A STUDY ON EARTHQUAKE RESPONSE OF AN ARMORED EMBANKMENT FOR ARTIFICIAL ISLAND

Setsuo IIZUKA[1], Toru MASAO[2], Yoshiji MORO[3] And Kouichi SATO[4]

SUMMARY

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 artificial 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 an artificial 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. There is the artificial island system as one of the most realistic new location systems of nuclear power plants. Sufficient examination for construction and selection of the land fill material for installing the offshore sea area by reclaiming, is necessary for this system. And, beforehand detailed examination for ensuring earthquake-resistant safety is necessary for the nuclear power plants constructed in this artificial island. In this paper, the behavior of the whole revetment is grasped from the nonlinear analysis technique by two-dimensional finite element method using the joint element in order to confirm behavior at earthquake of the caisson-method revetment with amrour units in the front. Furthermore, The equivalent linear analysis used as convenient method is carried out, and it is compared with the one after nonlinear response.

INTRODUCTION

The design of sea walls for artificial 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. Recently, the idea of the nuclear power plants constructed over artificial island [Tochigi,H, Kanatani,M and Kawai,T(1999)] has been exposed to the attention. Such method plays the role in which the revetment which covers the circumference of artificial island is very important. Especially, the revetment which received Hyogo-ken Nanbu Earthquake received many destruction conditions, and it confirmed the earthquake-resistant importance as a result of the field study and simulation. Therefore, it is urgent to establish stability assessment method that at the good accuracy the rule mathematical model object appropriately, and that prediction and evaluation are possible for the earthquake vibration in respect of the behavior of the object for the solution of this problem in respect of the earthquake vibration assumed in each point. In this study, in order to grasp whole behavior of revetment, the neighbourhood of revetment was modeled by two-dimensional finite element method, and nonlinear analysis in time domain was carried out. And, in ground physical property, the standard Toyoura sand was used, and it was based on the physical property of amrour units in model experiment[Taniguti,E(1999), Shimizu,T(1999)], and got strength and deformation characteristic were considered. In addition, the joint element was used in caisson and mound, soil ground and amrour units and between different materials of the ground in order to consider separation, sliding. The equivalent linear analysis used as a meanwhile convenient method is carried out, and it is compared with the one after nonlinear response.

[1] *Nuclear Power Engineering Corporation, Japan Email:iizuka@nupec.or.jp*
[2] *Tajimi Engineering Services, LTD. Japan Email:masao@pub.taisei.co.jp*
[3] *Nuclear Power Engineering Corporation, Japan Email:moro@nupec.or.jp*
[4] *Tajimi Engineering Services, LTD. Japan Email:otas@pub.taisei.co.jp*

ANALYTICAL MODEL

The cross section of the target structure is shown in figure 1. And, the analytical model of the target structure is shown in figure 2. The analytical model was assumed there being some the symmetry on site cross section, and it was made to be the 1/2 models. The following was modeled in the two-dimensional plane strain element: Soil ground, caisson, upper concrete, mound, backfill stone, amrour units and reclaimed soil. Between the materials of which the physical property differs, separation and sliding may be generated by scale and frequency characteristics of the earthquake. In this analysis, the joint element[Bethe,K.J.(1982), Potyondy,J.G.(1961), Miura,F(1984), Toki,K(1980)] was set in order to consider separation and sliding between such different materials. The configuration of the joint element is shown in figure 2. The bed rock was modeled to the 100m thickness in the two-dimensional plane strain element. The sea water is not modeled. The dynamic water pressure which affected the caisson from amrour units side was evaluated by calculating based on the Westergaad equation, and applying as added mass in the caisson seaward side. The caisson, backfill stone and reclaimed soil of the bottom from sea level +0.0m assumed as a saturation state, In the part of the top from these assumed as air-dried state. The boundary condition in the ground division does both way of sides with that perpendicular roller support and downward are always fixed in stress analysis, and in the dynamic analysis, viscous boundary, island side are made to be the horizontal roller support in respect of seaward side and downward. The slide wire of the hinterland board made internal frictional angle of the hinterland board to be 30°, and it was calculated from collapse angle of the active earth pressure.

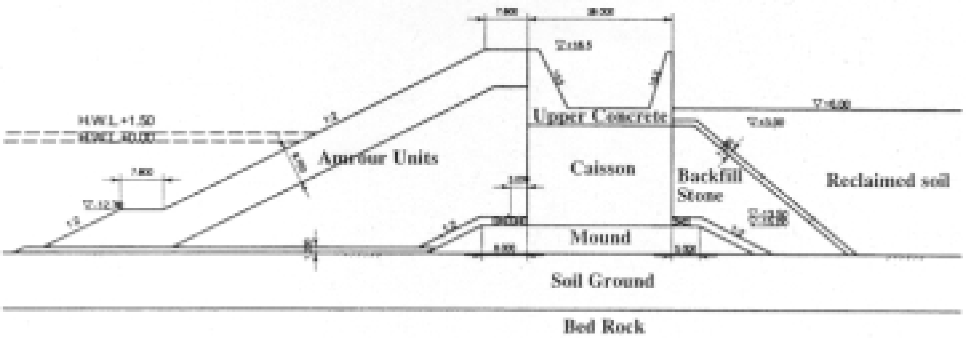

Figure 1: The Target Structure

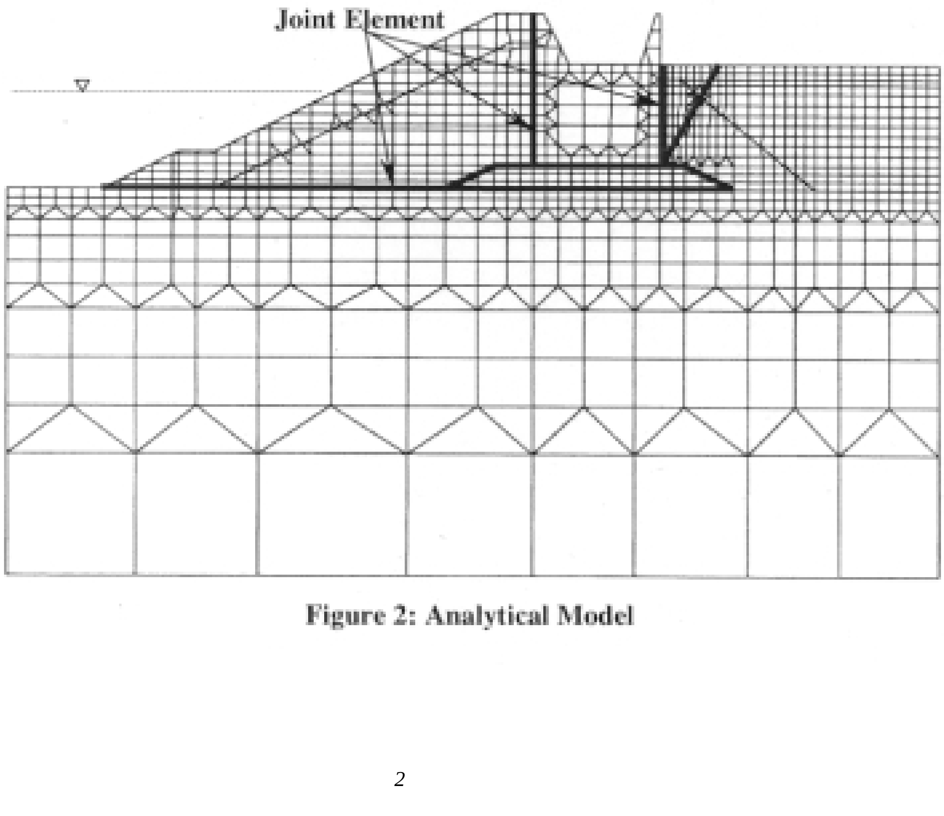

Figure 2: Analytical Model

INPUT ACCELERATION

Input earthquake vibration for dynamic response analysis was made to be the earthquake vibration of magnitude M=8.5, =68km hypocentral distance, 342.22gal maximum acceleration. Waveform and Fourier spectrum of input earthquake vibration are shown in figure 3. The release basis surface assumed shear wave propagation velocity of sea bed rock 700m/sec, and the input basis was made to be a position of 100m depth from the sea bed rock surface. Earthquake duration time of the nonlinear analysis did 60 seconds, and the integral time interval was made to be the 0.002 seconds. The earthquake duration time of the equivalent linear analysis it was made to be the for 40 seconds, and it was made to be the 0.01 seconds in the analysis time interval, and the cut-off frequency was made to be 20Hz.

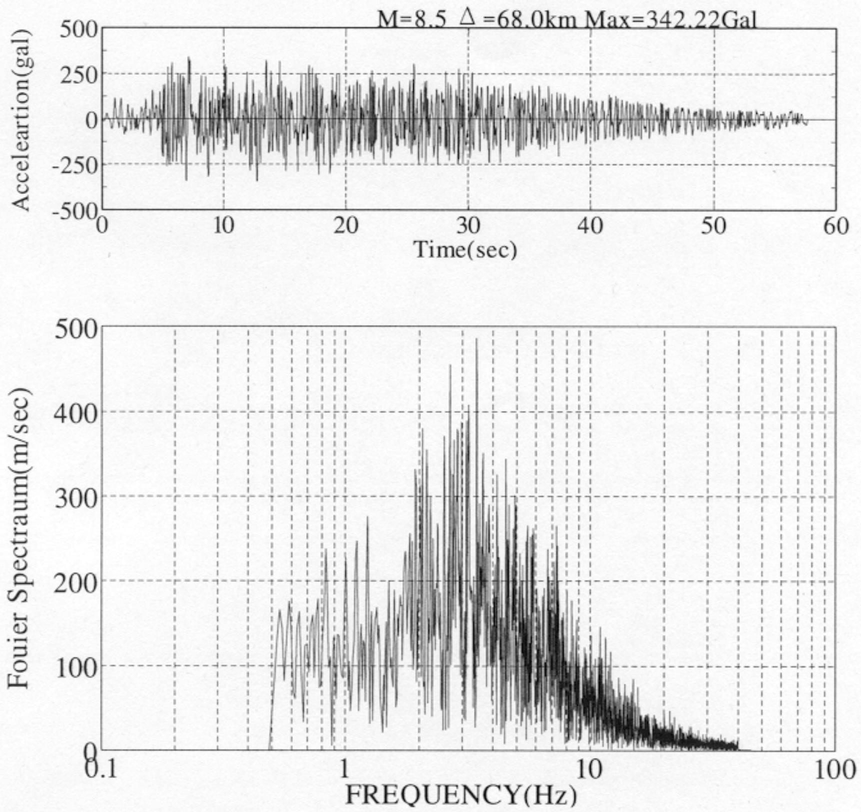

Figure 3: Input Acceleration and Fouier Spectrum

THE SETTING OF THE MATERIAL DIMENSION

Dynamic deformation characteristic of the soil ground, mound, backfill stone and reclaimed soil used the Ramberg-Osgood model (they are called the following, correction R-O model) and the strain dependence-ness was considered.

The skeleton curve : $\gamma_{xy} = \frac{\tau_{xy}}{G}\left(1+\alpha\left|\tau_{xy}\right|^{\beta}\right)$, $\alpha = \left(\frac{2}{\gamma_r G}\right)^{\beta}$, $\beta = \frac{2\pi h_{\max}}{2-\pi h_{\max}}$ (1)

where : G : Initial shearing modulus , $h_{\max}$: Maximum damping factor , γ_r : Reference strain

The setting of the void ratio

The void ratio used e_{max}=0.58 and e_{min}=0.95 void ratio of representative Toyoura sand. And the relative density of mound, backfilling stone and soil ground is made to be about 80%, and the void ratio of these parts becomes 0.65, when relative density of reclaimed soil is made to be about 60%, and the void ratio of this part becomes 0.73.

The physical property which depends on confining pressure

Mound, backfill stone, land fill soil, soil ground considered the constraint pressure dependency. The initial shearing modulus and reference strain of each properties used Eq.(2) and Eq.(3).

$$G = G' \frac{(2.17 - e)^2}{1 + e} \left(\sigma'_{m0}\right)^{0.5} \qquad (2)$$

$$\gamma_r = \gamma'_r \left(\sigma'_{m0}\right)^{0.5} \qquad (3)$$

where : σ'_{m0} : effective confining pressure(Pa)

G' of standard strain mound, backfilling stone and soil ground assumed 310000 and γ' with 1.6E-6, and G' of reclaimed soil assumed 260000 and γ' with 2.9E-6.

Other

The physical property which did not depend on confining pressure and strain of the material was made to be caisson, upper concrete and bed rock. However, in giving the deformation characteristic amrour units, it required it from the experiment using the centrifuge. In the modify R-O model, in the damping-strain curve of amrour units, damping of about 10% occurred in the low strain domain, and only maximum strain and standard strain would agree, since this phenomenon can not be considered. Since static initial stress causes stress and large effect in the final stability in the earthquake, in mound, backfilling stone, soil ground and reclaimed soil, physical property in initial stress was determined from the normal stress analysis. On the effect by vertical motion, dead weight analytical result in which perpendicular seismic intensity K_v=K_H/2=0.1(K_v:Vertical seismic intensity., K_H:Horizontal seismic intensity) was made to work using physical property characteristics in initial stress required in the superscription upward was set as an initial stress.

ANALYTICAL RESULT

Maximum acceleration distribution and maximum displacement distribution by the nonlinear analysis are shown in figure 4,5. And, acceleration and displacement time history waveform of the representative point are shown at figure 6,7. In each figure, the response result of the equivalent linear analysis is also shown. The maximum acceleration distribution of reclaimed soil became about 500gal in the upper surface, and it became about 250gal in the underside, and the amplification factor was on about the double. The maximum acceleration of upper surface of the upper concrete of the caisson became about 400gal, and it was about 280gal in the underside. Amplification factor of the caisson were about 1.4 times. The maximum acceleration of amrour units of the inside is larger than that of the slope face. However, the uniform acceleration distribution in the equivalent linear analysis from the underside to upper surface was shown. It seems to be because high frequency remarkably by response acceleration sensitively, since the joint element was used. The maximum displacement distribution of caisson and reclaimed soil it became 0.12m in upper surface of each part place, and it became 0.08m in the underside, and it became about 1.5 times amplification factor. And, maximum displacement of the amrour units were larger than interior response as well as maximum acceleration. For it, the upper surface of each part place of equivalent linear analysis became 0.09m, and the underside was 0.06m. The behavior of the nonlinear analysis can be simulated the phenomenon dragging by the joint element in the seaward, and considered rocking phenomenon by separation between caisson and mound, it seems that the response value of nonlinear is larger than it of equivalent linear. In addition, in the last time of nonlinear analysis, the residual deformation occurred in the seaward, and especially, the residual deformation of amrour units was remarkable.

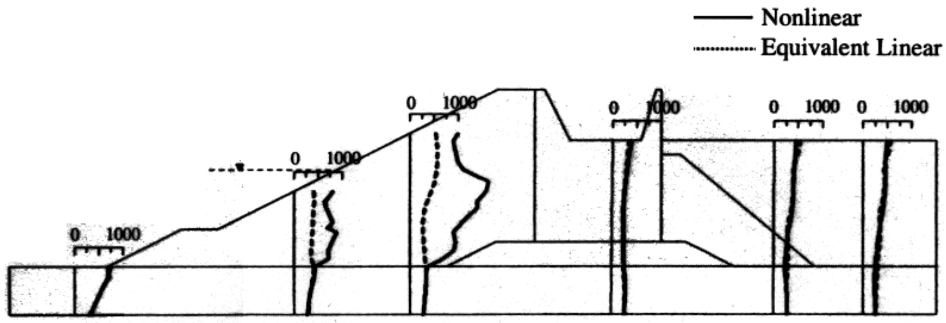

Figure 4: Maximum Acceleration Distribution(Unit:gal)

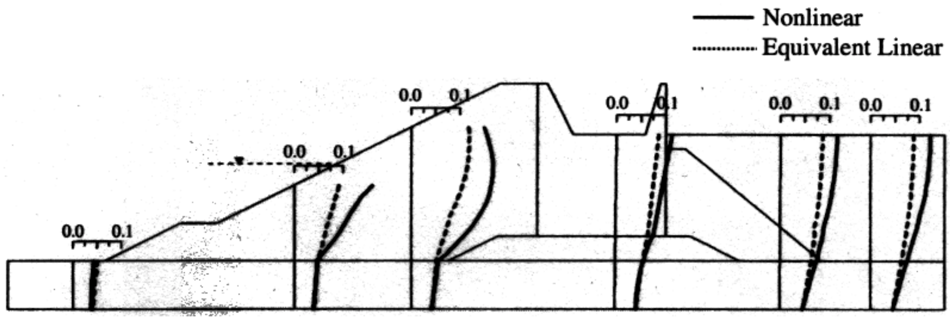

Figure 5: Maximum Displacement Distribution(Unit:m)

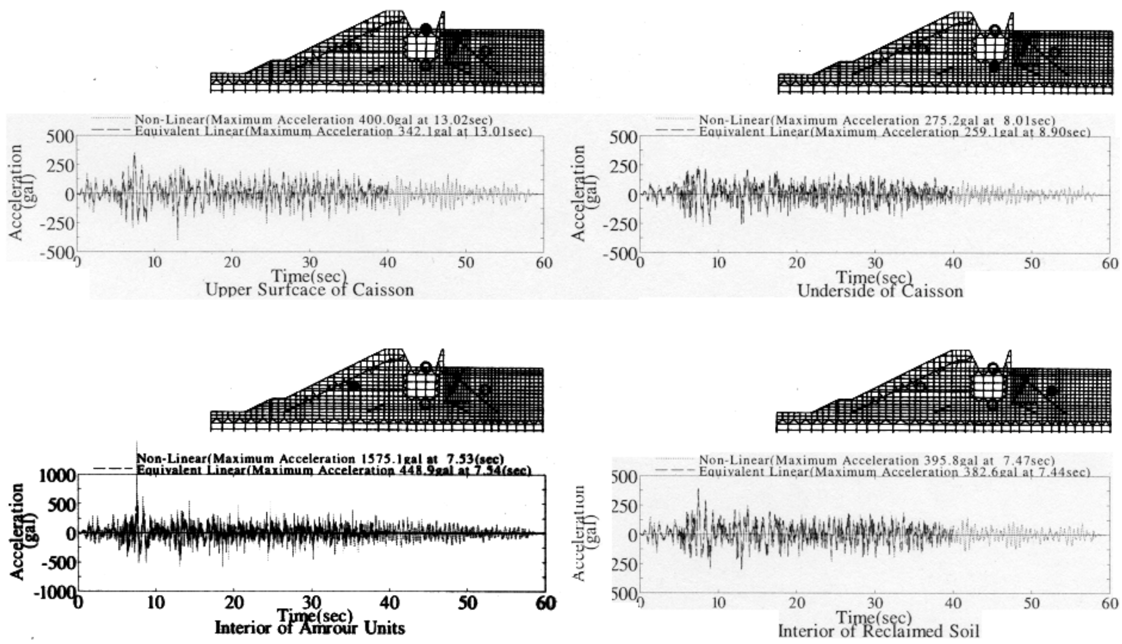

Figure 6: Acceleration Time History

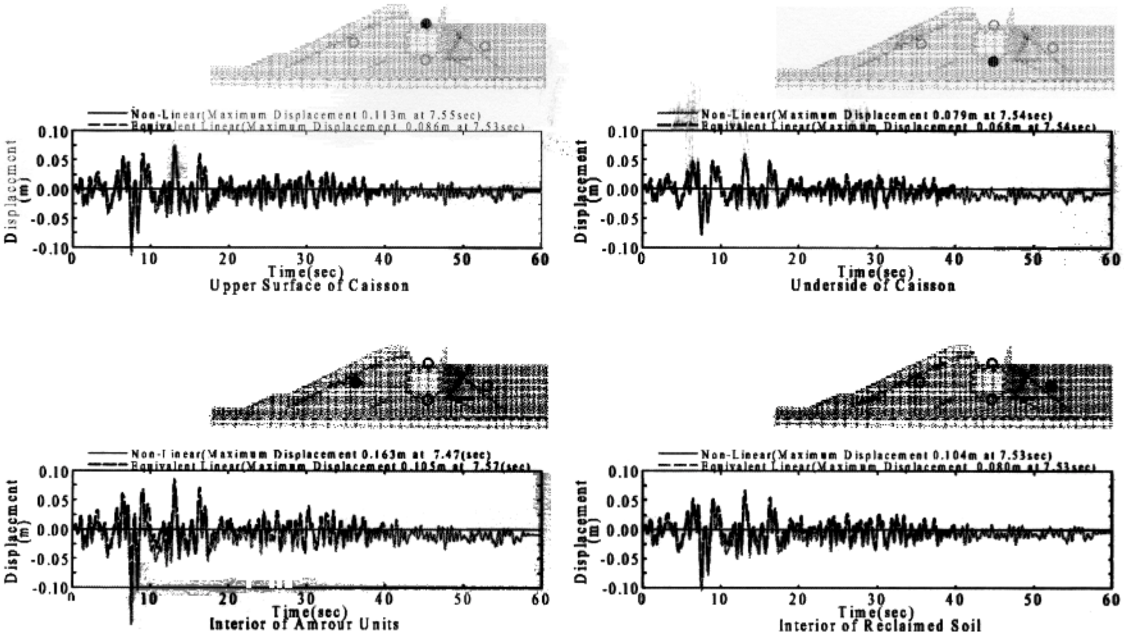

Figure 7: Displacement Time History

The maximum shearing strain distribution of nonlinear analysis and equivalent linear analysis is shown in figure 8,9. The maximum shearing strain of nonlinear analysis was larger than it of equivalent linear analysis, and the maximum shearing strain of reclaimed soil was about 0.35%, and maximum shearing strain of amrour units were about 1.0%. Especially, the shearing strain was remarkable a region of the lower from sea level of amrour units, and it was also large on both sides of the caisson.

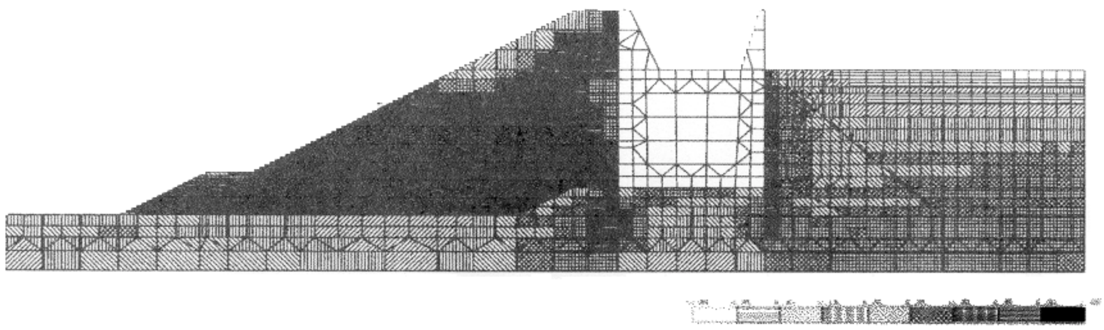

Figure 8: Maximum Shearing Strain Distribution of Nonlinear Analysis(Unit:%)

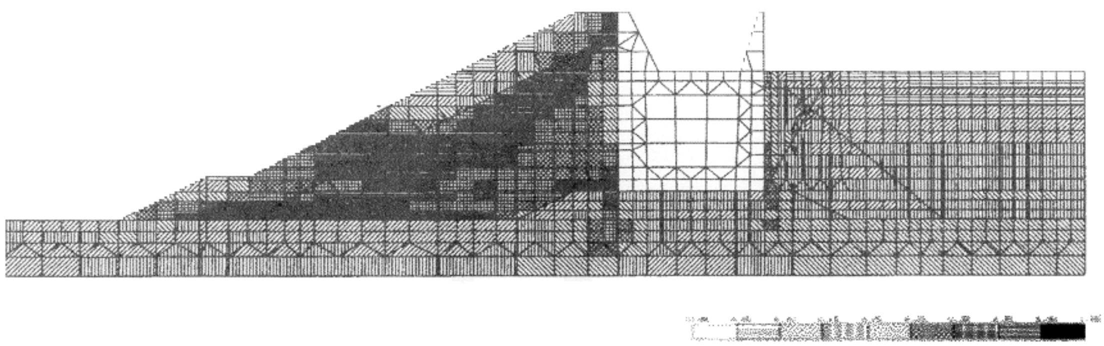

Figure 9: Maximum Shearing Strain Distribution of Equivalent Linear Analysis(Unit:%)

The response spectrum of upper surface and underside of the caisson, the response spectrum of the amrour units and reclaimed soil are shown in figure 10. In the upper surface of the caisson, there is predominant period at about 0.8sec, and in the underside, the predominant period also exists for about 0.8, 0.3 and 0.2sec. The natural period of total system was about 0.55sec, while It seemed to lengthen the period on this by degrading of shearing modulus and separation of joint element used for both caisson sides with the material plastication. It is anticipated that the material plastication is especially remarkable for the reason of extending natural period the response spectrum of equivalent linear analysis, because predominant period 0.8sec of nonlinear analysis and isomorphism almost are shown. However, the value of response spectrum of equivalent linear analysis is smaller than the response spectrum of nonlinear analysis. The response spectrum of reclaimed soil is excellent as well as response spectrum of the caisson at about 0.8sec, and it also agrees on the equivalent linear analysis almost. Though the response spectrum of amrour units is also excellent on nonlinear analysis and equivalent linear analysis at about 0.8sec, and in the region of high frequency, it is considerably big of the nonlinear analysis. This seems to be because the high frequency remarkably appeared, since the joint element was placed, as it was mentioned earlier. From these results, it also agreed on some nonlinear analysis of the thing on equivalent linear analysis caisson reclaimed soil some almost, and the good validity was shown. However, considerable difference produced the response of amrour units, since the behavior of nonlinear analysis and equivalent linear analysis is completely different. In such problem in the shape of the characteristic object, it is yet high the reality of the technique of the nonlinear analysis without sufficiently grasping in the technique of the equivalent linear analysis used until now. In addition, the analysis by the effective stress should be used in order to pursue the reality.

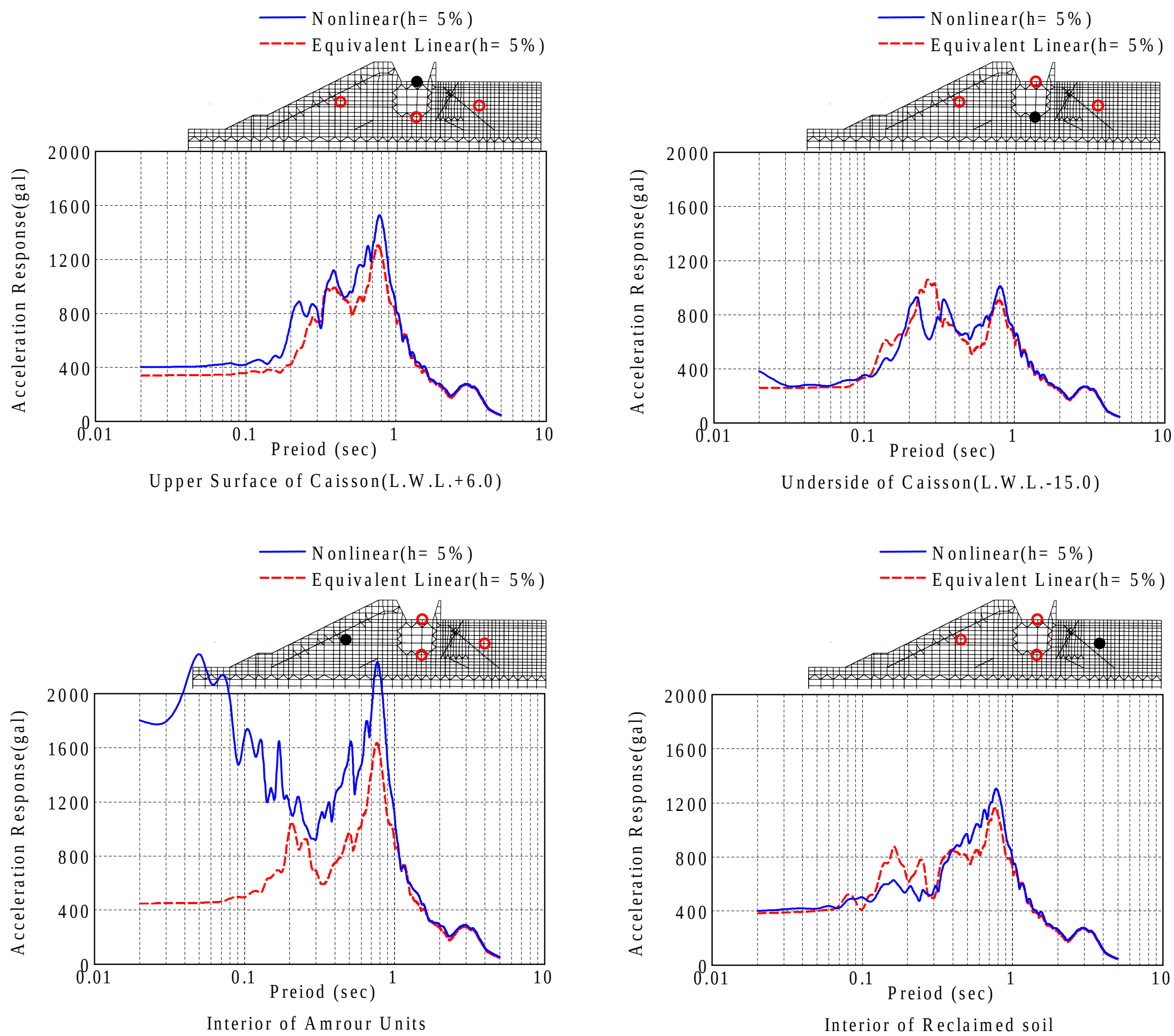

Figure 10: Response Spectrum

CONCLUSIONS

1) The maximum acceleration of upper surface in reclaimed soil by nonlinear analysis was on about the double of maximum acceleration of the underside. And maximum acceleration upper surface caisson maximum acceleration the about 1.4 time. These responses were almost equivalent to the equivalent linear analysis result.

2) The maximum acceleration of amrour units of the inside is larger than that of the slope face. However, the uniform acceleration distribution in the equivalent linear analysis from the underside to upper surface was shown. It seems to be because high frequency remarkably by response acceleration sensitively, since the joint element was used.

3) The maximum displacement of upper surface in reclaimed soil and caisson by nonlinear analysis was on about 1.5 of maximum displacement of the underside. And maximum displacement of the amrour units were larger than interior response as well as maximum acceleration.

4) The result of being comparatively appropriate even in the equivalent linear analysis was obtained acceleration response of the nonlinear analysis. However, considerable difference produced the response of amrour units, since the behavior of nonlinear analysis and equivalent linear analysis is completely different. In such problem in the shape of the characteristic object, it is yet high the reality of the technique of the nonlinear analysis without sufficiently grasping in the technique of the equivalent linear analysis used until now. In addition, the analysis by the effective stress should be used in order to pursue the reality.

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