International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

1995 - Third International Conference on Recent Advances in Geotechnical Earthquake Engineering & Soil Dynamics

04 Apr 1995, 10:30 am - 12:00 pm

Shaking Table Tests and Numerical Simulation of Seismic Response of The Seawall

Y. Nishimura
Tokyo Electric Power Services Co., Tokyo, Japan

S. Fukui
Tokyo Electric Power Services Co., Tokyo, Japan

M. Sato
Tokyo Electric Power Services Co., Tokyo, Japan

H. Kurose
Tokyo Electric Power Services Co., Tokyo, Japan

M. Fujitani
Tokyo Electric Power Company, Tokyo, Japan

Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 2–7, 1995, Volume I, St. Louis, Missouri

Shaking Table Tests and Numerical Simulation of Seismic Response of The Seawall

Paper No. 4.13

Y. Nishimura, S. Fukui, M. Sato and H. Kurose
Tokyo Electric Power Services Co., Tokyo, Japan

M. Fujitani
Tokyo Electric Power Company, Tokyo, Japan

SYNOPSIS: Shaking table tests of a caisson seawall model were conducted to investigate sliding phenomena of the seawall. The response characteristics of the caisson placed on the mound which was fixed to the shaking table were investigated in the six series of experiments with varying the situation of the model; with or without backfill, wave breaking works and water. These test results were utilized to validate a two-dimensional FEM analysis method with joint elements. The numerical model with the finer mesh division and joint elements showed fairly close results with the series of test results, resulting the better representation of the characteristics of sliding and plastic deformation nature of the seawall model.

INTRODUCTION

Because of their functional and economical importance, the offshore man-made islands must be designed to avoid serious damages due to major extreme loads including seismic forces and to ensure the designated function of the offshore islands encompassed by the caisson seawall structure; even when the seawall were forced to displace, the magnitude of the displacement should remain tolerable for securing the reclaimed land inside. At present, however, in the conventional design of the seawall the soundness of it is evaluated by means of merely its safety factor against sliding where the caisson is assumed as a rigid body and will undergo sliding, whereas any quantitative evaluation of the displacement and the consequence of the sliding is not pursued.

In this study, the results of a series of shaking table tests and the numerical simulation of them using a two-dimensional dynamic FEM model with joint elements are reported(Ref.1). Comparing the both results, the validity of the analysis method we propose is examined.

SHAKING TABLE TESTS

Test Method

A 1/40 scale model of a caisson seawall consisting of a caisson, a mound, wave breaking works and a backfill, as is shown in Figure 1, was placed in a steel frame box of 6.0m length, 1.0m width and 1.3m height, respectively, which was fixed to a shaking table of the size, 6.0m x 6.5m. The response acceleration, displacement, soil pressure, hydropressure and reactive load of wave breaking works were measured by installing those instruments at the locations which are shown in the figure. As the material for the mound, a silicone rubber was used for allowing the sliding of the model to occur at its upper surface without causing the other modes of failures. The surface of the mound was covered with a Teflon sheet to adjust the friction of the interface. The tests were conducted in six series of experiments with varying the situation of the model but the caisson was placed on the mound all through the cases as the core structure; with or without backfill, wave breaking works and water. These six test cases are explained in Table 1. The input motion mainly used was a 2 Hz sinusoidal motion with the maximum acceleration of 400 gals.

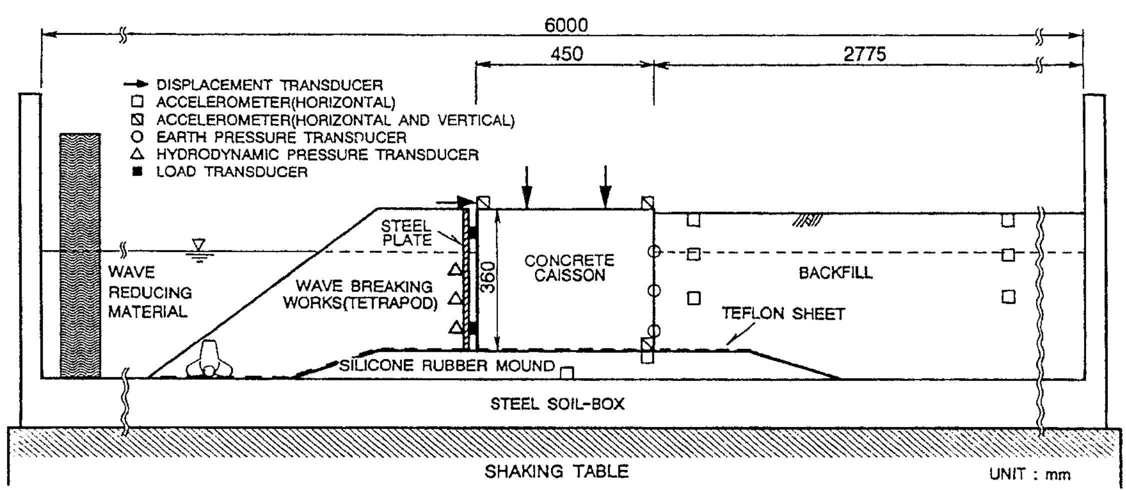


Figure 1. Test model and location of measuring

Table 1. Test cases

Test case No.	Presence or absence of water	Structural element	Test model	Input motion
1	absence	caisson		·Sinusoidal motion (2Hz 400gal 3waves)
2	presence	caisson		·Sinusoidal motion (2Hz 400gal 3waves)
3	absence	caisson backfill		·Sinusoidal motion (2Hz 400gal 3waves) ·El Centro 1940
4	presence	caisson backfill		·Sinusoidal motion (2Hz 400gal 7waves) ·El Centro 1940
5	absence	caisson backfill wave breking works		·Sinusoidal motion (2Hz 400gal 7waves)
6	presence	caisson backfill wave breking works		·Sinusoidal motion (2Hz 400gal 7waves)

Test Results and Its Analysis

The contribution of each structural element to the behavior of the caisson was analyzed from the test results.

The presence of water led to a reduction in the response multiplication factor and resonance frequency of the caisson, whereas the resonance peak of the caisson was increased with the increased rigidity of the structural system as a whole when either the wave breaking works or backfill was placed, or the both were placed onto the caisson.

The dynamic friction angle at the caisson-mound interface, which was identified through reverse calculations from each response acceleration at the time of sliding of the caisson, ranged from 12.4° to 15.4° ; the values almost same as those having been obtained in laboratory tests and etc.

When the caisson alone was placed on the mound and the model was submerged with water, the water caused the caisson to increase the sliding due to the effect of buoyancy. When the caisson was provided also with a backfill, however, the sudden sliding movement of the caisson to the seaward direction generated a negative pore water pressure in its interface with the backfill and acted in turn to reduce the amount of sliding. The direction of the hydrodynamic pressure acting on the front face of the caisson coincided with direction of the inertia force of the caisson, and the pressure distribution was approximately in agreement with Westergaard's formula.

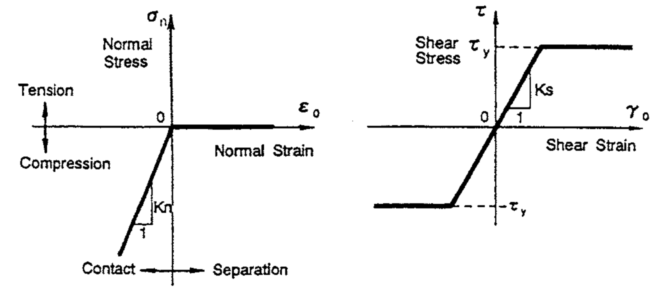
The dynamic earth pressure acting on the caisson was greater than the hydrodynamic pressure, and its phase angle was found to point the opposite direction to that of the inertia force of the caisson. When there was no water in the backfill, the force by the dynamic earth pressure was 1/2 to 1/4 times the caisson inertia force, and when there was water in the backfill, the force amounted close to the caisson inertia force. The failure plane angle of the backfill approximately agreed with the active failure angle estimated from the Mononobe-Okabe formula.

The pressure acting from the wave breaking works to the caisson, if taken account as a load, was found significantly smaller than the inertia force acting to the caisson, however, it was also found that the presence of the wave breaking works helped reduce the seaward sliding of the caisson.

SIMULATION OF TEST RESULTS

Analysis Method and Analysis Model

Among the series of the test cases shown in Table 1, the Cases 3 and 5, both without water, were used for the simulation study. The two-dimensional FEM analysis method proposed by Toki and Miura(Ref.2), which utilizes completely elasto-plastic joint elements and solid elements, was adopted for the numerical analysis (Figure 2). The physical properties used in the analysis, which were derived from laboratory element tests, horizontal loading tests and etc., are shown in Tables 2 and 3.



(a) Normal component (b) Tangential component

Figure 2. Constitutive relations of the joint element

Table 2. Physical properties used in the analysis

	Unit weight (t/m³)	Shear wave velocity (m/sec)	Angle of internal friction (degree)
Caisson	2.23	2000	—
Mound	1.16	26	—
Backfill	1.61	43	30
Wave breaking works	1.14	80	40

Table 3. Friction angle at interface

	Static friction angle (degree)	Dynamic friction angle (degree)
Caisson—Mound	15.2	12.5
Caisson—Backfill	20.0	20.0
Backfill—Mound	15.2	12.5
Caisson—Wave breaking works	16.0	16.0
Wave breaking works—Mound	12.7	11.3

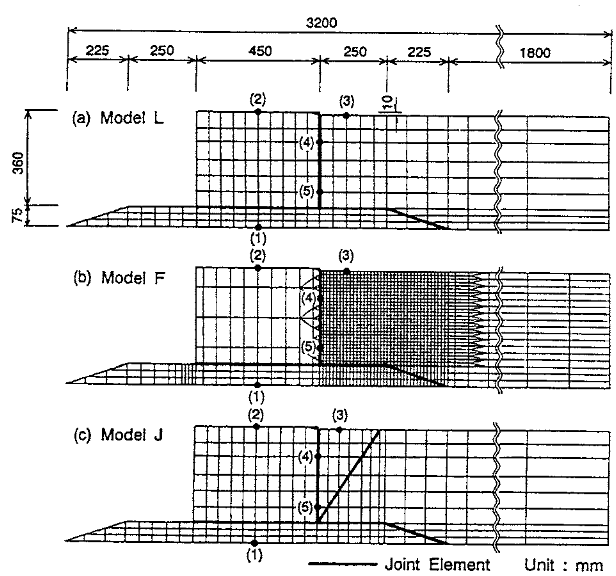


Figure 3. Finite element meshes for Case 3

Three kinds of finite element mesh layouts of Case 3 are shown in Figure 3. For all three models shown in this figure, the caisson and the mound are represented by elastic solid elements, whereas the backfill is represented by elasto-plastic solid elements. Joint elements are used at the all contact points with different physical properties. The model(hereafter referred as "Model L") shown in Figure 3(a) utilizes relatively large solid elements. As for the model("Model F") in Figure 3(b), the division of mesh for the solid elements representing the backfill is very fine. But for the model("Model J") in Figure 3(c), the fineness of the mesh for the solid elements has been kept as close as to the size used in Model L, in which joint elements have been used in part in the backfill elements. The angle of these joint elements in the backfill region was determined from the active failure angle of the backfill material considering also the internal friction angle of the material and almost agrees with the angle of the failure plane observed in the backfill during the tests.

The finite element mesh arrangement of Case 5 is shown in Figure 4. In this model, the wave breaking works, represented by elasto-plastic solid elements, have been added to Model J of Case 3.

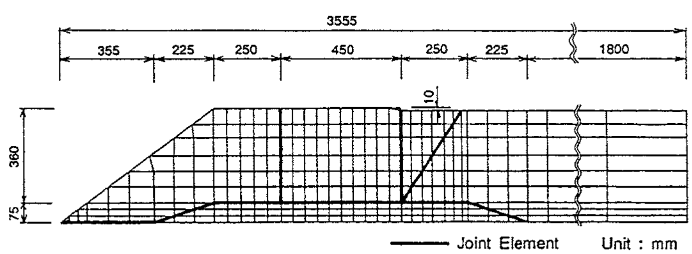


Figure 4. Finite element mesh for Case 5

Analytical Results

The measured and calculated time histories for Case 3 are compared in Figure 5. In the following simulation analysis, the acceleration time history, which was obtained at the base of the soil-box and is shown at the top of this figure, was used as the input motion. Also the displacement time histories are those of relative displacements to the shaking table, taking positive sign for seaward direction. For the earth pressures, the dynamic components are shown by offsets from the zero axis which corresponds to the static condition and the positive values indicate compressive status. The above each component of test results is compared with the corresponding simulation results obtained from the analytical models L, F and J on the simultaneously plotted time histories.

The earth pressure acting on the caisson shows the most remarkable differences with these models.

In case of Model L, high earth pressure is generated at the shallow measuring point (4) subsequently after the onset of seaward sliding of the caisson, whereas the pressure at the deep measuring point (5) is all time low probably because of occurrence of separation of the caisson from the backfill. And also the earth pressure in Model L is lower than those obtained in other models throughout the duration time of analysis.

In case of Model F, the earth pressures at the both points (4) and (5) are generated following the initial sliding of the caisson and a remarkably high earth pressure appeared at the point (4) after the occurrence of the second sliding of the caisson. This may be attributed to the finer mesh division used for this analytical model, where the plastic deformation of the backfill elements as a whole was made rather easy to occur than the previous model. In case of Model J, it seems that no separation throughout the duration of analysis has occurred, and so far the greater earth pressure was generated than in other models, and resulting the earth pressure time history of this model more closely resembling to the measured

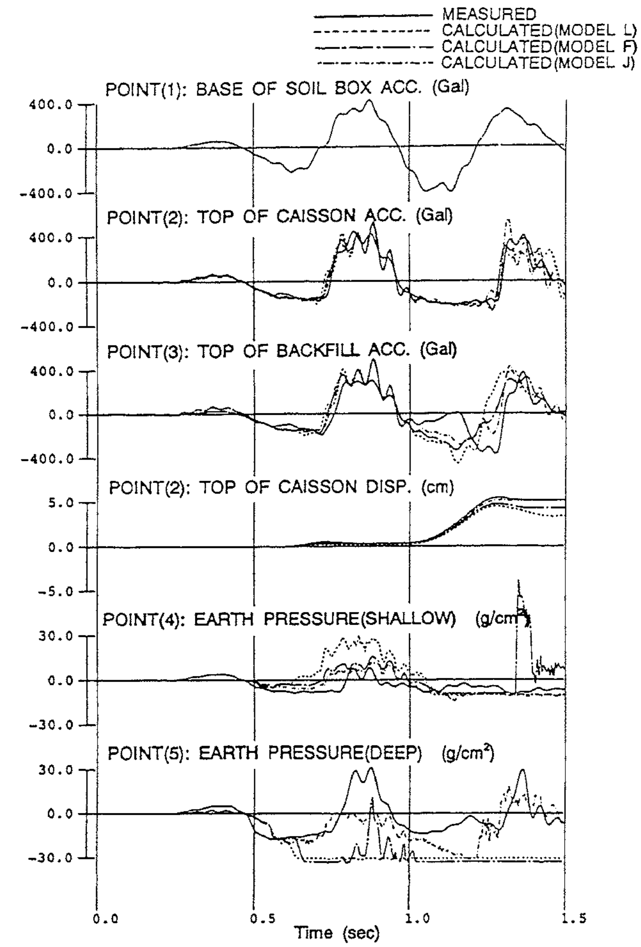


Figure 5. Comparison between measurement and calculation (Case 3)

The above difference in the earth pressures acting on the caisson may be well explained by the differences in the displacement time histories of the caisson at the measuring point (2); as the coincidence between the measured and computed of the displacement time history is improved in the order from Model L, Model F and Model J, the coincidence of the earth pressure is also improved in that order.

The deformation pattern of each model at the end of computation(1.5 seconds) is compared with that obtained in the test Case 3 as is shown in Figure 6. From the deformation patterns as illustrated in the figure, it may also be pointed out that the caisson and the backfill are completely separated in Model L, that a greater deformation of the backfill occurs in Model F than in Model L, and that the portion of the backfill soil in-between the joint elements of Model J has slid down, thus allowing the portion to maintain its contact with the caisson.

The measured and computed time histories for Case 5 are compared in Figure 7. The pressure acting from the wave breaking works denotes the resultant force acting to the caisson(per centimeter width) and the positive values here correspond to the pressure acting seaward from the backfill. The both time histories of the measured and computed relative displacements show a close agreement; not only in wave form but also in phase. The measured pressures of the wave breaking works are not necessarily reliable if the difficulty of measurement is considered, however, the overall magnitude and direction of the load exerted by the wave breaking works derived from computation are found, as a whole, consistent with the measured ones.

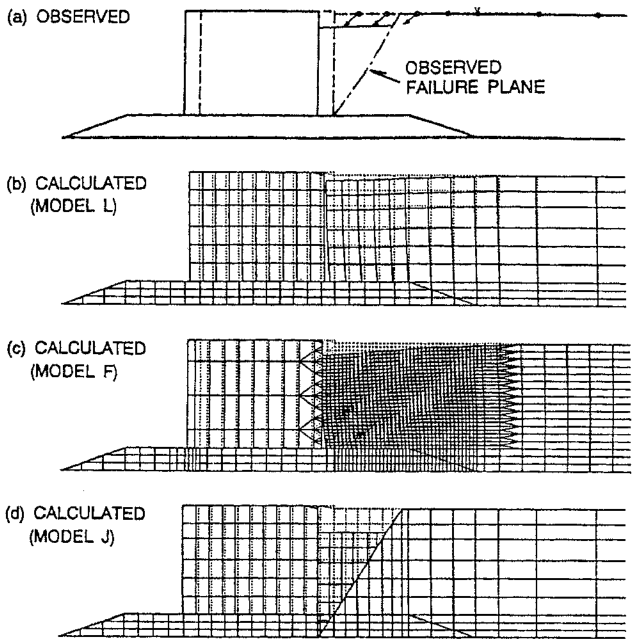


Figure 6. Comparison of deformation between observation and calculation (Case 3)

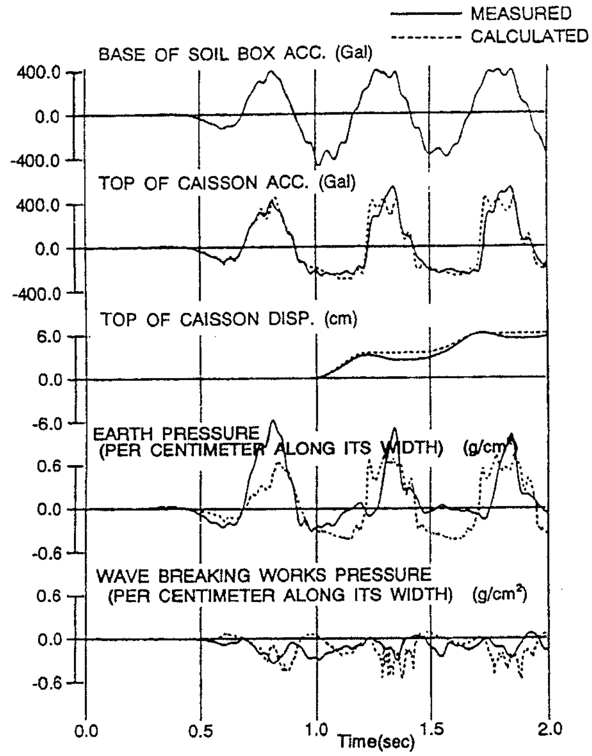


Figure 7. Comparison between measurement and calculation (Case 5)

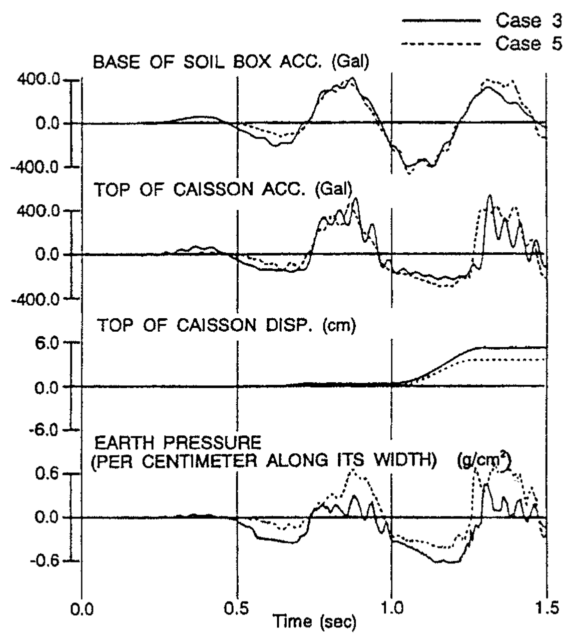


Figure 8. Comparison of time histories between Case 3 and Case 5

The computed time histories, obtained by using Model J and the common input time history for both Case 5 and Case 3, are compared in Figure 8 for the time period up to 1.5 seconds. By the presence of the wave breaking works, the displacement of the caisson in Case 5 is significantly smaller than the displacement which has appeared in Case 3, which is fairly consistent with the results obtained by the test.

CONCLUSION

Shaking table tests of a caisson seawall model were conducted to investigate sliding phenomena of the seawall. The response of the caisson placed on the mound which was fixed to the shaking table were investigated in the six series of experiments with varying the situation of the model; with or without backfill, wave breaking works and water. These test results were utilized to validate a two-dimensional FEM analysis method with joint elements.

The numerical model with the finer mesh division and joint elements showed fairly close results with the series of test results, resulting the better representation of the characteristics of sliding and plastic deformation nature of the seawall model.

The effect of a wave breaking works in suppressing the seaward sliding of a caisson could be numerically evaluated by introducing the wave breaking works into an appropriate analytical model as approximately idealized by a continuous body with the equivalent physical properties.

The further extension of this study is under consideration as a part of the research work for evaluating practically the seismic response and stability of seawall structures through numerical analysis, considering the situation that it is difficult for us to test and collect actual seismic response data of such prototype structure as a seawall.

ACKNOWLEDGEMENTS

The authors wish to express his sincere gratitude to professor Fusanori Miura of the Faculty of Engineering of Yamaguchi University for his valuable suggestions.

REFERENCES

1) Fujitani, M., et al., "Shaking Table Model Tests Concerning The Caisson Seawall and Their Numerical Simulation," 21st Earthquake Engineering Research Convention, JSCE, 1993. (in Japanese)
2) Toki, K. and Miura, F., "Non-linear Seismic Response Analysis of Soil-structure Interaction System," Earthquake Engineering and Structural Dynamics, Vol.11, pp.77-89, 1983