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EXPERIMENTAL STUDY ON DEVELOPMENT OF LONG-SPAN FLAP-GATE TYPE SEAWALL FOR TSUNAMI AND STORM SURGE

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Outline

- Background
- Flap-gate type seawall　-NEORISE SYSTEM-
- Long-span type NEORISE SYSTEM
- Hydraulic experiments
- Conclusions

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Background

- The 2011 Tohoku Earthquake gave damages to power machineries and communication systems of tsunami barrier gates and these tsunamis caused many casualties who tried to operate and close these gates.
- Structures for tsunami protection are required so as to avoid machinery failure and risk of operators. NEORISE system satisfies both of these requirements.

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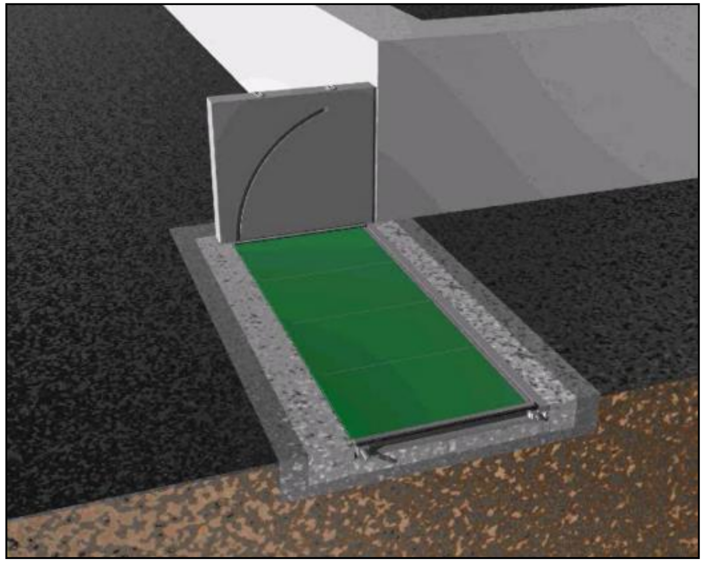
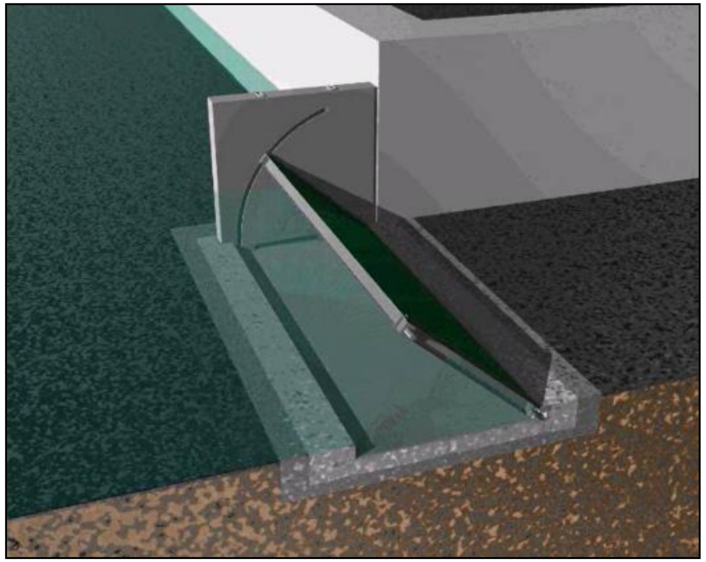
Flap-gate type seawall -NEORISE SYSTEM-

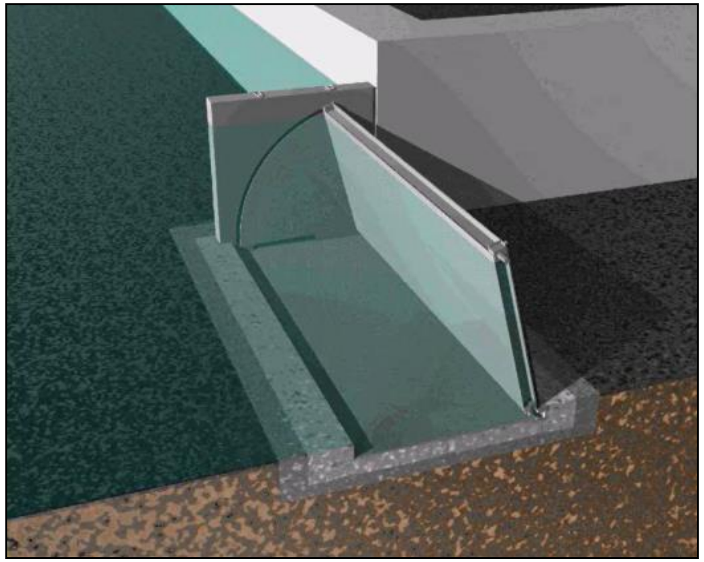
Using Water Pressure due to Flooding



Lying position



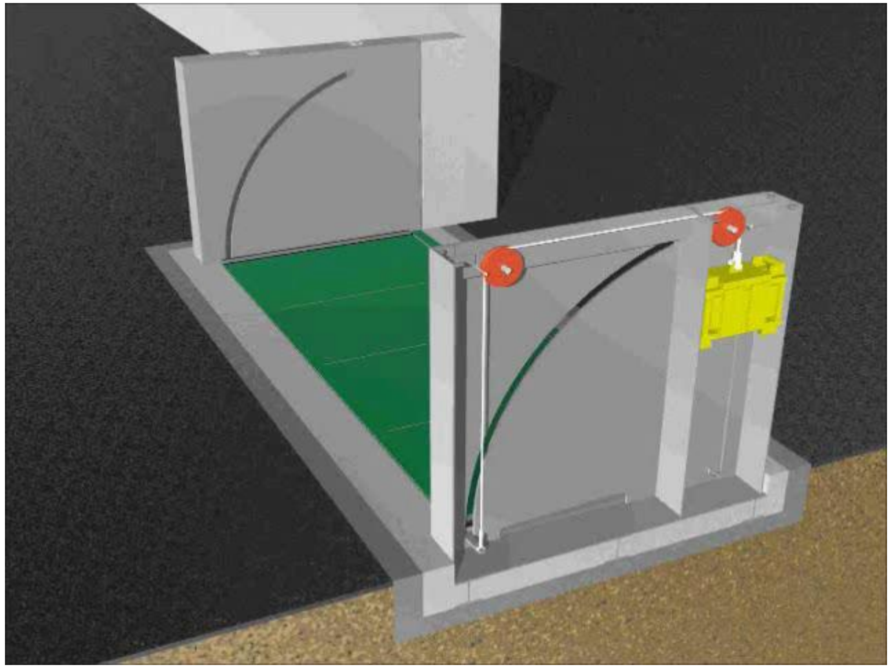
Rising



Standing position

- A flap-gate type movable seawall, which usually lies down on the ground, rises up automatically by buoyancy during inundation by tsunamis and storm surges, and then it forms a continuous seawall.

Flap-gate type seawall -NEORISE SYSTEM-



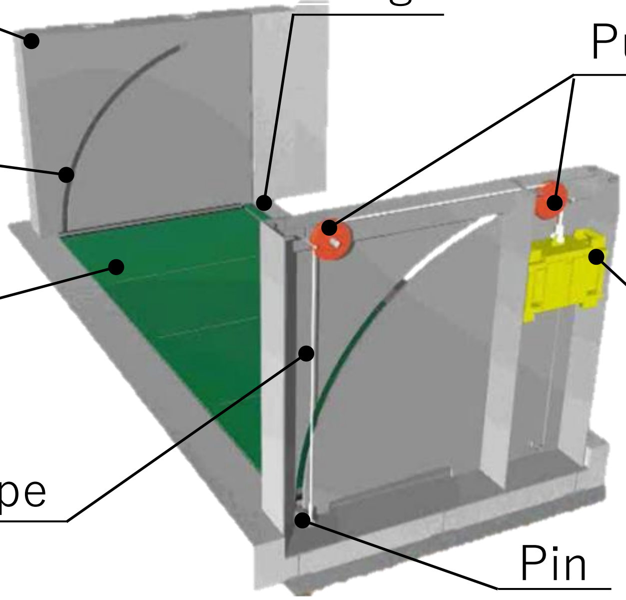
No Energy and No Operation Rising Seawall

Features

<u>No.1</u> Self-actuating by water
<u>No.2</u> Barrier-free in usual time
<u>No.3</u> Low maintenance cost

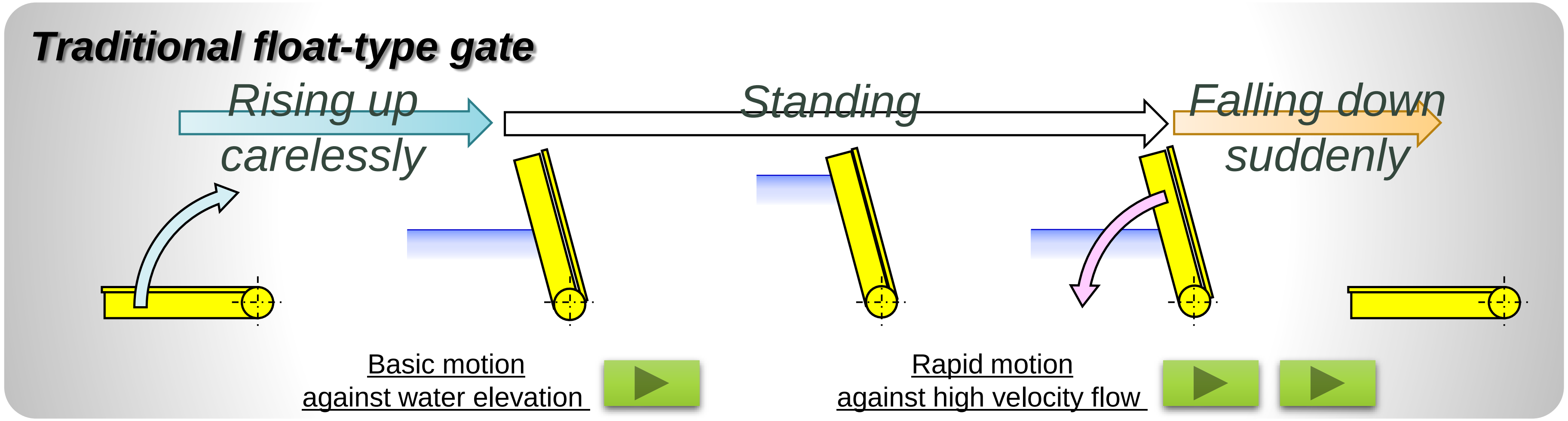
- This structure keeps lying in usual time to secure traffic and landscape. In emergence time, it protects a target area against inundation without power machineries and human operation.
- It is called NEORISE which means No Energy and no Operation RIsing SEawall.

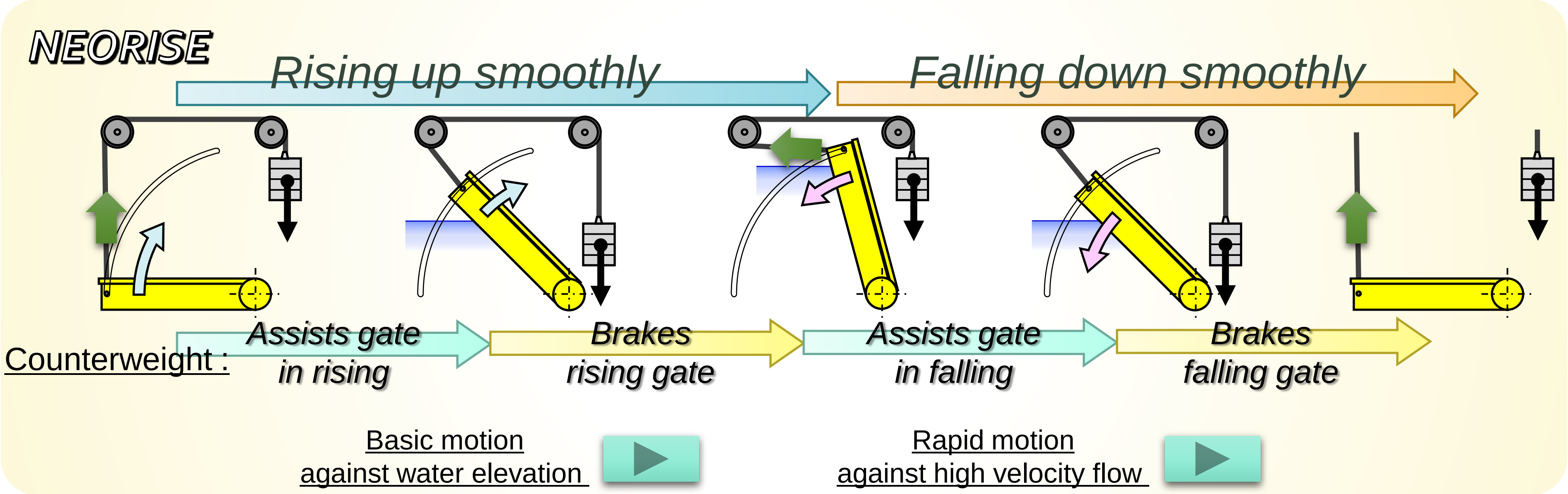
Flap-gate type seawall -NEORISE SYSTEM-



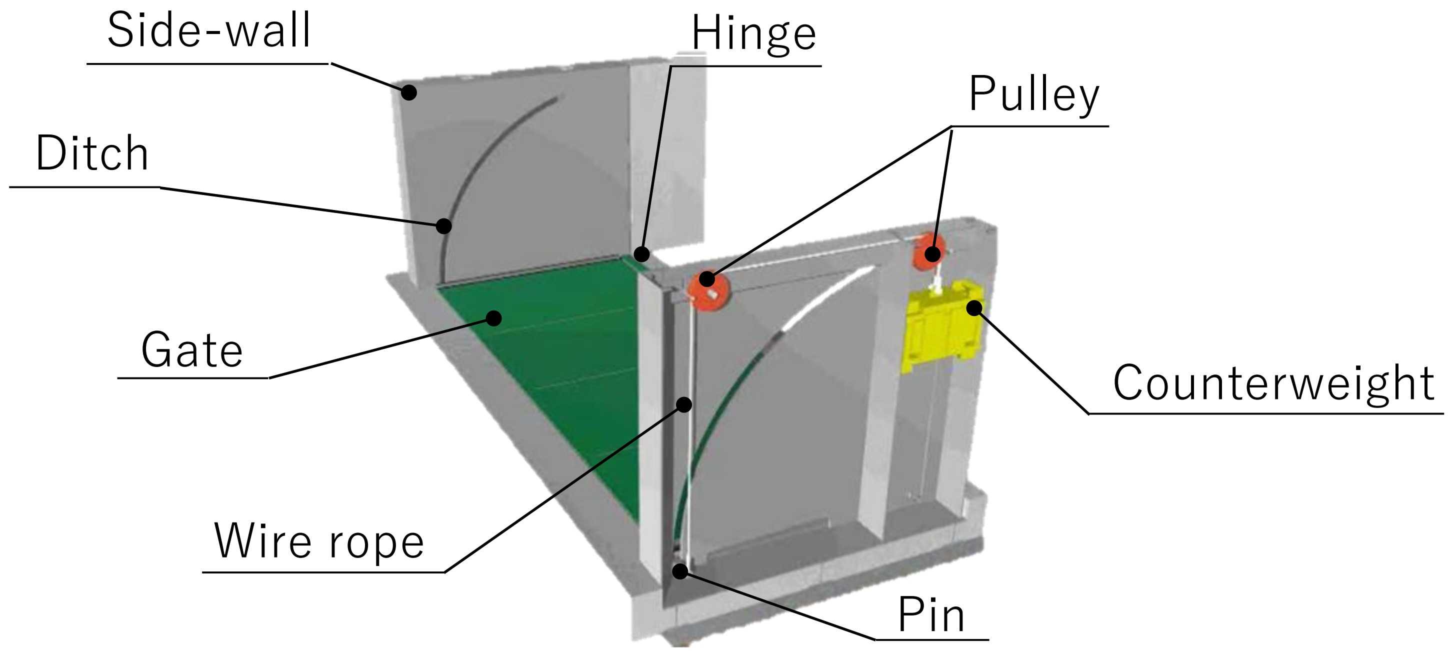
- The NEORISE system equips counterweights inside side-walls installed on both sides of the gate, and the counterweight assists the gate in rising and standing.

Differences between Traditional float-type gate and NEORISE





Flap-gate type seawall -NEORISE SYSTEM-



- However, it is complicated to design cross direction members of the widened NEORISE system economically since a supporting interval by wire ropes connecting each counterweight extends according to an increase of the gate width.

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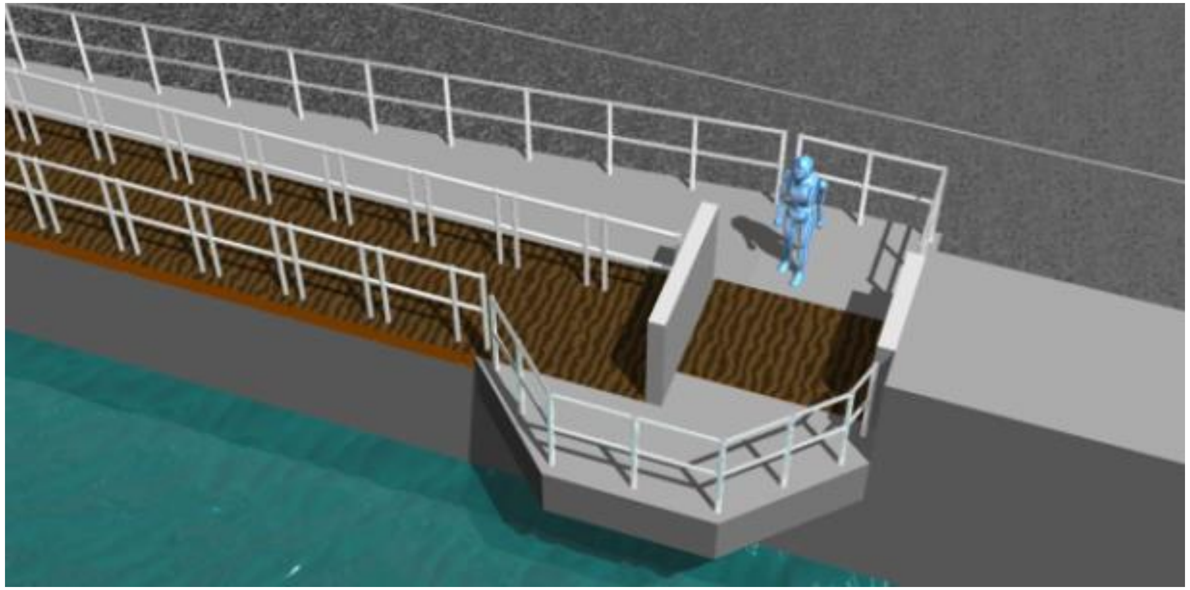
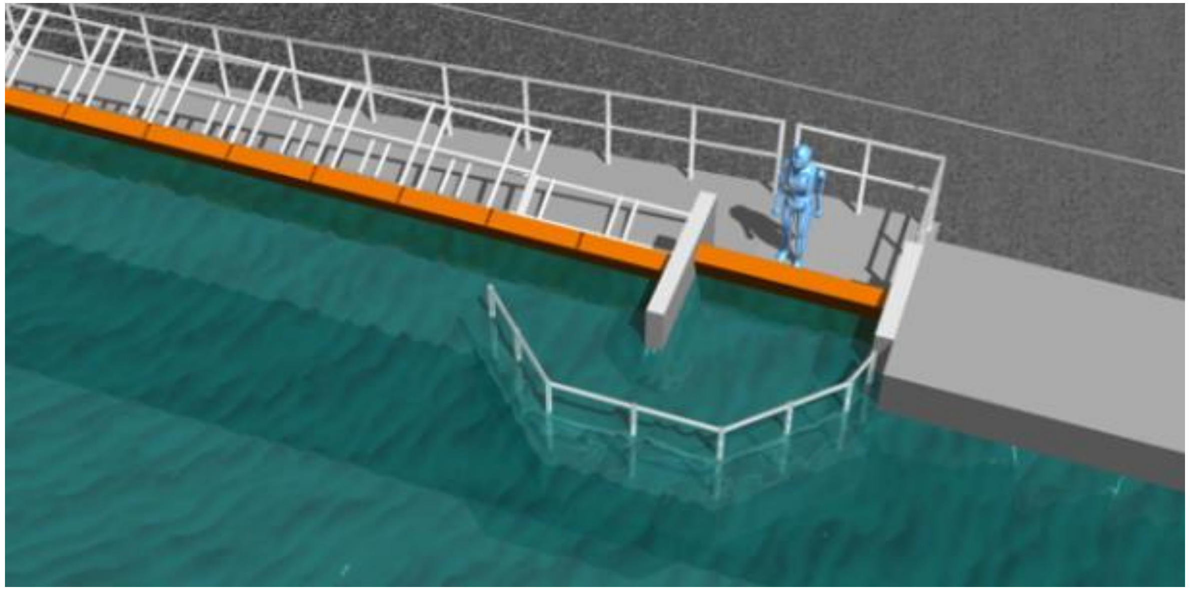
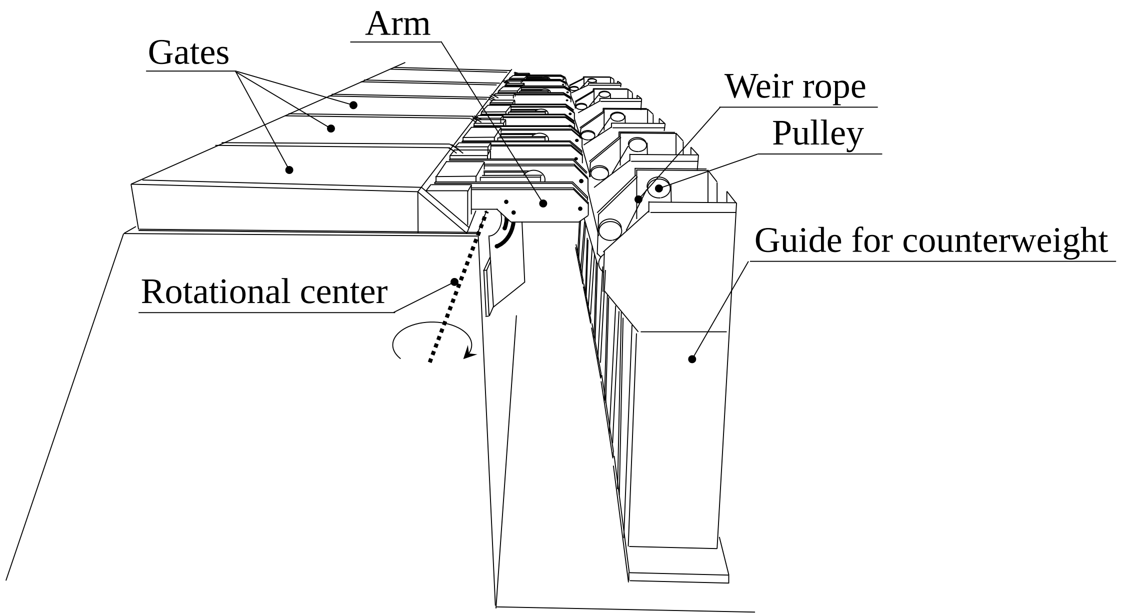
Long-span type NEORISE SYSTEM





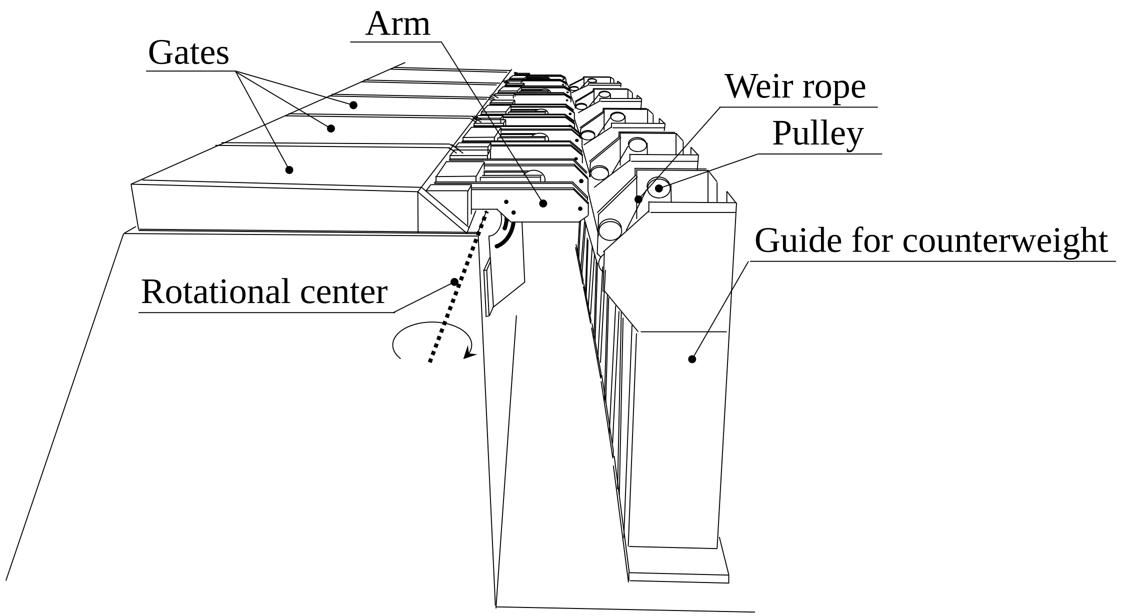
- In order to realize the economical design, a long-span type NEORISE system ,which can prevent the supporting interval from widening by setting the counterweight behind the gate, has been developed.

Long-span type NEORISE SYSTEM



- The long-span NEORISE can be applied to gaps of inundation defense, whose width is not restricted, by installing the same pattern gate continuously along an across direction.
- Each gate equips arms on anti-gate side to rotational center.
- Counterweights are hung by wire rope connecting with the top of the arm through some pulley and assist motions of the gate as the NEORISE's one.

Long-span type NEOROSE SYSTEM



- Seal rubbers are set between each gate which can move independently.
- Tensile members are installed on gaps between adjacent gates so as not to broaden differences of these gate’s angles beyond a prescribed angle in order to prevent the seal rubbers from tearing.

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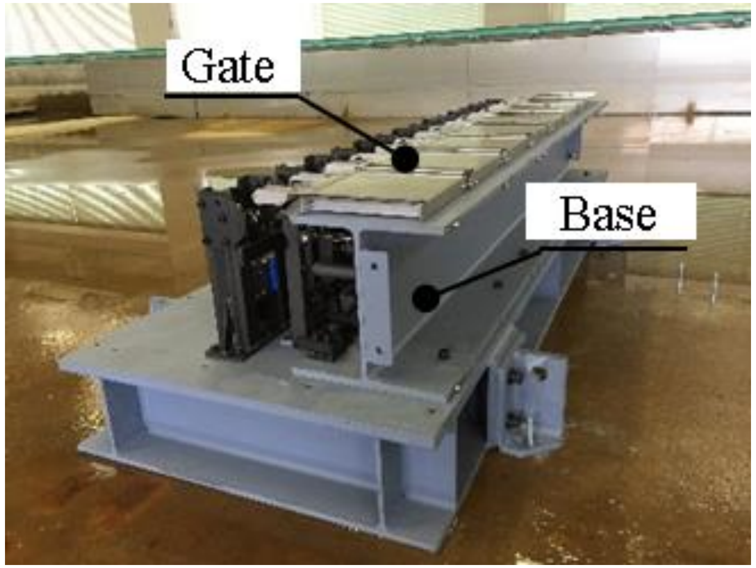
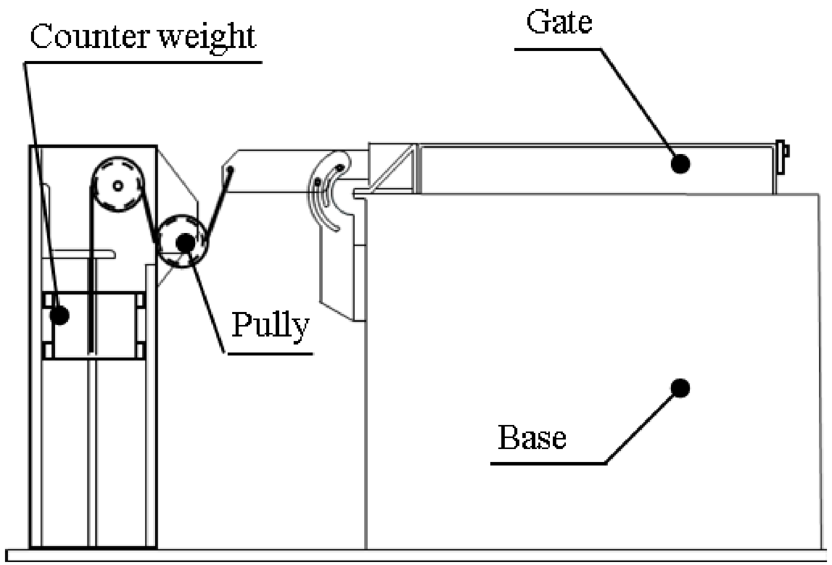
- In this experiment, both characteristics of responses and reliability of disaster prevention of the long-span NEORISE were evaluated by using two type experimental water tanks.

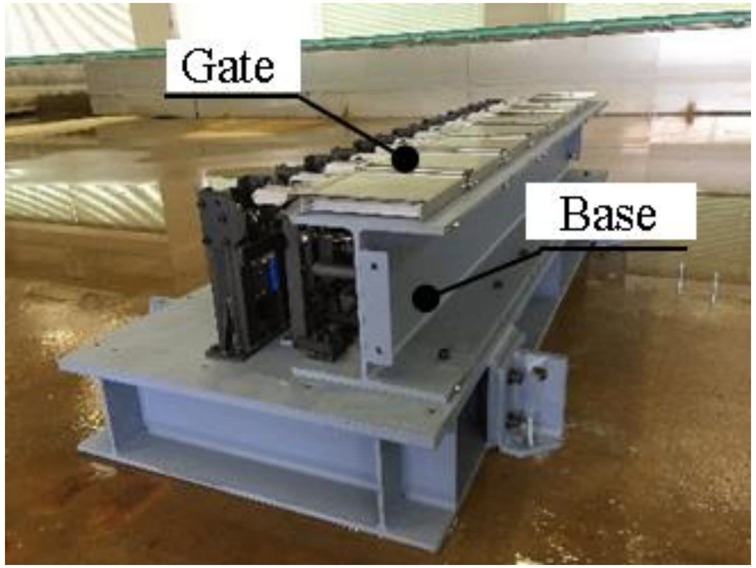
Experimental model

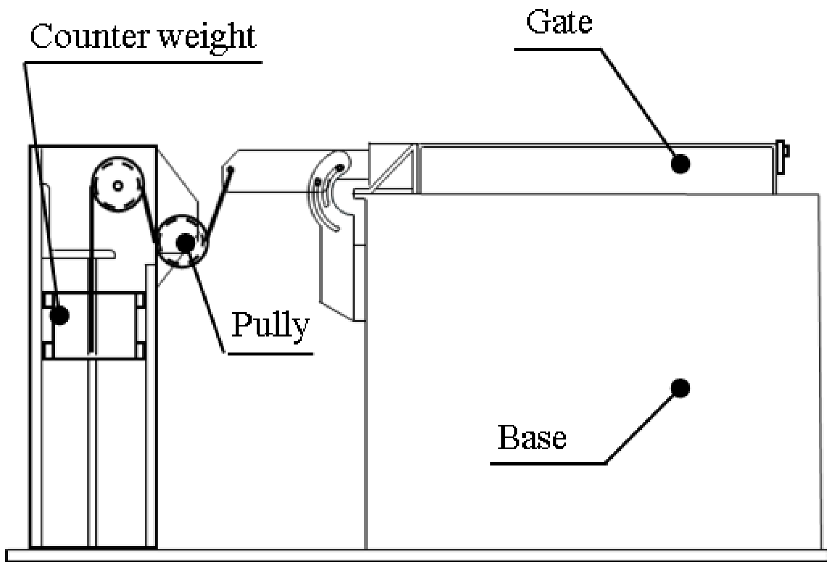




- A series of experiments was carried out using a 1/4 scale experimental model.
- The experimental model consisted of 8 gates and each gate was connected to adjacent gates like a practical structure.
- A size of gate was 0.26 m high, 0.25 m wide, and 0.03 m thick.

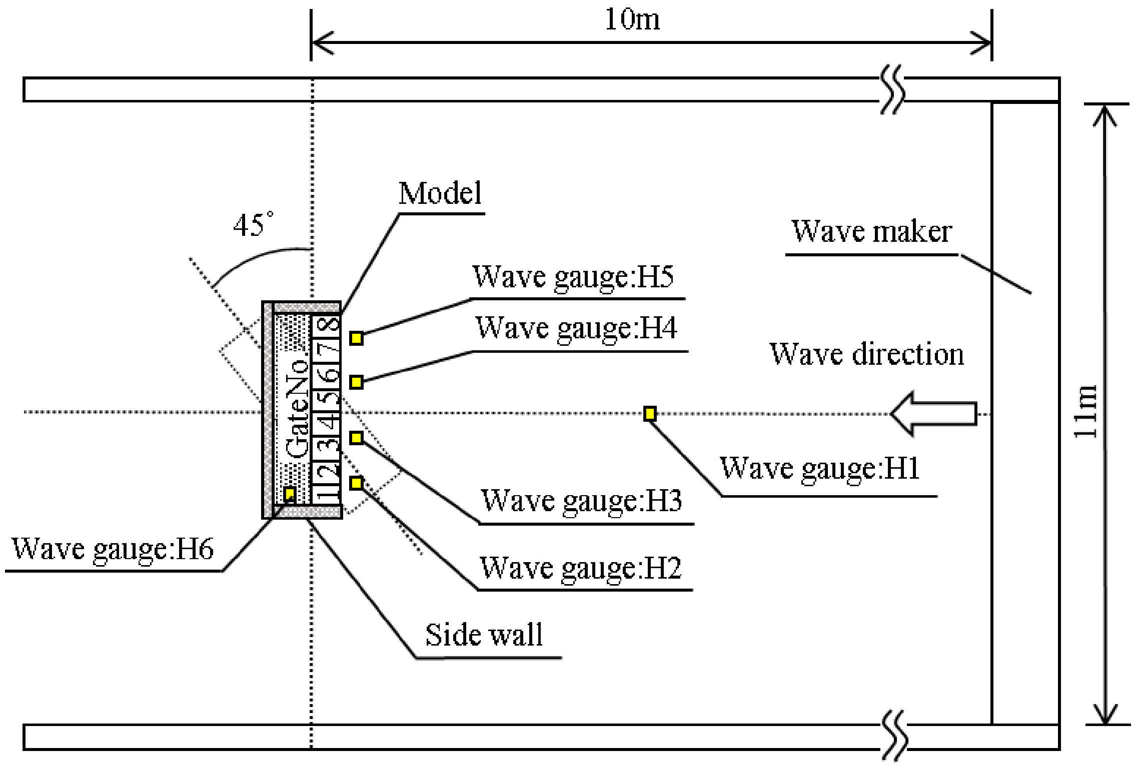
Experimental model





- These gates were set on a base representing a revetment or an embankment .
- A vessel was equipped behind the gates to measure an amount of overtopping beyond the lying gates.

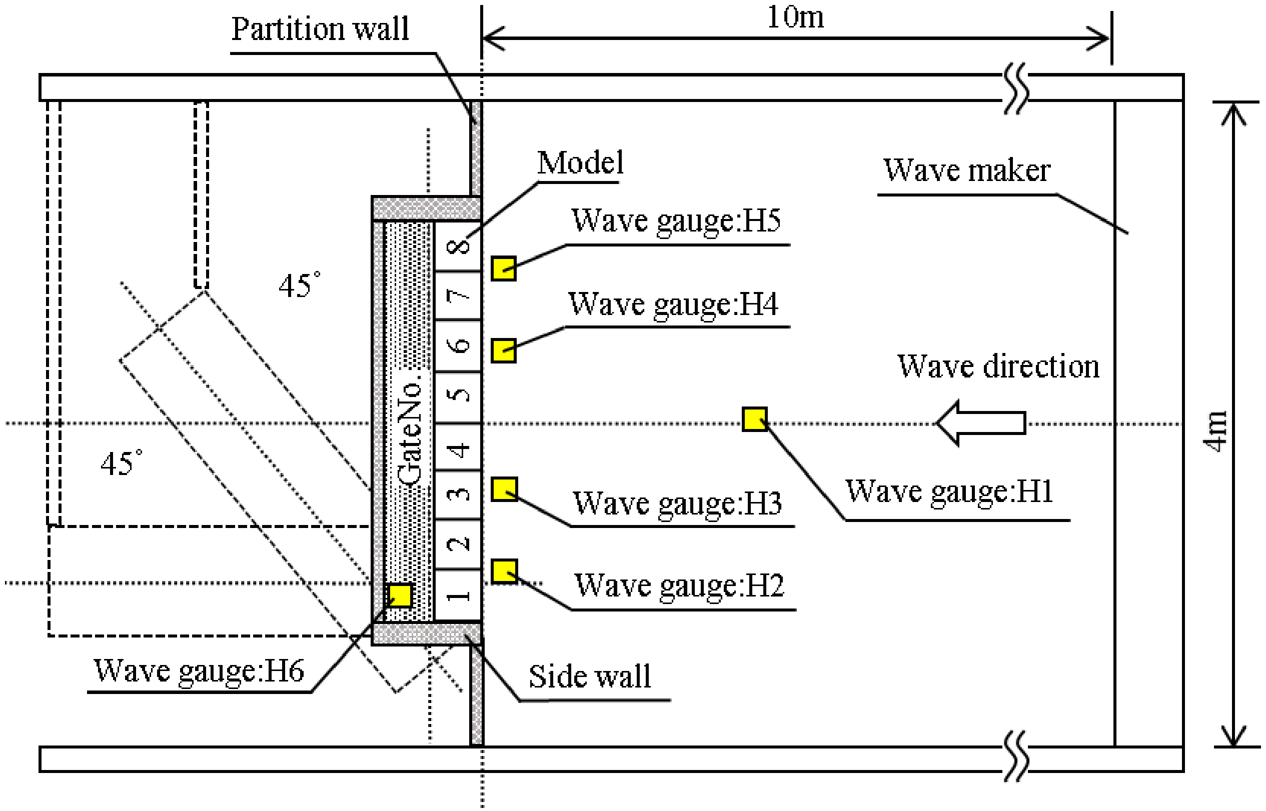
Plane water tank



Item	Plane water tank
Size	11m(W)×28m(L)×0.8m(H)
Wave maker	Piston-type

- The plane water tank, which is 11 m wide, 28 m long, and 0.8 m deep, equips a piston-type wave maker.
- Conditions of the experimental tsunamis were measured with wave gauges H1 – H5 and overtopping discharges were measured with a wave gauge H6.

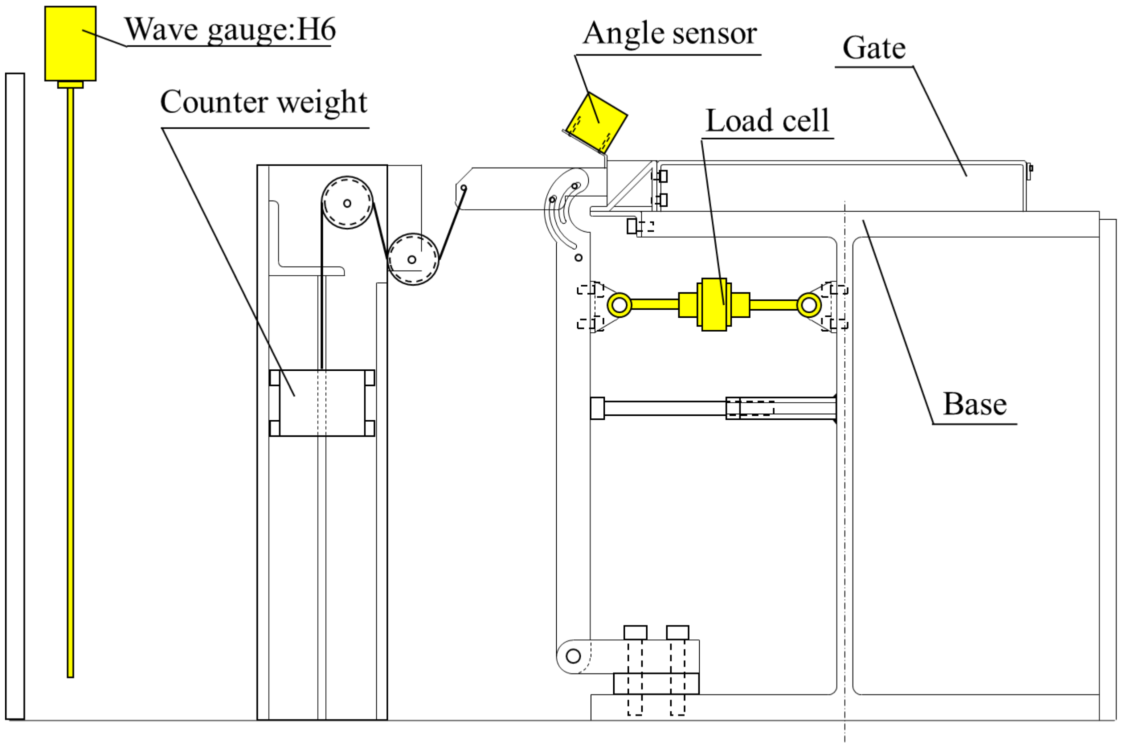
Tsunami generator tank



Item	Tsunami generator tank
Size	4m(W)×45m(L)×2.5m(H)
Wave maker	Piston-type, Pump-type, Dam-break-type

- On the other hand, the tsunami generator tank, which is 4 m wide, 45 m long, and 2.5 m deep, equips a piston-type, a pump-type, and a dam-break-type wave maker.
- The piston-type maker generating short-period waves and the pump-type maker generating long-period waves were used so as to make experimental waves similar to real tsunamis.

Arrangement of sensors



- Angle sensors were installed around the bottoms of each gate in order to reduce influence of angular acceleration caused by motions of the gates upon the angle sensors.
- Wave force acting on each gate was measured with load cells installed between the base and arms supporting the bottoms of each gate.
- The overtopping was calculated from change of the water level in the vessel behind the model by the wave gauge H6.

Experimental conditions

Case	Water tank	Waveform	Wave direction	Initial state
1	Tsunami generator	Pump type : 25cm	90°	Fixed
2				Movable
3			45°	
4			0°	
5		Pump type : 20cm + Piston type : 5cm	90°	Fixed
6				Movable
7			45°	
8			0°	
9		Pump type : 15cm + Piston type : 10cm	90°	Fixed
10				Movable
11			45°	
12			0°	
13		Pump type : 10cm + Piston type : 15cm	90°	Fixed
14				Movable
15			45°	
16			0°	
17	Plane water tank	Piston type Wave period : 8s Wave hieght : 12.8cm	90°	Fixed
18				Movable
19			45°	
20		Piston type Wave period : 4s Wave hieght : 12.6cm	90°	Fixed
21				Movable
22			45°	

- Maximum water levels of experimental tsunamis were adjusted to 0.25 m so as not to exceed the upright gates.
- Depending on hydraulics and local topography conditions, elevation in front of each gate may not uniformly occur.
- In order to represent such conditions, the model in the plane water tank was set in 2 ways experimental tsunamis arrive from the front or diagonal, and the model in the tsunami generator tank was set in 3 ways these tsunamis arrive from the front, diagonal or side.

Experimental conditions

<table>
<tr><th>Case</th><th>Water tank</th><th>Waveform</th><th>Wave direction</th><th>Initial state</th></tr>
<tr><td>1</td><td rowspan="16">Tsunami generator</td><td rowspan="4">Pump type : 25cm</td><td rowspan="2">90°</td><td>Fixed</td></tr>
<tr><td>2</td><td rowspan="3">Movable</td></tr>
<tr><td>3</td><td>45°</td></tr>
<tr><td>4</td><td>0°</td></tr>
<tr><td>5</td><td rowspan="4">Pump type : 20cm
+
Piston type : 5cm</td><td rowspan="2">90°</td><td>Fixed</td></tr>
<tr><td>6</td><td rowspan="3">Movable</td></tr>
<tr><td>7</td><td>45°</td></tr>
<tr><td>8</td><td>0°</td></tr>
<tr><td>9</td><td rowspan="4">Pump type : 15cm
+
Piston type : 10cm</td><td rowspan="2">90°</td><td>Fixed</td></tr>
<tr><td>10</td><td rowspan="3">Movable</td></tr>
<tr><td>11</td><td>45°</td></tr>
<tr><td>12</td><td>0°</td></tr>
<tr><td>13</td><td rowspan="4">Pump type : 10cm
+
Piston type : 15cm</td><td rowspan="2">90°</td><td>Fixed</td></tr>
<tr><td>14</td><td rowspan="3">Movable</td></tr>
<tr><td>15</td><td>45°</td></tr>
<tr><td>16</td><td>0°</td></tr>
<tr><td>17</td><td rowspan="6">Plane water tank</td><td rowspan="3">Piston type
Wave period : 8s
Wave hieght : 12.8cm</td><td rowspan="2">90°</td><td>Fixed</td></tr>
<tr><td>18</td><td rowspan="2">Movable</td></tr>
<tr><td>19</td><td>45°</td></tr>
<tr><td>20</td><td rowspan="3">Piston type
Wave period : 4s
Wave hieght : 12.6cm</td><td rowspan="2">90°</td><td>Fixed</td></tr>
<tr><td>21</td><td rowspan="2">Movable</td></tr>
<tr><td>22</td><td>45°</td></tr>
</table>

- In order to design foundations of a movable structure such as the long-span NEORISE, it is necessary to compare with stresses acting on the foundations of a fixed structure as a coastal embankment against tsunamis.
- The stability of foundations was evaluated using the model whose gates were fixed as an upright state in addition to the model with movable gates.

Evaluation of wave force

Conditions	Values
Load acting on stanfing fixed type / (Hydraulic load calculated by water level of standing fixed type)	2.02
Load acting on movable type / Load acting on stanfing fixed type	1.32

- This Table shows averages of maximum values of the wave force acting on both the fixed upright type and the movable type in the experimental cases 17 and 20 using the plane water tank.
- The wave force acting on the fixed upright type was divided by the hydrostatic load. The wave force acting on the movable type was made dimensionless by using the wave force of fixed upright type.

Experimental conditions

Case	Water tank	Waveform	Wave direction	Initial state
1		Pump type : 25cm	90°	Fixed
2				Movable
3			45°	
16			0°	
17	Plane water tank	Piston type Wave period : 8s Wave hieght : 12.8cm	90°	Fixed
18				Movable
19			45°	
20		Piston type Wave period : 4s Wave hieght : 12.6cm	90°	Fixed
21				Movable
22			45°	

Experimental case 17 21

Evaluation of wave force

Conditions	Values
Load acting on stanfing fixed type / Hydraulic load calculated by water level of standing fixed type	2.02
Load acting on movable type / Load acting on stanfing fixed type	1.32

- The load acting on the fixed type was 2.02 times as large as hydrostatic loads obtained from some experiments under the same conditions.
- Although this value was larger than conventional knowledge concerning wave forces acting on an upright wall, it was due to the method of experimental setup and wave conditions and it was not abnormal level.

Evaluation of wave force

Conditions	Values
Load acting on stanfing fixed type / Hydraulic load calculated by water level of standing fixed type	2.02
Load acting on movable type / Load acting on stanfing fixed type	1.32

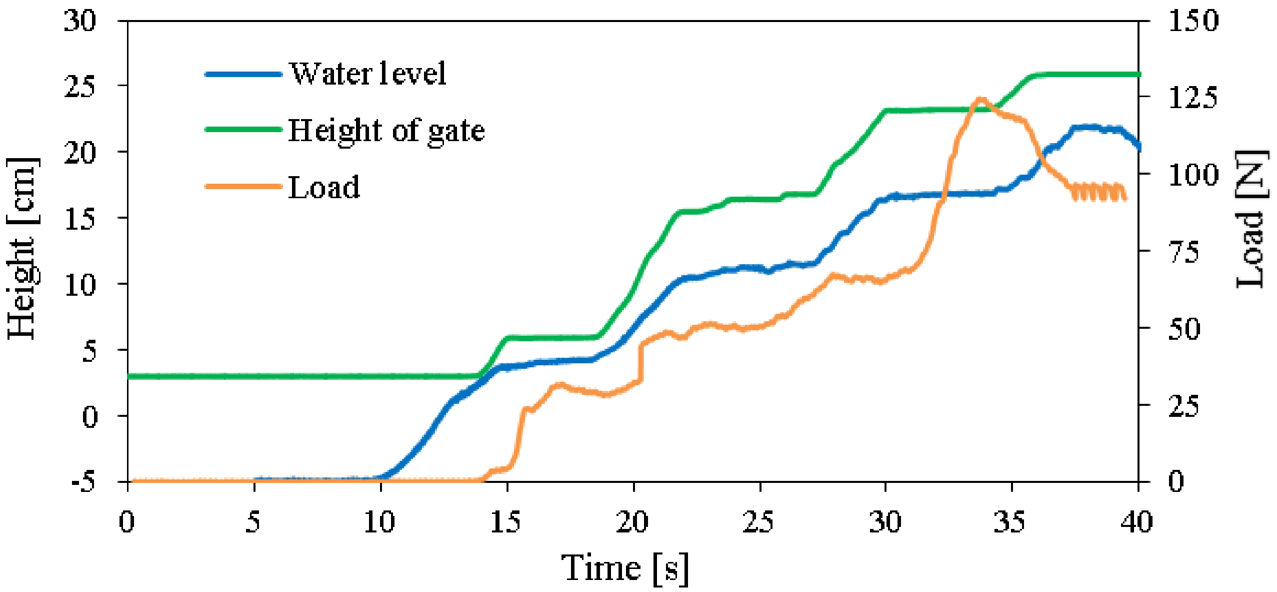
- An average of the maximum values of wave force acting on the movable type was 1.32 times as large as wave force acting on the fixed upright type.
- Since the gates have momentum in response to the wave force, this momentum of gates acted on the arms supporting the bottoms of gates in addition to the wave force at the moment gates stood up.

Evaluation of wave force

Conditions	Values
Load acting on stanfing fixed type / (Hydraulic load calculated by water level of standing fixed type)	2.02
Load acting on movable type / (Load acting on stanfing fixed type)	1.32

- As a result, the wave force of movable type increased by about 30 % compared with the fixed upright type.
- However, force such as impact was mitigated because of the counterweight, and it was proved that the counterweight was effective in braking.

Evaluation of wave force



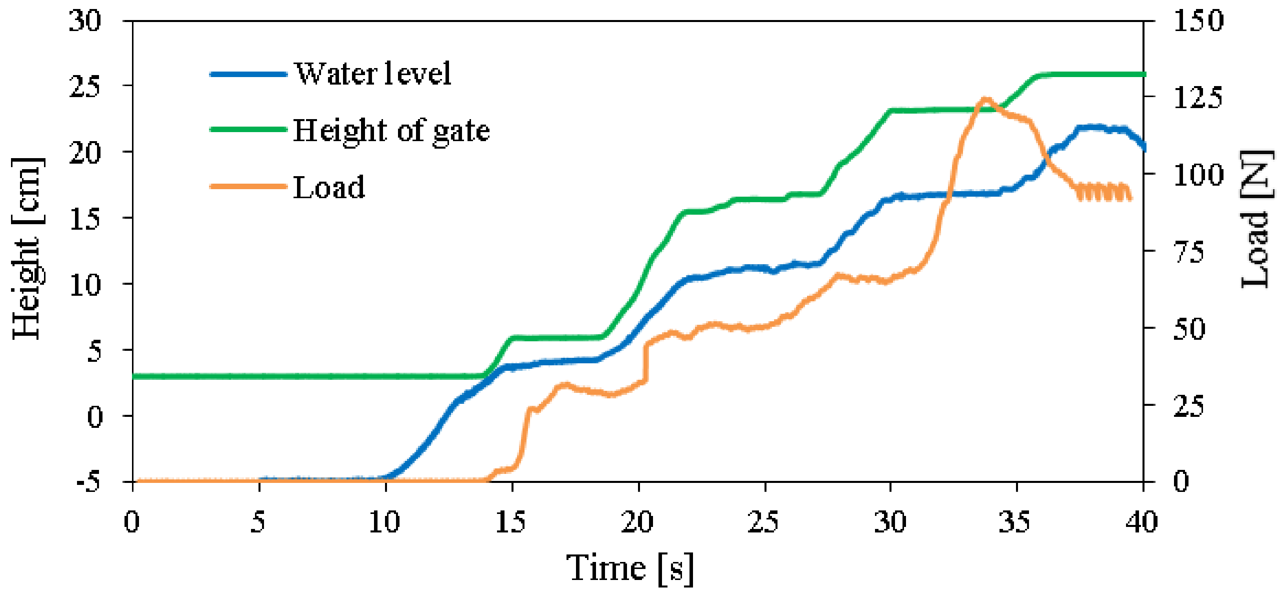
- This graph shows a time series of a water level in front of the model, the height of gate calculated from the angle sensor, and a load acting on the base in the experimental case 2.
- Because of characteristics of the pump, a shape of the water level changes stepwise. An average of elevation velocity in the experimental case 2 was 1.26 cm / s in model scale (= 1.51 m / min. in real scale).

Experimental conditions

Case	Water tank	Waveform	Wave direction	Initial state
1	Tsunami generator	Pump type : 25cm	90°	Fixed
2				Movable
3			45°	
4			0°	
5		Pump type : 20cm + Piston type : 5cm	90°	Fixed
6				Movable
7			45°	
8			0°	
9		Pump type : 15cm + Piston type : 10cm	90°	Fixed
10				Movable
11			45°	

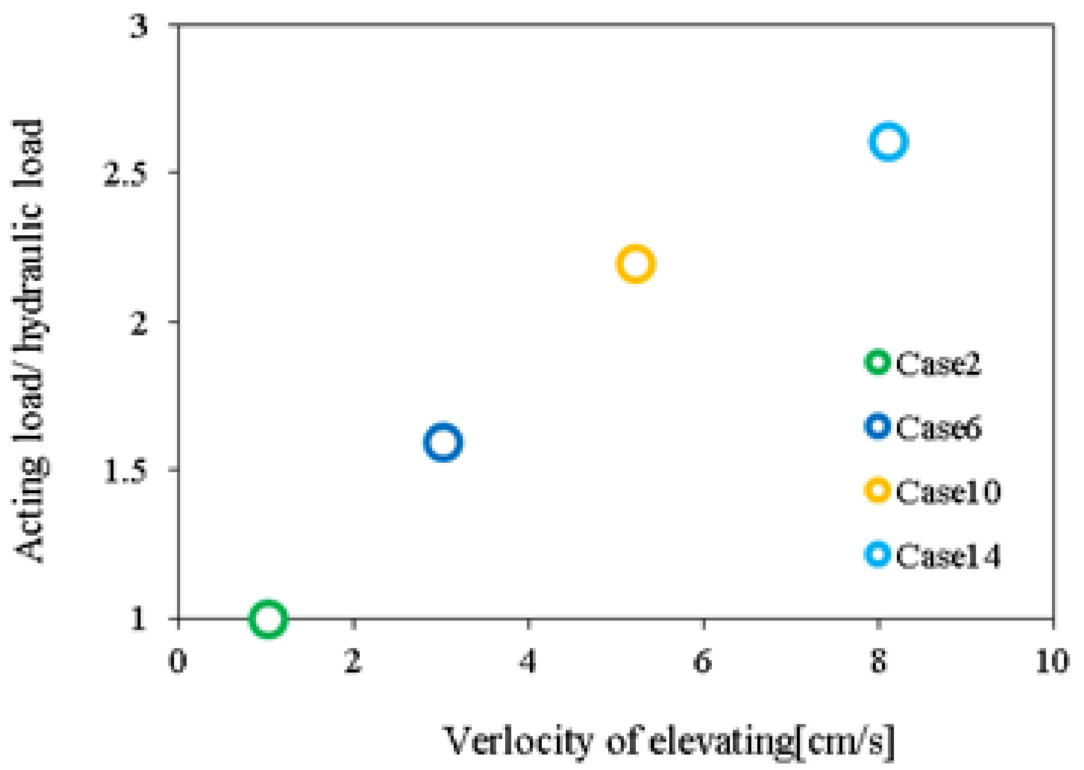
Experimental case 2

Evaluation of wave force



- The gates moved slowly and the hydraulic loads acting on the gates and weight of the gates including the counterweights were balanced.
- Therefore, the result of the experimental case 2 was a standard to evaluate the wave force of other cases using the tsunami generator tank since it is estimated that the wave force in the experimental case 2 was caused by the static load.

Evaluation of wave force



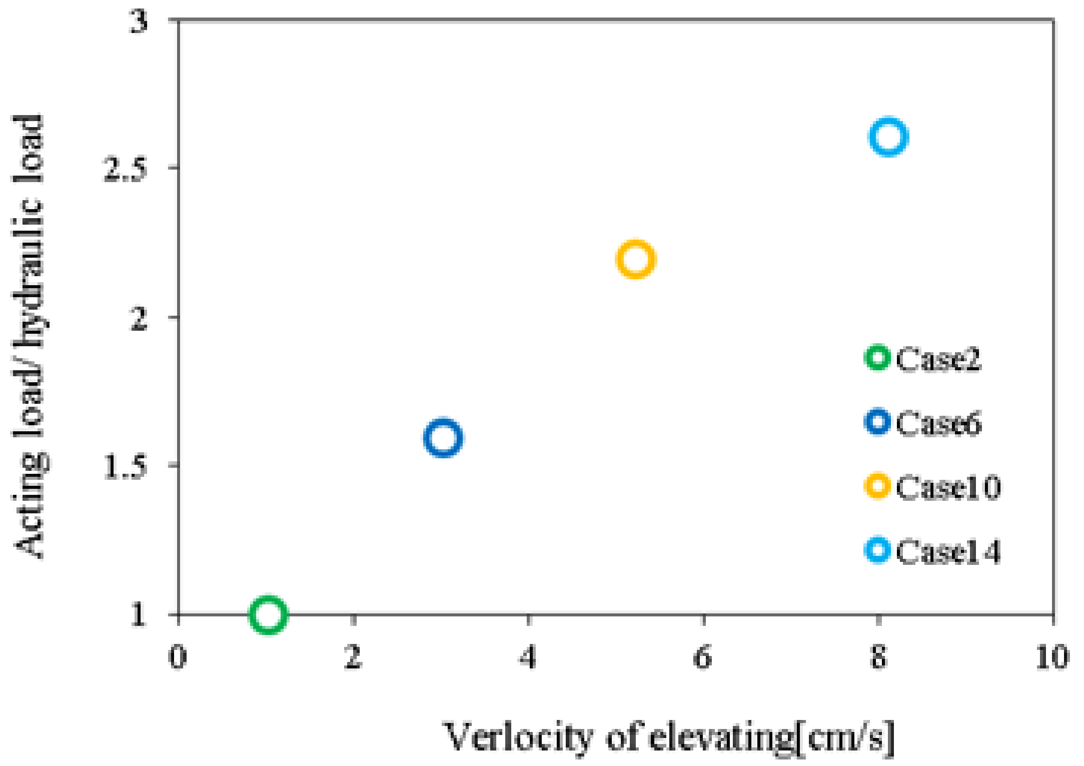
- This graph shows maximum hydraulic loads acting on the gates in the experimental cases 6, 10, and 14.
- These values were divided by the load of experimental case 2.
- In the experimental case 14 where a velocity of elevation was the fastest, the load acting on the gates was about 2.7 times as large as the hydraulic load of the experimental case 2.

Experimental conditions

Case	Water tank	Waveform	Wave direction	Initial state
1	Tsunami generator	Pump type : 25cm	90°	Fixed
2				Movable
3			45°	
4			0°	
5		Pump type : 20cm + Piston type : 5cm	90°	Fixed
6				Movable
7			45°	
8			0°	
9		Pump type : 15cm + Piston type : 10cm	90°	Fixed
10				Movable
11			45°	
12			0°	
13		Pump type : 10cm + Piston type : 15cm	90°	Fixed
14				Movable
15			45°	
16			0°	

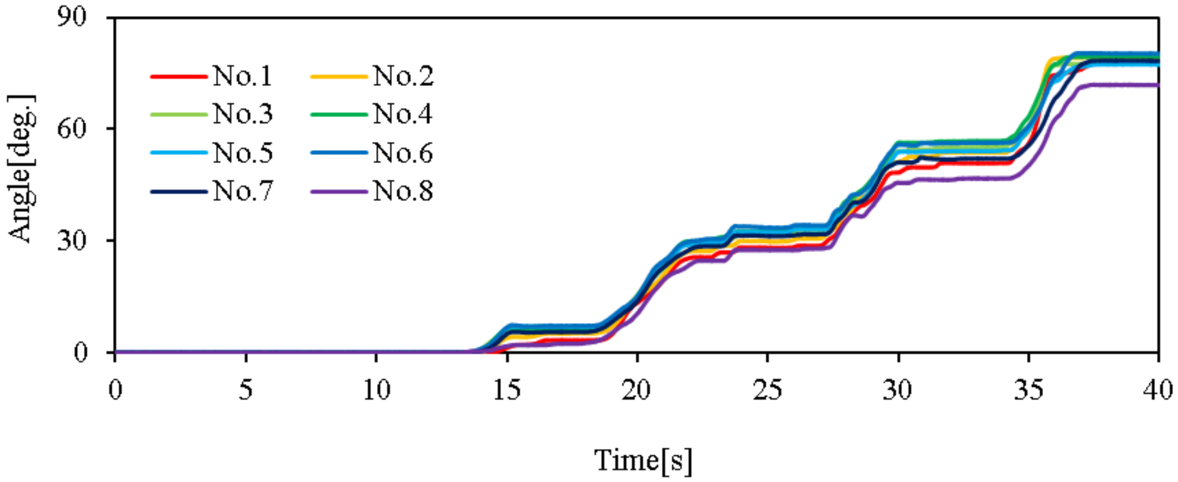
Experimental case 6 10 14

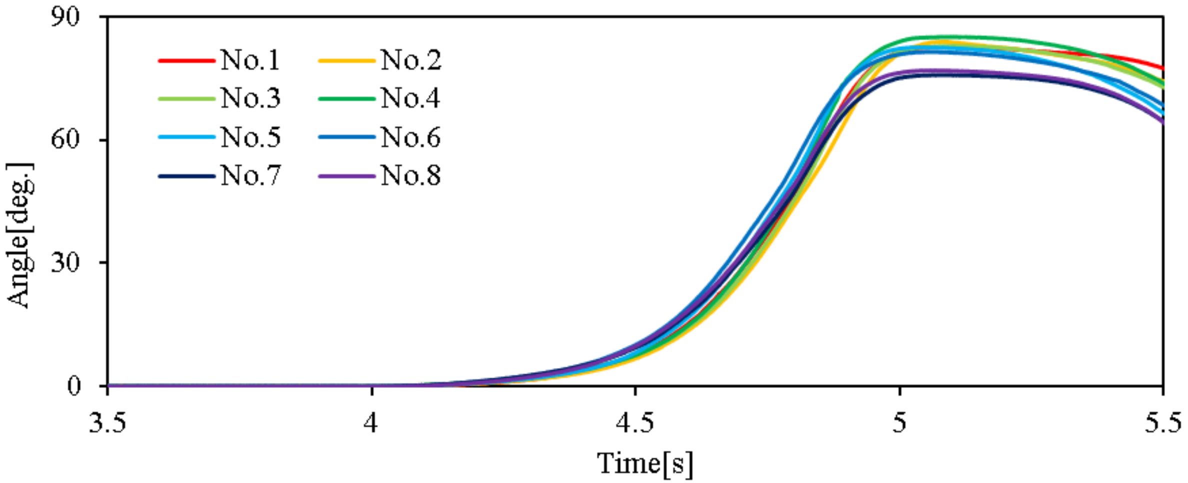
Evaluation of wave force



- This result was consistent with an extra coefficient (2.02 × 1.32 = about 2.67 times) calculated through the experiment using the plane water tank.
- However, 8.3 cm / s in the model scale corresponds with 9.96 m / min in the real scale, and this velocity is beyond a usual design condition.
- A design condition of wave force acting on the movable gate should be about 1.3 times as large as a design condition of fixed upright walls against usual tsunamis with safety as a prerequisite.

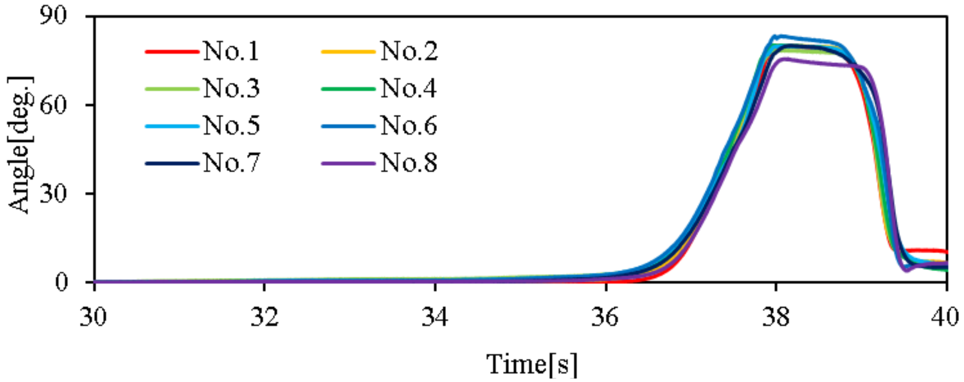
Characteristics of gate response

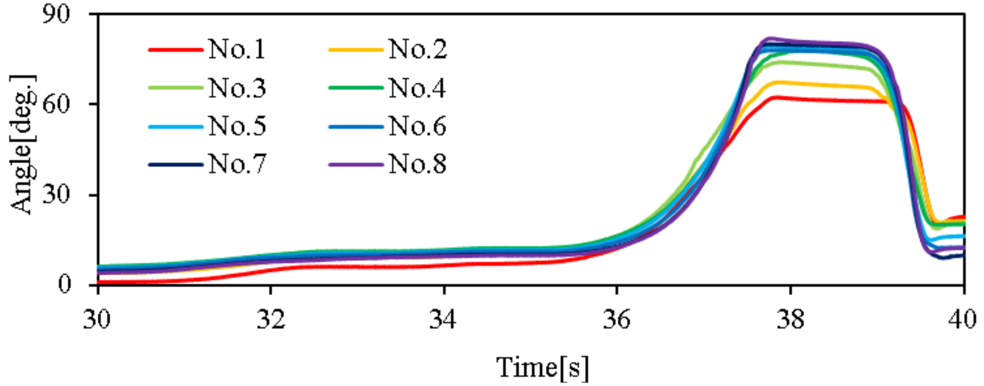


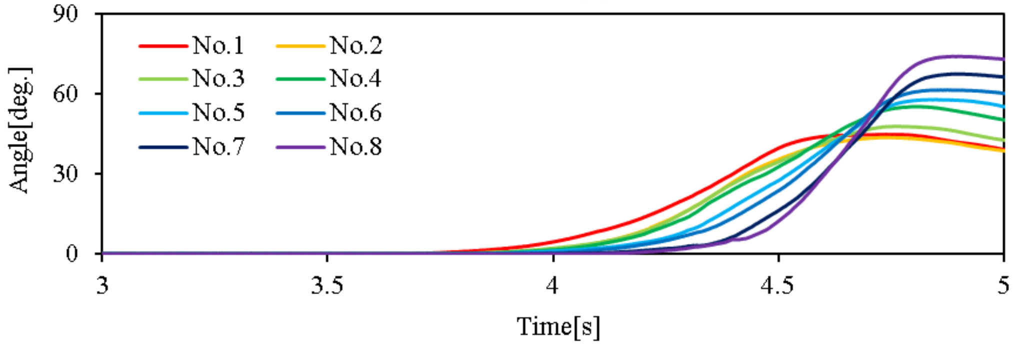


- First, cases where the experimental tsunamis arrived from the front of model are described.
- A time series of angles of gates in the experimental cases 2 and 18.
- All gates moved without remarkable phase differences and reached upright position.

Characteristics of gate response







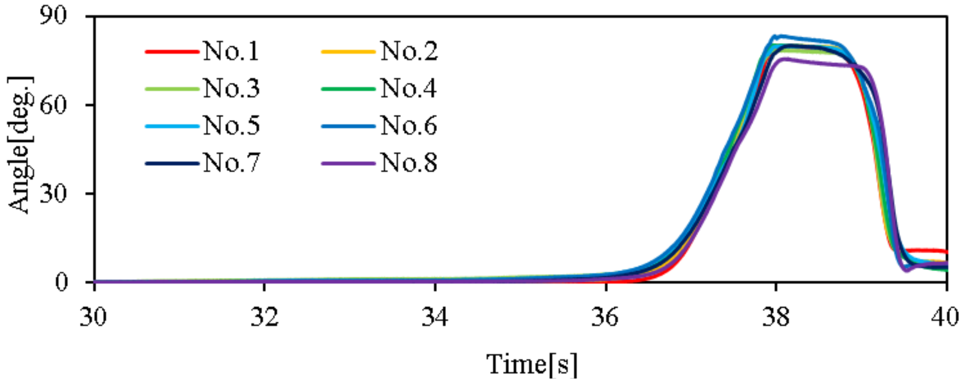
- These graph a time series of angles of gates in the experimental cases 15, 16, and 19.
- When experimental tsunamis arrived obliquely or directly from a side of gates, each gate started rising in order of an arrival of experimental tsunamis from the gate (No.1) on an offshore side.

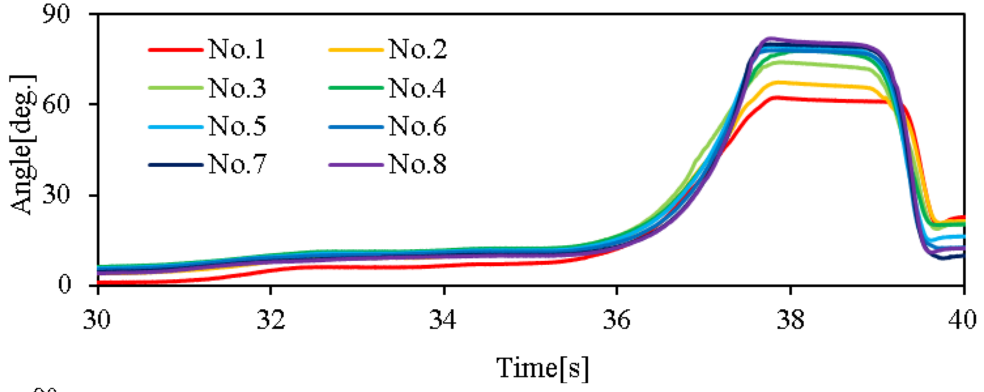
Experimental conditions

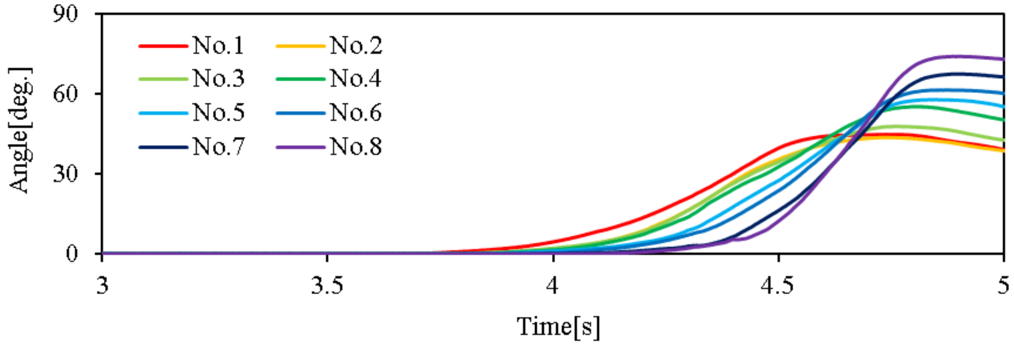
Case	Water tank	Waveform	Wave direction	Initial state
1			90°	Fixed
13	Tsunami generator	Pump type : 10cm + Piston type : 15cm	90°	Fixed
14				Movable
15			45°	
16			0°	
17	Plane water tank	Piston type Wave period : 8s Wave hieght : 12.8cm	90°	Fixed
18				Movable
19			45°	
20		Piston type Wave period : 4s Wave hieght : 12.6cm	90°	Fixed
21				Movable
22			45°	

Experimental case 15 16 19

Characteristics of gate response







- Any gates did not get enough water levels to make themselves upright.
- The tops of adjacent gates were connected to each other with metal parts so as to keep an angular difference between gates less than thickness of the gate.
- Due to these metal parts, the gates could move appropriately against experimental tsunamis arriving except from the front of model and a continuous seawall could be formed.

Evaluation of overtopping

Water tank	Elevation velocity (m/min.)	Overtopping (m^3/m)
Plane water tank	13.9	0.16
	15.4	0.18
Tsunami generator tank	9.97	0

- This table shows the overtopping per 1 m width on the actual scale in the experiments using the plane water tank and the tsunami generator tank.
- As mentioned in the above slide, no overtopping exceeding the lying gates occurred in the experiments using the tsunami generator (case 1-16), however, the initial overtopping occurred in the experimental cases using the plane water tank because the velocity of elevation was very rapid.
- It is not estimated that the amount of the overtopping such as 0.16 - 0.18 m^3 / m damage an area behind the long-span NEORISE.

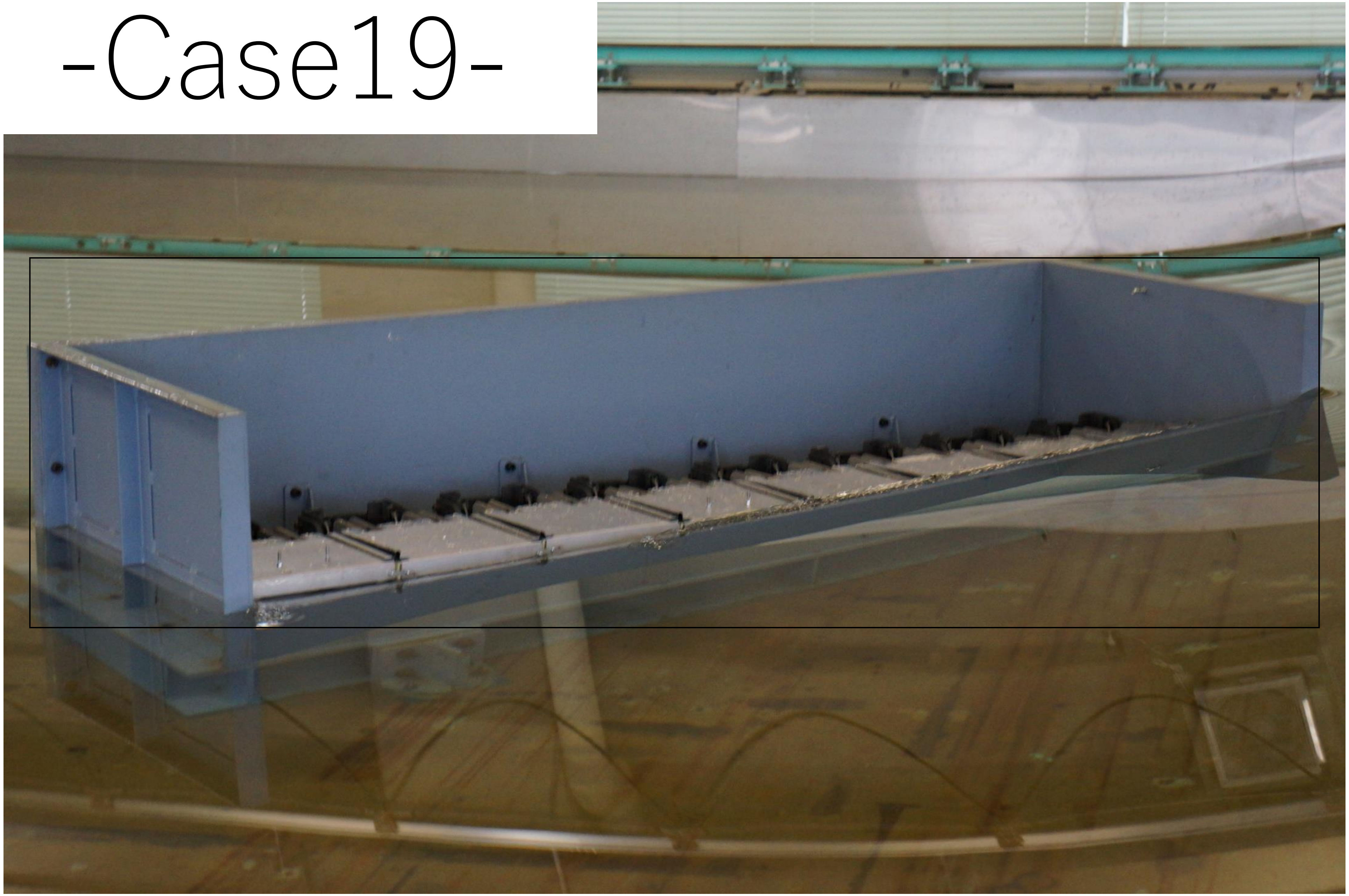
Conclusions

- In this study, motions of gates and wave force acting on gates were examined through a series of hydraulic experiments using the model of the long-span NEORISE.
- As a result, wave force acting on the gates was within ranges in which the NEORISE can be designed reasonably.
- It was proved that the long-span NEORISE has good performance to protect target areas against tsunamis and storm surges.

Thank for Your Attention

Video　-Case10-

-Case19-



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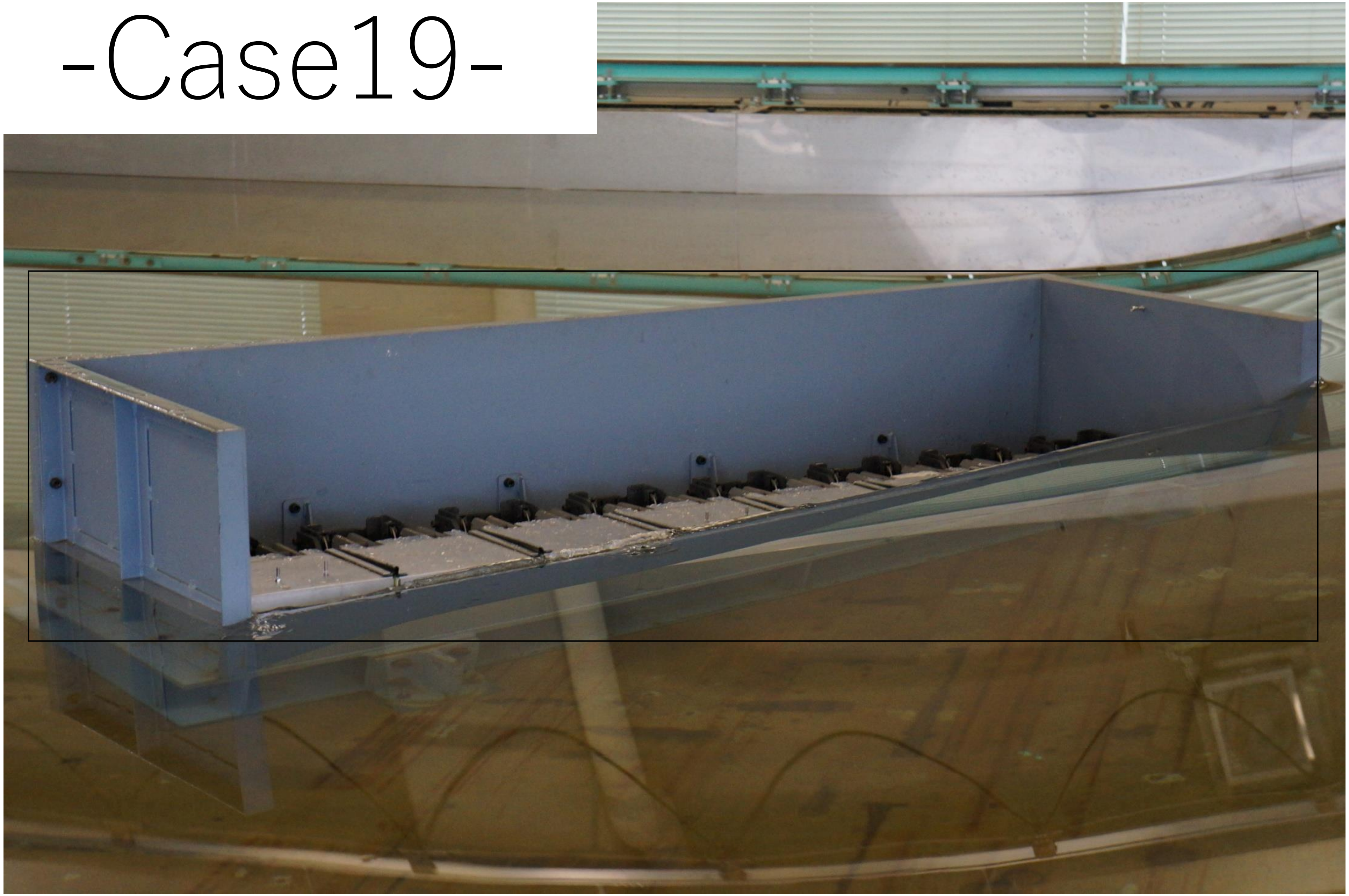

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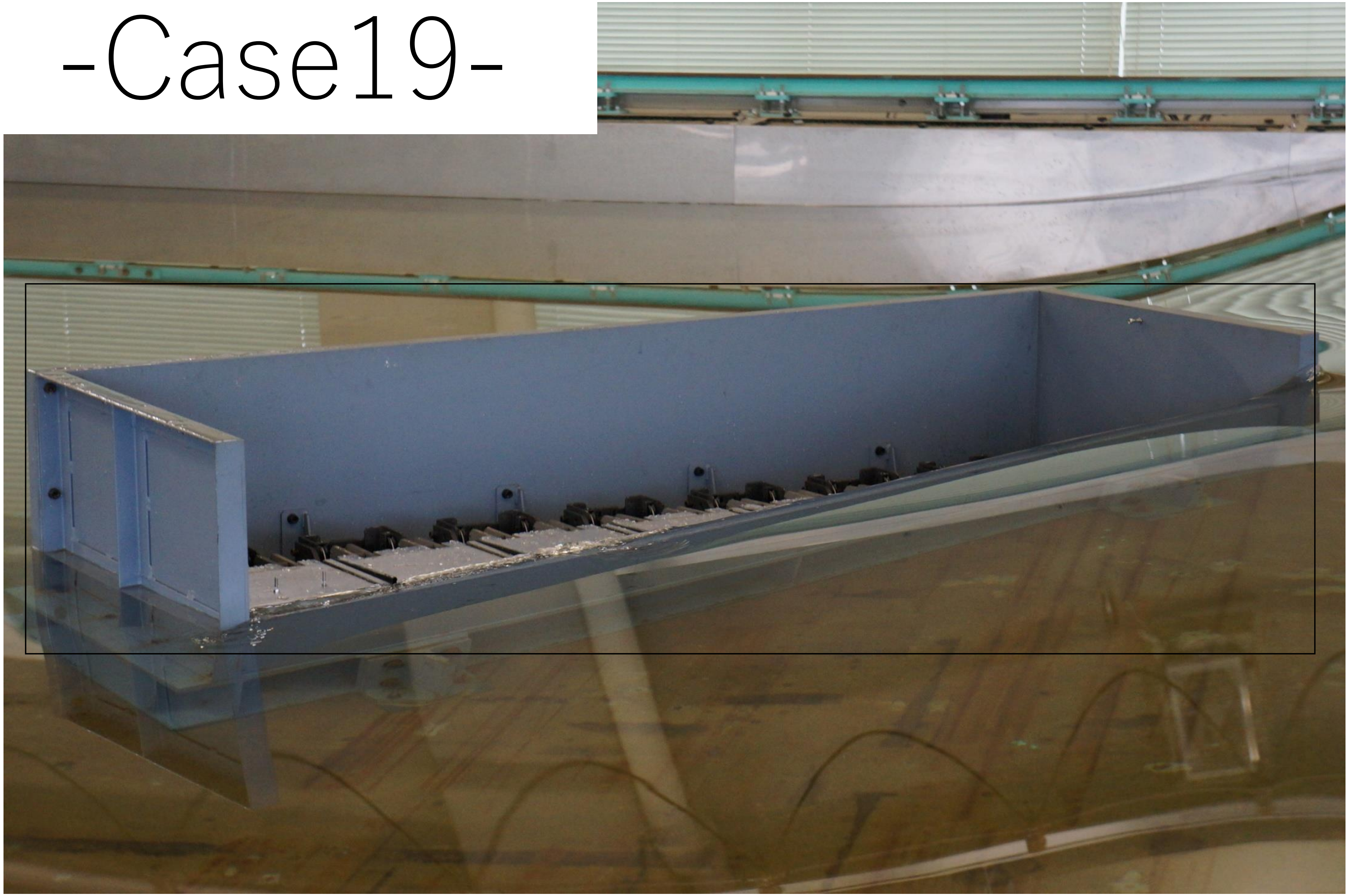

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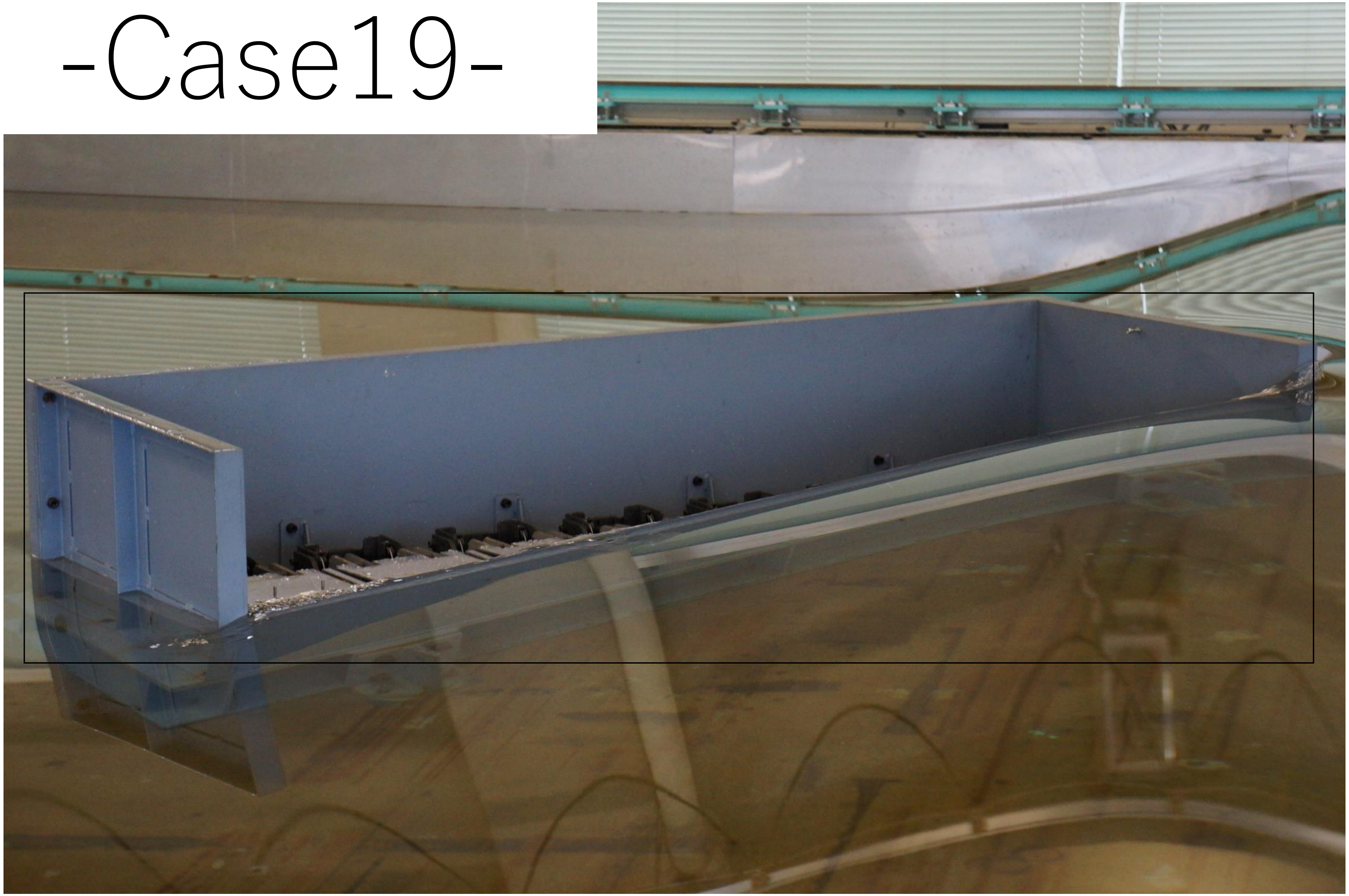

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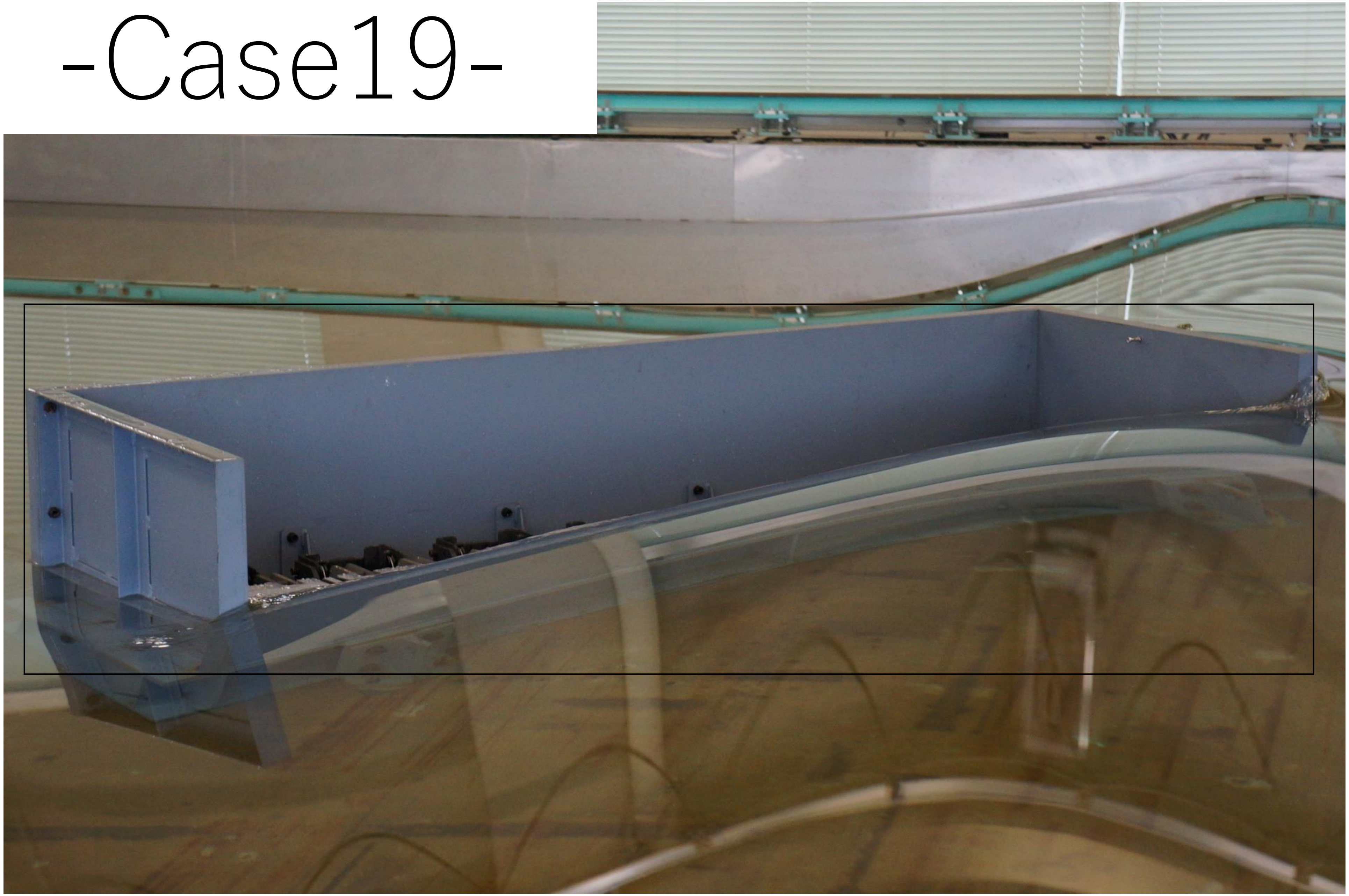

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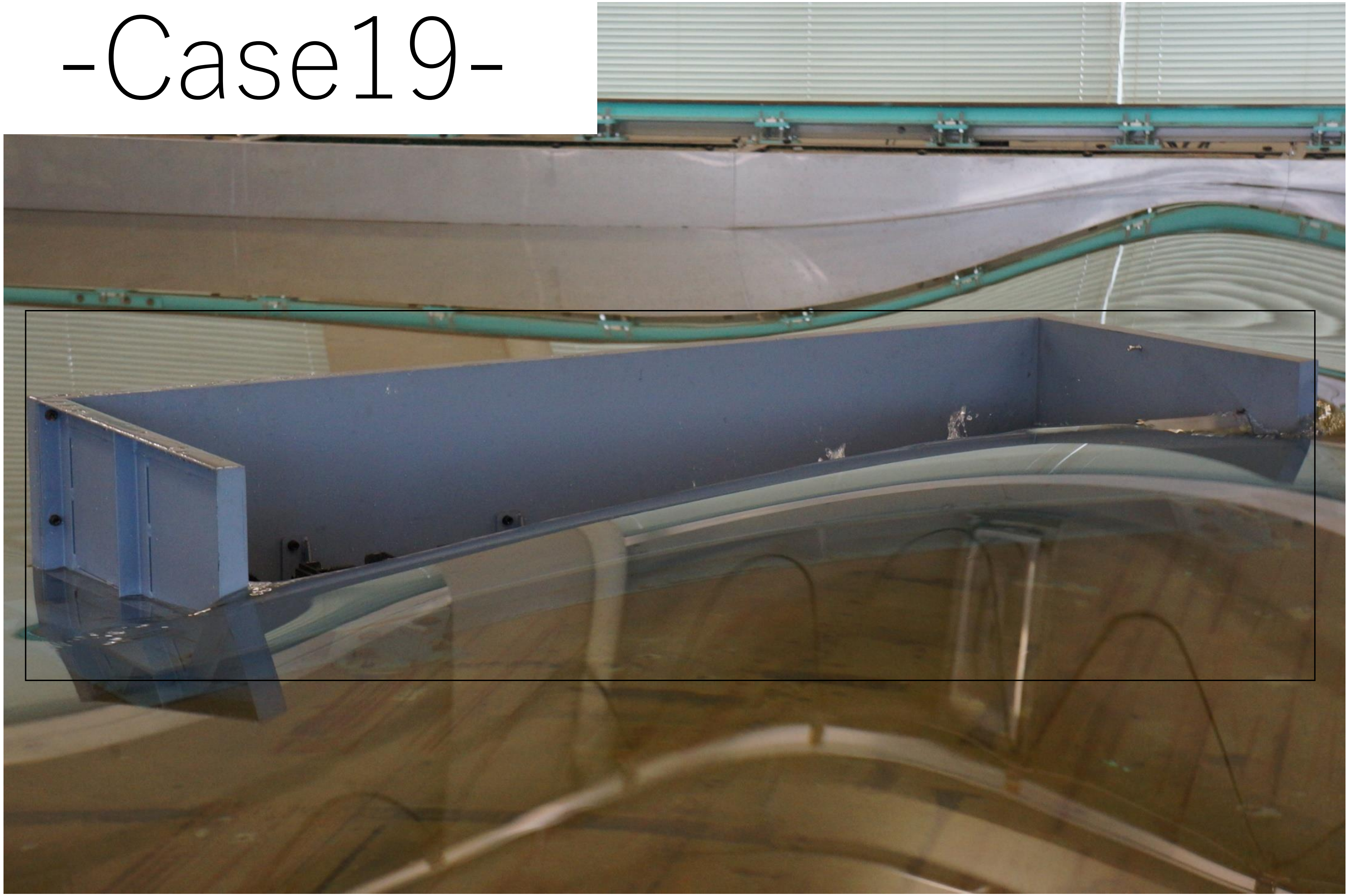

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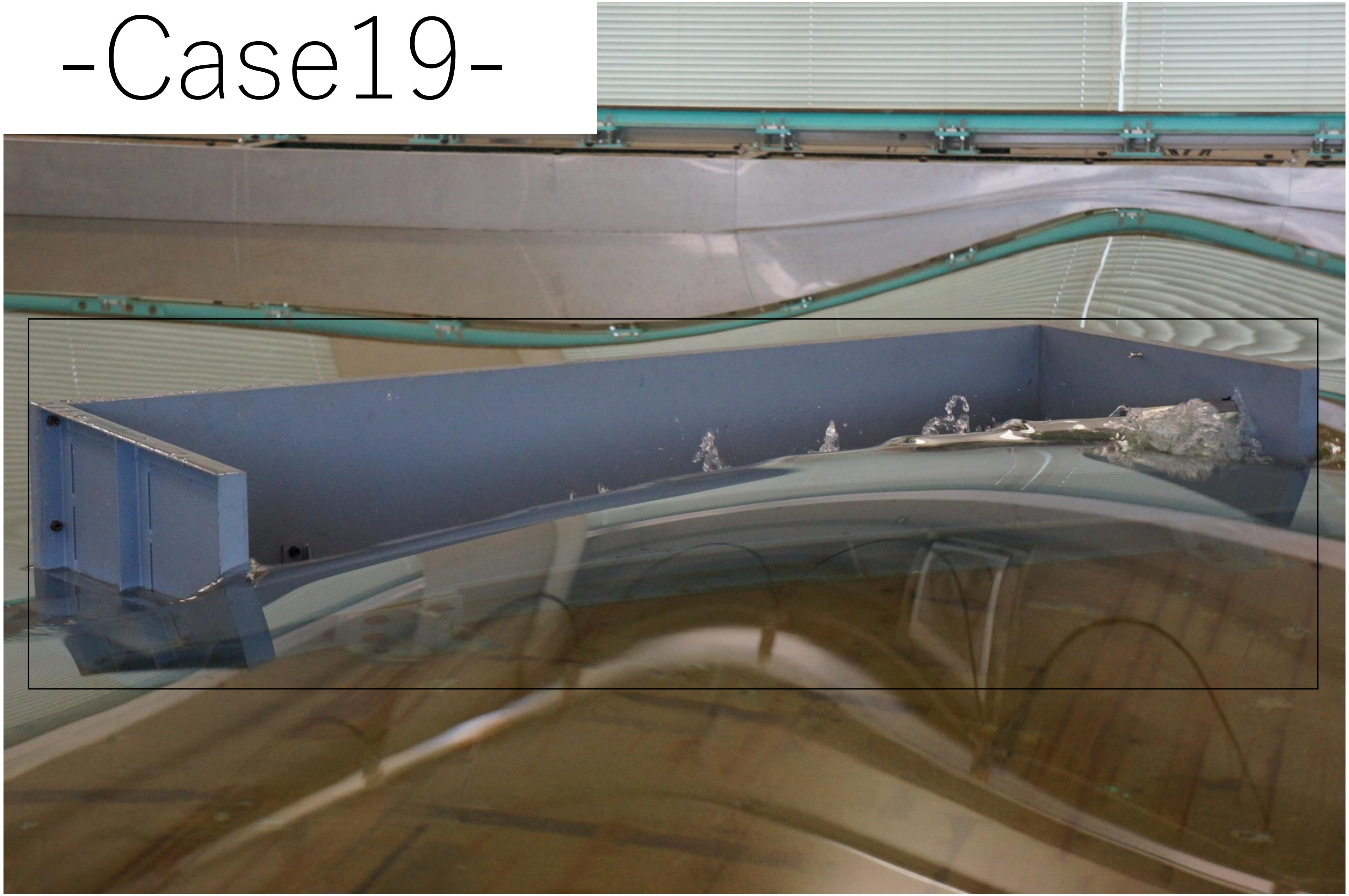

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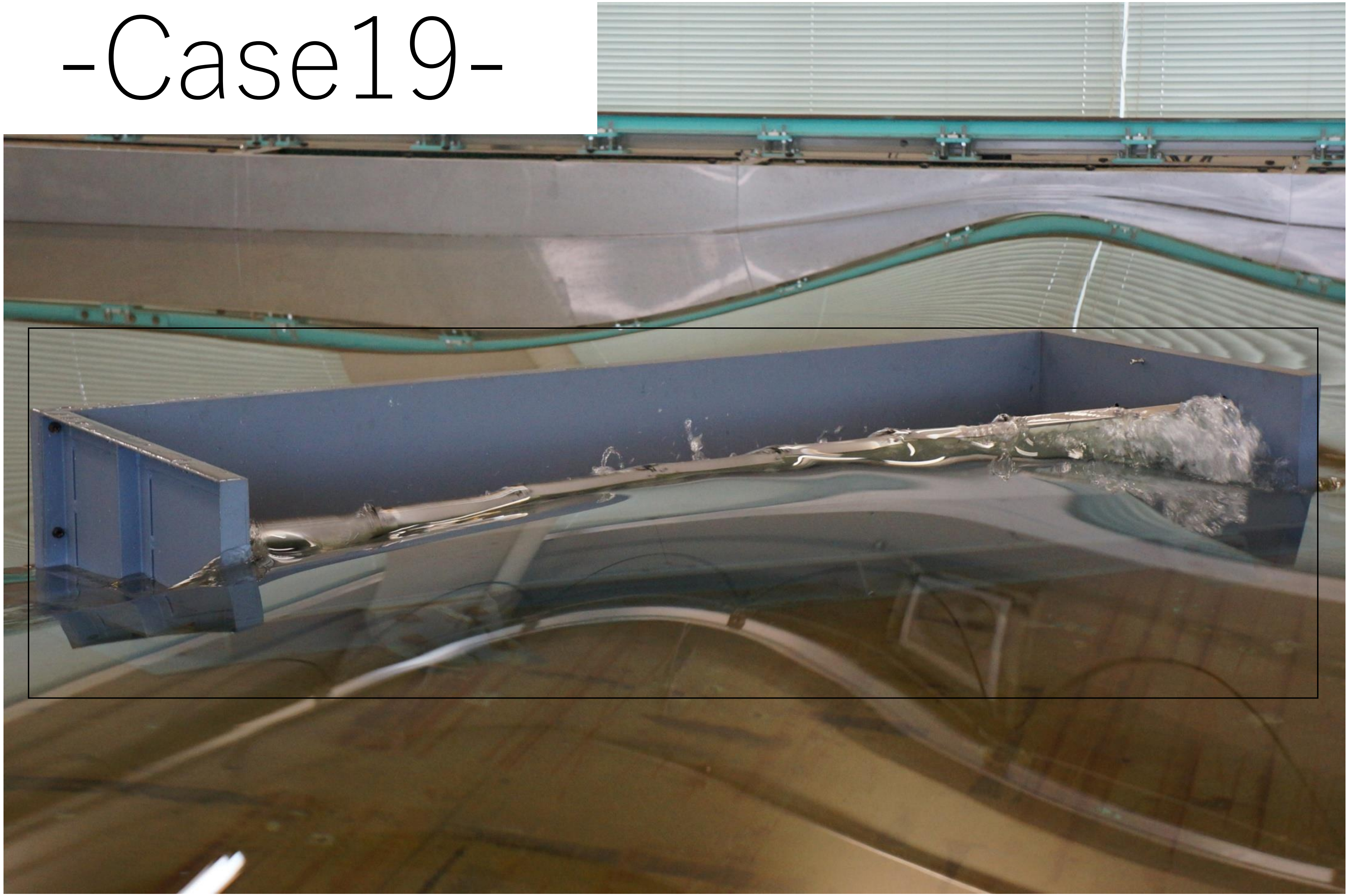

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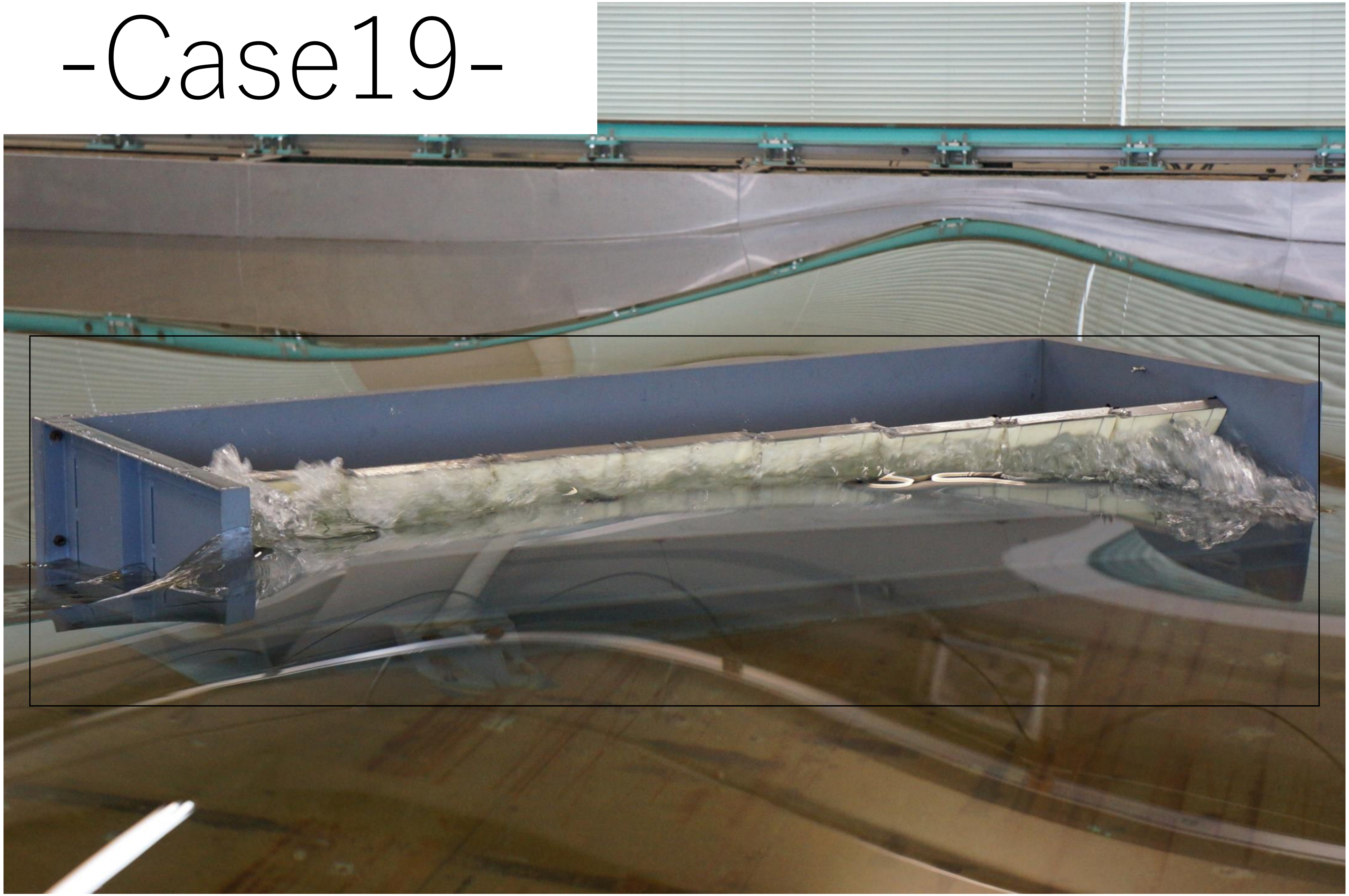

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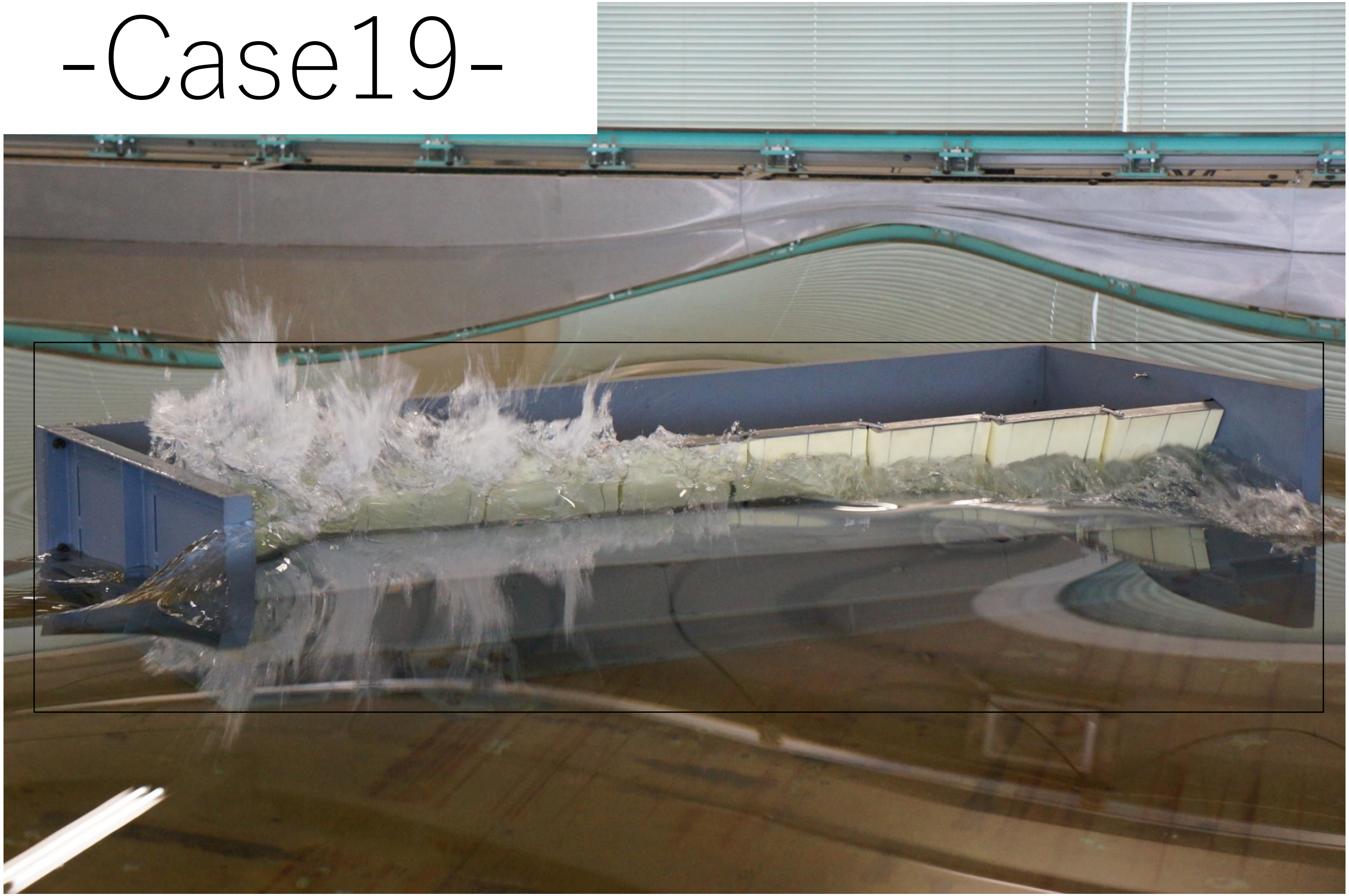
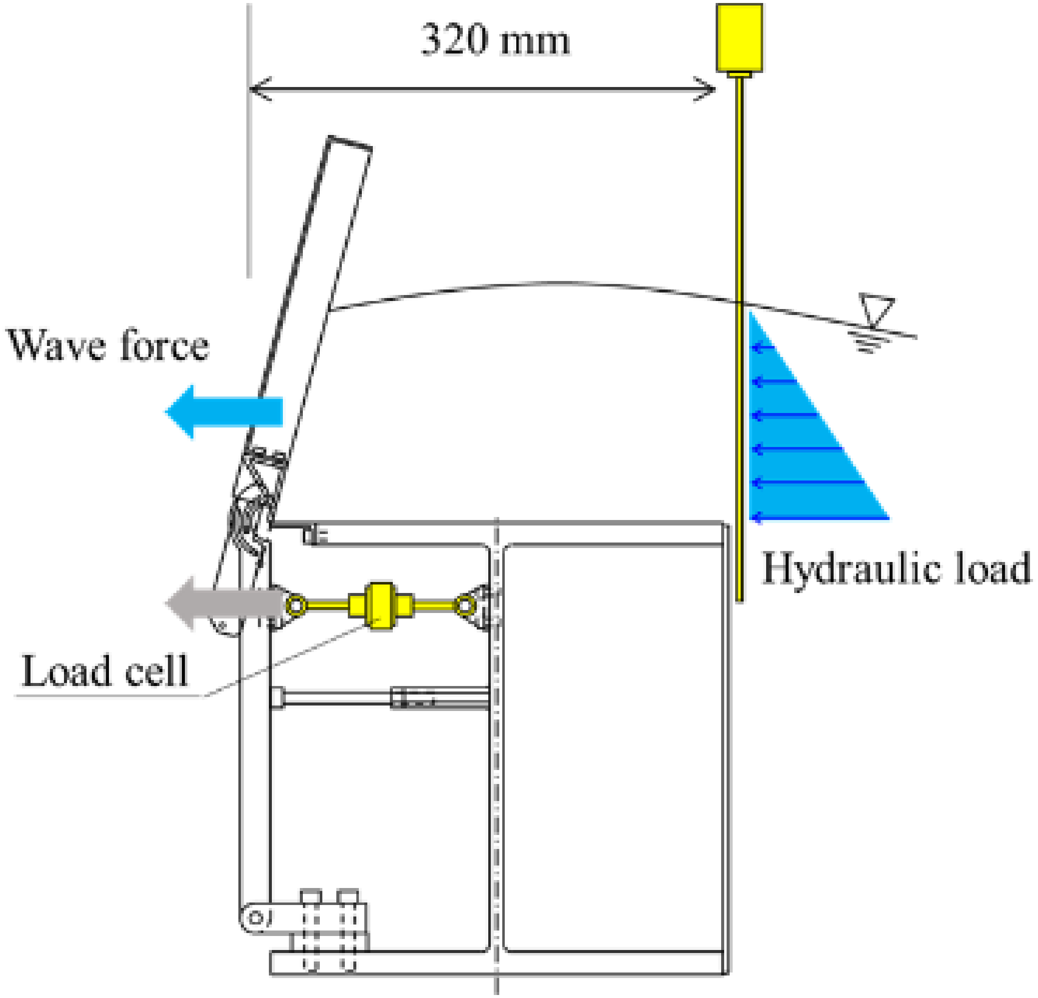


Conclusions



Stability of foundation

Conditions in real scale	Coefficients
Extra coefficient for fixed upright type in case of as over 1.5 m/min.	1.32
Extra coefficient for fixed upright type in case of as under 1.5 m/min.	1

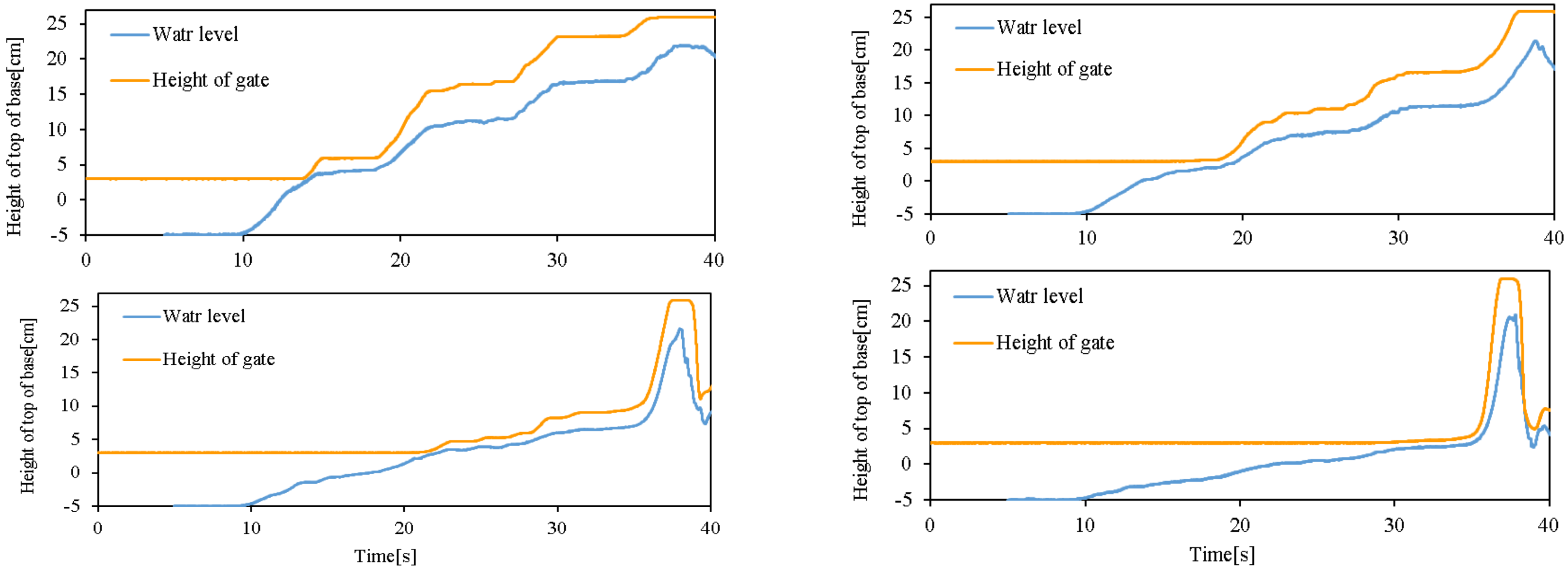
- Bearings are set on the foundation using anchors when the long-span NEORISE is constructed, and therefore it is necessary to evaluate loads supported by the foundation.
- Design conditions of foundation should be based on the wave force acting on the gate, and it is briefly shown in Table 4 since the results about the wave force have already been described in the above section.

Stability of foundation

Conditions in real scale	Coefficients
Extra coefficient for fixed upright type in case of as over 1.5 m/min.	1.32
Extra coefficient for fixed upright type in case of as under 1.5 m/min.	1

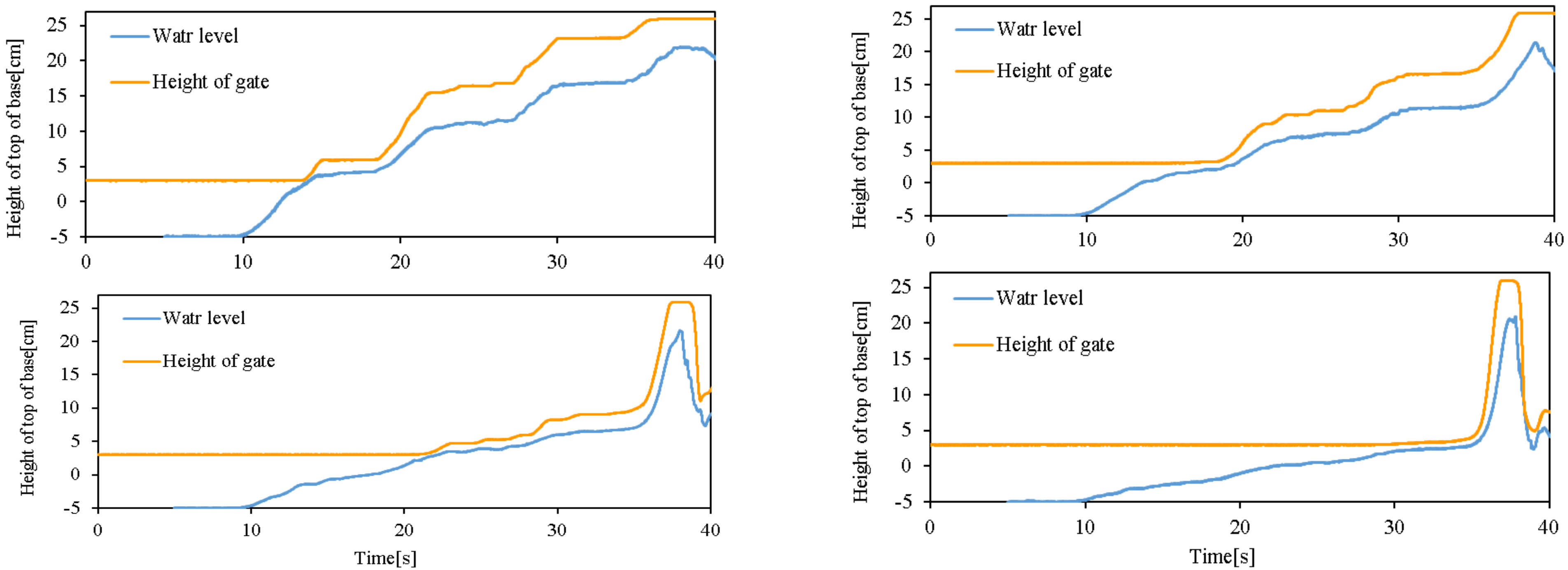
- As shown in Table 4, when periodic tsunamis with elevating velocity of about 1.5 m / min such as the experimental case 2 are estimated, design conditions about an external force are equivalent to fixed upright walls.
- On the other hand, when immediate elevations over 1.5 m / min are estimated, a safety rate of 1.32 times should be adopted to secure the gate and the foundation against these tsunamis.

Characteristics of gate response



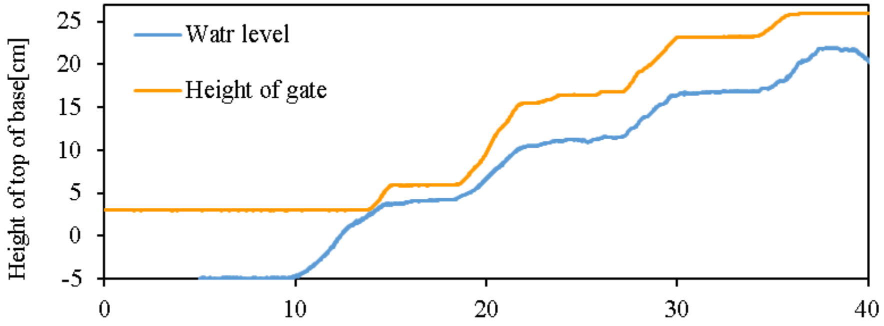
- A time series of both heights of gates and water levels in front of the model against experimental tsunamis arriving from the front of model such as the experimental cases 2, 6, 10, and 14 (tsunami generator).
- A vertical axis shows heights from the top of base on which gates were installed.

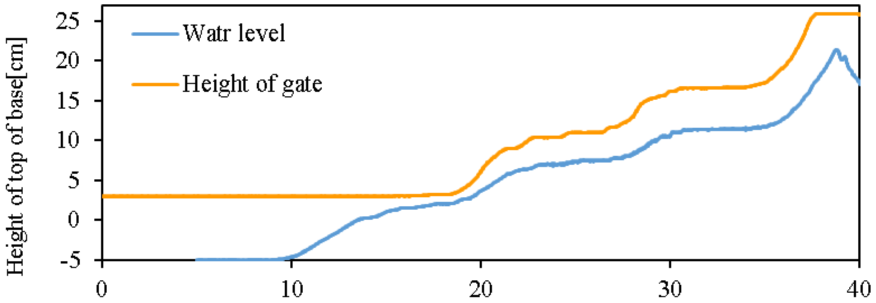
Characteristics of gate response

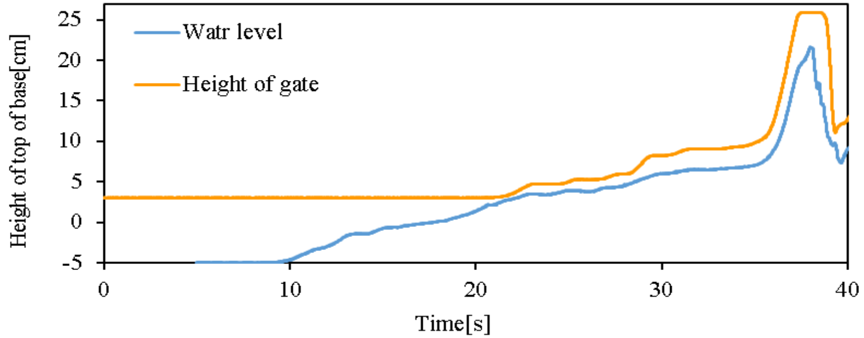


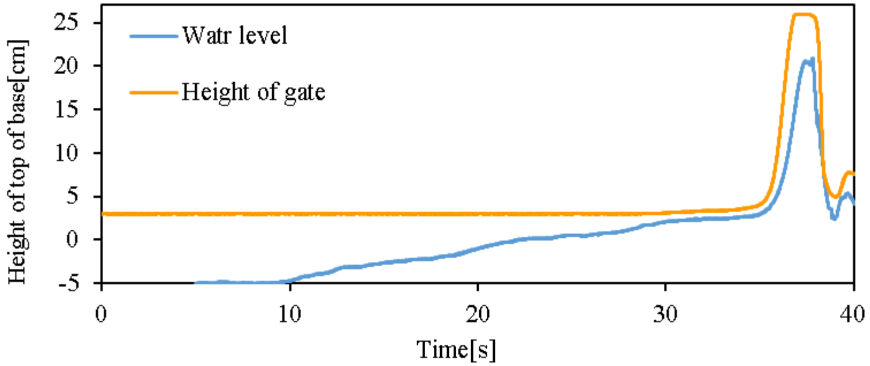
- The gates rose according to the water level and reached upright position.
- Although differences between the water level and the tops of gates were the smallest when the gates started rising, the tops of gates always kept higher than the water level.

Characteristics of gate response



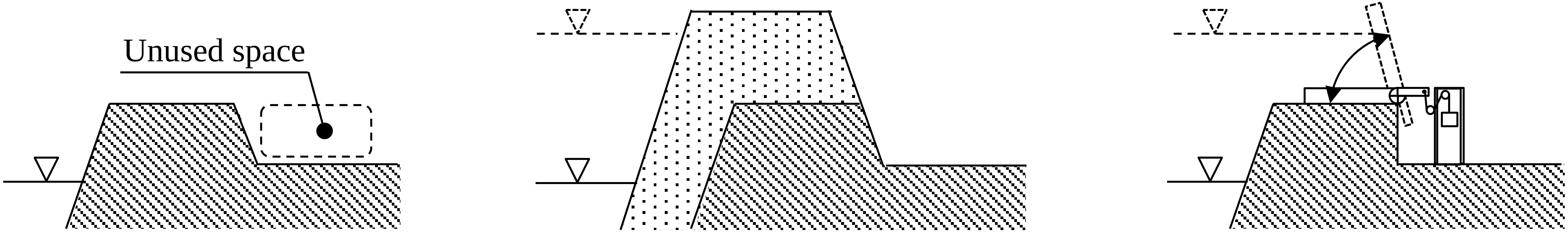






- Therefore, no overtopping occurred beyond the gates.
- Through all experimental cases using the tsunami generator, no overtopping occurred as the same with the experimental cases 2, 6, 10, and 14.

Long-span type NEORISE SYSTEM



(a) Existing embankment (b) Raising by mound (c) Raising by Long-span NEORISE

- The counterweight which is set behind the gate has to be installed under the land surface in order to keep level around this system and it has to lift and drop within underground space.
- Although digging holes for the counterweights underground may be expensive, it is effective to apply the long-span NEORISE to raising an embankment, by utilizing unused space just behind the previous structure.