairs, and according to the existing criteria it becomes impossible to pass through stairs if the overflow reaches a depth of 0.5m. In inundation, the studied space also becomes very dangerous due to the difficulty in evacuating.

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INTRODUCTION

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Recent urban floods such as Fukuoka floods in Japan in 1999 and in 2003 and Seoul flood in Korea in 2001 induced inundation into underground spaces such as basements, underground malls and subways. Underground

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spaces are located in the deepest areas of the city, therefore they are very likely to be damaged by floods, and it is very important to examine inundation flow behavior in underground space from the hydraulic and disaster preventive aspects.

As far as the water inundation into underground space is concerned, Takahashi et al. (4), authors (6) and Sekine and Kawakami (3) have developed numerical simulation methods. In their studies, however, the validity of computation results or the applicability of the model to real underground spaces is not examined sufficiently. In addition, inundation flow configurations cannot be simulated in detail by using a model in the case of really complicated underground spaces including stairs. Therefore, experimental study is also important in helping to understand the flow configuration and in obtaining data for calibration of simulation model.

This paper deals with a hydraulic model test of inundation in the multiple storied underground spaces comprising a shopping mall, parking lots and a subway station. Through numerous experiments under the various conditions, inundation flow behaviors in the underground space including stairs are studied in detail. Also, the possibility of evacuation from underground space in inundation and necessity of suitable evacuation system are discussed.

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STUDIED AREA AND EXPERIMENTAL SETUP

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Studied area

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The underground space which was studied (Kyoto Oike underground space) is located in the central area of Kyoto, Japan. The Kamo River runs in the near east side (see Fig. 1). This underground space is a multiple storied one, and consists of a shopping mall, a subway station concourse and a parking lot on the first basement floor (B1F), a parking lot on the second basement floor (B2F) and a subway platform on the third basement floor (B3F) (see Fig. 2). The horizontal area of B1F and B2F is about 650m×40m with the ceiling height of 3.5m, and on both B1F and B2F, there is a 1.5m step on the center, and the east side is 1.5m lower than the west side. The area of B3F is about 100m×8m with the ceiling height of 2.7m, and the walls and doors with openings at 2.4m high are installed on the subway platform (see Photo 1). The platform doors are closed while there are no trains in the station. The total floor area of this underground is about 50×10^3 m^2 and the volume is about 180×10^3 m^3.

Entrances to the underground are shown in Fig. 3. On the ground level, there are three car entrances (11, 14, 29) and twenty-four stair entrances (1~10, 12, 13, 17~28) to the underground on B1F. The parking lot on B2F is connected to the ground through the two car entrances on the east side (15, 16) and connected with the parking lot on B1F by the two car passing routes on the west side (dotted lines). The subway platform on B3F is only connected to the subway concourse on B1F (dotted line). The shape and width (prototype scale) of the stairs are shown in Table 1.

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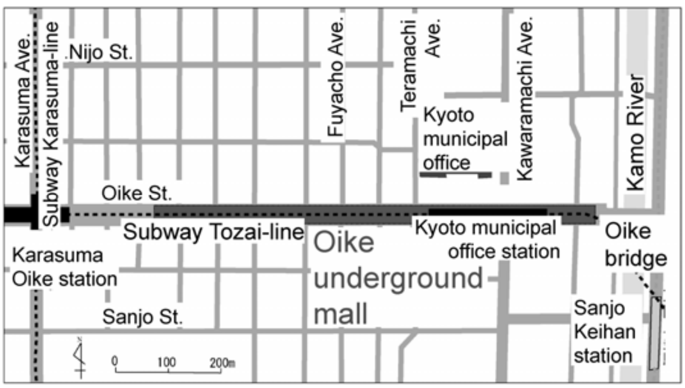

Fig. 1 Location of Kyoto Oike underground space

Photo 1 Doors of the subway platform

Table 1 Width and shape of entrances

No. of stairs	width(m)	shape
1	1.8	stairs
2	3.21	stairs
3	0.81,0.99	escalator
4	3.21	stairs
5	2.7	stairs
6	2.85	stairs
7	2.7	stairs
8	2.7	stairs
9	3.21	stairs
10	3.27	stairs
11	4.29	car slope
12	1.65	stairs
13	1.65	stairs
14	3.54	car slope
15	3.6	car slope
16	3.6	car slope
17	2.61	stairs
18	6	stairs
19	2.7	stairs
20	3.0, 1.0, 1.0	stairs , escalator
21	3.21	stairs
22	3.21	stairs
23	3.21	stairs
24	4.0, 1.0, 1.0	stairs , escalator
25	3.21	stairs
26	3.21	stairs
27	1.65	stairs
28	1.65	stairs
29	3.54	car slope

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Experimental setup

A hydraulic model of the underground space is furnished which is made of acryl (see Photo 2). The model is undistorted with a scale of 1/30. The Froude similarity law can be applied to this hydraulic model study, and hydraulic quantities in a model are converted to those of a prototype according to the law. In this paper, the hydraulic quantities are all expressed by the prototype scale except for special cases. The relationship between hydraulic quantities of the prototype and the model by the Froude similarity law are shown as follows:

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$$L_m/L_p=1/30 \quad (1)$$

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$$V_m/V_p=1/5.48 \quad (2)$$

Neither period nor comma is needed.

$$T_m/T_p=1/5.48\ ; \quad Q_m/Q_p=1/4930 \quad (3)$$

Use semicolon to separate two or more equations.

where, L = length; V =velocity; T = time; and Q =discharge. Subscripts m and p show the model value and the prototype value, respectively. Eqs. 1 and 2 are

Use "=" for narrative definitions.

Please observe the example strictly.

REFERENCES

1. Ishigaki, T., Toda, K. and Inoue, K. : Hydraulic model tests of inundation in urban area with underground space, Proc. of XXX IAHR Congress, Theme B, pp.487-493, 2003.
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3. Toda, K., Kuriyama, K., Oyagi, R. and Inoue, K. : Inundation analysis of complicated underground space, Journal of Hydroscience and Hydraulic Engineering, Vol.22, No.2, JSCE, pp.47-58, 2004.
4. Lamb, H. : Hydrodynamics, 6th ed., Cambridge University Press, U.K., 1932.

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APPENDIX – NOTATION

The following symbols are used in this paper:

Symbols to be presented in alphabetical order.
Small letters precede capital letters.
Greek symbols follow English symbols.

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g = gravity acceleration; Semi-colon

h_s = water depth on stairs;

L_m = length of the model; and

μ = discharge coefficient of the step flow formula. period

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