EXPERIMENTAL STUDY ON DROWNING ACCIDENT RISK IN RIVER AND SIDE DITCH

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ABSTRACT

Climate change increases the frequency of torrential rains and drowning accident frequently occurs. Therefore, it is very important to study the hydrodynamic force exerted on the human body in flood water. In this study, two kinds of the flume experiments were conducted using a small-scale model of the human body. First, we measured the drag force exerted on the human body in flood water. Second, we examined the drowning accident risk in a narrow side ditch. Flume experiments were conducted by changing the flume width (In real scale, B=1.6m, 0.8m, 0.4m). Drag force exerted on the human body model was measured by a Force gauge. The results can be used as primary assessment to define the drowning risk in a river or a channel after torrential rain.

Keywords: flood water, drag force coefficient, sitting position, standing position, narrow ditch

1. INTRODUCTION

Climate change increases the frequency of torrential rains and drowning accident frequently occurs. Therefore, it is very important to study the hydrodynamic force exerted on the human body in flood water.

Fujita & Ito (2011) measured the resistance force to falling down using the spring scale and evaluated the safety of the walking evacuation in flood water. Ogawa et al. (2014) also evaluated the safety of the walking evacuation considering the drag force exerted on a human body and friction force. Kitamura & Nishida (2017) measured the drag force exerted on the human body considering falling down in the flood water. Still more works are needed because the critical condition of drowning accident is not understood.

So, in the present study, incipient velocity for drowning accident was estimated using drag force coefficient. Flume experiments were conducted using a small-scale model of the human body (1/10, 1/4 scale). First, we measured the drag force exerted on the human body in flood water. Second, we examined the drowning accident risk in a narrow side ditch.

2. EXPERIMENTAL METHOD

The experiments were carried out in a 10.0m long and 40.0cm wide tilting flume, as shown in Fig.1. x, y and z are the streamwise, vertical and spanwise coordinates, respectively. The vertical origin, y=0 was chosen on the channel bed. H is the water depth.

Fig.1 shows the drag force measurement set-up. Hydrodynamic force on the human body model (1/10 scale) in x-direction was measured by a force gauge. Sampling rate is 10Hz and sampling time is 60s. For measuring the drag force, a gap (1-2mm) is required between the human body model and the channel bed to remove the effect of the bed-friction resistance (see Takemura & Tanaka (2007)).

Table 1 Hydraulic condition (1/10 scale)

	Model scale		Real scale		Fr	Posture of human body model	Effect of clothing
	U_m(m/s)	H(m)	U_m(m/s)	H(m)			
Case 1-1	0.316	0.035	1.0	0.35	0.54	standing, sitting	clothed, unclothed
Case 1-2		0.050		0.50	0.45	standing, sitting	clothed, unclothed
Case 1-3		0.070		0.70	0.38	standing, sitting, supine	clothed, unclothed
Case 2-1	0.474	0.035	1.5	0.35	0.81	standing, sitting	clothed, unclothed
Case 2-2		0.050		0.50	0.68	standing, sitting	clothed, unclothed
Case 2-3		0.070		0.70	0.57	standing, sitting, supine	clothed, unclothed
Case 3-1	0.633	0.035	2.0	0.35	1.08	standing, sitting	clothed, unclothed
Case 3-2		0.050		0.50	0.90	standing, sitting	clothed, unclothed
Case 3-3		0.070		0.70	0.76	standing, sitting, supine	clothed, unclothed

Table 2 Hydraulic condition (1/4 scale)

Real scale			Model scale			Fr	Posture of human body model
B(m)	U_m(m/s)	H(m)	B(m)	U_m(m/s)	H(m)		
1.6	1	0.2	0.4	0.5	0.05	1.01	standing, sitting
0.8	1	0.2	0.2	0.5	0.05	1.01	standing, sitting
0.4	1	0.2	0.1	0.5	0.05	1.01	standing, sitting
	0.4	0.12, 0.15, 0.2		0.2	0.03, 0.0375, 0.05	0.37, 0.33, 0.29	sitting
	0.6	0.12, 0.15, 0.2		0.3	0.03, 0.0375, 0.05	0.55, 0.49, 0.43	sitting
	0.8	0.12, 0.15, 0.2		0.4	0.03, 0.0375, 0.05	0.73, 0.66, 0.57	sitting
	1	0.12, 0.15, 0.2		0.5	0.03, 0.0375, 0.05	0.92, 0.82, 0.71	sitting
	1.2	0.12, 0.15, 0.2		0.6	0.03, 0.0375, 0.05	1.1, 0.99, 0.86	sitting

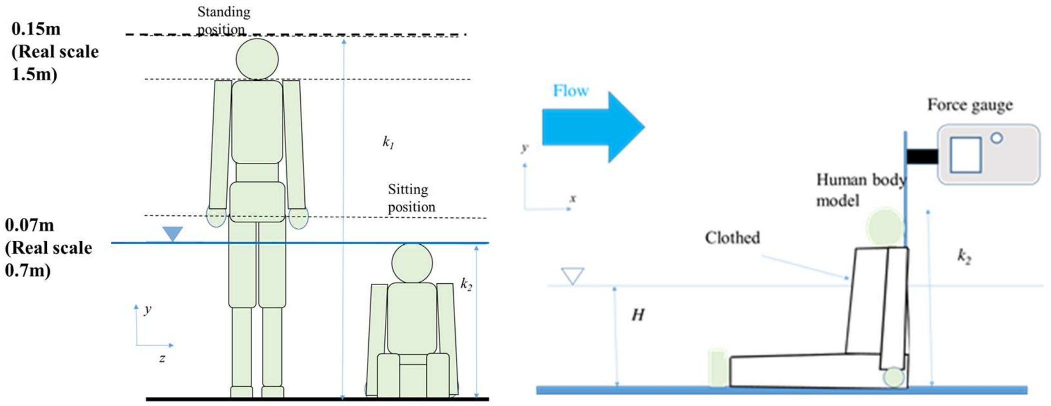

Fig.1(a) Posture change of human body model (1/10 scale), (b) Drag force measurement

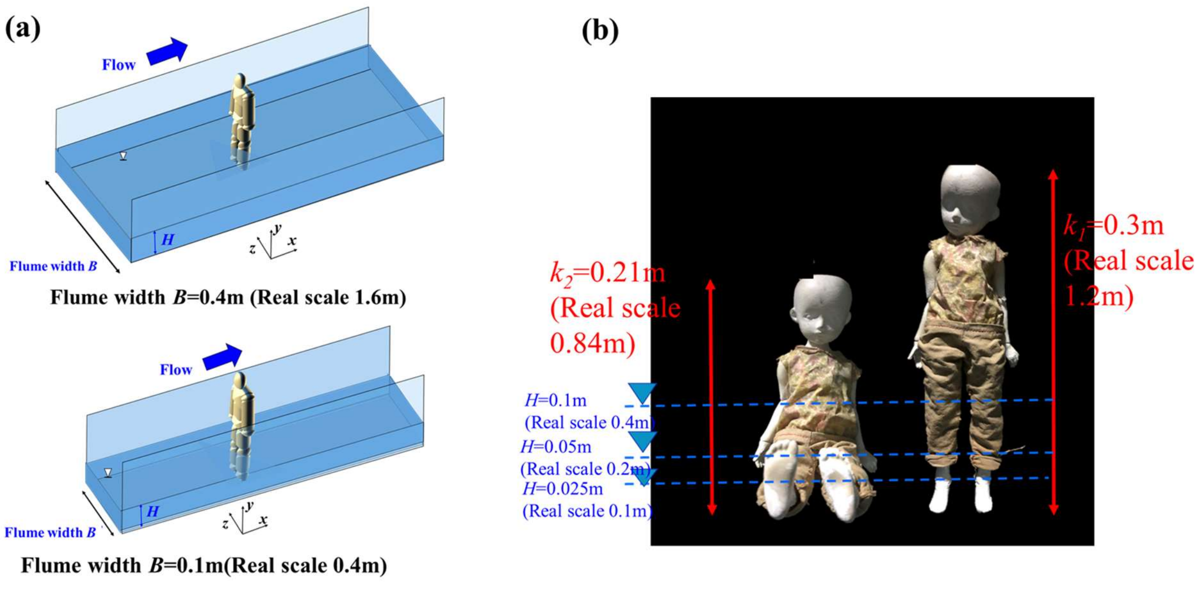

Fig.2(a) Change of flume width, (b) Posture change of human body model (1/4 scale)

Considering falling down in the flood water, the posture of the human body was changed (standing and sitting). Human body model heights are k_1=15cm (real scale: 1.5m, 12-year child) for standing position and k_2=7cm (real scale: 0.7m) for sitting position. To investigate the effect of clothing, we put cotton clothes on the human body model. Bulk mean velocity U_m and water depth H were changed (In real scale, flow depth H=0.35, 0.50, 0.70m

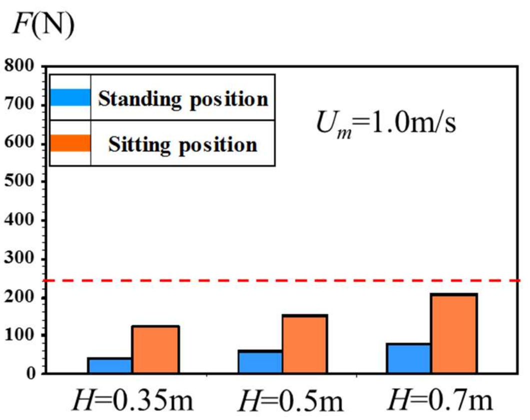

Fig.3 Drag force exerted on human body (effect of posture change)

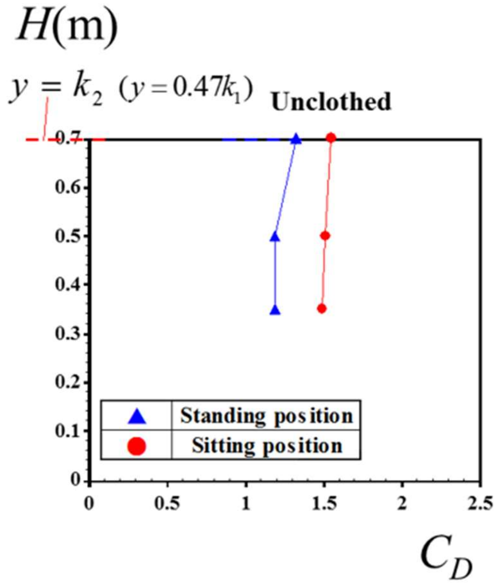

Fig.4 Drag force coefficient of human body (effect of posture change)

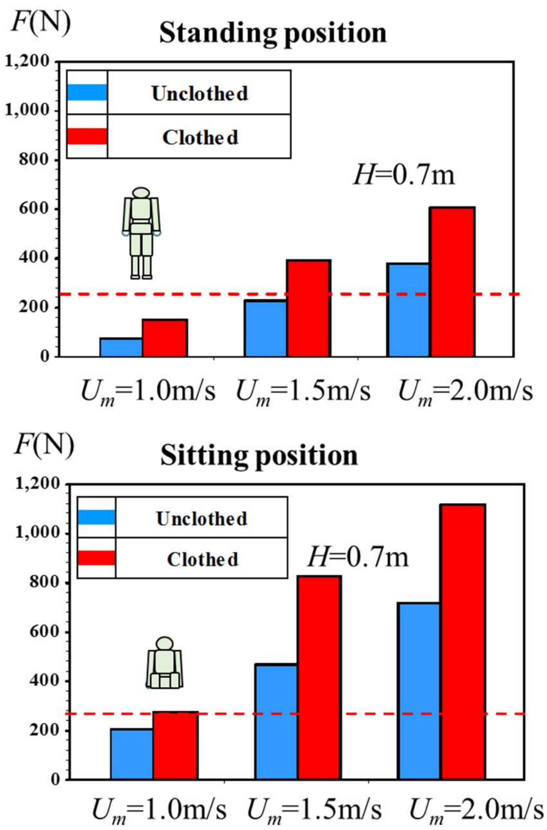

Fig.5 Drag force exerted on human body (effect of clothing)

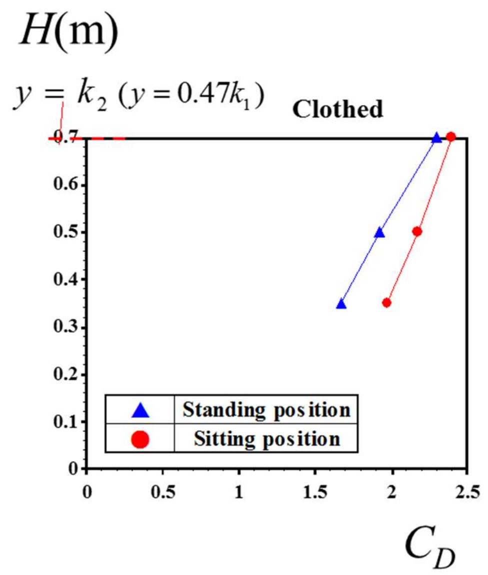

Fig.6 Drag force coefficient of human body (effect of clothing)

and flow velocity U_m= 1.0, 1.5, 2.0m/s). When H=0.7m, the leg was submerged for standing position and the whole body was submerged for sitting position. Table 1 shows the hydraulic condition.

Second, flume experiments were conducted by changing the flume width (In real scale, B=1.6m, 0.8m, 0.4m), as shown in Fig.2. Drag force exerted on the human body model (1/4 scale) was measured by a force gauge. Human body model heights are k_1=30cm (real scale: 1.2m, 8-year child) for standing position and k_2=21cm (real scale: 0.84m) for sitting position. Table 2 shows the hydraulic condition.

3. RESULTS

3.1 Drag force coefficient of human body

Fig.3 compares the values of the drag force exerted on the human body (1/10 scale) in a standing position and in a sitting position (unclothed case). The drag force values were converted to the force values in real scale. The experiment data showed that the drag force in a sitting position is 2-3 times larger than that in a standing position.

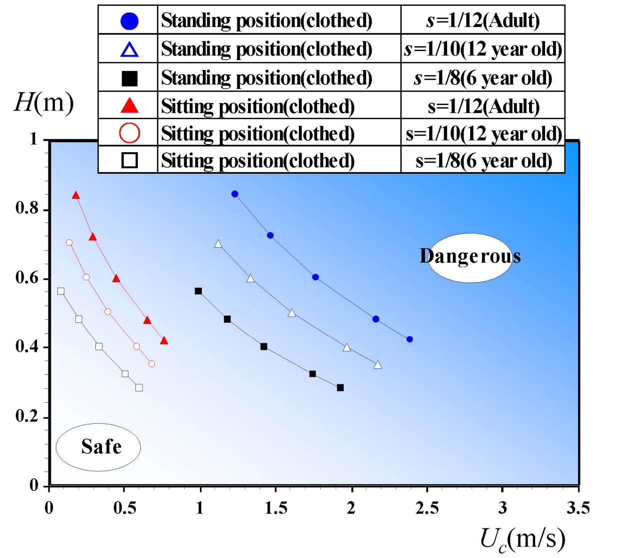

Fig.7 Critical condition for drowning accident (6 year old, 12 year old, adult)

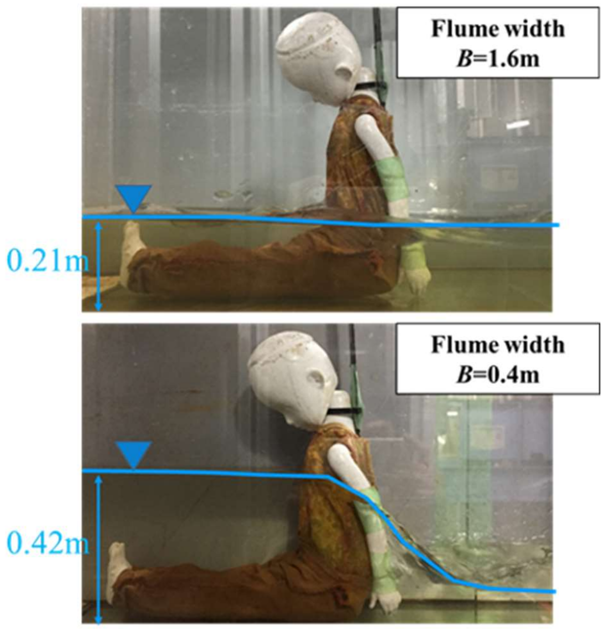

Fig.9 Backwater rise in narrow side ditch

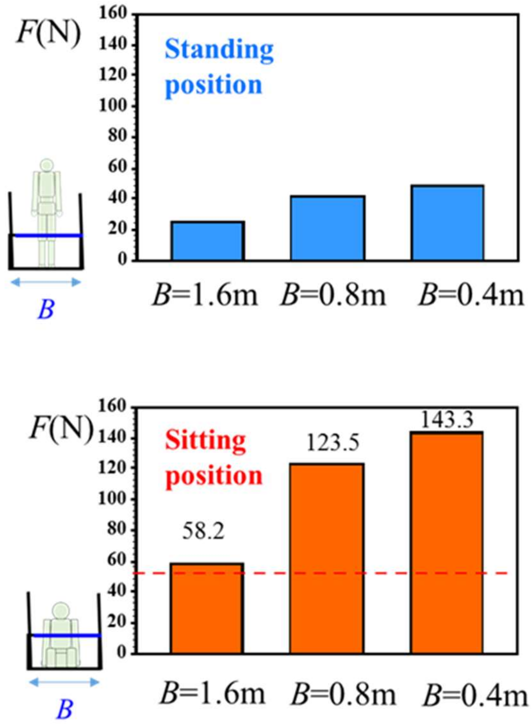

Fig.8 Drag force exerted on human body (effect of flume width)

This is because the projected area normal to the incoming flow increases in a sitting position, considering the falling down in flood water.

Fig.4 shows the relation between relative depth H/k and drag coefficient C_D in a standing position and in a sitting position. Drag force exerted on the human body model is calculated as follow:

$$F_D = 0.5 \rho C_D U_m^{\ 2} A_x \tag{1}$$

C_D is drag force coefficient of human body. A_x is projected area normal to the incoming flow. It is observed that the drag force coefficient has the almost constant values in a standing position and in a sitting position. For standing position, C_D =1.2. This value is similar to drag force coefficient of a single cylinder. For standing position, C_D =1.5. This value is similar to drag force coefficient of a square rod.

Fig.5 compares the values of the drag force exerted on the human body (1/10 scale) for unclothed and clothed cases. The flow depth is H=0.7m in real scale. In a standing position, the drag force exerted on the human body increases by 57% for clothed case compared with that for unclothed case. This is because the projected area normal to the incoming flow increases, considering the effect of clothing. In a sitting position, the drag force exerted on the human body increases by 42% for clothed case. There is little difference in the projected area normal to the incoming flow between clothed case and unclothed case. This difference is due to the surface resistance.

Fig.6 shows the relation between relative depth H/k and drag coefficient C_D for clothed cases. In a standing position, the drag force coefficient values range from 1.7 to 2.2. The drag force coefficient is larger for clothed case compared with that for unclothed case. It is also observed that the values of C_D increase as relative depth increases. In a sitting position, the drag force coefficient values range from 2.0 to 2.3.

3.2 Critical velocity for drowning accident in a river

At the critical condition which the drowning accident occurs, the drag force exerted on the human body is equal to the frictional resistance S as follows:

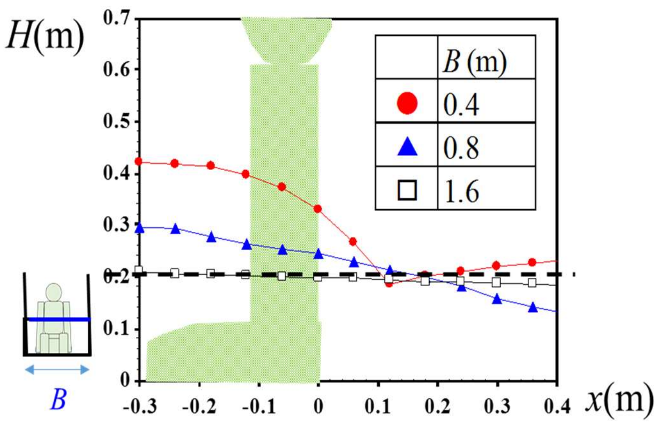

Fig.10 Distribution of flow depth

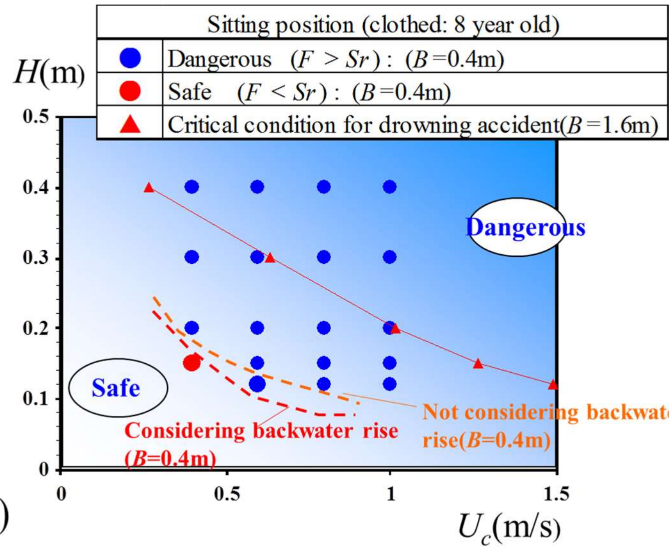

Fig.11 Critical condition for drowning accident in narrow side dicth

$$F_D = 0.5\rho C_D U_c^2 A_x = S = \mu(Mg - F_b) \quad (2)$$

μ is the dimensionless coefficient of friction (=0.7). M is the body weight and F_b is the buoyancy force. F_b is calculated as follows:

$$F_b = \rho g Vo \quad (3)$$

Vo is the volume of human body in water. By using Eqs. (2) and (3), we can calculate the incipient velocity U_c.

Fig.7 shows the critical velocity U_c of 12-year child (M=46kg) for drowning accident in a wide channel. The critical velocity U_c for 8-year child (M=23kg) was also calculated using scale ratios.

For the same water depth, the incipient velocity in a sitting position is smaller than that in s standing position. There are two reasons. First, the drag force exerted on the human body increases in a sitting position compared with that in a standing position. Second, the submerged volume of human body becomes larger in a sitting position and consequently, the frictional resistance S decreases in Eq.(2).

Considering falling down in the flood water, the drowning accident occurs when the water depth is H=0.5m and flow velocity is U=0.5m/s for 12-year child.

3.3 Critical velocity for drowning accident in a narrow side ditch

Fig.8 compares the values of the drag force exerted on the human body (1/4 scale) in a wide channel and a narrow channel. The experiment data showed that the drag force in the narrow channel is twice larger than that in the wide channel.

For a narrow channel, the backwater rises in front of the human body (Figs.9 and 10) and the hydrostatic pressure is exerted on the body. The buoyancy force acting on the body increases due to the backwater rise.

Fig.11 shows the critical velocity U_c for 8-year child (M=23kg) calculated from the 1/4 scale model using scale ratios. For a narrow channel, the buoyancy force acting on the body increases due to the backwater rise. The hydrostatic pressure is exerted on the body. Consequently, the drowning accident occurs even in a low water-depth condition. For 8-year child, the drowning accident occurs when the water depth is H=0.12m and flow velocity is U=0.6m/s.

4. CONCLUSIONS

In the present study, two kinds of the flume experiments were conducted using a small-scale model of the human body. First, we measured the drag force exerted on the human body in flood water and examined the effect of posture change and clothing. Second, flume experiments were conducted by changing the flume width to examine the drowning accident risk in a narrow side ditch. The results can be used as primary assessment to define the drowning risk in a river or a channel after torrential rain.

Main findings are as follows:

1. The drag force exerted on the human body in a sitting position is 2-3 times larger than that in a standing position, considering falling down in the flood water.

2. The drag force exerted on the human body increases by 57% for clothed case compared with that for unclothed case.

3. Due to the backwater rise, the drag force in a narrow channel is 2-3 times larger than that in a wide channel.

4. Incipient velocity for drowning accident was estimated using a small-scale model of the human body. For 8-year child, the drowning accident occurs when the water depth is H=0.12m and flow velocity is U=0.6m/s in a narrow channel.

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