Experiment Study on Floating Car in Flooding

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2009/11/11
JR和歌山駅前にある「けやき大通り地下駐車場」の地下2階が浸水し、駐車中の車両24台が、約50センチ水没
Flooded under-pass (29.7.2008, Kyoto)
Flooded under-pass of highway in Kyoto (14.8.2012)

(2012.8.14 Yomiuri news paper)
Hong Kong Flood, 1966
Piled up cars by flood (15.7.2010)
11.3.2011 Tohoku earthquake
津波直撃 奇跡の生還

東日本大震災の取材中、地元紙記者が津波に襲われた。その後、記者は瀬流にのまれたが、奇跡的に助かった。3月11日午後3時25分ころ、岩手県釜石市（写真撮影、提供：国土交通省釜石港湾事務所）

＝27面に記事
Flood in New York
(30.10.2012)

(2.11.2012 NHK News)
Past flood in Hong Kong (1966)

- 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.

What may happen?

Water related disasters

- Flood inundation
- Tsunami inundation
Previous studies (1)


Recently, critical incipient floating condition was studied by Oshikawa et al. (2011) and Shu et al. (2011).

Evacuation difficulties from a partially submerged car were conducted by using a real-size model car by Ishigaki et al. (2009).
Xia et al. (2011)* developed an integrated model to assess the flood hazard degrees for people and cars in flash flood and applied it to the flash floods in the UK and France.

1. We execute incipient floating condition of partially submerged cars and behavior of floating cars 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 prototype ones.
   (1/10 scaled sedan and 1/18 scaled minivan)
Experiments of floating cars

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 prototype.
Model cars

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 (car)

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

direction of car

with handbrake
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.
Experiments

流  量: 9.6 l/s
水  深: 0.027 m
平均流速: 0.356 m/s
## Experiment cases and critical condition of incipient motion

The table below shows the experiment cases and critical condition of incipient motion. The value in parenthesis means the real scale value.

<table>
<thead>
<tr>
<th>Case</th>
<th>existence of hand brake</th>
<th>direction (degree)</th>
<th>existence of board</th>
<th>incipient motion condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sedan (scale: 1/10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>flow velocity (m/s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>flow velocity (m/s)</td>
</tr>
<tr>
<td>A</td>
<td>Yes</td>
<td>0</td>
<td>No</td>
<td>0.63 (2.00)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.55 (2.35)</td>
</tr>
<tr>
<td>B-1</td>
<td>No</td>
<td>0</td>
<td>No</td>
<td>0.50 (1.57)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.41 (1.74)</td>
</tr>
<tr>
<td>B-2</td>
<td>No</td>
<td>90</td>
<td>No</td>
<td>0.63 (2.00)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.51 (2.16)</td>
</tr>
<tr>
<td>B-3</td>
<td>No</td>
<td>45</td>
<td>No</td>
<td>0.57 (1.80)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.52 (2.19)</td>
</tr>
<tr>
<td>A’</td>
<td>Yes</td>
<td>0</td>
<td>Yes</td>
<td>0.38 (1.20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.37 (1.57)</td>
</tr>
<tr>
<td>B-1’</td>
<td>No</td>
<td>0</td>
<td>Yes</td>
<td>0.33 (1.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.29 (1.24)</td>
</tr>
</tbody>
</table>
Force exerted on the partially submerged car

\[ F = S = \mu(Mg - F_b - L) \]

\[ F = 0.5\rho C_d U^2 A_x \]

\[ F_b = \rho g V \]

\( V \): net volume of partially submerged car

<table>
<thead>
<tr>
<th>car type</th>
<th>direction (degree)</th>
<th>existence of hand brake</th>
<th>coefficient of static friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>sedan</td>
<td>0</td>
<td>No</td>
<td>0.073</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Yes</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>No</td>
<td>0.565</td>
</tr>
<tr>
<td>minivan</td>
<td>0</td>
<td>No</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Yes</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>No</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Force exerted on the partially submerged car

\[ F = S = \mu(Mg - F_b - L) \]

\[ F = 0.5 \rho C_d U^2 A_x \]

\[ F_b = \rho g V \]

\( V \): net volume of partially submerged car

Relation between net volume of model car and water depth
Force exerted on the partially submerged car

\[ F = S = \mu(Mg - F_b - L) \]

\[ F = 0.5\rho C_d U^2 A_x \]

\[ F_b = \rho g V \]

\( V \): net volume of partially submerged car

Relation between drag coefficient and relative water depth
Diagram of critical incipient motion

\[ F = S = \mu (Mg - F_b - L) \]
\[ F = 0.5 \rho C_d U^2 A_x \quad F_b = \rho g V \]

Application to prototype car:

We need to consider the following parameters.

(1) coefficient of static function \( \mu \)

(2) void space of car \( p \)

(3) additional weight (passengers, goods) \( M' \)
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.

Here, the criterion cited above was applied to an inundation flow simulation in the central area of Kyoto City, the old capital of Japan.
Studied area
Kyoto City, Japan

ground elevation
Kyoto Flood in 1935

昭和10年の京都水害の様子

賀茂堤防の被災状況

京都大学名誉教授・中川博次先生より by Prof. Nakagawa emeritus
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: over 1.5m/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.
Concluding remarks (1)

- Unexpected disasters may occur in urban areas due to heavy rainfall, and climate change may exacerbate this. When we treat urban flood problems, we keep in mind that the modern society is a motorized society and cars are closely related to various damages by urban flooding. We can predict if cars are floated or not in flooding by combining 2-D inundation flow simulation and the car incipient floating criterion obtained here.
Concluding remarks (2)

• We need to develop our research on car related problems further by experimental method and computer simulation in the future. One of the important research topics is to study behaviour of floating cars in urban area with steep slope in flooding.
Thank you for your attention

Lay up for a rainy day.
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
Experiments of floating vehicles (part 2)

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

![Test flume diagram]
In the sedan typed vehicle, its floating velocity amounts to 70-80% of the flow velocity as the flow velocity becomes higher.