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Analysis of Critical Evacuation Condition on Inundated Stairs Using Numerical Simulation

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Abstract. Recently heavy rainfall have caused inundations in urban areas of Koera. Inundation of underground facilities puts people in danger. Especially, inundation of undergroudn stairs makes people's evacuation difficult. In this paper, inundated flow condition of stairs are simulated numerically using commecial 3 D CDF model(FLOW 3D). From the results, critical evacuation conditions are evaluated according to flow depth and slopes of stairs.

Keywords: Critical Evacuation Condition, Inundated Stairs, Safety Analysis, 3 D Numerical Simulation

1 Introduction

Recently floods of urbanized areas in Korea are increased by heavy rainfall due to the global climate changes. These rainwater flooding is caused by heavy rainfall exceeding over the design rainfall. Underground facilities such as subway stations and underground shopping arcades are susceptible to inundation by heavy rainfall.

Underground inundations occurred in Korea cities of Seoul, Incheon and Pusan in recent years. Most important matter in inundation of underground facilities is safe evacuation of people. Although stairs are the only evacuation passages in the inundation, they are not designed considering safe evacuation in inundation condition.

In this paper, hydraulic features of stairs in inundation conditions are investigated by 3D CFD model. Evacuation conditions are evaluated by criteria presented by Ishigaki et al.(2011).

2 Preview Study

Criteria of safe evacuation conditions (Table 1 and Fig. 1) was suggested by Ishigaki et al.(2011) by using a real size model of stairs. They evaluated the force due to the inundation with water depth, h, and flow velocity, u and suggested specific force, $M_0 = u^2h/g + h^2/2$ as main factor.

There are no cases studying hydraulic features of stairs in inundation condition. Flow over stairs is very close to flow over stepped spillways. Sorensen (1985)

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suggested characteristics of flow structures and energy dissipation on stepped spillways. Chamani et al. (1999) analyzed skimming flow, corner vortex, and air entrainment of stepped spillways. Chen et al. (2002) analyzed numerically corner vortex and air entrainment by using VOF (Volume of Fluid) scheme.

Table 1. Criteria of safe evacuation by the specific force (Ishigaki et al., 2011)

	Limit of safe evacuation	Difficult without any help
Male	0.125	0.250
Elderly male	0.100	0.200
Female	0.100	0.200
Elderly femail	0.080	0.160

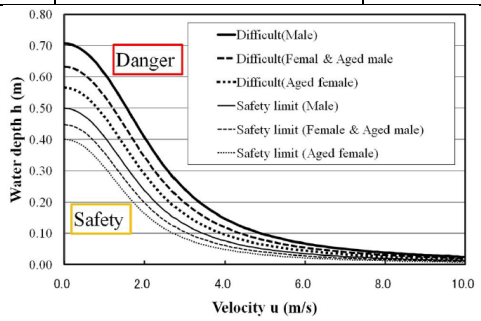


Fig. 1. Criteria of safe evacuation described by water depth and velocity [3]

3 3D Numerical Simulation

For the simulation of flow over stairs, a fully three-dimensional computation fluid dynamic model, FLOW-3D was applied. Inlet discharge conditions were 0.3 m^3/s, 0.5 m^3/s, 0.7 m^3/s and 1.0 m^3/s. RNG $k-\epsilon$ turbulent model and VOF were applied.
Stair model in this paper has been constructed based on the Korean regulation of criteria on house construction published by ministry of land, infrastructure and transport. The specifications of stairs are presented by Table 2 and Fig. 2. Meshes were constructed as Fig. 2 and number of total mesh is about 2 million.

Table 2. Specifications of stairs.

Width(m)	Tread length(m)	Riser height (m)	Total length (m)	Total height (m)	Slope (°)
1.200	0.280	0.144	5.600	2.880	27.22

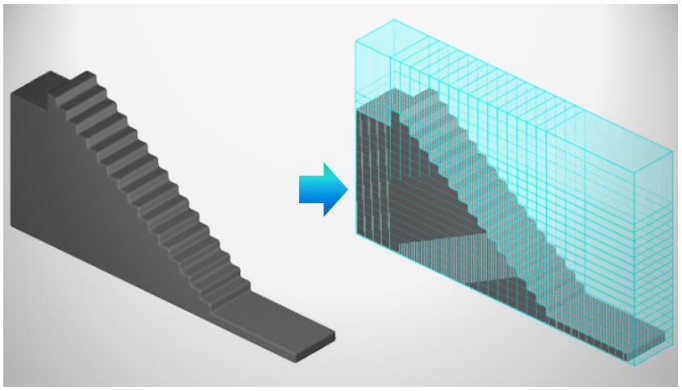


Fig. 2. Geometry and mesh generation of the stair model

4 Result

Simulation results with discharge conditions are presented as Table 4. Velocities and water depth increase with discharge increase. Using these velocities and water depths, specific foresee are evaluated along the center lines of stairs(Fig. 3). Evaluated specific forces are compared with criteria of safe evacuation.

In the case of Q=0.5 m^3/s, specific forces show from 0.12 – 0.20 which means that every people including male, can't evacuate safely and elderly female and young female can't escape alone.

As shown in Table 4, elderly female could be dangerous only in the water depth of 20cm. With flow depth over 0.36cm, every people including young male can't escape with any other help.

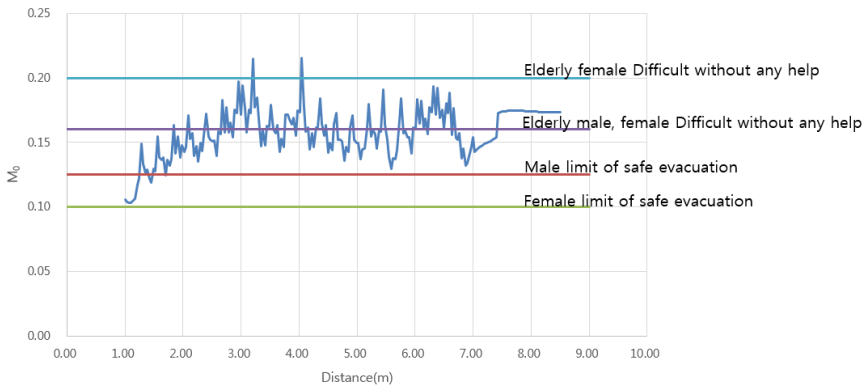
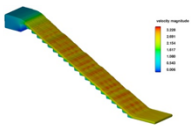
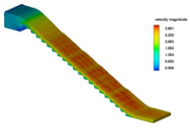
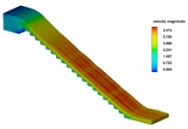
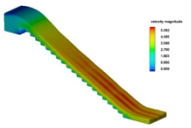


Fig. 3. 3D Specific force evaluation (Q=0.5 m^3/s)

Table 4. Results of numerical simulation and evacuation conditions

Discharge	0.3 m³/s	0.5 m³/s	0.7 m³/s	1.0 m³/s
Contour (velocity)				
Inlet Depth	0.21 m	0.30 m	0.36 m	0.44 m
Safety	- Elderly female limit of safe evacuation	- Male limit of safe evacuation - Elderly female Difficult without any help	- Male Difficult without any help	- Male Difficult without any help

4 Conclusion

In this paper, flows over stairs are simulated by 3D CFD model to investigate the flow characteristics and safe evacuation conditions. From the results, it is found that flow depth only over the 20cm could cause the danger in the evacuation along stairs. In the flow depth over 0.36cm, every people including young male, could not escape alone without any help.

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