Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999 K09/2

Study on Seismic Performance of Sea Walls, Part 1: Outline of Study

Setsuo Iizuka[1], Yoshiji Moro[1], Yoshio Suzuki[2] and Eisuke Tanimoto[2]

1) Nuclear Power Engineering Corporation, Japan
2) Takenaka Corporation, Japan

ABSTRUCT: The Ministry of International Trade and Industry (MITI) commissioned NUPEC, the Nuclear Power Engineering Corporation, to examine the possibility of siting nuclear power stations at sea, on man-made islands, and NUPEC is currently surveying the prospects of establishing a practice for constructing nuclear power plants at sea. For the safety in terms of earthquake-resistance of plant built on a man-made island, the sea walls encircling the island must be built to withstand wave and earthquake damage, but in studying the safety of sea walls in these respects, little is known of the dynamic characteristics of armor units, one of the structural components of sea walls. The objectives of the following tests were to determine the strength and deformation characteristics of armor units and the sliding characteristics between caisson and mound. The tests were conducted using centrifuge apparatus.

1. INTRODUCTION

The design of sea walls for man-made islands supporting nuclear power plants must not only fulfill sea wall stability standards used for general port facilities. It must also be affirmed that they can maintain their vital protective function in the face of even more severe external forces such as rough waves, earthquakes, etc. From the proposals of the nuclear power civil engineering committee of Japan Society of Civil Engineers for engineering to diversify locational options for nuclear power plants, the basic flow chart for the design of sea wall sections for man-made islands at sea is shown in Fig. 1. In the study of whether they can maintain their function, the deformation of sea walls from a design earthquake S2 is predicted through dynamic analysis, but nothing is currently known of the strength and deformation characteristics of armor units, needed as analytical constants. On the sliding characteristics between caisson and mound, data on the static coefficient of friction is available, but at present there is hardly any data available on the dynamic characteristics.

The effect armor units have on the stability of sea walls was demonstrated in the Great Hanshin Earthquake of 17 January 1995. Photo 1 shows the difference in damage sustained by sea walls in that earthquake, according to whether or not they were protected with armor units. Elucidating the dynamic characteristics of armor units is thus important not only for sea-wall design for the construction of nuclear power plants at sea, but also for the seismic performance of designs for all types of port and harbour facilities.

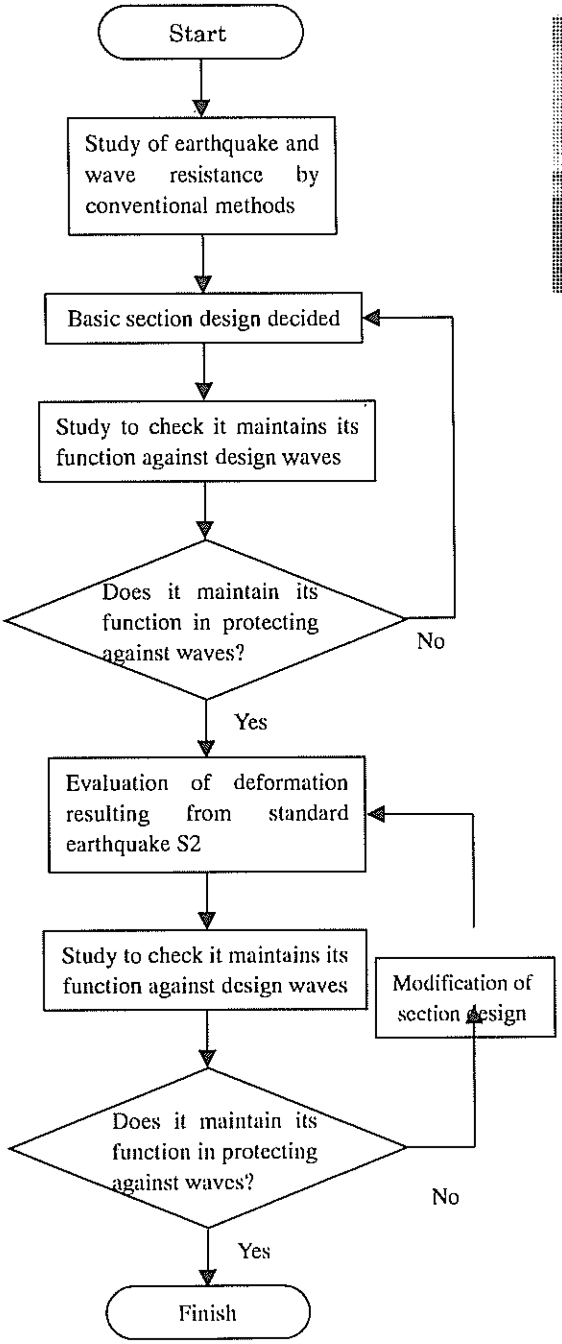
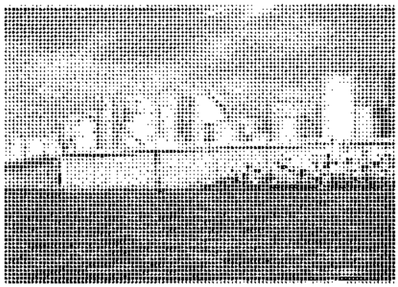
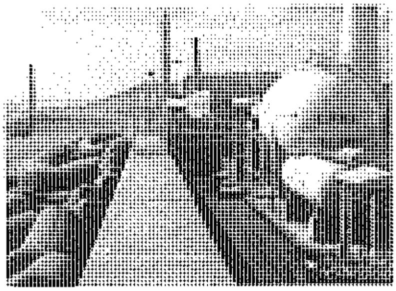


Fig. 1 Flow chart for design of sea wall section



(a) Damaged sea wall



(b) Undamaged sea wall

Photo 1 Damage to sea walls in Great Hanshin Earthquake, 17 Jan. 1995

2. SELECTION OF METHOD OF TESTS

These tests use scale models in a centrifugal force field. The reasons for this choice are as follows.

To undertake corroborative tests one can choose between tests using full-sized armor units, and scale model tests. Although the results of tests using full-sized armor units will be highly reliable, the test specimen, the shear test apparatus, measuring equipment etc. will all have to be extremely large, rendering such tests realistically impossible. Model tests using small scale models, on the other hand, are extremely advantageous in terms of cost, time and safety, but must satisfy the necessary similarity law to ensure the reliability of the data obtained. Furthermore, scale model tests can be undertaken in a gravitational field, or in a centrifugal force field using a centrifuge apparatus. Reproducing the weight of individual scale models of armor units in the specimen may be expected to greatly affect the strength and deformation characteristics of the aggregate of units. Therefore, the most appropriate method of test is a scale model test in a centrifugal force field that can reproduce the internal stresses, and their distribution, sustained by actual armor units, and that satisfies the similarity law on the effect of the weight of the models of armor units within the specimen, to ensure the reliability of the data obtained. The characteristics of these three types of test are summarized in Table 1.

Table 1 Suitability for armor unit tests and sliding tests between caisson and mound

Test method	Centrifugal force field	Gravitational field	
	Model tests	Full-sized tests	Model tests
Specimen	Can be made with scale models	Made with full-sized armor units	Can be made with scale models
Similarity law	Clear law exists	–	Does not satisfy similarity law with regard to weight of units
parameter study	Many tests can be undertaken, so parameter study possible within fixed period	Each test takes much time, so test conditions very limited.	Many tests can be undertaken, so parameter study possible within fixed period
Precedents	None	None	None
Cost	Reasonable	Prohibitively high	Reasonable
Duration	Reasonable	Lengthy	Reasonable
Overall evaluation	Highly suitable	Unsuitable	Marginal

3. OUTLINE OF TESTS

3.1 Overall plan for tests

A section of the type of sea wall for which these tests are designed is shown diagrammatically in Fig. 2. The overall plan for the tests is summarized in Fig. 3. For the strength and deformation characteristics of armor units, they consist of cyclic simple shear tests and elastic wave tests to determine the deformation characteristics of armor units at the very small strain level to middle strain level. For sliding characteristics between caisson and mound, cyclic sliding tests are to determine the dynamic coefficient of friction between caisson and mound.

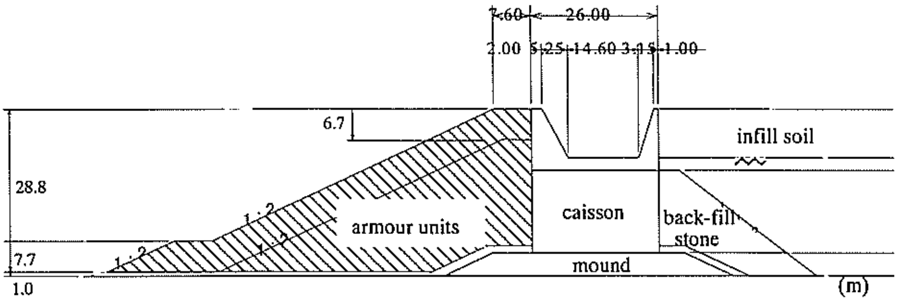


Fig. 2 Configuration of sea wall in tests

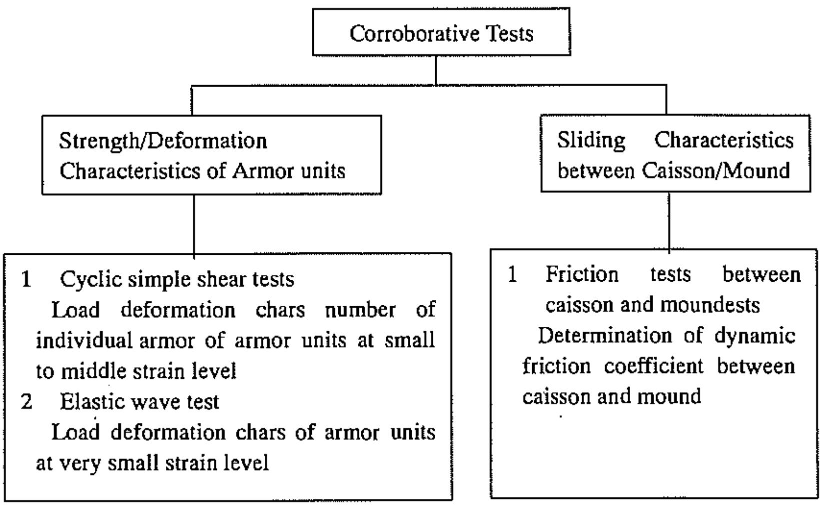


Fig. 3 Overall plan for tests

3.2 Test apparatus

The simplified configuration and performance specifications of the centrifuge apparatus used for these tests are shown in Fig. 4 and Table 2. The centrifugal model test apparatus is the beam type, with a platform fitted at the ends of two beams. A counterweight fitted on the opposite side to the platform maintains the balance of the apparatus during beam rotation.

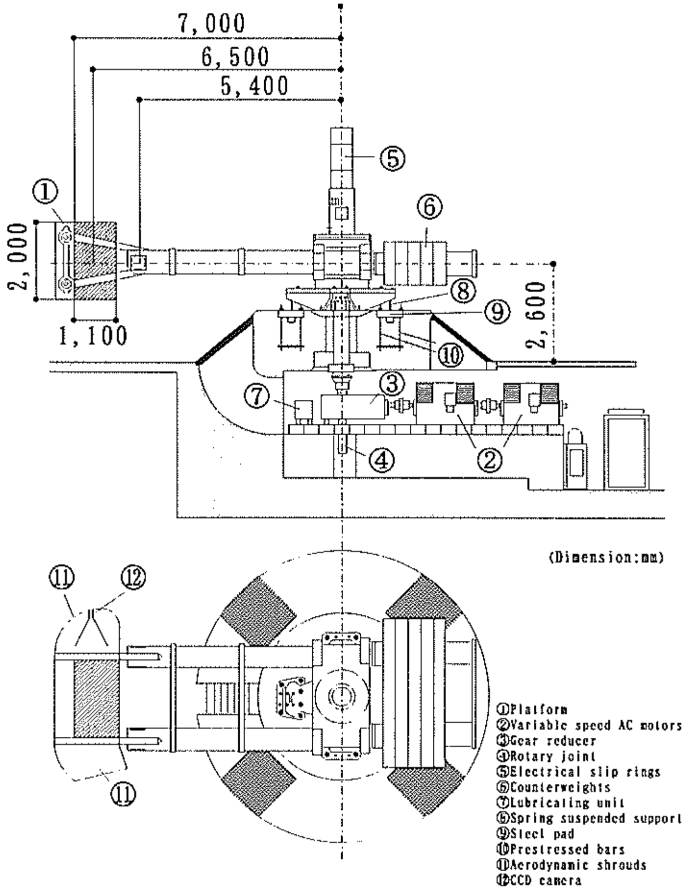


Fig. 4 Centrifugal Loading Apparatus

Table 2 Specifications of Test Apparatus

Max. centrifugal acceleration		200g	
Effective radius of rotation		6.5m	
Pay load	100g centrifugal force field	5,000kg	
	200g centrifugal force field	2,000kg	
Platform dimensions		width	2,000mm
		depth	2,000mm
		usable height	1,100mm

3.3 Test cases

Test cases for the strength and deformation characteristics tests for armor units are shown in Tables 3, and for sliding tests between caisson and mound in Table 4. The largest 80 ton unit size was used as the standard size of armor unit, in consideration of site conditions.

Table 3 Cases of armor unit tests

<table>
<tr><th>Test case</th><th>Armor unit type</th><th>Armor unit size (ton)</th><th>Centrifugal acceleration (g) #1</th><th>Overburden pressure (MPa)</th><th>Loading conditions</th><th>Model scale (80ton type)</th></tr>
<tr><td>CASE 1-1</td><td rowspan="9">Type1</td><td rowspan="3">16</td><td rowspan="3">57</td><td>0.000</td><td rowspan="15">Loading frequency 0.1Hz

loading speed 1.0mm/min</td><td rowspan="9">1/100</td></tr>
<tr><td>CASE 1-2</td><td>0.098</td></tr>
<tr><td>CASE 1-3</td><td>0.196</td></tr>
<tr><td>CASE 2-1</td><td rowspan="3">40</td><td rowspan="3">77</td><td>0.000</td></tr>
<tr><td>CASE 2-2</td><td>0.098</td></tr>
<tr><td>CASE 2-3</td><td>0.196</td></tr>
<tr><td>CASE 3-1</td><td rowspan="3">80</td><td rowspan="3">100</td><td>0.000</td></tr>
<tr><td>CASE 3-2</td><td>0.098</td></tr>
<tr><td>CASE 3-3</td><td>0.196</td></tr>
<tr><td>CASE 4-1</td><td rowspan="6">Type2</td><td rowspan="3">40</td><td rowspan="3">77</td><td>0.000</td><td rowspan="6">1/100</td></tr>
<tr><td>CASE 4-2</td><td>0.098</td></tr>
<tr><td>CASE 4-3</td><td>0.196</td></tr>
<tr><td>CASE 5-1</td><td rowspan="3">80</td><td rowspan="3">100</td><td>0.000</td></tr>
<tr><td>CASE 5-2</td><td>0.098</td></tr>
<tr><td>CASE 5-3</td><td>0.196</td></tr>
</table>

#1 Centrifugal acceleration was adjusted to reproduce the effect of different sizes of armor unit (80ton, 40ton and 16ton) using 1/100 scale models of the 80ton unit.

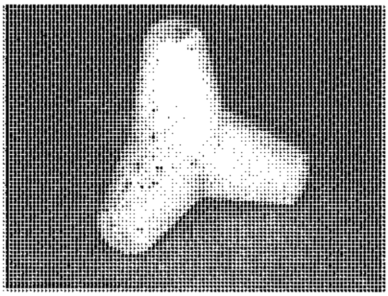
Table 4 Sliding tests between caisson and mound

Test case	Caisson type	Mound material	Mound thickness	Centrifugal acceleration	Loading speed
CASE 6	Gravity-type concrete	Rubble	5cm	100g	1.0mm/min

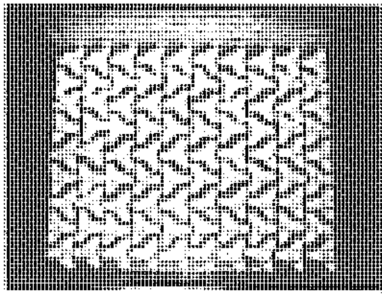
3.4 Scale model units

Two types of armor unit were selected for these tests, the frequently used Type1, and a hollow triangular unit whose strength and deformation characteristics are believed to differ from those of the Type1. Envisaging the use of a centrifugal force field of 100g, 1/100 scale models of the 80 ton size of armor unit were made. Photo 2 and 3 show a single example of each type of armor unit model and arrangements of models in the shear test apparatus. The units were arranged regularly only in the base layer; from the next layer up they were piled randomly.

A 1/100 scale model of a caisson was used in the sliding tests. Table 6 gives a comparison of actual section dimensions and the model.

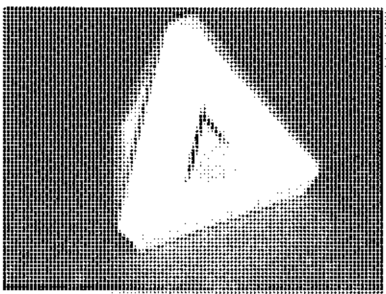


(a) Individual Type1 model

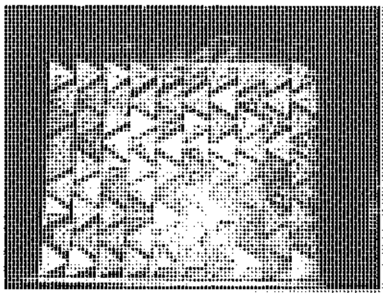


(b) Base layer arrangement

Photo 2 Type1 model



(a) Individual type2 model



(b) Base layer arrangement

Photo 3 Type2 model

Table 6 Dimensions of caisson/mound model

	Standard section type	1/100 model	Remarks
Caisson dimensions	26m wide	0.26m wide	
Contact pressure	$50.4 tf/m^2$	$0.504 tf/m^2$	density $2.1 g/cm^3$
Mound thickness	5.0m	50mm	
Mound material	100 mm - 1000mm	4 mm -9.5mm	

4. CONCLUSION

With the objective of deducing from the results of past research those structural components of sea walls that make the greatest contribution to their stability and earthquake-resistance, tests of the dynamic characteristics of armor units and sliding characteristics of caisson/mound were selected for corroborative test in Part Two. Details of these tests are given in Part Two.