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EFFECT OF NONLINEAR SOIL PROPERTY ON EARTHQUAKE RESPONSE OF NUCLEAR BUILDING

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SUMMARY

This paper examines the effect of nonlinear soil property on the earthquake response of nuclear building. The soil is treated to be an isotropical nonlinear material governed by the Drucker-Prager's yield condition. The forced vibration analyses and the earthquake response analyses are executed from the viewpoint of structure response. It is well-known fact that the structure response decreases due to the soil nonlinearity. In this research, some case of nonlinear dynamic analyses are carried out to point out the reason why the structure response decreases in respect of the plastic energy dissipation.

INTRODUCTION

In the seismic design of nuclear power plants against the most severe earthquake capable to occur, it is required that all plant facilities shall be maintained to prevent any radioactive damage. As one of the design procedure for confirming the seismic safety of reactor building, the dynamic analyses should be executed in consideration with the nonlinear characteristics of buildings. In such cases, It is easily expected that not only the building but also the soil, in particular the building supporting soil, will show nonlinear behavior. However, the equivalent linearization method is sometimes adopted, and the soil is commonly dealt as the linear material in the recent design procedure. The soil-structure interaction effect is very significant factor for the earthquake response of buildings, the dynamic analyses against the strong motion should be carried out by the nonlinear soil-structure interaction model with appropriate constitutive equations for the soils. The authors have studied the effect of nonlinear soil property on the earthquake response.[1,2] In this research, the effect of nonlinear soil property on the structure response is investigated with respect to the plastic energy dissipation.

ANALYSIS CONDITION

1. Nonlinear Characteristics The soil is assumed to be an isotropical material governed by the Drucker-Prager's yield condition and the modified Prager's flow rule by Ziegler. And the multi-yield surface model is employed to represent the continuous hysteretic loop.

2. Numerical procedure The finite difference method is adopted for time progressive integration, and the finite element procedure is adopted for the

spatial discretization. The wave propagation equation in 2-dimensional space for discretized system can be written.

$$\Delta u_i^{t+\Delta t} = \frac{\Delta t^2}{M_i} P_i + \Delta u_i^t \qquad (1)$$

where, $P_i = \int_v [B]^T [D][B] dV, \ M_i = \int_v [H]^T \rho [H] dV$

Only for the yield element, the stiffness matrix[D] in equation(1) is replaced to the elasto-plstic stiffness matrix[Dp].

ANALYSIS CASE

1. One Element Analysis In order to understand the basic characteristics of material nonlinearity, the sinusoidal exciting analysis is carried out for the one nonlinear element shown in Fig.1a, its nonlinear skeleton is shown in Fig.2. The maximum exciting strain is controlled at 0.15% and applied normal and shear direction independently. As the parameter of nonlinearity, the internal friction angle(ϕ=0,20°) are investigated. This value may describe lower and upper limit of the internal friction angle for typical cohesive soil.

2. Forced Vibration Analysis The forced vibration analysis is executed in order to evaluate the dissipative energy from the structure foundation to the soil. The analytical model is shown in Fig.1b, The rigid foundation is set on the half-space soil bounded by the viscous damping. The sinusoidal force is applied to the foundation in swaying and rocking direction. The constants of soil property is summarized in Table 1.

3. Earthquake response Analysis The earthquake response analysis is executed from the viewpoint of structure response. The nonlinear soil property is given to the building supporting soil. The structure model is an idealized BWR type reactor building. The boundary of analytical region is treated as the viscous boundary, and the correcting vertical force is applied to the both of side-boundary. Its mesh layout is shown in Fig.1c. The earthquake record Taft(1952,EW) is employed as the input motion, and applied to the bottom of model. Its maximum acceleration is normalized to 500gal.

RESULTS

The influence of material nonlinearity could be evaluated by the amount of the plastic energy dissipation. Among the energy distribution of the elasto-plastic material under the dynamic excitation, the damping and plastic strain energy are the dissipative energy. Otherwise, the kinetic and elastic strain energy are the conservative energy. The former is equal to the cumulative loop area of hysteretic loop, and it indicates how much energy dissipates. Moreover, the dissipative energy ratio in each loading cycle is defined as the ratio of them. This value relates to the damping factor.

1. One Element Analysis Fig.3 shows the hysteretic loop of the stress vs. strain. It is found that the larger loop is obtained by shear excitation than normal excitation, because the deviatoric stress depends on the shear stress especially in 2-dimensional plane strain analysis. Fig.4 shows the dissipative energy ratio, the result of shear excitation shows higher ratio than that of normal excitation.

2. Forced Vibration Analysis Fig.5 shows the hysteretic loop of foundation displacement vs. its reaction force. In nonlinear cases, it is found that the

stiffness is degrading gradually with increase of the response amplitude. As a verification of the method employed in this research, Fig.6 shows the linear hysteretic loop calculated under the same condition by the Boundary Element Method. They show good agreement and it is verified that this method is quite useful for the soil-structure interaction model. Fig.7 shows the cumulative loop area. In case of rocking analysis, the loop area decreases as the nonlinearity is considered. On the contrary, the nonlinear loop area increases in the swaying analysis. But in respect to the dissipative energy ratio, shown in Fig.8, the nonlinear cases show higher ratio than linear case in the both direction, and the swaying analysis shows higher ratio than the rocking analysis. It implies the radiation damping factor increases due to the soil nonlinearity, and the plastic energy dissipation is governed by the swaying vibration.

3. Earthquake Response Analysis The swaying and rocking hysteretic loop and the cumulative loop area are shown in Figs.9,10. The same tendency as the results of the forced vibration analyses mentioned above are obtained. That is, the swaying loop area increases and the rocking one decreases due to the effect of soil nonlinearity. Fig.11 shows the acceleration response spectra and Fig.12 shows the distribution of structure response. The response of nonlinear analyses is smaller than that of linear analyses. This result is caused by the increase of energy dissipation due to the soil nonlinearity investigated in this research.

CONCLUSION

Some case of 2-dimensional dynamic response analyses in consideration with the nonlinear soil property are executed from the viewpoint of structure response. The fact that the structure response decreases due to the soil nonlinearity is well-known. This research could explain the reason by evaluating the plastic energy dissipation. The concluding remarks obtained in this research are as follows.

a)According to the results of one element analyses, the dissipative energy ratio of shear excitation is higher than that of normal excitation. It means that the nonlinear material governed by the Drucker-Prager's yield condition shows bigger damping factor in the shear direction than normal excitation.

b)That is also confirmed by the forced vibration analyses. The dissipative energy ratio of swaying excitation is higher than that of rocking excitation, and they increase as the nonlinearity is considered. It is found that the radiation damping factor of swaying vibration is also bigger than that of rocking vibration, and they increase in regardless of the exciting direction due to the soil nonlinearity. In respect of the cumulative loop area, the swaying loop area increases, and the rocking one decreases, and the sum of them increases due to the soil nonlinearity. It is noted that the total dissipative energy increases and is shared by the swaying vibration.

c)When the soil nonlinearity is considered, the structure response decreases due to the increase of dissipative energy to the soil, because the earthquake response is governed by the swaying soil-structure interaction effect strongly.

The increase of horizontal energy dissipation, that is the main reason why the structure response decreases due to the soil nonlinearity. In this research, the strong nonlinearity is not considered, but the structure response decreases definitely even the weak nonlinearity is assumed. This result means it is necessary that the nonlinear soil characteristics should be taking into account in order to make a reasonable evaluation of structure response.

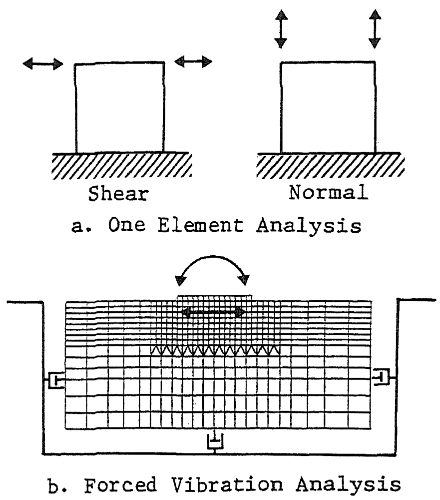


Fig.1 Analytical Model

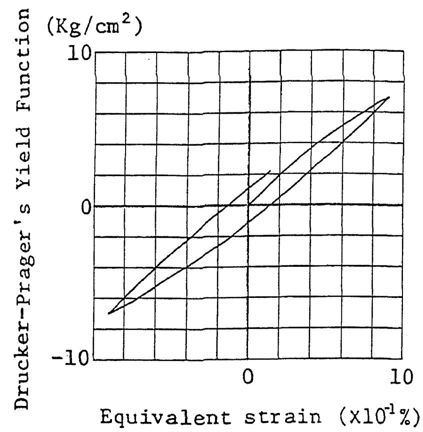


Fig.2 Nonlinear Soil Skeleton

Table.1 Constants of Soil Property

Shear velocity Vs	300m/s
Mass density ρ	2.0
Poisson's ratio ν	0.3

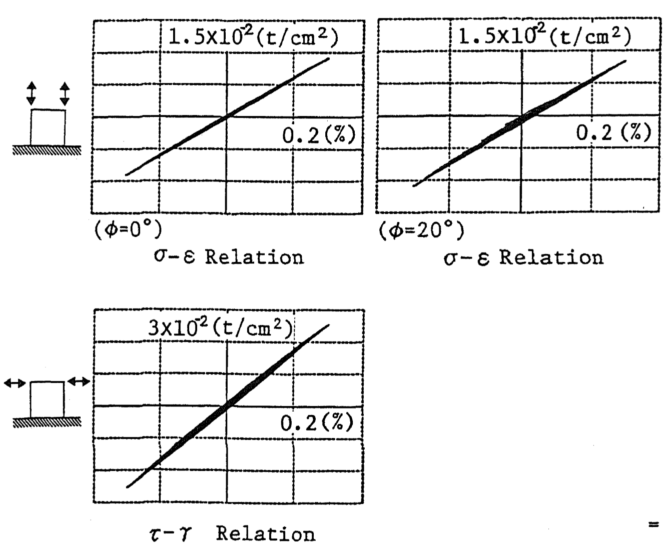


Fig.3 Hysteretic Loop of Element Stress Vs. Strain

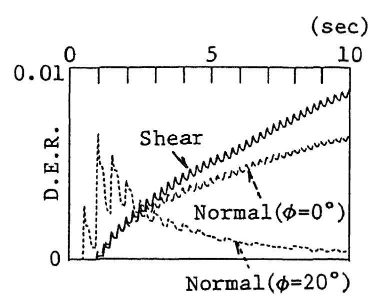


Fig.4 Dissipative Energy Ratio

Dissipative Energy Ratio

D.E.R.

$$= \frac{\text{(Plastic Strain + Damping) Energy}}{\text{(Elastic Strain + Kinetic) Energy}}$$

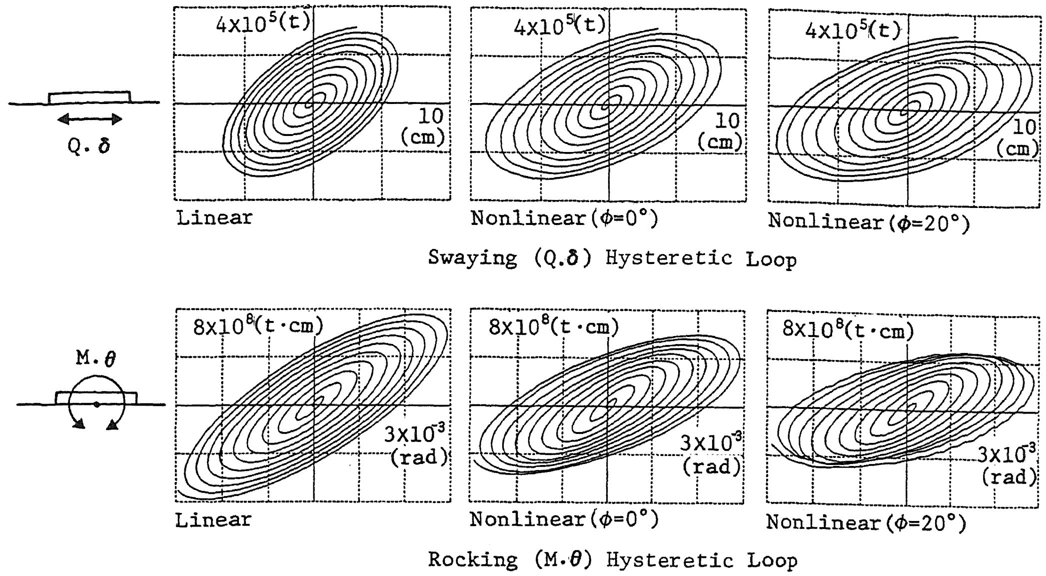
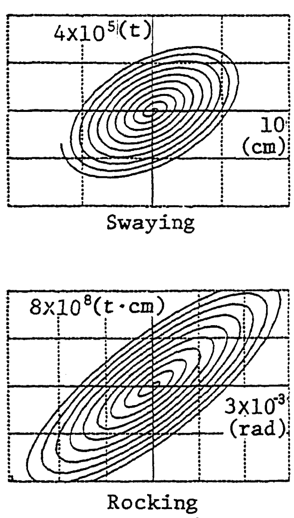
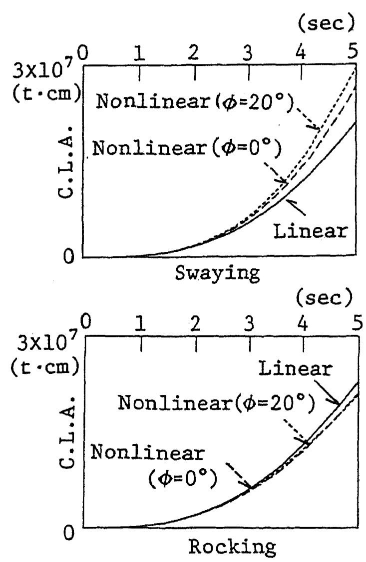


Fig.5 Hysteretic Loop of Foundation Displacement Vs. Reaction Force (Forced Vibration Analysis)





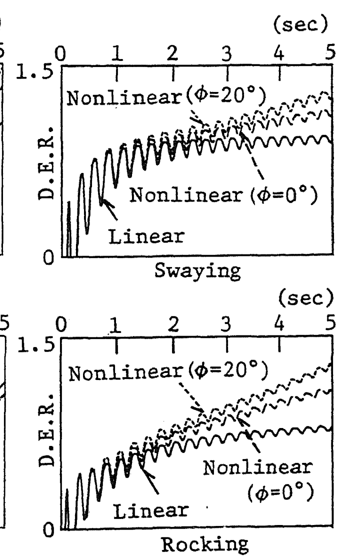


Fig.6 Hysteretic Loop Calculation by Alternative Method (BEM)

Fig.7 Cumulative Loop Area

Fig.8 Dissipative Energy Ratio

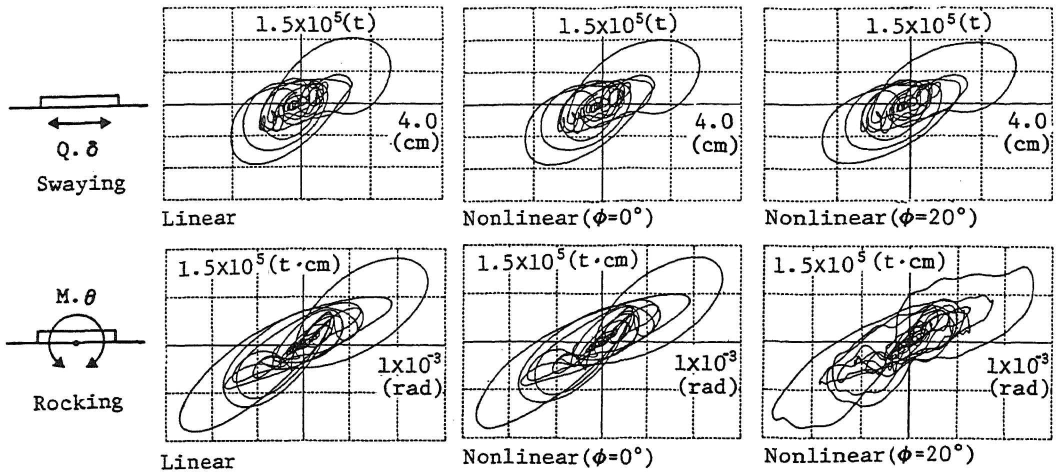


Fig.9 Hysteretic Loop of Foundation Displacement Vs. Reaction Force (Eathquake Response Analysis)

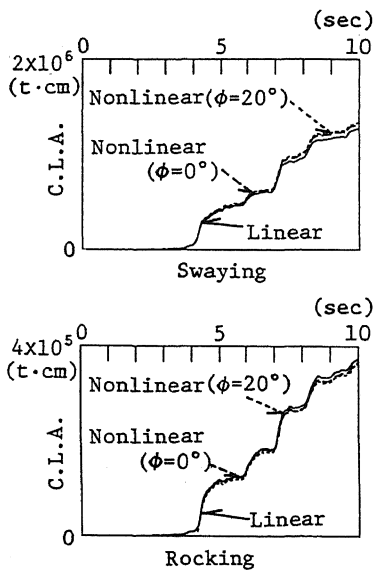


Fig.10 Cumulative Loop Area

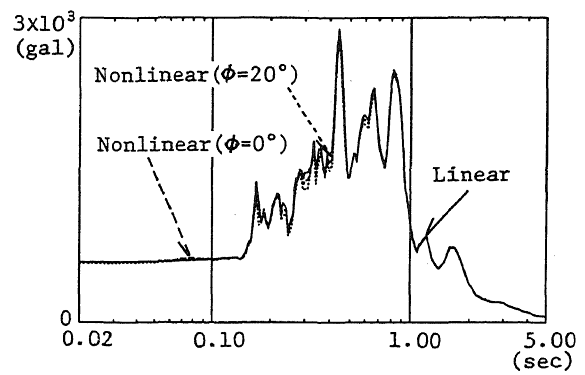


Fig.11 Response Spectra (Refueling Floor)

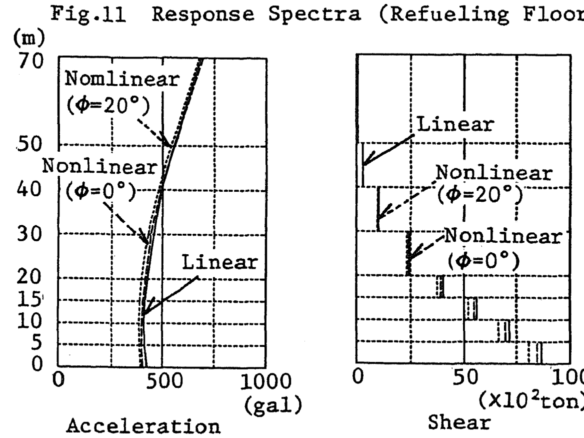


Fig.12 Distribntion of Stracture Response

REFERENCES

1.Yamada A., Miura K., Kobori T. "The Propagation Characteristics of Nonlinear Seismic Waves.", 7th Japan Earthquake Engineering Symposium, 1986.
2.Yamada A., Miura K., "Effects of Nonlinear Backfilling Soil on Earthquake Response of Reractor Building" , AIJ Annual Meeting, 1988.(In Japanese)