THE DEVELOPMENT OF THE SUCTION FOUNDATION

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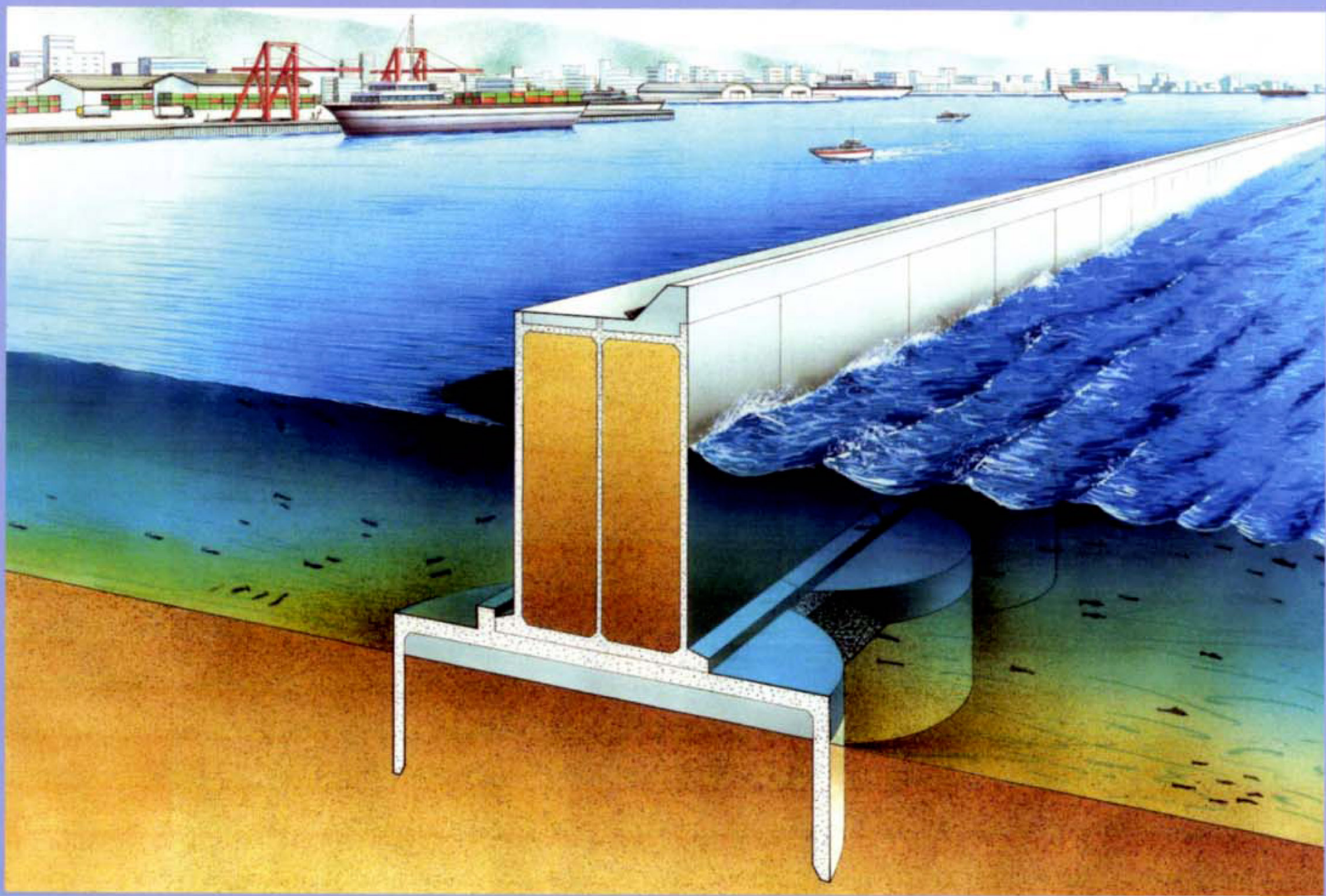


Our challenge to create new technology
for reduction of the construction cost.

Development of the Suction Foundation

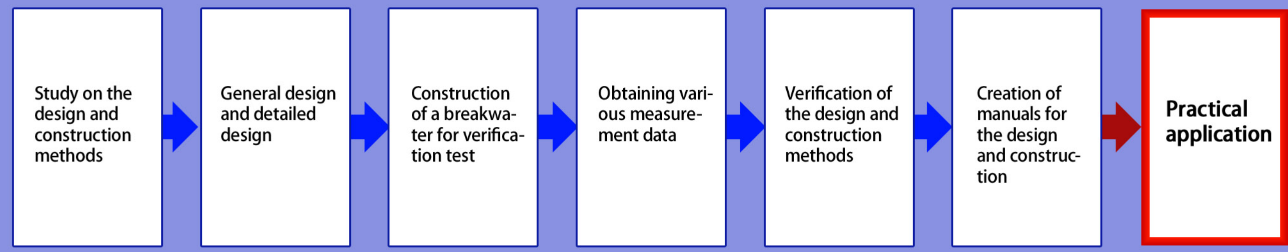
Niigata Research and Engineering Office for
Port and Airport, Hokuriku Regional Development Bureau,
MLIT (Ministry of Land, Infrastructure and Transport);

We are working on the development of suction foundation for the reduction of construction cost.

With the coastal structures being larger, recently constructed at offshore site, the construction costs are increasing. The construction cost for a suction foundation is expected to be lower than that for a conventional gravity-type coastal structure, in favor of the structural features and the construction performance. In actual, however, no practical method to design and construct a foundation structure has yet established, except for only a case of the similar coastal structure constructed at the Kobe Port in 1960s (Note 1).
In this context, Niigata Research and Engineering Office for Port and Airport, Hokuriku Regional Development Bureau, MLIT, is dedicated to working on "the development of suction foundation" as a new technological development for reduction of the construction cost.

(Note 1) Other than coastal structures, there are some application cases after 1980s such as the constructions of foundations for oil-drilling rig in the North Sea,.

Development flow to the practical application



1 Features of the suction foundation

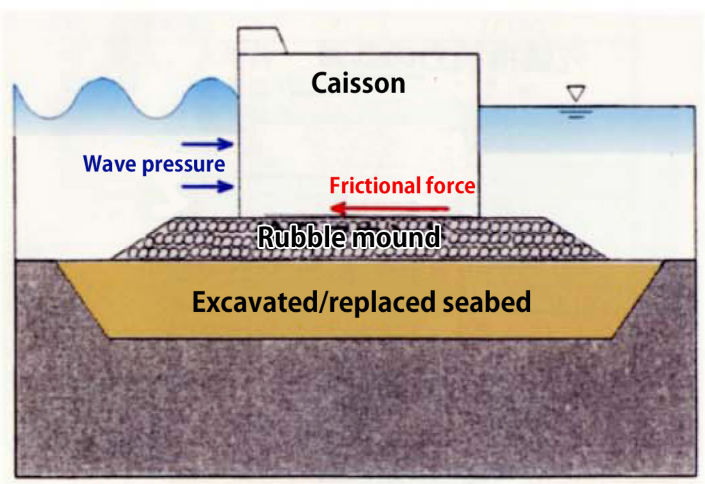
Suction foundation is a base structure in shape of an upside-down teacup. The foundation unit is directly embedded onto the seabed. It is considered that it has a high stability with significant resistance against slide, over-turn, and pull-out.

Advantages of Suction Foundation

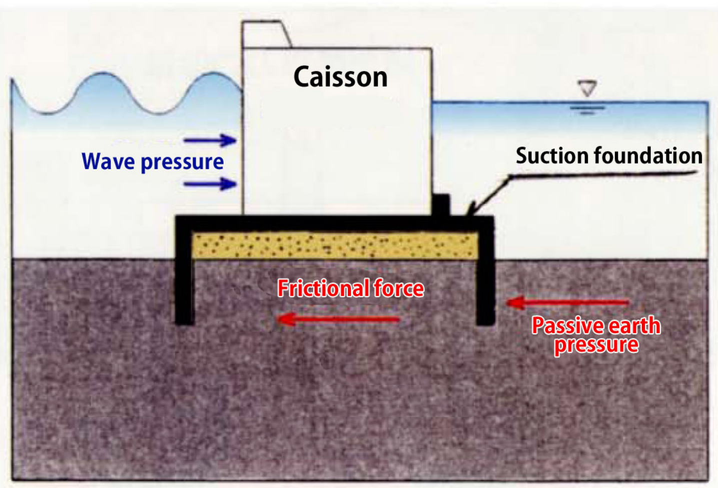
Gravity-type coastal structures are commonly used in the conventional breakwaters and quays. They can resist slide and over-turn by its own weight. To support the own weight of the main body including caisson, a base is constructed with rubble-mound on the seabed. At some sites with a weak sea-bed, however, seabed excavation and replacement are needed to reinforce the sea-bed.
On the other hand, the suction foundation is directly embedded onto the seabed and accordingly doesn't need such base. The advantages of the suction foundation are as follows.

1. No need of rubble-mound, seabed excavation, and replacement will result in smaller cross-section of the structure and shorter construction period.
2. No need of specific construction machine.
   It can be constructed in principle at least with drainage pumps to supply the suction power and crane ships to install in good arrangement.
3. Against any external force including wave pressure causing the structures to slide, a sufficient resistant force to withstand against sliding can be ensured by the frictional force of the bottom soil under the foundation and also the earth pressure at the back wall of the foundation embedded onto the seabed. In addition, against any pull-out force causing the foundation to turn-over, a suction force will be generated to resist it as the inside of the foundation is airtight.
   These will result in reduction of the construction cost.

Composite breakwater (conventional type)

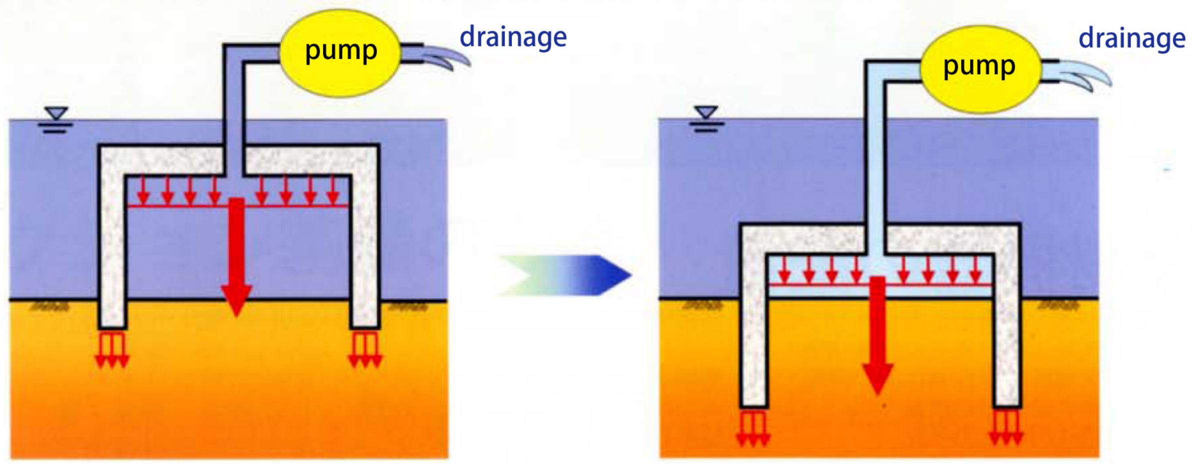


Suction foundation breakwater

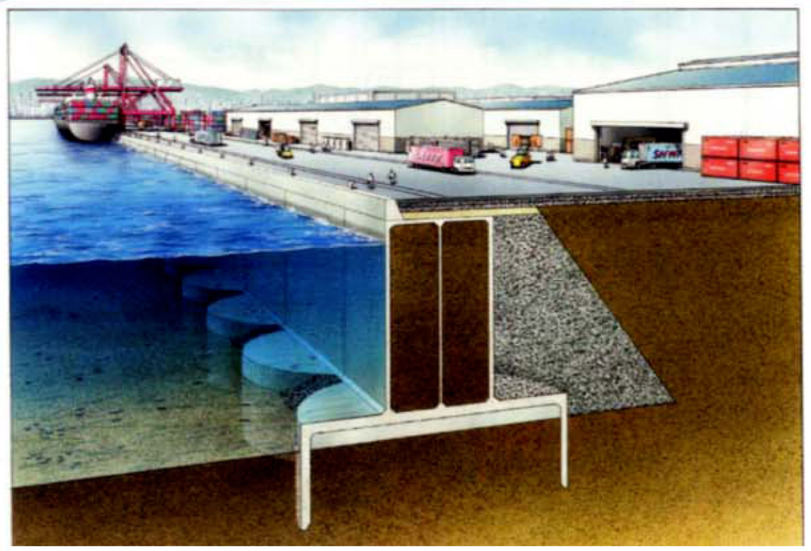


2 Method to submerge the Suction Foundation

The suction foundation is located on the seabed soil facing the aperture of the foundation unit downward. When the inside of the foundation unit is sealed with the seabed surface, the inside water is drained forcibly using a pump. This will result in difference of hydraulic pressure between inside and outside of the foundation unit. This suction force generated by the difference of hydraulic pressure is used as a press force to submerge the foundation unit onto the seabed soil. Accordingly, the foundation can be submerged (embedded) in a shorter time.



3 Applicable structures – Possible applications:

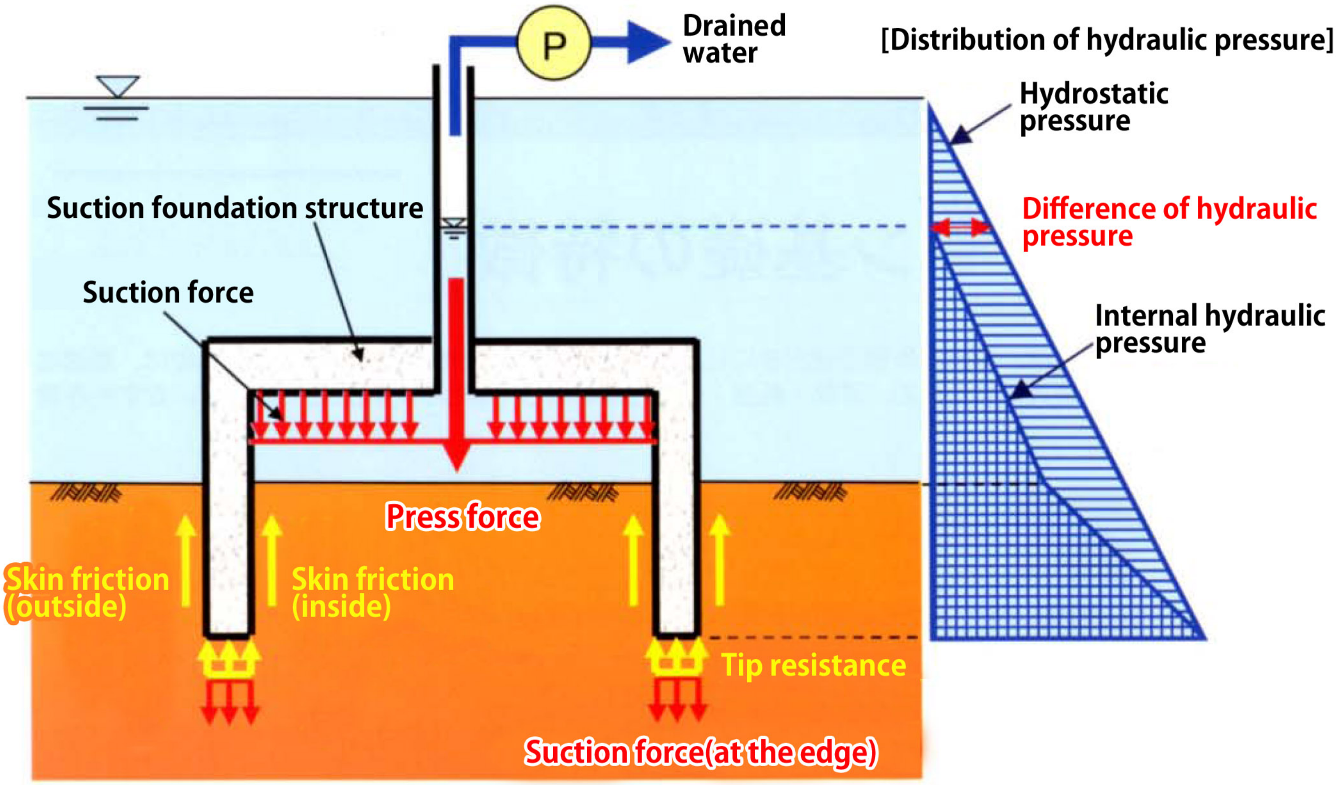


Example of applications: Quay (Integrated unit of suction foundation and upper caisson)

- Foundation of breakwater: Moundless breakwater
- Foundation of quay and shore protection: Reinforced quay against earthquakes
- Moored buoy: Suction anchor
- Foundation for the floating structure; Foot protection to prevent scouring

4 Mechanism of submerging

The press force at the suction foundation can be computed with the suction force, which is generated by the difference of hydraulic pressures between the inside and the outside of the foundation, caused by the forced water drainage, as well as the sum of the weights of the foundation and the upper structure. When the suction foundation is submerged, a resistance force is acted from the seabed supporting it. Such resistance force includes skin frictions (inside and outside) generated on the surface contacting the seabed and tip resistance forces (see the figure below).
In addition, with the decrease in the pressure inside of the foundation caused by the forced water drainage when the suction foundation is submerged, the overburden pressure in the seabed and the earth pressure onto the contacting surface of the foundation will vary. As the result, the decrease in the tip resistance and the skin friction will help facilitate pressing the foundation.

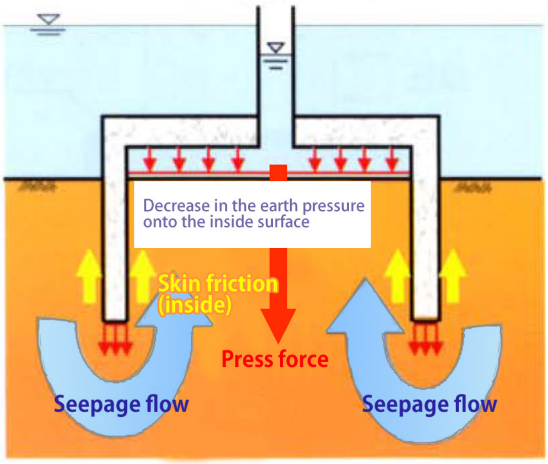


Relationship between forces needed to submerge the foundation:
Press force (suction force + own weights) > Penetration resistance force (Tip resistance + skin friction)

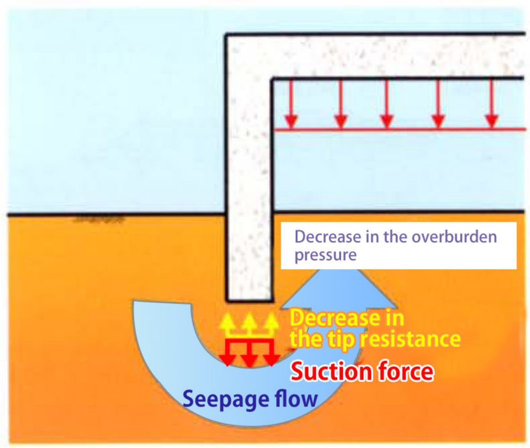
Decrease in skin friction and tip resistance

It is considered that a skin friction is decreased due to decrease in the earth pressure onto the inside surface and that a tip resistance is decreased due to decrease in the overburden pressure.

Decrease in the skin friction

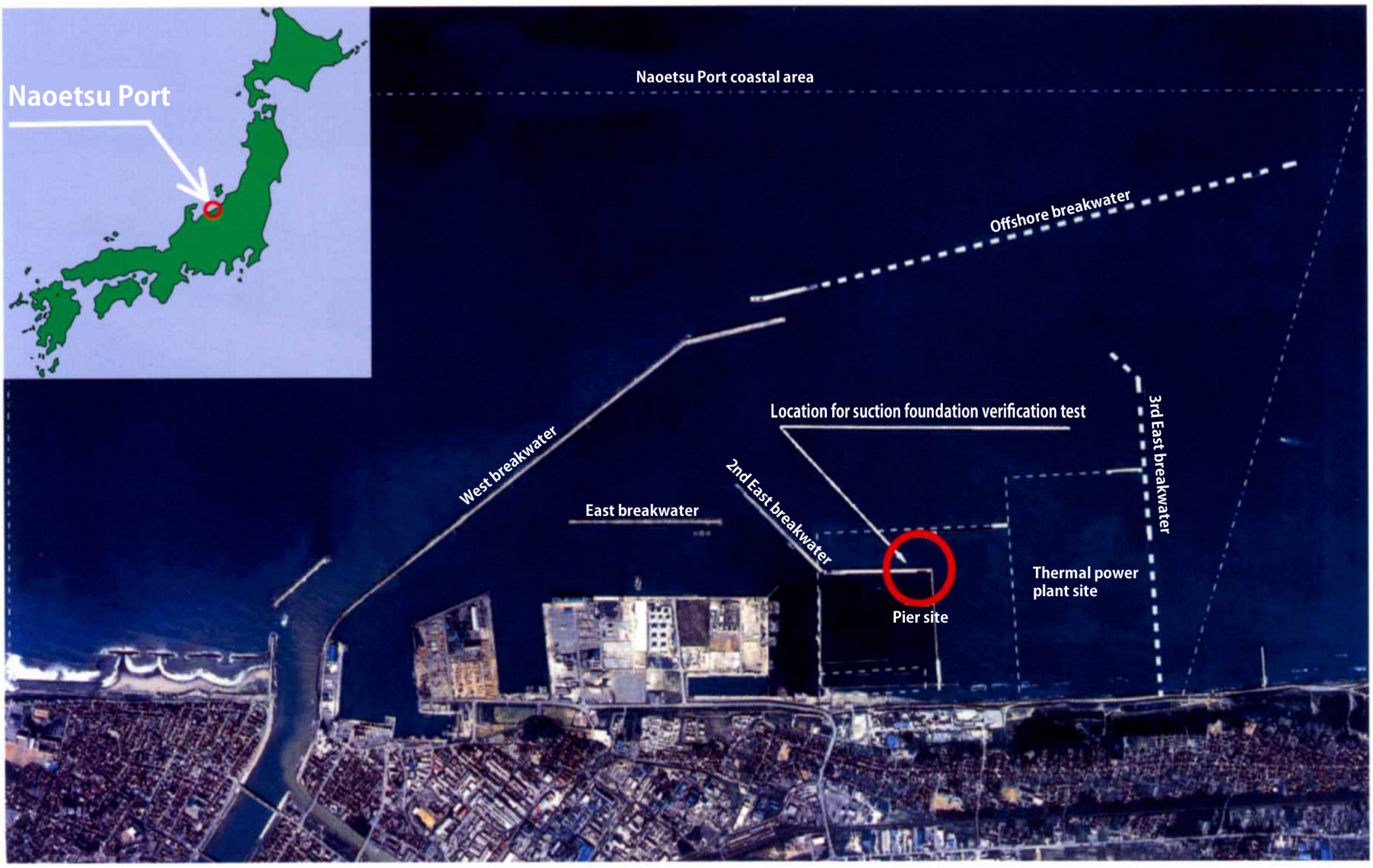


Decrease in the tip resistance



Overview of the breakwater for verification test <Naoetsu Port>

Some issues on the design and construction of the suction foundation have not yet solved. As for items that cannot be known by numerical analysis or model experiment, verification test should be implemented to solve the issues.
For this purpose, two units of suction foundation breakwaters have been experimentally constructed at a section of the breakwater area in the operation site of the Naoetsu Port, Niigata prefecture. The verification tests have been implemented there. Various data obtained from these tests are used as valuable verification data to solve the issues.



Design requirements

Parameters		Designed values
1. Tidal level	H.W.L L.W. L	D.L. +0.50 m D.L.+-0.00 m
2. Depth		D.L.-10.00 m
3. Sea-bottom slope		1/120
4. Wave	Incidence angle Significant wave height H1/3 Maximum wave height Hmax Frequency T1/3	0 deg. 5.7 m 8.3 m 12.1 sec.
5. Crown height		7.5 m
6. Soil condition	-10.0 to -10.6 m	Sand layer γ'=1.00tf/m^3 ϕ=25 deg
	-10.6 to -15.0 m	Clay layer γ'=1.00tf/ m^3 C=5.0tf/ m^3
	-15.0 to -20.4 m	Sand layer γ'=1.00tf/ m^3 ϕ=35 deg

Appearance of the suction foundation (RC)

Steps to construct the breakwater for verification test

The suction foundation and the upper caisson were constructed from December 1998 to August 1999. After constructed on the land at the Kashiwazaki Port, Niigata prefecture, these were towed to the Naoetsu Port using 3000 ton crane ship and dolphin dock and installed.
In connection with the construction, various measurements were conducted at submerging. And also additional measurements have been conducted at wave actions from time to time.


①Platform for the suction foundation (December 1998)


②Construction of the suction foundation (RC) (March 1999)


③Construction of the suction foundation (Steel) (March 1999)


④Construction of the upper caisson (March 1999)


⑤Loading of the suction foundation (RC) (May 1999)


⑥Towing of the suction foundation (June 1999)

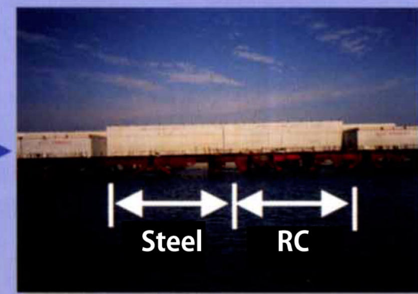

⑦Just before installing the suction foundation (June 1999)


⑧Beginning of the installation of the suction foundation (RC)


⑨Installing the suction foundation (RC)


⑩Penetration status after the suction foundation was completely submerged


⑪Installing the upper caisson (July 1999)

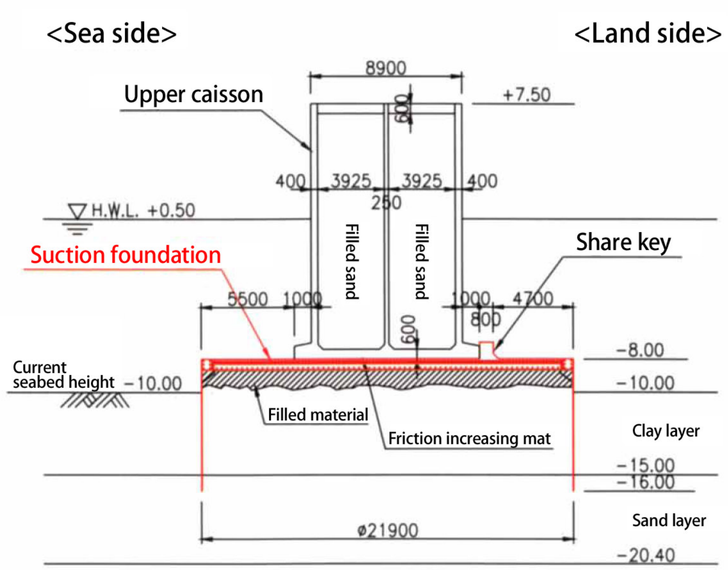


⑫Completion of the breakwater for verification test (August 1999)

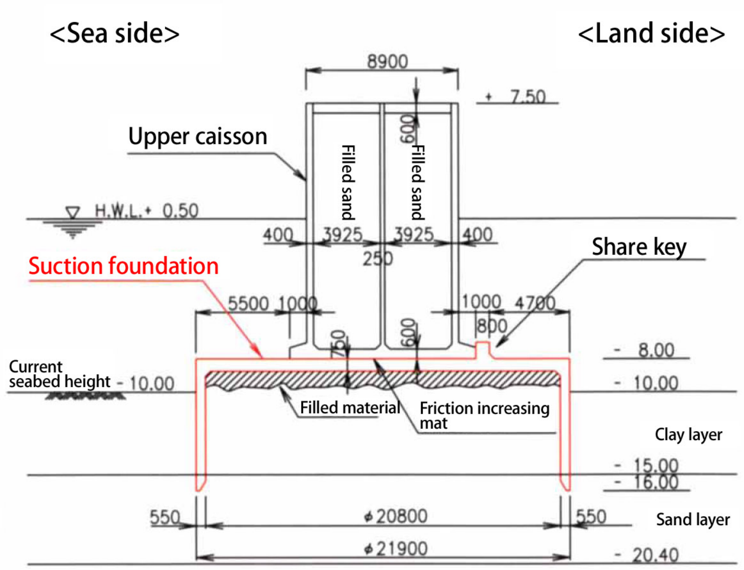
Configuration of the suction foundation

A structure separated into the suction foundation and the upper caisson was adopted.
Two types of materials, steel and RC (reinforced concrete), were adopted to allow us to study the construction performance, the stability of the breakwater body, and the economics, comparing the difference in weight, rigidity, and side wall thickness.

Standard cross section view (Steel foundation)



Standard cross section view (RC foundation)

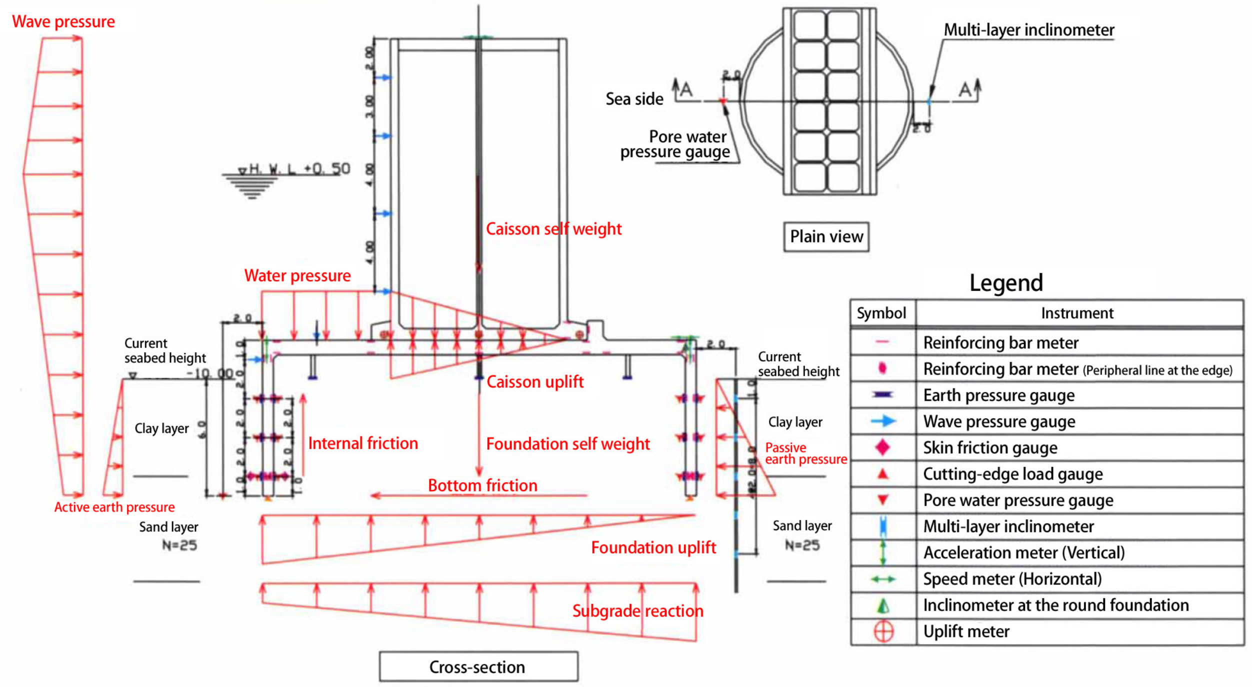


Allocation of the instruments

The suction foundation and the upper caisson are provided with instruments to obtain various measurement data. [Major instruments used in each verification]

- Verification for suction force when submerging: Pore water pressure gauge; Earth pressure gauge
- Verification for penetration resistance: Cutting-edge load gauge; Skin friction gauge; Earth pressure gauge
- Verification for behavior of the breakwater body: Inclinometer; Speed meter; Strain gauge
- Verification for wave pressure under wave action: Wave pressure gauge; Pore water pressure gauge, etc.

Layout of the measuring instruments



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