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Hydrostatically Supported Sand Structures as Ship Collision Barrier

Structures hydrostatiques, en sable, contre les collisions de navires

Hydrostatisch unterstützte Sandstrukturen als Schiffsaufprallabfänger

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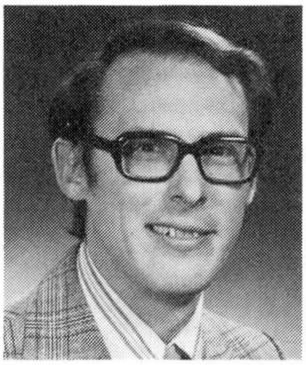

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SUMMARY

This paper describes the application of hydrostatically supported sand structures to ship collision barriers. The hydrostatically supported sand structures basically consist of sand and rubber walls. Their use in offshore engineering presents a highly competitive alternative to steel and concrete structures. Various model tests and prototype experiments have proven that hydrostatically supported sand structures are highly stable and that bearing capacity against horizontal forces is also high. A new type of ship collision barrier having high ship collision energy absorbability is proposed for low construction cost and expeditious execution of work.

RÉSUMÉ

Le présent article décrit l'emploi de structures hydrostatiques, en sable, comme barrières contre les collisions de navires. Ces structures sont essentiellement constituées de parois de sable et de caoutchouc. Leur mise en oeuvre dans la technologie offshore fait d'elles un concurrent très sérieux des structures en acier ou en béton. Plusieurs essais sur modèles et diverses expériences de prototypes ont prouvé que ces structures soutenues de manière hydrostatique étaient particulièrement stables et que leur capacité de charge vis-à-vis de forces horizontales était également importante. Une nouvelle forme de barrière contre les collisions de navires, dotée d'une grande puissance d'absorption de l'énergie produite par les collisions de ces navires, est ainsi proposée, mettant de ce fait en relief les propriétés de ces structures de sable pour un coût modique de construction et une rapide exécution des travaux.

ZUSAMMENFASSUNG

Dieses Dokument beschreibt die Anwendung hydrostatisch unterstützter Sandstrukturen als Stoßfänger bei Schiffszusammenstößen. Die hydrostatisch unterstützten Sandstrukturen bestehen im Grunde aus Sand- und Gummiwänden. Ihre Anwendung in der küstenfernen Technik stellt eine äußerst wettbewerbsfähige Alternative zu Stahl- und Betonkonstruktionen dar. Verschiedene Modell- und Prototypversuche haben ergeben, daß hydrostatisch unterstützte Sandstrukturen hochstabil und ihre Lagerungseigenschaften gegen horizontale Kräfte auch hoch sind. Hier wird ein neuer Typ von Stoßfängern bei Schiffskollisionen vorgeschlagen, wobei die Eigenschaften hydrostatisch unterstützter Sandstrukturen bei geringen Baukosten und schneller Arbeitsausführung verfügbar sind.

1. INTRODUCTION

The concept of hydrostatically supported sand structure was first conceived in 1974. Since then the feasibility of applying this concept to various offshore structures has been confirmed through model tests in laboratories and prototype experiments.

As shown in Fig. 1, the hydrostatically supported sand structures basically consist of sand and impervious rubber walls. The principle is based on its ability to dewater the sand during construction thus reducing the internal porewater pressures and providing stability for the sand mass. During and after construction, the membrane acts as a diaphragm by which the hydrostatic pressure is converted to a horizontal confining force on the sand mass. Theoretically, the membrane can be non-load bearing, its sole function being to act as an impervious wall. However, for efficiency in handling and to provide an additional safety margin during construction, membranes having nominal tensile strength will be used.

To finalize the construction technique and to prove the structure's stability, a 17 m high prototype structure "Sandisle Ann" was installed in Christchurch Bay in 1975. Christchurch Bay, Hampshire, off the southern coast of England was chosen as the location for the prototype because of the suitable water depth quite close to the shore, its seabed conditions provided a suitable foundation, and a fetch of over 300 km in the southwesterly direction of the prevailing winds was ideal as a severe marine testing environment. This prototype structure consisted of a steel deck unit within a bag fabricated of nylon-reinforced neoprene membrane. The prototype experiment demonstrated that the method of constructing hydrostatically supported sand structures was sound.

Since the construction of "Sandisle Ann", theoretical and experimental research on hydrostatically supported sand structures has continued with the development of various specific applications including ship collision barrier discussed in this paper.

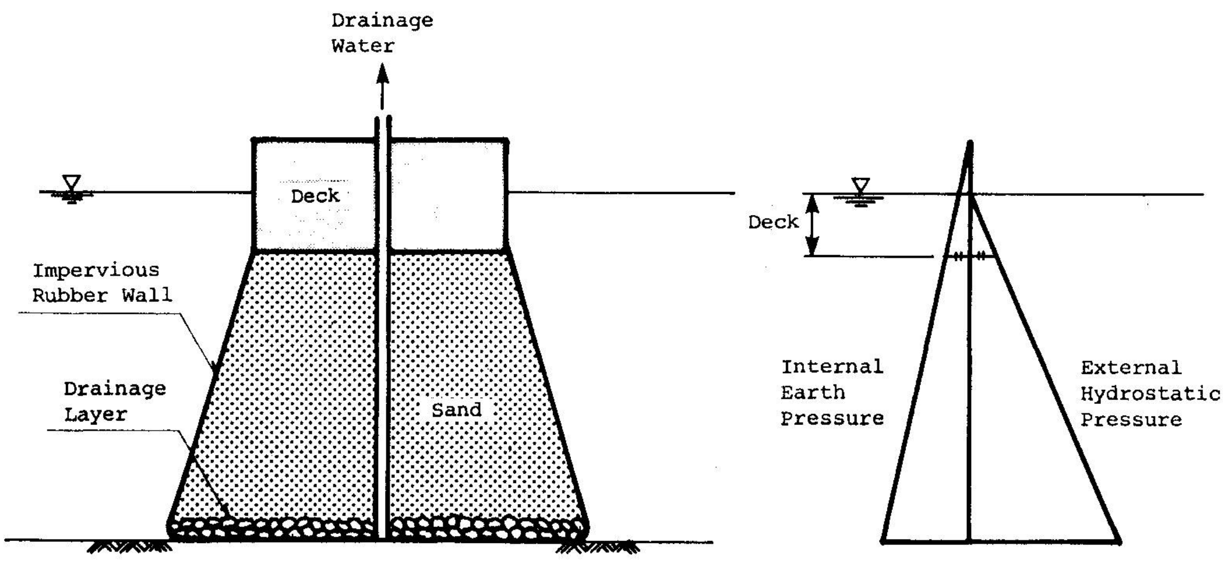


Fig. 1 Concept of Sandisle structures

2. CONSTRUCTION PROCEDURE

2-1 Stability during construction

The hydrostatically supported sand structures are not constructed within a strong, rigid container but within a relatively weak flexible bag. It is of fundamental interest to determine the stresses this bag must tolerate during the filling process. As previously stated, once the structure is completed, the membrane is only required to be impervious and carries no hoop stresses.

Sand is added into the water at the same rate as the water draining out through the base of the cell. The actual stresses in the sand are considered in terms of effective stress. In Fig. 2, an element of sand Z at a distance of z above the drainage layer is examined.

Horizontal effective stress $\sigma_H' = (x - Z)\dfrac{\gamma_w D}{x}$

Vertical effective stress $\sigma_V' = (x - Z)\left(\gamma' + \dfrac{D\gamma_w}{x}\right)$

Internal shear stress $\dfrac{\sigma_V'}{\sigma_H'} = \dfrac{x\gamma_w' + D\gamma_w}{D\gamma_w}$

$= 1.7$ (when $x = D$)

$= 1.0$ (when $x = 0$)

The mobilized angles of friction are calculated as follows.

$x = D$	$x = 0$
$\dfrac{\sigma_V'}{\sigma_H'} = \dfrac{1 + \sin\phi}{1 - \sin\phi} = 1.7$	$\dfrac{\sigma_V'}{\sigma_H} = \dfrac{1 + \sin\phi}{1 - \sin\phi} = 1.0$
Mobilized $\phi = 15°$	Mobilized $\phi = 0°$

The interesting conclusion drawn from this calculation is that the mobilized angle of internal friction is constant throughout the sand mass for any individual height of fill and increases from 0° at the start of filling to about 15° at the end of filling. With the ultimate angle of internal friction at least 35° in the majority of sands, the level of shear strength mobilization is quite low. Therefore no hoops stress will act in the membrane.

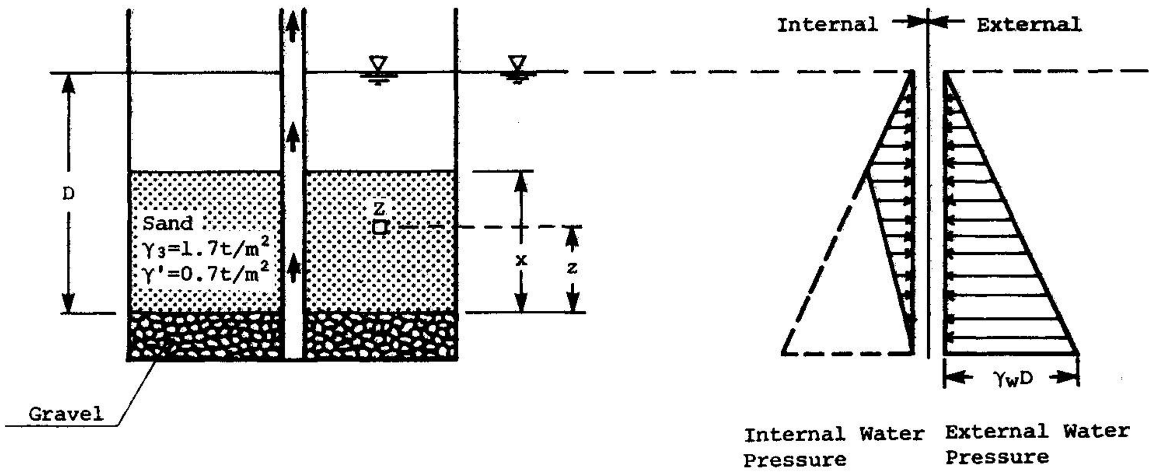


Fig. 2 Effective stresses in Sandisle construction

2-2 Construction of prototype "Sandisle Ann"

The prototype structure consisted of a steel deck unit within a bag fabricated of nylon-reinforced neoprene member. The deck was fitted with the membrane in Southampton and the prototype module was then towed from Southampton and moored alongside the attendant control vessel. After a day of preparation, construction started at 2 a.m. on Wednesday, September 15, 1976. The bag was first deployed by filling it with water. After the divers confirmed that it was properly extended and in contact with the seabed, the first fill was dropped from a central hopper within the deck unit. The wells and instrumentation were lowered into place, the buoyance of the deck trimmed, and the sand filling process began.

The following is an abbreviated construction schedule. Actual construction took only two days.

September 15	
0200	Deployment of bag.
0300	Placement of initial ballast in bag.
0300 to 0700	Lowering and preparation of main wellscreens.
0700 to 1100	Completion of gravel base layer.
1100 to 1900	Placement of pressure relief wells and connection of piezometers.
1900 to 1000 (Sept.16)	Balancing of pumping and filling system.
September 16	
1000 to 1700	Main sand filling and dewatering. Intensive monitoring of instruments.
1700 to 1900	Wait for slack water.
2100 to 2400	Filling of final meter of sand.
2400	Touchdown.

The actual filling and dewatering of the sand proceeded precisely in the textbook manner predicted from the extensive laboratory testing program. The short life of the prototype structure demonstrated the soundness of hydrostatically supported sand structure construction method.

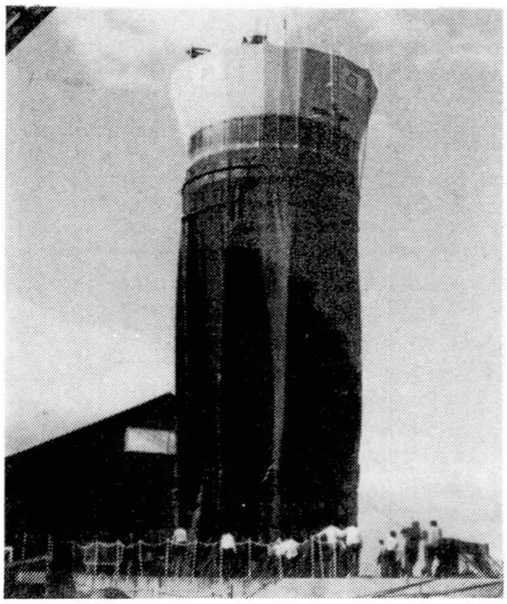


Fig. 3 Sandisle Ann being assembled at dockside

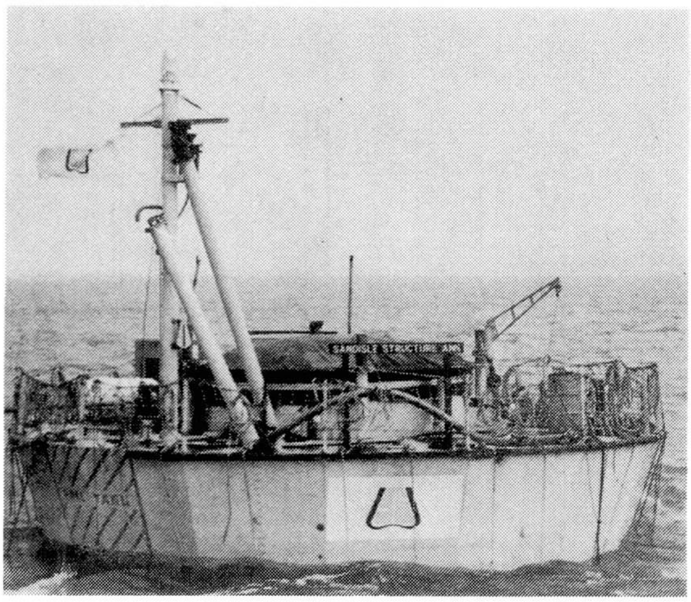


Fig. 4 Completed Sandisle Ann in Christchurch Bay

3. APPLICATION OF CONCEPT TO SHIP COLLISION BARRIER

There have been many reports submitted on accidents caused by the collision of ships with piers or offshore structures which have caused serious damage. So when constructing piers or offshore structures, sufficient protection from ship collision damages is necessary. From the structural and functional considerations, a ship collision protection should:

- Have high absorptivity of collision energy produced by oncoming ships.
- Take up the least amount of space so as not to interfere with the navigation of ships.
- Be easy to construct and at low cost.
- Be easy and inexpensive to maintain.

Needless to say, the actual design of a ship collision protection greatly depends on ship size, collision speed, water depth, condition of foundation ground, etc. Currently, there are two methods in use as ship collision protection. The most widely used method is where rubber fenders or buffers are attached directly onto piers or offshore structures, but this method is effective only when the colliding ship is of a small scale and if a large scale ship collides against it, piers or offshore structures may be seriously damaged. In the other method, independent ship collision protection structures are provided around piers or offshore structures and is effective against collision of relatively large scale ships, although its drawback is the generally high construction cost.

The hydrostatically supported sand structure, on the other hand, has none of the drawbacks of the above two methods. It is highly durable, due to the large sand mass, against great collision impact and advantageous because of its low construction cost and its short construction period.

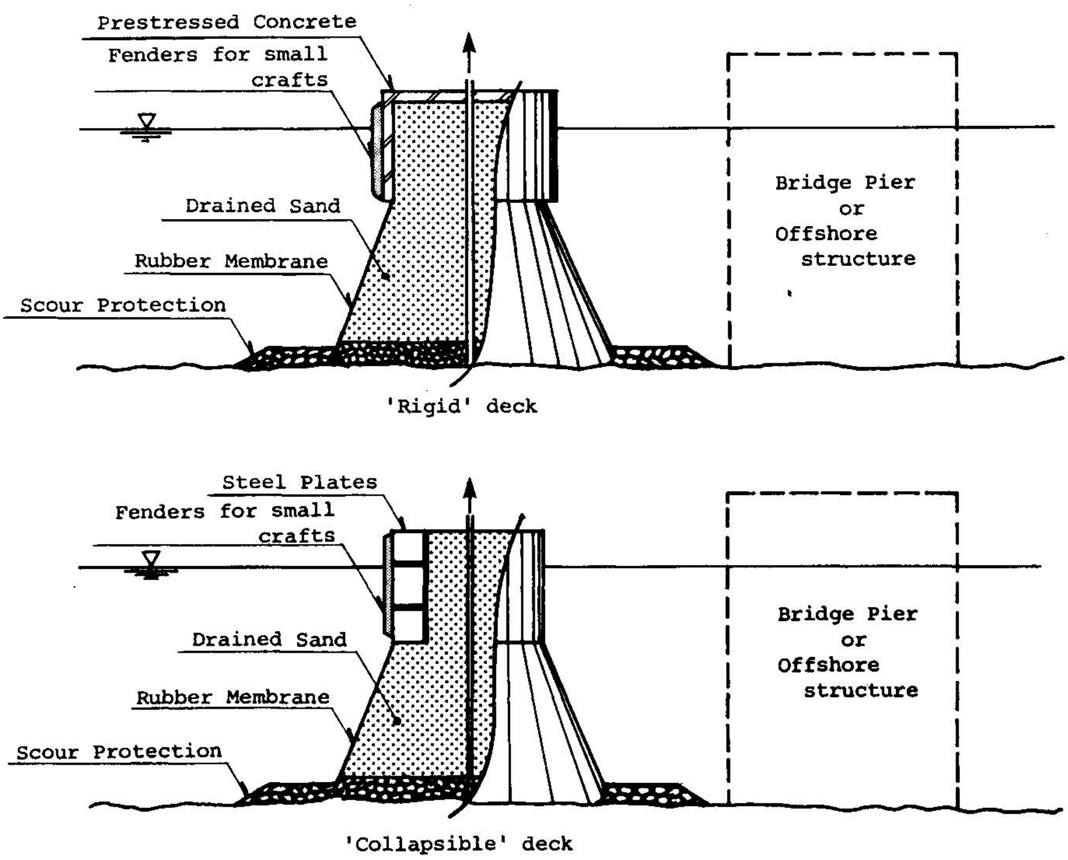


Fig. 5 Two types of ship collision barrier

Two basic types of hydrostatically supported sand structure for use as a collision protection or fendering structure are illustrated in Fig. 5. The first type of structure has a very "rigid" deck unit --- the collision energy of the oncoming ship is dissipated by crushing of the ship's bow. This results in severe damage to the ship but little damage to the Sandisle unit. The second type has a "collapsible" deck unit --- the ship's momentus is largely absorbed by crushing of the deck unit and the penetration of the ship's bow into the drained sand mass. Damage to the ship is minimized but a major portion of the Sandisle would probably be destroyed and would have to be replaced.

In designing the aforesaid hydrostatically supported sand structures, other considerations must be given such as collision of small ships and scouring at seabed around the structure. The possibility of small ship's colliding is high, but its impact force is low. To minimize the damage to both the structure and small ships, attaching rubber or timber fenders around the deck unit of the structure is recommended. Scour protection should be designed by taking into consideration the maximum tidal current velocity and the wave height at the site.

4. MODEL TEST AND ANALYSIS

When hydrostatically supported sand structures are used as collision protection or fendering structure, the most important point in designing is to grasp the behavior of such structure against horizontal impact force. Laboratory tests and analyses of the finite element method were carried out to observe and determine the maximum resistance and failure modes of the structures.

4.1 Summary of tests

A horizontal load test was carried out under two different conditions. The first condition was when the water in the model was well drained. The horizontal load was gradually increased until the model failed. The deformation and the maximum horizontal load were measured during the test. The other condition was when the water was flowing into the model, where 90% of the maximum horizontal load was applied.

The model consisted of a soft vinyl bag filled with sand and was reinforced with acryl frame at the upper half of the model. The acryl frame was provided with an opening of 6 cm x 6 cm so that the water can flow into the model. Table 1 shows the profiles of the three types of models. All models were rectangular and 60 cm high.

Fig. 6 shows the instruments used in the tests. The load was applied horizontally with a jack at a position 50 cm from the bottom of the models. Deformations of the models were measured with the four dial gauges shown in Fig. 6. The water level in the water tanks was 50 cm from the bottom of the models. The friction coefficient between the bottom of the models and the bottom of the water tank was measured to be 0.58.

4.2 Consideration

Fig. 7 shows the relationship between the applied horizontal loads and displacement at the model crest. The maximum resistance of each model was about 20 kg, 95 kg, and 210 kg, respectively. Each load-displacement curve shows that the structure undergoes a serious non-linear deformation under the horizontal force. The fact that resistance remains at a certain level despite deformation increase after yielding shows the large energy-absorbing capacity of the structure against horizontal force.

As clearly seen in Figs. 8 and 9, the failure mode against horizontal force is a sort of shear failure. Failure starts from the model's compressive side and propagates to the whole structure with an increase in horizontal force. Fig. 10 shows the distribution of principal stresses of model A obtained in an FEM analysis and the failure zone when Mohr-Coulomb's Failure Criteria is used. Failure occurs on the model's compressive side, which coincides with the model test results.

Table 2 shows the elapsed time before the models failed while the water was flowing into the model. As shown in Table 2, it took a considerably long time before the models failed. This shows that even though the deck unit is damaged at the moment of ship collision, there is no negative effect on the stability of the structure for a short period.

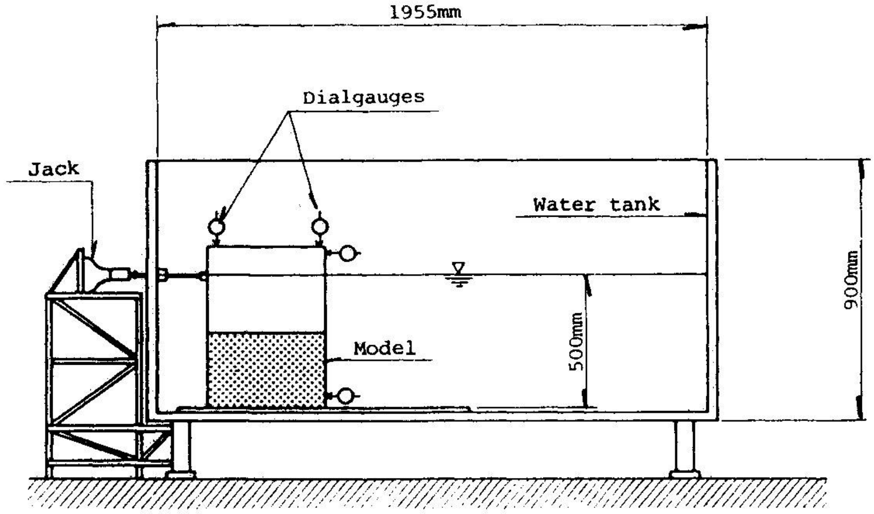


Fig. 6 Side view of test apparatus

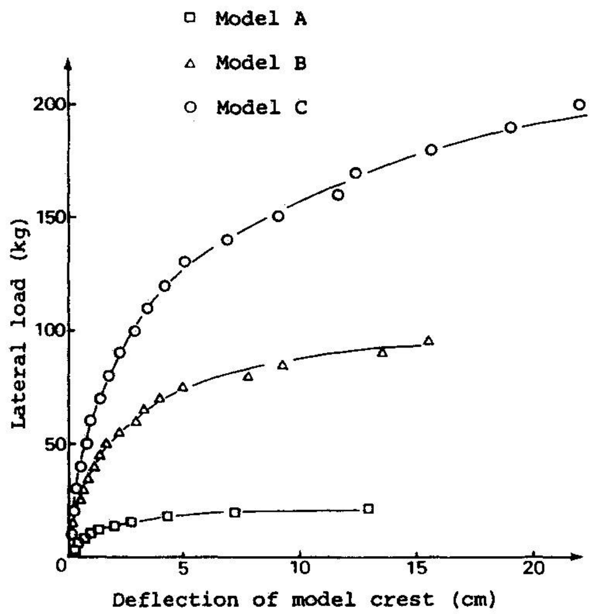


Fig. 7 Model crest deflection versus lateral load

Model	A	B	C
Height (cm)	60	60	60
Width (cm)	40	60	80

Table 1 Profiles of models

Model	A	B	C
Time (min)	7	21	42

Table 2 Elapsed time before model fail

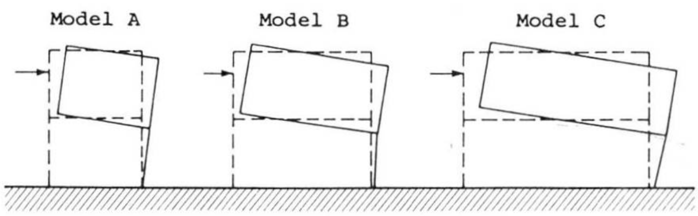


Fig. 8 Failure mode of models

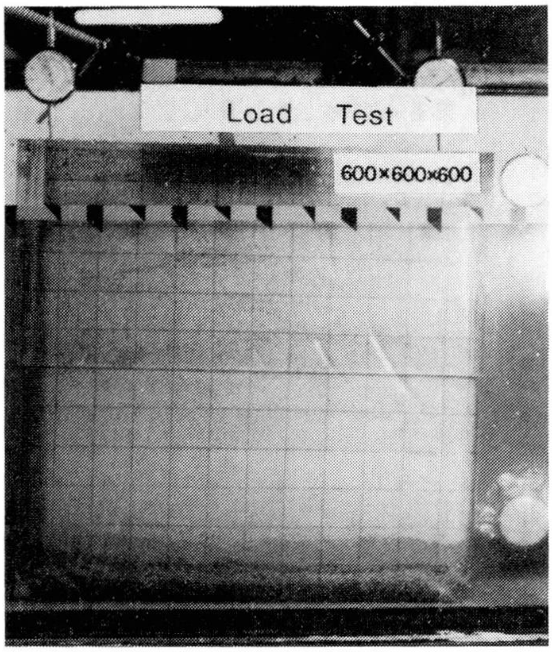
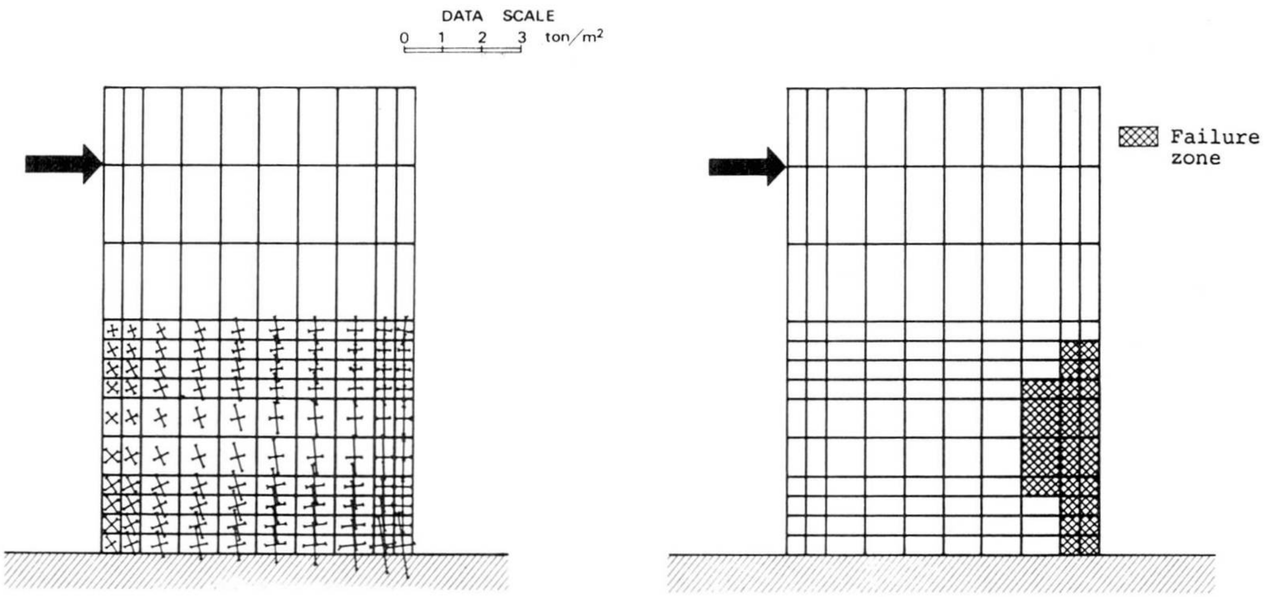


Fig. 9 Photo of failure mode



(a) Principal stress

(b) Distribution of failure zone

Fig. 10 Result of analysis

5 CONCLUSION

Two types of hydrostatically supported sand structures for use as a collision protection or fendering structure are proposed in this paper. The prototype experiments demonstrated that the structure is highly stable and the construction method is sound. The load displacement curve obtained from the model test showed that the structure has large capacity of energy absorption against horizontal forces. The failure mode of the structure is a sort of shear failure and the failure starts at the compression side of the structure.

The results obtained from an FEM analysis sufficiently explains the behavior of the structures used in the laboratory test.