“Car Related Problems in Flooding”

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Experimental Study of Evacuation from a Partially Submerged Vehicle

Experimental Study on Floating Vehicles in Flooding

Evacuation Experiment by Bicycle in Flood Water

Evacuation from a partially submerged vehicle

Underpass, road under railway or highway is the dangerous place.

・The ground level there is 2m or more lower than the around place.

⇒In flooding, inundation water depth may become higher than 1m.

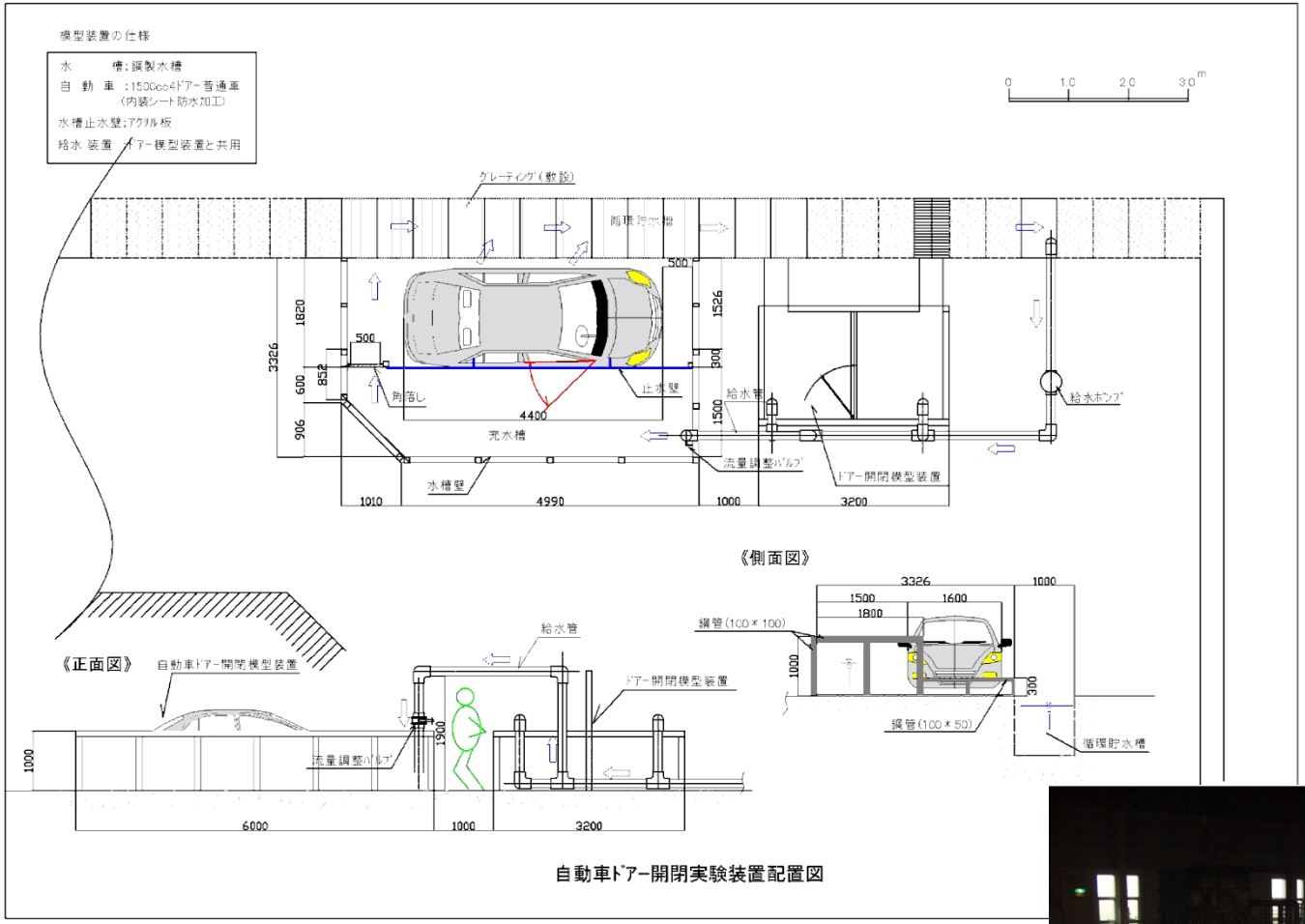
・If vehicles enter the submerged underpass by mistake, passengers cannot evacuate easily by high hydrostatic pressure.

Evacuation from a partially submerged vehicle

- Many accidents have been reported in Japan.

For example, one woman was drowned to death in the small vehicle at Kanuma City, Tochigi, in August, 2008.

We have studied the evacuation difficulties by experiment using a real sized car model.



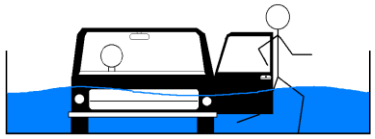
Ujigawa Open Laboratory,

DPRI, Kyoto University

Experimental setup

Engine and other mechanical parts are removed.

Seats are waterproof as water comes into the inside of a vehicle.



The height from the ground surface to the bottom of door is about 30cm.

Men inside the vehicle try to evacuate by opening a door.

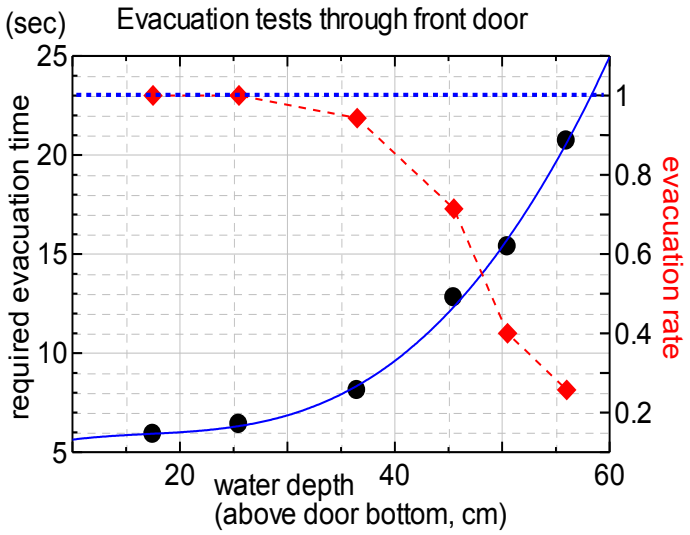
Evacuation limit criteria is studied.

Assume that the inside of vehicle is not submerged.
The width of front door is about 100cm.

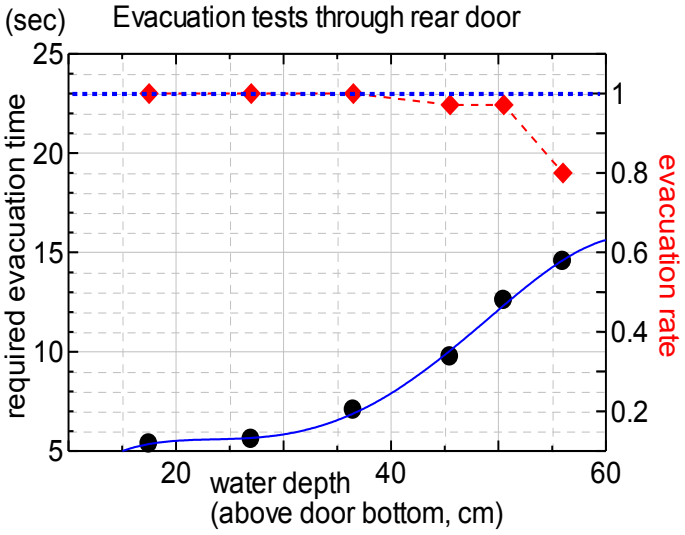
For male adults:

The water depth from the ground of 75cm to 80cm is the evacuation limit.

Evacuation from front door



Evacuation from rear door



In Nagasaki Flood in 1982, the driver said

“The car door could not be opened easily when the water depth was about 60cm.”

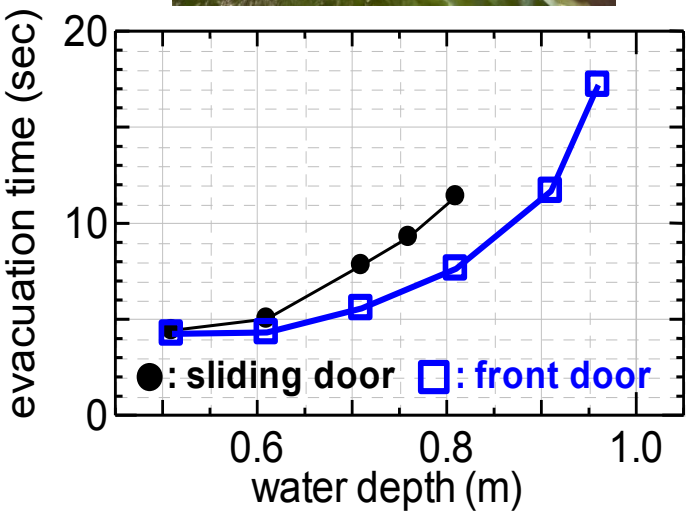
Recent experiments by Japan Automobile Federeation,JAF（by use of Mini Van)

⇒Both of front and rear could not be opened when the water depth was 90cm.

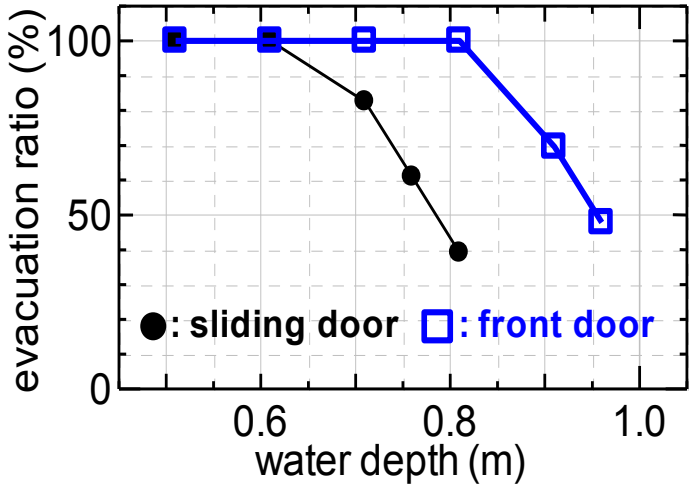
Water depth of 75～80cm is the critical evacuation condition.

An experiment by small vehicle with open typed front door and slide typed rear door

Evacuation from slide typed door is almost same or more difficult than open typed door.



water depth from the ground (m)



water depth from the ground (m)

Experimental Study of Evacuation from a Partially Submerged Vehicle

Experimental Study on Floating Vehicles in Flooding

Evacuation Experiment by Bicycle in Flood Water

Study on Floating Vehicles in Flooding

Past flood in Hong Kong

flood inundation

Water related disasters

Tsunami inundation

What may happen?

- Vehicles and passengers inside are swept away.
- Evacuation becomes very difficult if evacuation route is blocked by vehicles.
- Floating vehicles crash and destroy buildings and structures.

1. We execute incipient floating condition of partially floating vehicles and behavior of floating vehicles by hydraulic experiments.

Experiment 1：

We study Incipient floating condition of combination of flow velocity and water depth.

Experiment 2：

We study the velocities of floating vehicles.

2. We convert the model values to the proto type ones.

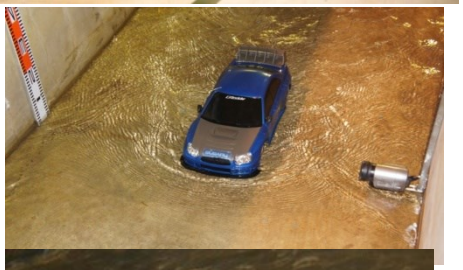
（1/10 scaled sedan and 1/18 scaled minivan）

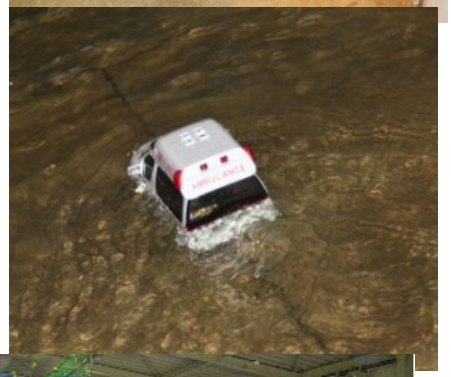
Experiments of floating vehicles

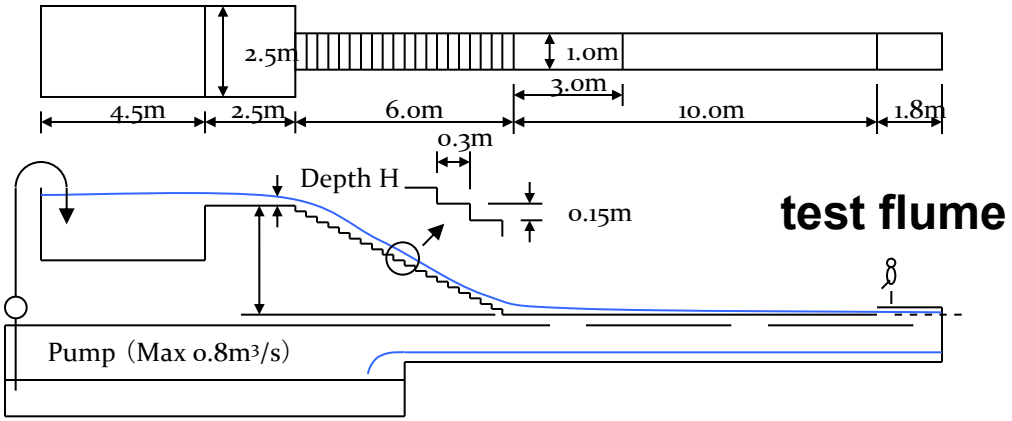
The experiments were done at Ujigawa Open Laboratory, DPRI, Kyoto University.

We set the 1/10 and 1/18 scaled model vehicles in the flume. And by increasing the discharge, namely, the combination of flow velocity and water depth, we obtained the critical condition of incipient motion of vehicles.

Specific gravities are same for model and proto type.







Model vehicles

sedan typed car　scale:1/10

model size：　length 0.47m, width 0.20m, height 0.15m, weight 1350g

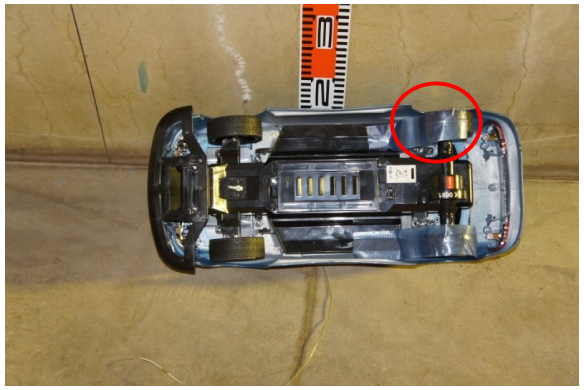
minivan（ambulance）　scale: 1/18

model size：　length 0.26m, width 0.10m, height 0.12m, weight 384g

Experimental conditions（vehicle）

1. with handbrake
   （0° direction to the flow） caseA
2. without handbrake
   （0° direction to the flow） caseB−1
3. without handbrake
   （90° direction to the flow） caseB−2
4. without handbrake
   （45° direction to the flow ） caseB−3

with handbrake

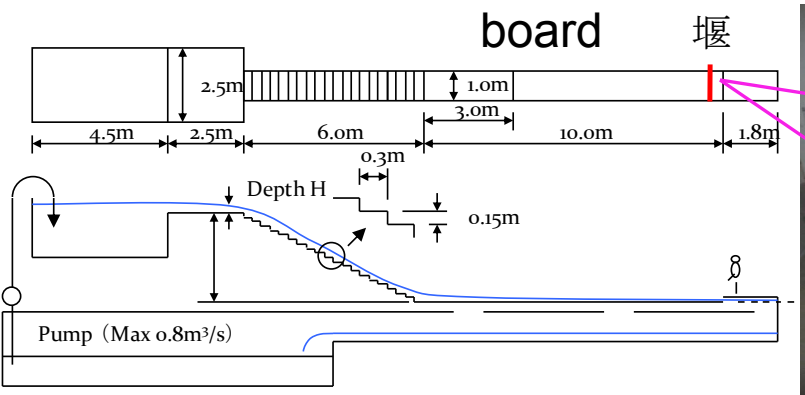


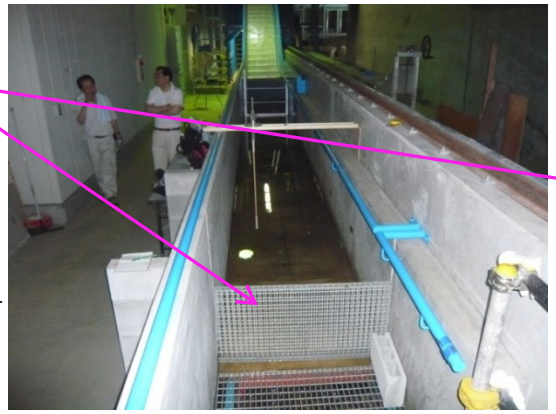
direction of vehicle

Experimental conditions（high water depth）

5. with handbrake
（0° direction to the flow）caseA´

6. without handbrake
（0° direction to the flow）caseB-1´

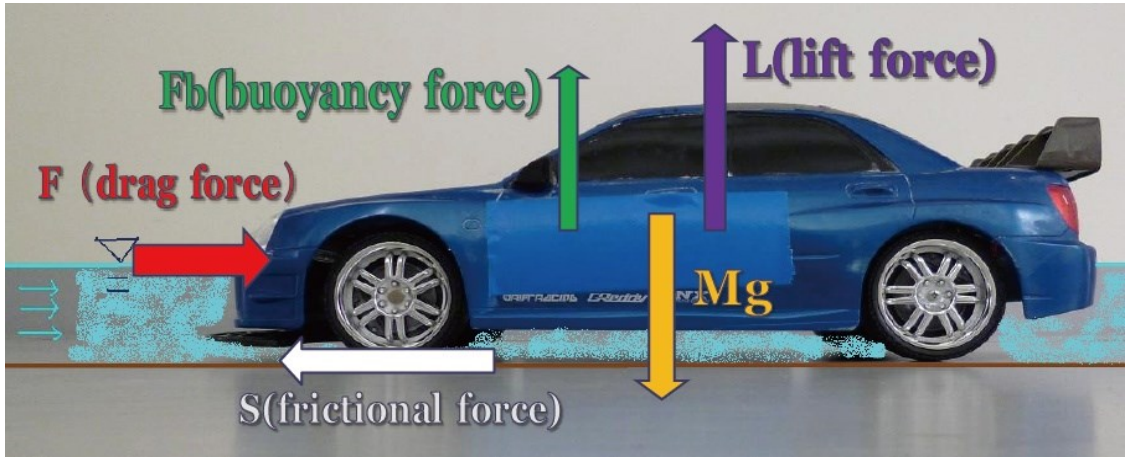




・By setting the flash board at downstream, we changed the relation between flow velocity and water depth.

Experiment cases and critical condition of incipient motion

Case	existence of hand brake	direction (degree)	existence of board	incipient motion condition (The value in parenthesis means the real scale value.)			
				sedan (scale: 1/10)		minivan (scale: 1/18)	
				flow velocity (m/s)	water depth (m)	flow velocity (m/s)	water depth (m)
A	Yes	0	No	0.63 (2.00)	0.041 (0.41)	0.55 (2.35)	0.035 (0.63)
B-1	No	0	No	0.50 (1.57)	0.030 (0.30)	0.41 (1.74)	0.024 (0.43)
B-2	No	90	No	0.63 (2.00)	0.041 (0.41)	0.51 (2.16)	0.032 (0.57)
B-3	No	45	No	0.57 (1.80)	0.036 (0.36)	0.52 (2.19)	0.032 (0.57)
A'	Yes	0	Yes	0.38 (1.20)	0.069 (0.69)	0.37 (1.57)	0.067 (1.21)
B-1'	No	0	Yes	0.33 (1.05)	0.051 (0.51)	0.29 (1.24)	0.039 (0.70)



Force exerted on the partially submerged vehicle

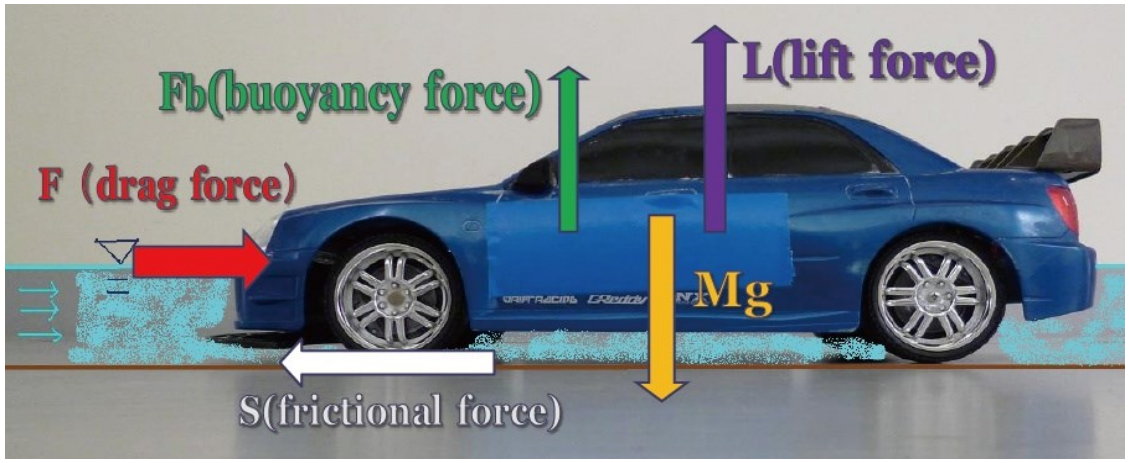
$$F = S = \mu(Mg - F_b - L)$$

$$F = 0.5\rho C_d U^2 A_x$$

$$F_b = \rho g V$$

V: net volume of partially submerged vehicle

car type	direction(degree)	existence of hand brake	coefficient of static friction
sedan	0	No	0.073
	0	Yes	0.26
	90	No	0.565
minivan	0	No	0.1
	0	Yes	0.42
	90	No	0.65



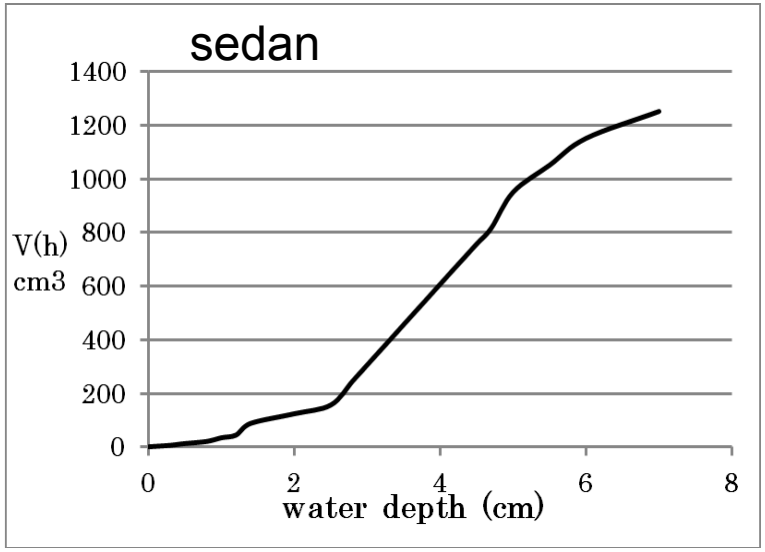
Force exerted on the partially submerged vehicle

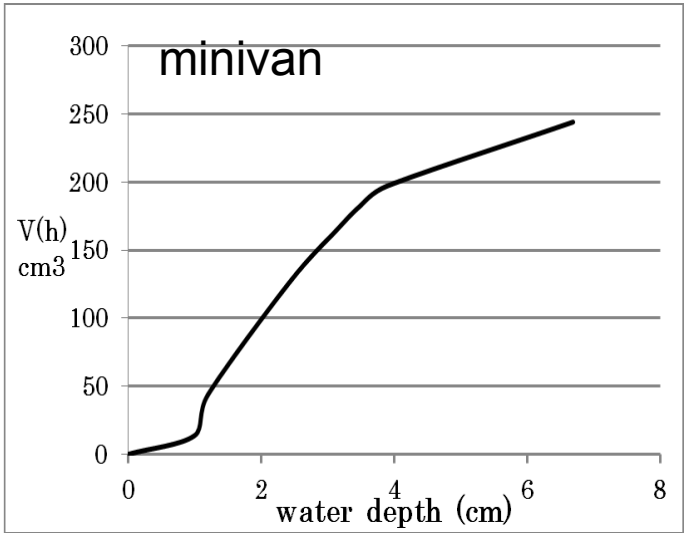
$$F = S = \mu(Mg - F_b - L)$$

$$F = 0.5\rho C_d U^2 A_x$$

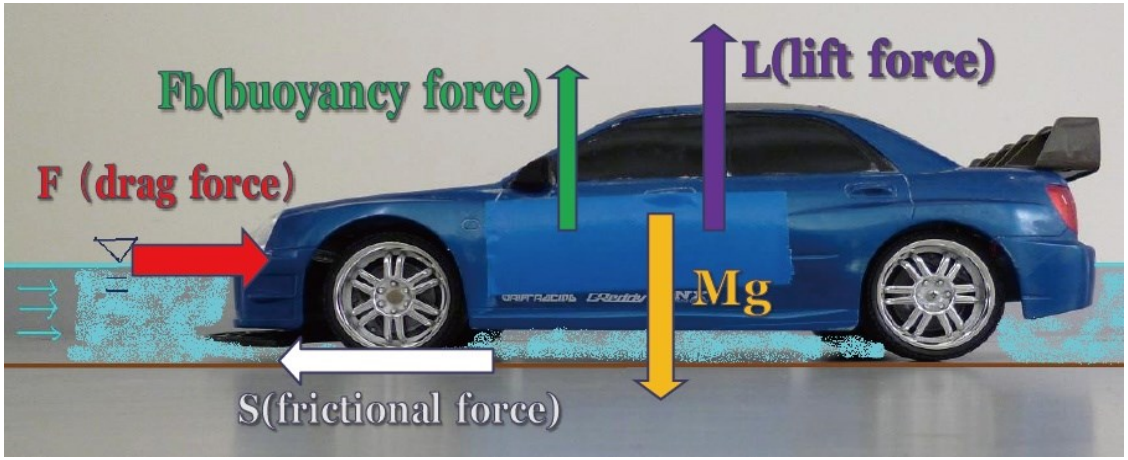
$$F_b = \rho g V$$

V: net volume of partially submerged vehicle





Relation between net volume of model vehicle and water depth



$$F = S = \mu(Mg - F_b - L)$$

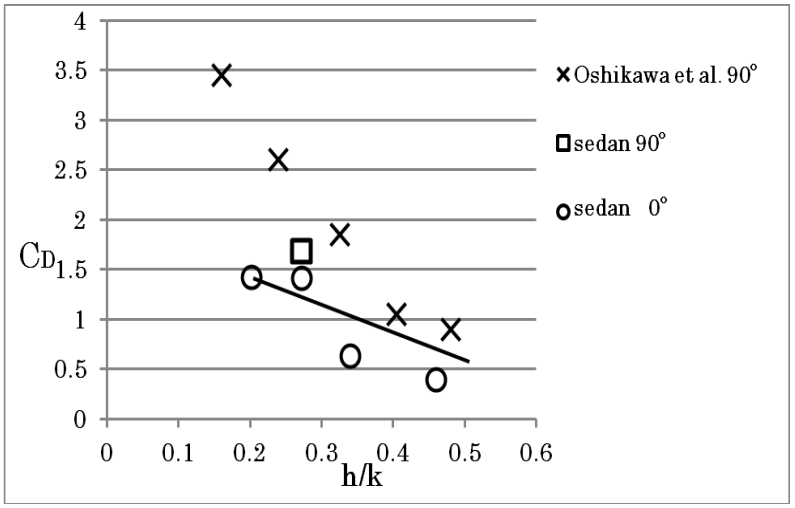
$$F = 0.5\rho C_d U^2 A_x$$

$$F_b = \rho g V$$

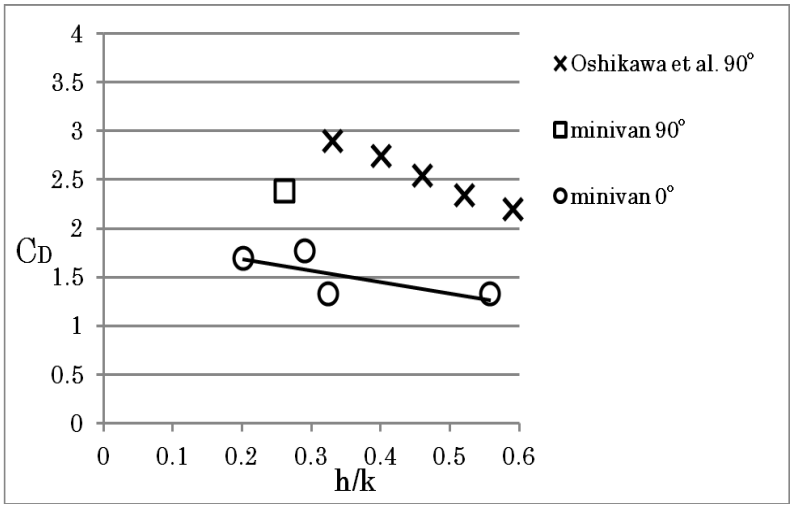
V: net volume of partially submerged vehicle

Force exerted on the partially submerged vehicle

sedan

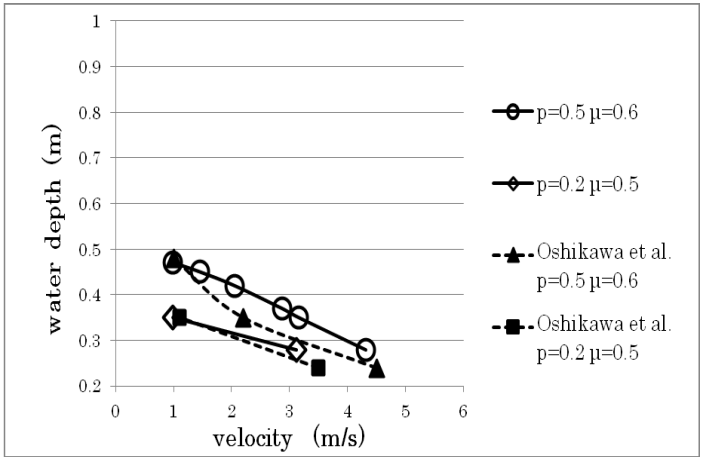


minivan



Relation between drag coefficient and relative water depth

sedan M'≒100kg



minivan M'≒100kg

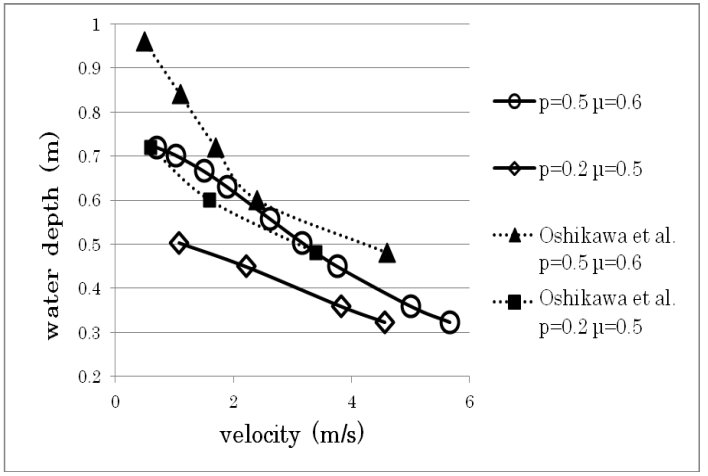


Diagram of critical incipient motion

$F = S = \mu(Mg - Fb - L)$

$F=0.5\rho C_d U^2 A_x$ $F_b=\rho g V$

$V = (1-p)\ V0$

V0: volume of partially submerged car
V: net volume of it

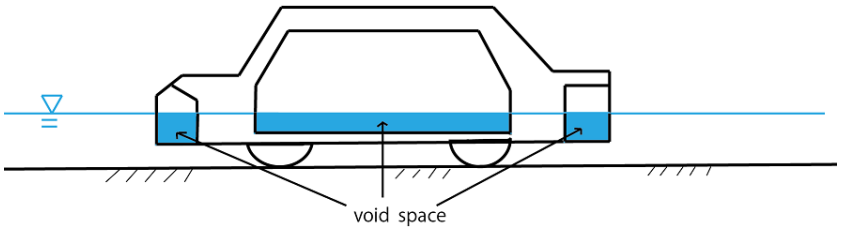
Application to prototype vehicle:

We need to consider the following parameters.

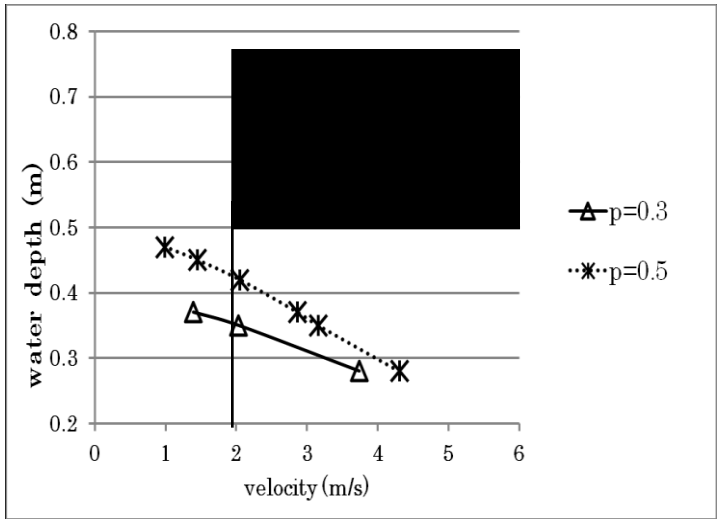
(1) coefficient of static function μ

(2) void space of vehicle *p*

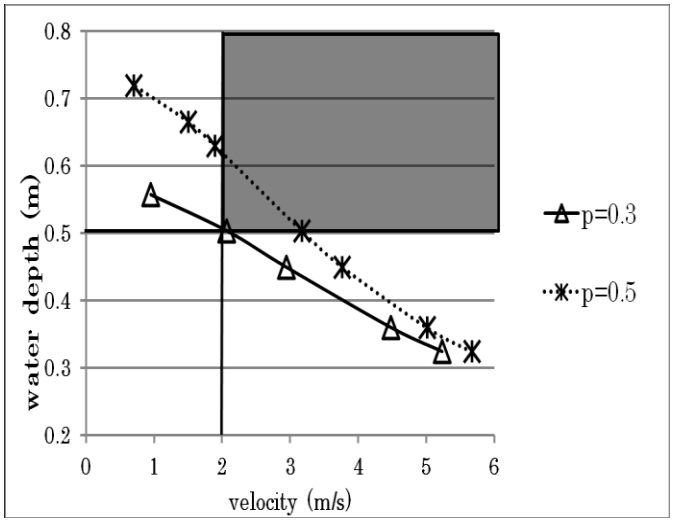
(3) additional weight (passengers, goods) *M'*



sedan



minivan



μ=0.6, p=0.3,0.5, M'=100kg

Diagram of critical incipient motion

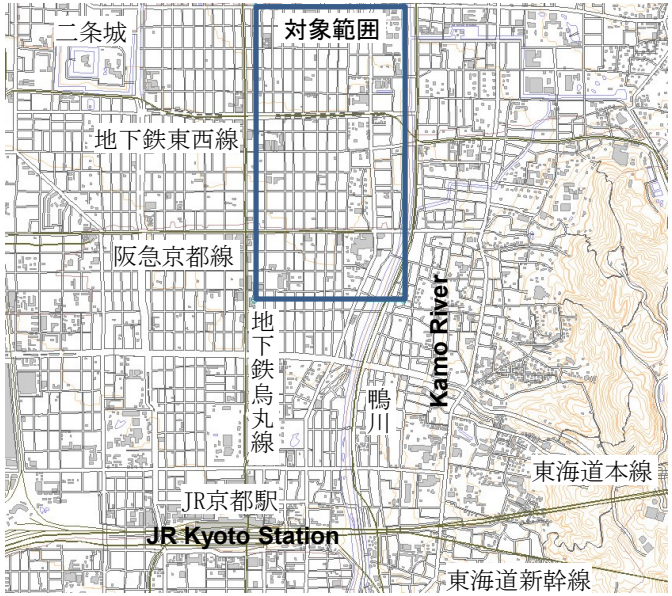
If the flow velocity is higher than 2m/s and the water depth is more than 0.5m, then vehicles are likely to begin to move.

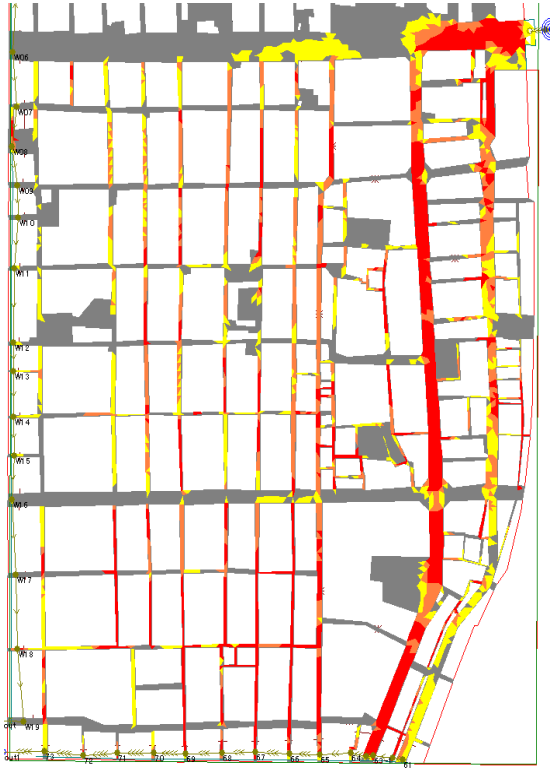
Possibility of floating of vehicles due to flooding in Kyoto, Japan

Overflow of 100m3/s from the Kamo River .

Inundated water runs through the roads.

We examined the distribution of flow velocity and water depth there.





overflow point

velocity

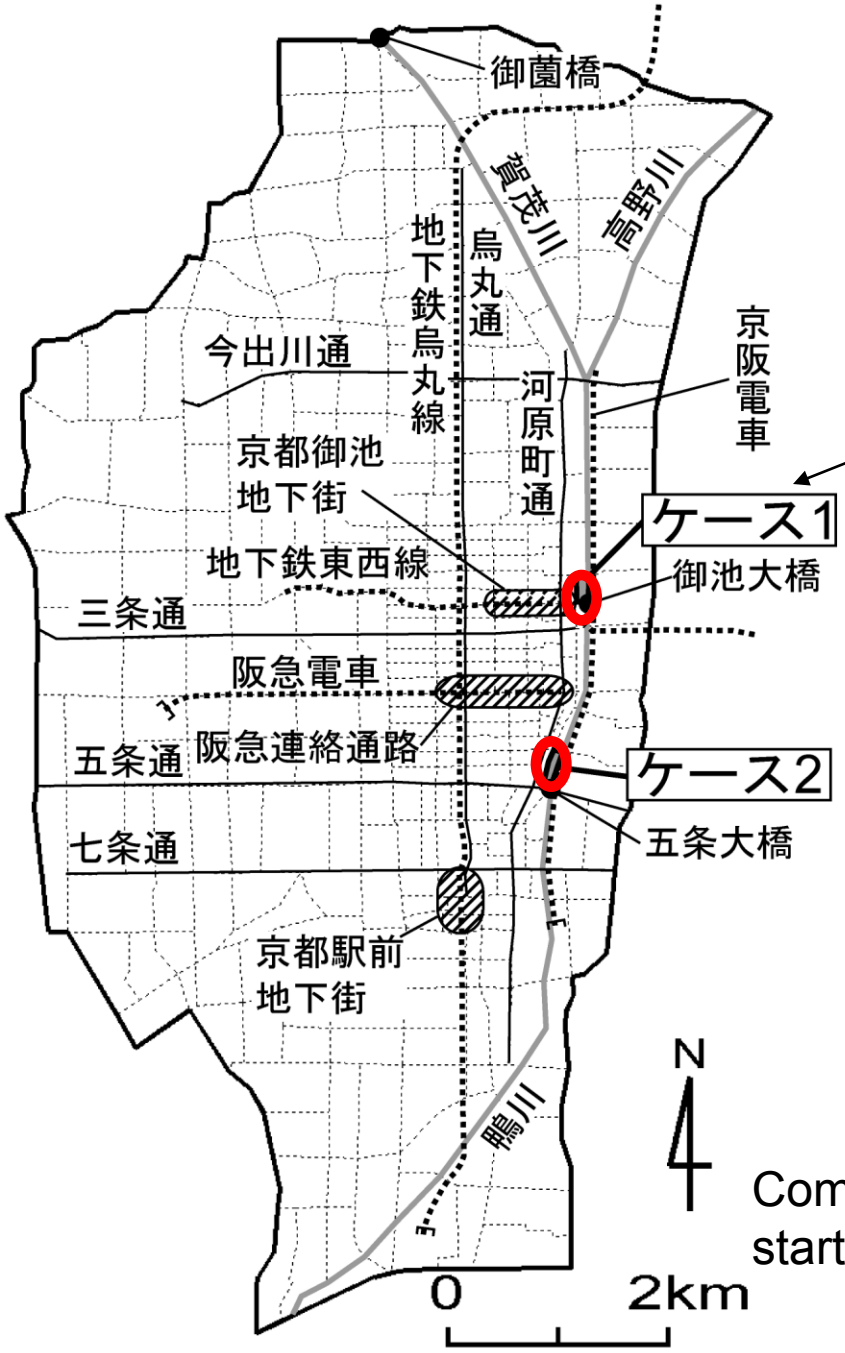
yellow：over 1m/s

orange：over1.5m/s

red：over 2m/s

The black area is that flow velocity is higher than 2m/s, and water depth is more than 0.5m.

vehicles are likely to begin to move in downtown.



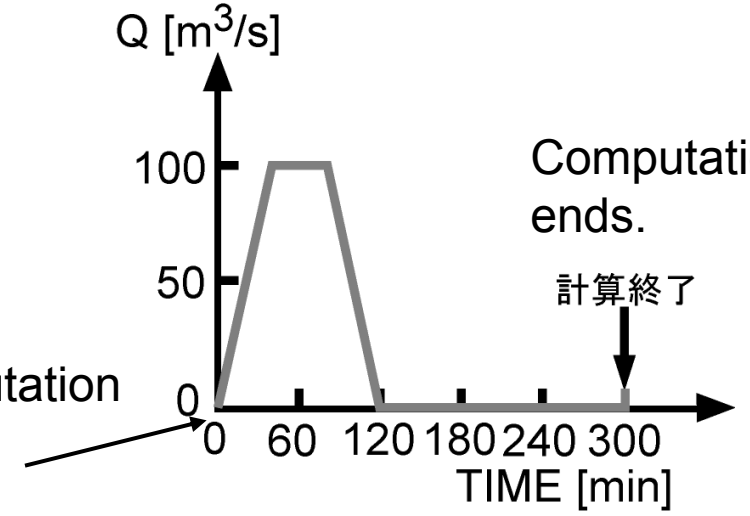
In the similar computational condition, we examined the danger of underground inundation.

Case1: Overflow from Oike bridge

Case2: Overflow from Gojo bridge

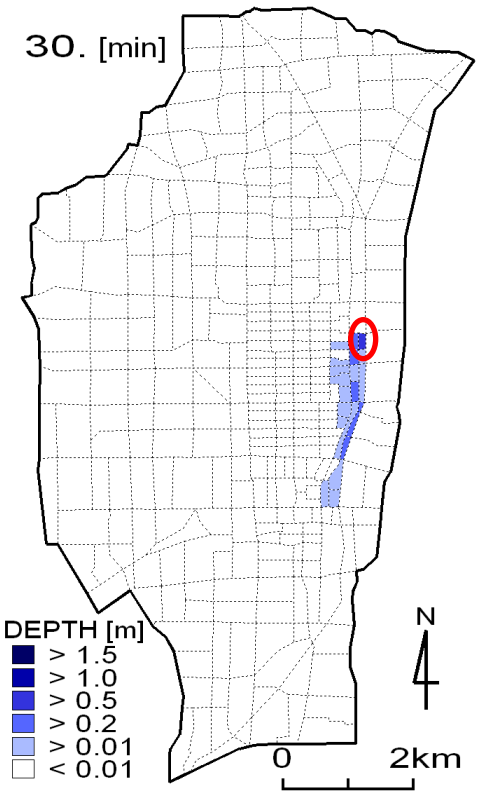
Inundation starts at t=0.0hr.

Inundation water does not flow back to the river.

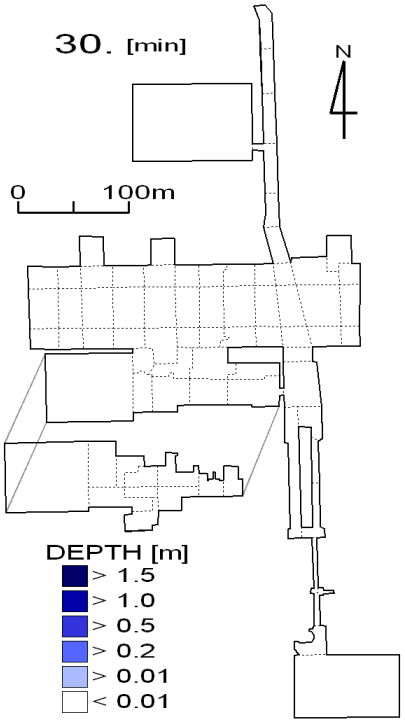


ケース1，30分後

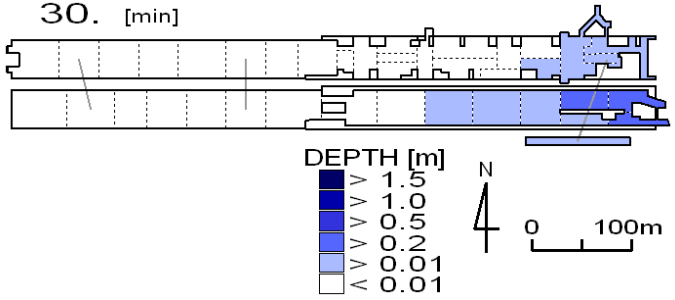
Case1: 30min. after



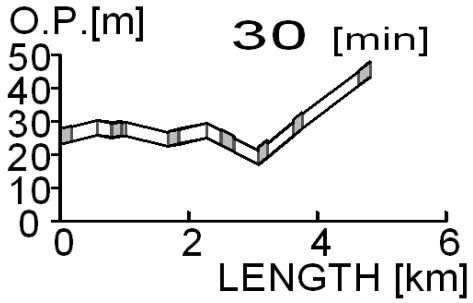
地上 ground



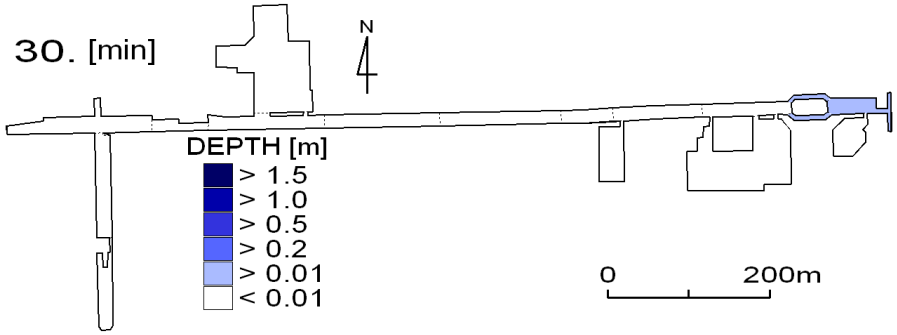
京都駅前地下街
Kyoto station underground mall



京都御池地下街
Kyoto Oike underground mall



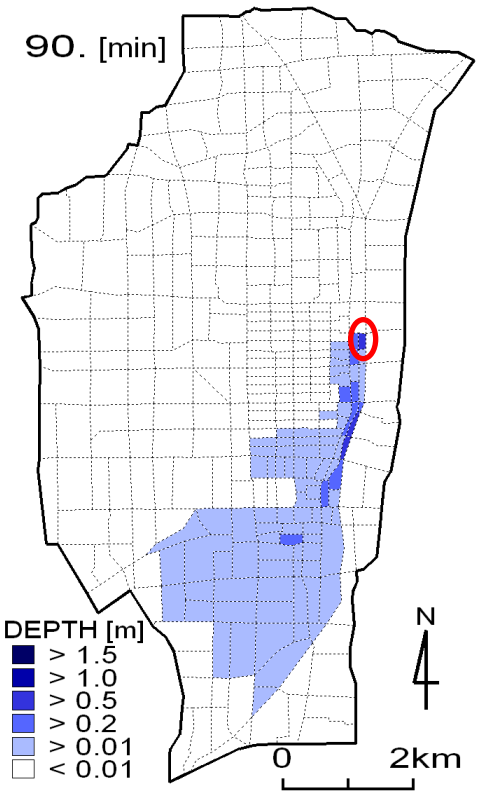
地下鉄東西線 (subway Tozai line)



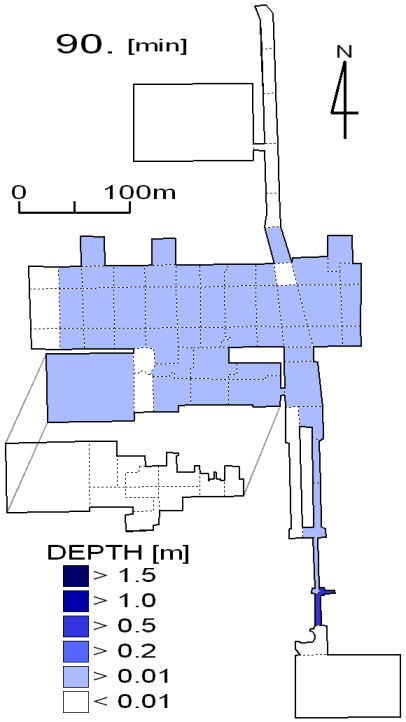
阪急連絡通路 (connection path)

ケース1，90分後

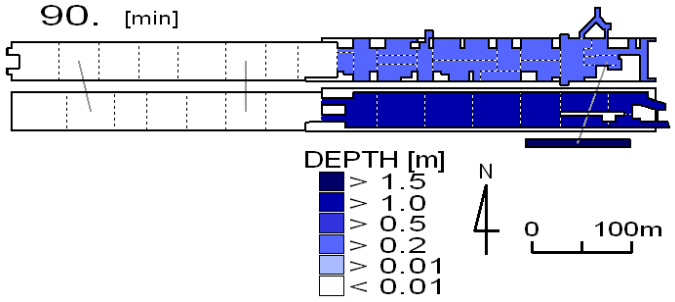
Case1: 90min.after



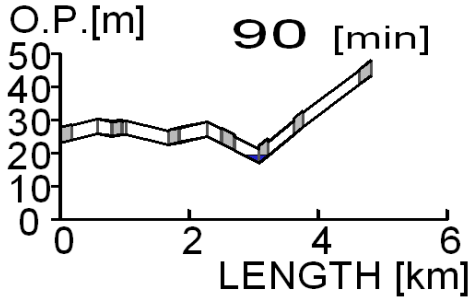
地上(ground)



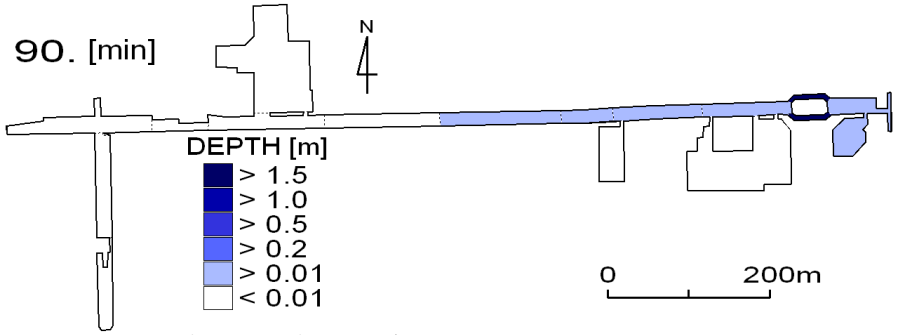
京都駅前地下街
Kyoto station underground mall



京都御池地下街
Kyoto Oike underground mall



地下鉄東西線(subway Tozai line)



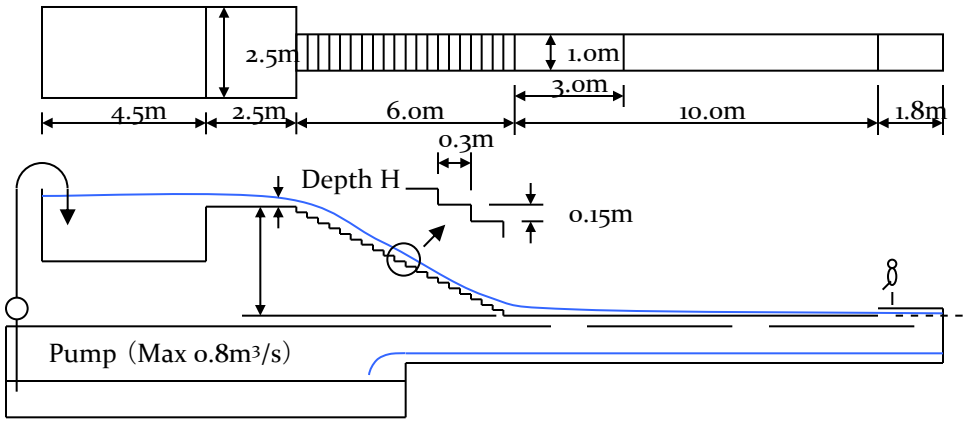
阪急連絡通路(connection path)

Experiments of floating vehicles (part2)

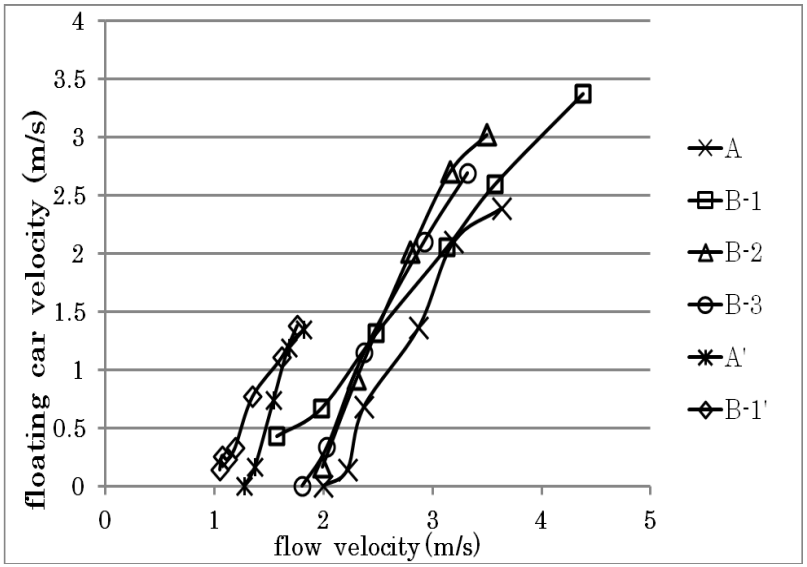
The experiments were done at Ujigawa Open Laboratory, DPRI, Kyoto University.

We used the 1/10 and 1/18 scaled model vehicles in the flume. And by taking the movie by video camera, we obtained the velocity of floating vehicles.

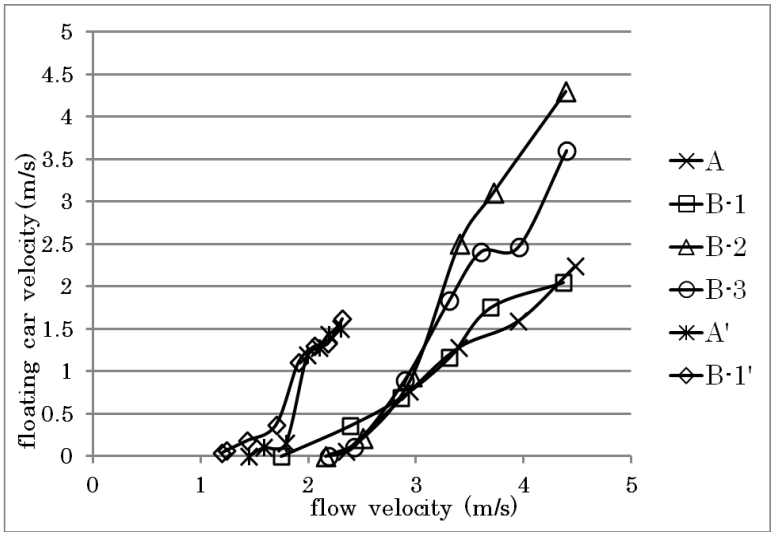
Test flume



sedan



minivan



Case	existence of hand brake	direction (degree)	existence of board
A	Yes	0	No
B-1	No	0	No
B-2	No	90	No
B-3	No	45	No
A’	Yes	0	Yes
B-1’	No	0	Yes

In the sedan typed vehicle, its floating velocity amounts to 70-80 % of the flow velocity as the flow velocity becomes higher.

Experiment of floating vehicles by use of miniature model of urban area with steep slope

The scale of vehicles is about 1/60.

We examined the behavior of vehicles imposing a flash flood upstream.

We found that vehicles crash each other at intersection, and that they are piled up at downstream end.

Experiment of floating vehicles by use of miniature model of urban area with steep slope (part 2)

In the worst case, the severe flood disaster such as in Hong Kong may occur again.

In order to prevent water related accident,

1. Traffic regulations in flooding:

- instruction by local government
- co-operation of administrators of river, road, and disaster mitigation
- measures not to enter submerged underpass

2. Prompt and exact information transmission to drivers:

- advanced information transmission system by use of GPS
- advanced prediction technique of rainfall and subsequent flooding

3. Improvement of driver's awareness to disaster prevention:

- more education activities to flood disasters

Experimental Study of Evacuation from a Partially Submerged Vehicle

Experimental Study on Floating Vehicles in Flooding

Evacuation Experiment by Bicycle in Flood Water

The evacuation from underground space is very dangerous.

It has been well known that evacuation on foot or by car is also very dangerous.

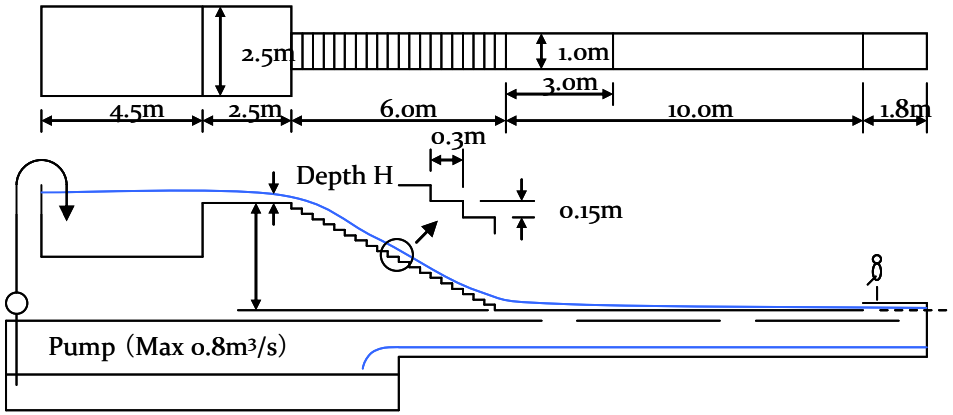
However, the difficulty of evacuation by bicycle in flood water has not been studied as far as we know.

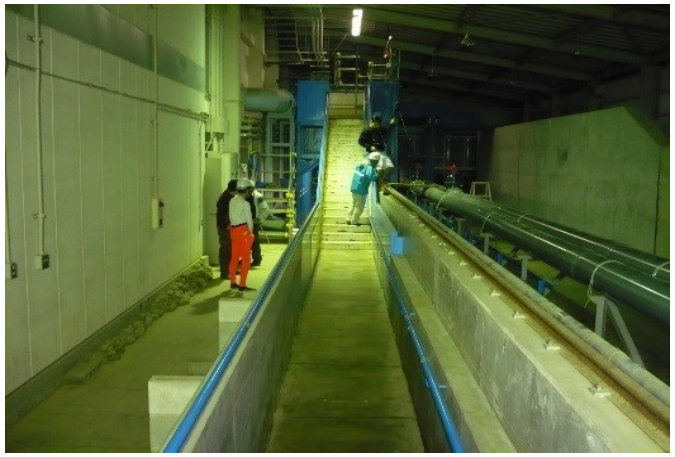
We have conducted evacuation experiments using real size models and studied the difficulty of evacuation by bicycle.

Evacuation experiment by bicycle

To simulate real flow in a road, an almost actual-sized channel was installed at DPRI, Kyoto University.

The channel has about 10m long, 1m wide with height of about 1m.



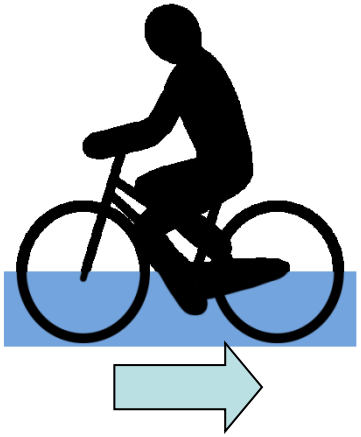


Evacuation experiment by bicycle

The water was supplied from the upstream tank and flood water in a road was simulated.

For the flow velocities of 0.25m/s and 0.5m/s, the depths were changed from 0.1m to 0.4m in units of 0.1m.

20 participants, 17 men and 3 women, pedaled bicycles in flood water, and their run speed was measured.



Evacuation experiment by bicycle

Two types of bicycles :26 inches and 20 inches

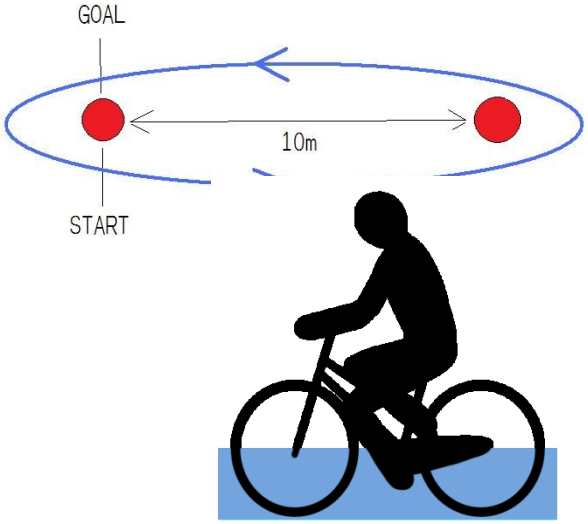
Participants wore a helmet and an elbow pad.

We also executed questionnaire survey to participants.

Evacuation experiment by bicycle

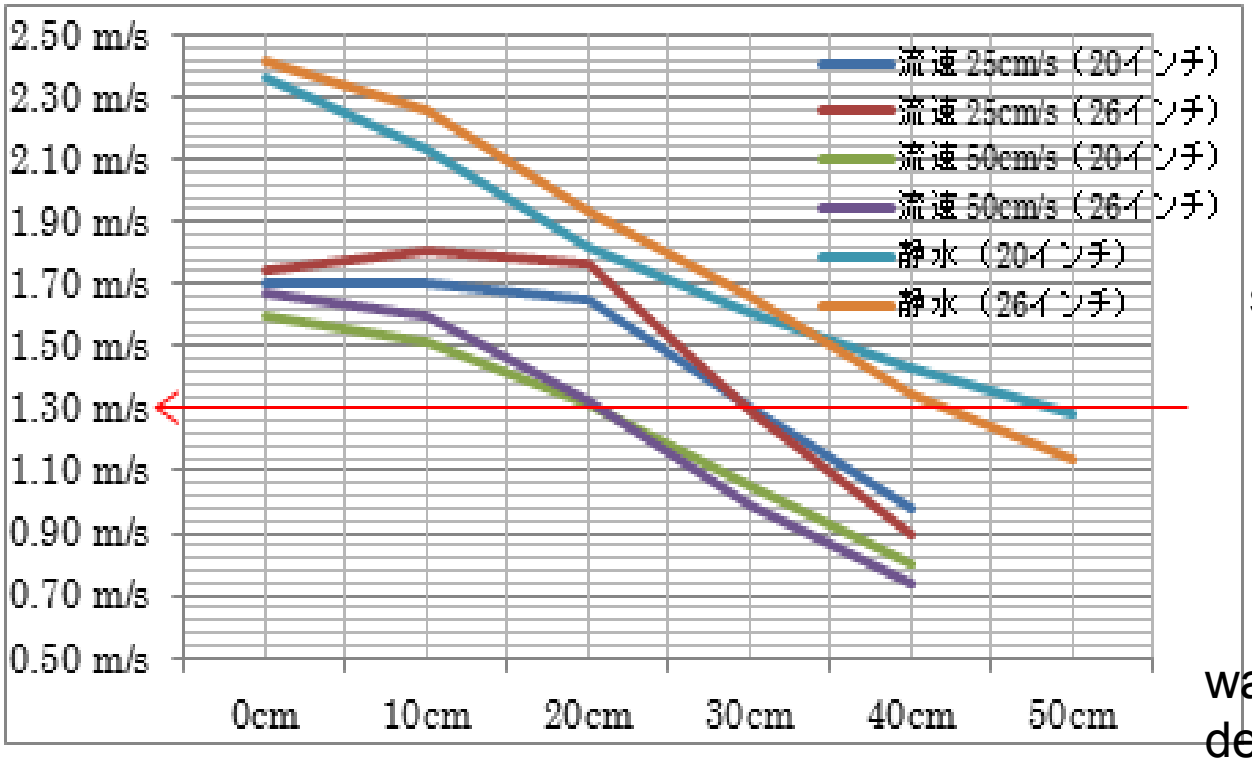
For the still water condition, we used a big wide channel at the laboratory of Kansai University.

Participants went around the course.



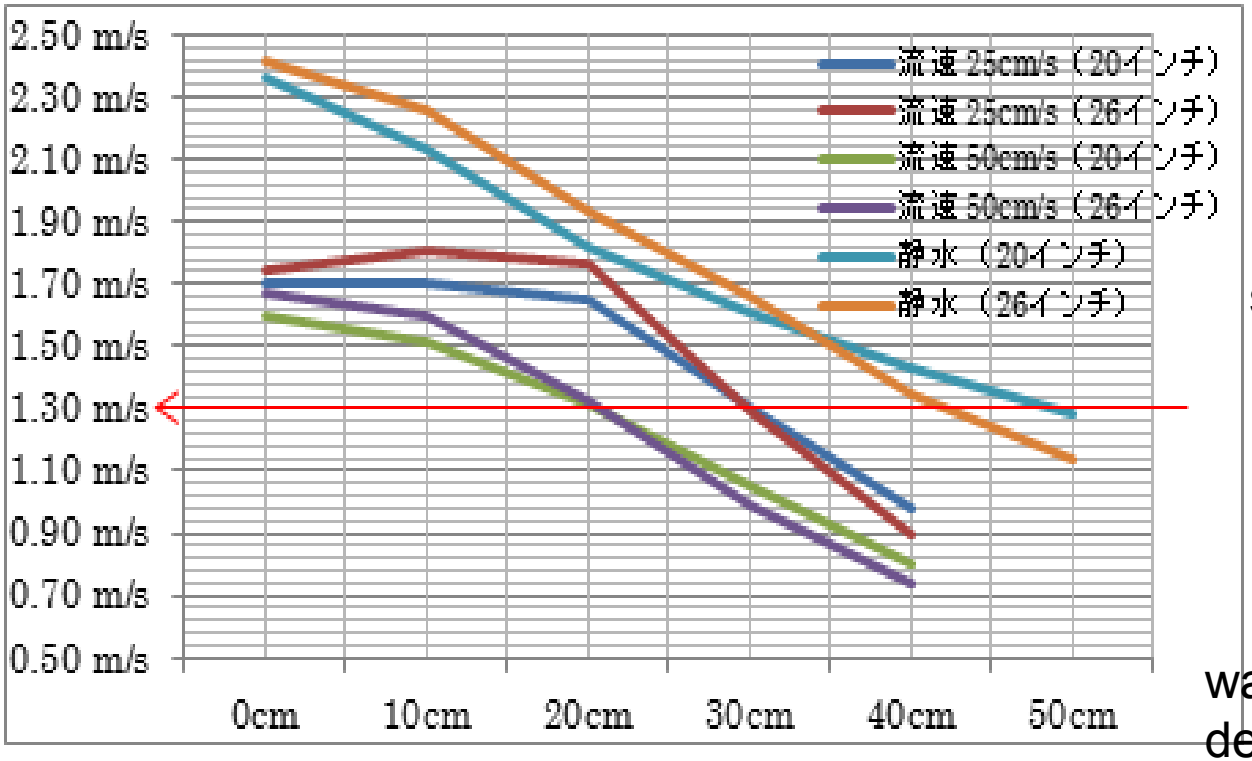
no velocity condition

The run speed by bicycle was almost the same as the walking speed without water of 1.33m/s (4.8km/h) under the condition of flow velocity of 0.5m/s and the water depth of 0.2m and flow velocity of 0.25m/s and the water depth of 0.3m.



As the water depth increases, run speed of bicycle of 26 inches becomes lower than 20 inches.

run speed (m/s)



v=0.25m/s

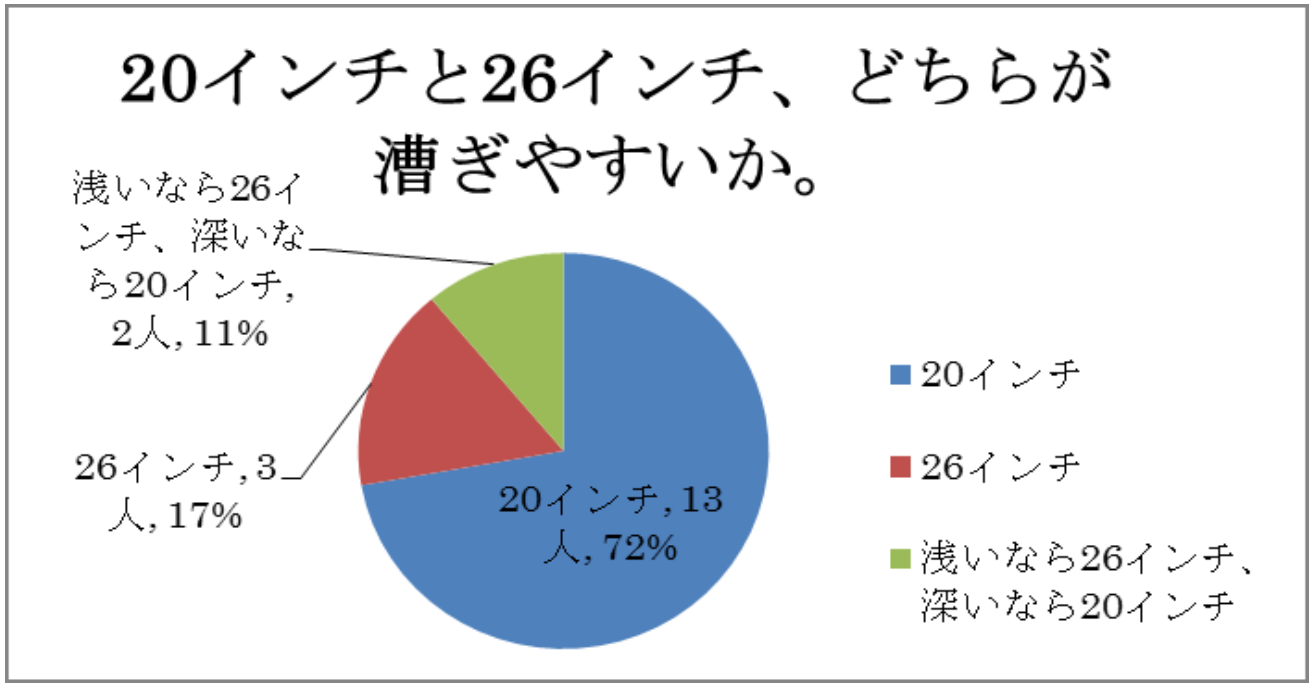
v=0.50m/s

still water

water depth(m)

Questionnaire survey after experiment of v=0.5m/s

Which is easier to run a bicycle, 20 inch one or 26 inch one? ⇒20 inch one is easier.



in flooding

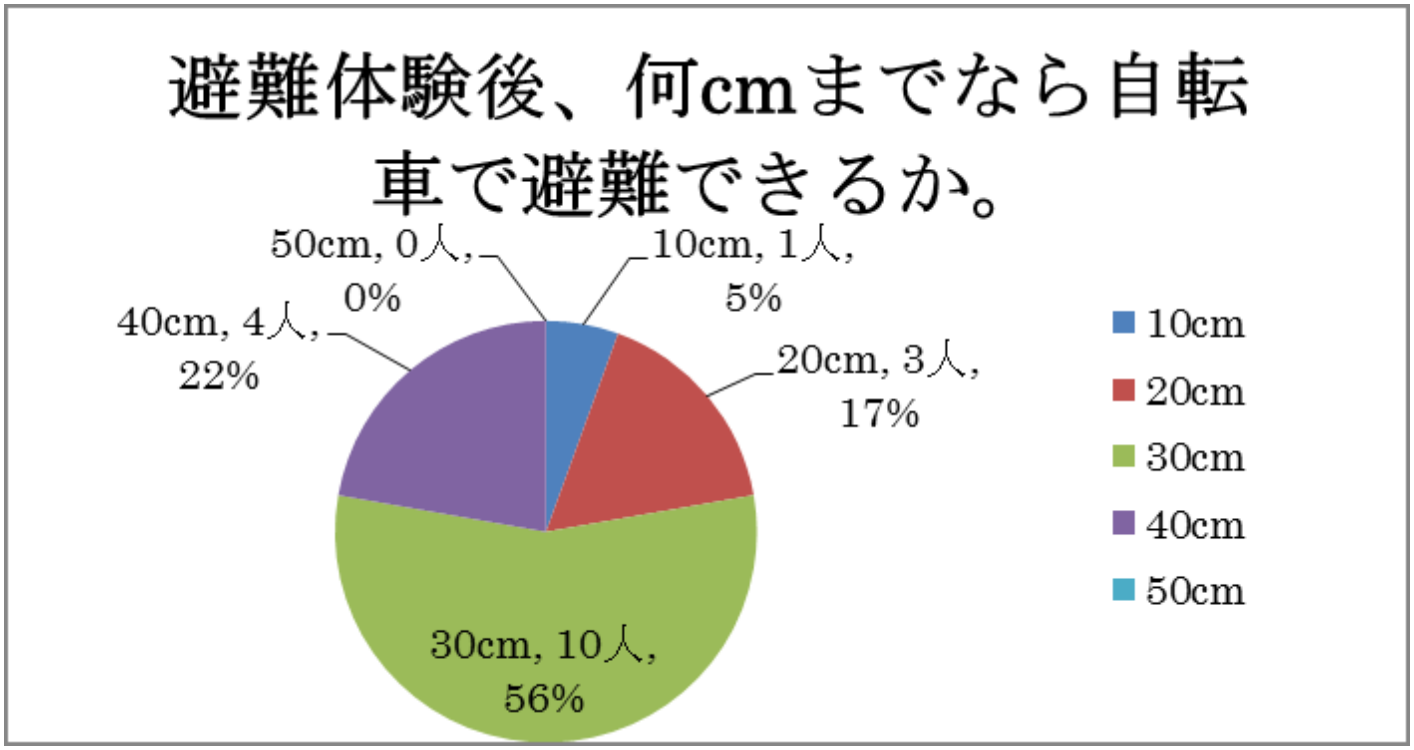
20 inches

26 inches

26 inches for shallow case, 20 inches for deep case

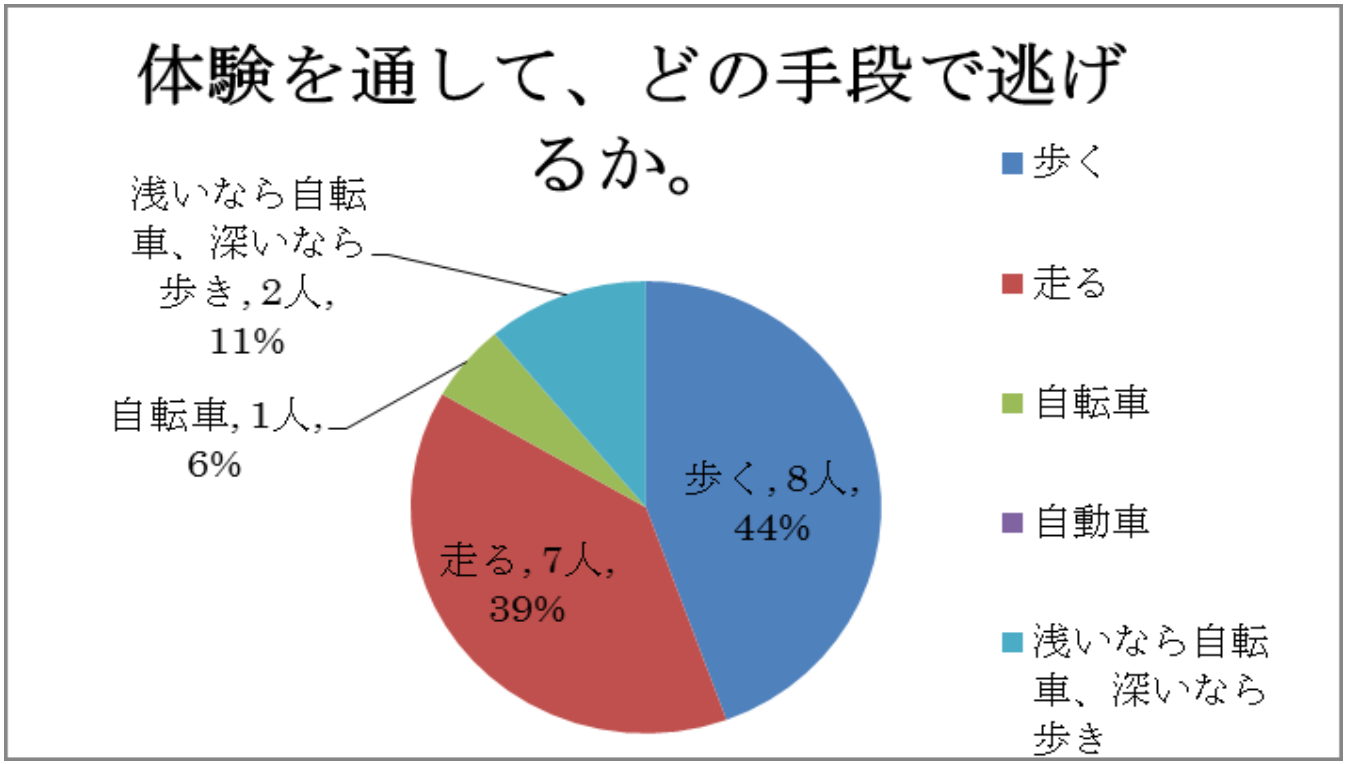
Questionnaire survey after experiment of v=0.5m/s

What water depth is the critical evacuation condition? ⇒2/3 participants answered 0.2m or 0.3m.



Questionnaire survey after experiment of v=0.5m/s

What means do you take in evacuation? ⇒Most participants answered on foot or by running.



on foot

by running

by bicycle

by car

by bicycle for shallow case, on foot for deep case

Concluding Remarks

Under the flow velocity condition this time, the water depth of 0.2m to 0.3m can become a critical condition of evacuation by bicycle in flood water.

Future Tasks

participation of women and elderly persons.
experiment of higher velocity case.
experiment of adverse flow case.

Thank you.

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