Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.III)

5-2-21

EARTHQUAKE RESPONSE OF TORSIONALLY EXCITED SOIL-STRUCTURE SYSTEMS

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Summary

In this paper, elasto-plastic response of a structure with eccentricity on a rigid foundation embedded into an elastic half space to a horizontally travelling earthquake motion is analyzed in the time domain. A mathematical model used for the present analysis composed of an upper structure supported by four elasto-plastic columns on a rigid square foundation. Main parameters in the response analysis are six earthquake excitations, the maximum velocity amplitude of these ground motions, shear wave velocity of elastic soil medium, stiffness of the upper structure (or the natural frequency of the upper structure), and eccentricity of the upper structure. Concluding remarks from the response analysis are :

(1) In case of the highly interacted structure with soil ground, the horizontal plastic response of the upper structure becomes large for an intensive excitation, though the torsional deformation does not increase so obviously.
(2) Eccentricity of the upper structure affects its torsional response on a hard soil ground.
(3) In case of a soft soil ground, the plastic deformation of columns arises to suppress the effect of its eccentricity on the torsional deformation.

1. Introduction

Torsional motion of a structure generally occurs with the eccentricity of itself. However, in recent years, torsional vibration caused by travelling seismic waves has been taken an interest. Influence of soil-structure with eccentricity is hardly treated. In the present study, dynamic response of an elasto-plastic structure with eccentricity subjected to the horizontally propagating earthquake ground motion is analyzed.

2. Mathematical model for analysis

Mathematical model of a soil-structure with eccentricity-system for the analysis is shown in Fig.1. An upper structure is supposed to a single-story structure supported by four elasto-plastic columns, which has three degree-of-freedom (two horizontal components and torsion) on a rigid rectangular foundation with five degree-of-freedom (two horizontal components, two rocking components and torsion) embedded into an elastic half space. Using the results of the three dimensional soil-foundation interaction analysis

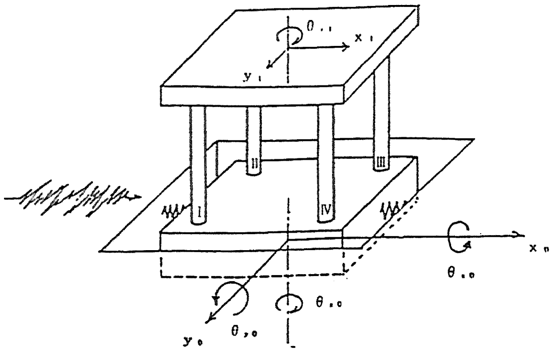

Fig. 1 Mathmatical Model of Soil-Foundation-Structure System

through the boundary element method in frequency domain, stiffness and damping matrices of the soil-foundation system are expressed as the real and imaginary parts of the inverse of the compliance matrix. Numerical value of elements of matrices is assumed to have a constant value in frequency domain considered and determined to the value at the fundamental natural frequency of the upper structure with a rigid base.

Horizontal and torsional excitations to the foundation mass are evaluated by integration for the foundation volume of acceleration wave of six strong motion earthquakes, which are assumed here to propagate along x-axis. Six earthquake records adopted are:

El Centro	, 1940,	NS and EW
Taft	, 1952,	NS and EW
Sendai TH030,	1978,	NS and EW

Elasto-plastic restoring force characteristics of the upper structure is represented by the plastic yielding of columns. Eq. (1) shows the foundation of yield condition with interaction of two horizontal components of each column. Eqs. (2) to (4) show the plastic flow rule with hardening in the plastic zone and the relation of the plastic stiffness matrix to the elastic one.

$$f(q,o)=\sqrt{(q_x-o_x)^2+(q_y-o_y)^2} \tag{1}$$

$$\{de^p\}=\left(\frac{\left\{\frac{\partial f}{\partial q}\right\}\left\lfloor\frac{\partial f}{\partial q}\right\rfloor[D^e]}{g+\left\lfloor\frac{\partial f}{\partial q}\right\rfloor[D^e]\left\{\frac{\partial f}{\partial q}\right\}}\right)\{de\} \tag{2}$$

$$[D^p]=[D^e]-\frac{[D^e]\left\{\frac{\partial f}{\partial q}\right\}\left\lfloor\frac{\partial f}{\partial q}\right\rfloor[D^e]}{g+\left\lfloor\frac{\partial f}{\partial q}\right\rfloor[D^e]\left\{\frac{\partial f}{\partial q}\right\}} \tag{3}$$

$$\{dq^p\}=[D^e]\{de\} \tag{4}$$

Main parameters for response analysis are chosen as the maximum velocity amplitude of ground motion Vmax, shear wave velocity of elastic soil medium Vs, nondimensional stiffness of the upper structure K, and eccentricity of rigidity along x-axis of the upper structure Rex.

3. Results of analysis

Fig. 2 shows typical response curves of an elastic and elasto-plastic structural system subjected to the El Centro earthquake, NS components. It Seems that the fundamental vibration mode is predominant and that the torsional deformation of the upper structure caused by the torsional excitation is as large as the horizontal displacement at the perimeter of the upper structure. Because of the plastic yielding of column, it can be seen that the response of the upper structure has a considerable permanent plastic deformation. Fig. 3 shows that increase of the horizontal displacement of a flexible upper structure is apparent if plastic range. On the other hand, for the torsional deformation of the upper structure, the ratio of increase is not so large at higher excitation level. From Fig. 4, ductility factor of columns increases remarkably to the intensity of excitation.

In Figs. 5 to 11, there are shown the average of six response values and one standard deviation zone with a vertical segment. For a flexible upper structure, the elasto-plastic horizontal displacement response ratios are not so large and show no increase to the excitation intensity, but for a rigid upper structure, response ratio increases linearly. the torsional deformation response ratio generally shoes decrease to the intensive excitation. From the figures of response ratios to shear wave velocity, the soil-structure interaction effect is more evident in the elastic horizontal displacement response than the elasto-plastic one. Though the torsional response ratio seems nearly constant for Rex=0, the response ratio of the upper structure with eccentricity decreases to shear wave velocity. The ductility factor of column Ⅲ in Fig. 9 shows an increasing trend to shear wave velocity especially for a rigid upper structure. Fig. 11 shows that the torsional response ratio is almost smaller than unity and that it decreases to the eccentricity factor. Then, the influence of eccentricity of the upper structure is decreased in the elasto-plastic response to the strong excitation.

4. Concluding remarks

From these analysis, the following concluding remarks are pointed out:

(1) The Elasto-plastic horizontal displacement response of a rigid upper structure on a soft soil ground increases considerably.
(2) The increase of the elasto-plastic torsional response of the upper structure to intensity of excitation is not large compared with the horizontal displacement response.
(3) The influence of eccentricity of the upper structure is obviously in the case of a hard soil ground.
(4) Elasto-plastic deformation of columns arises to decrease the torsional deformation of the upper structure.

References

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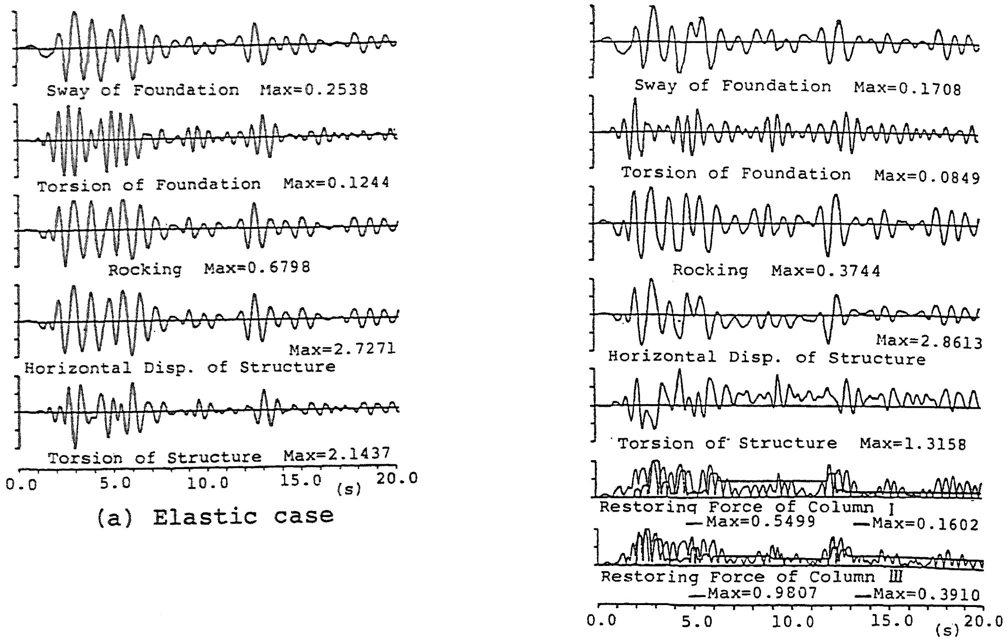
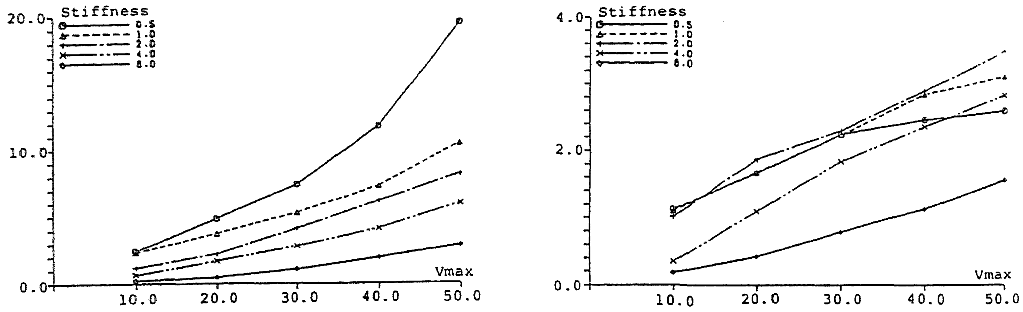


(a) Elastic case

(b) Elasto-plastic case

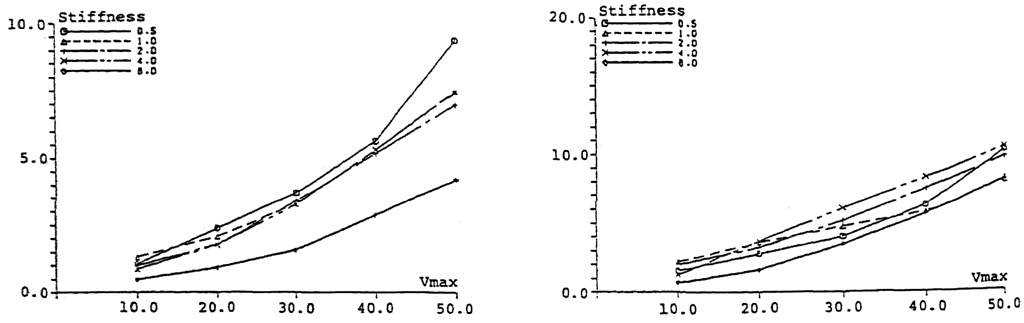
Fig.2 Response Curves of Structural Systems:El Centro, Vmax=20cm/s, Vs=200m/s, K=2.0, Rex=0.3



(a) Horizontal displacement

(b) Torsion

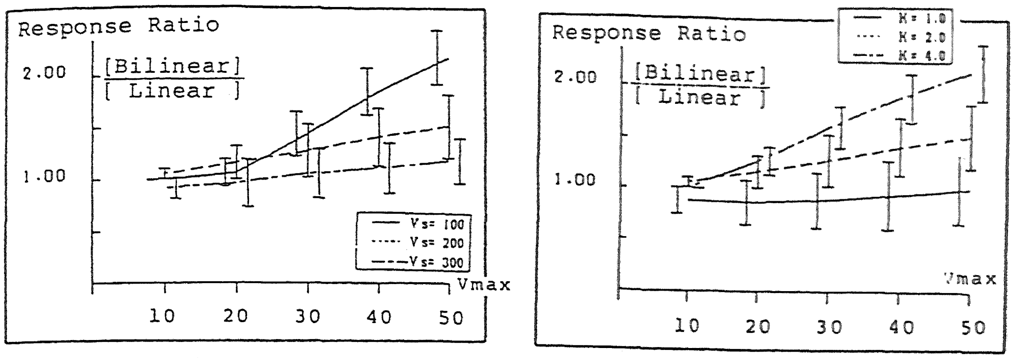
Fig.3 Response of Structure:El Centro, Vs=200m/s, Rex=0.0



(a) Column I

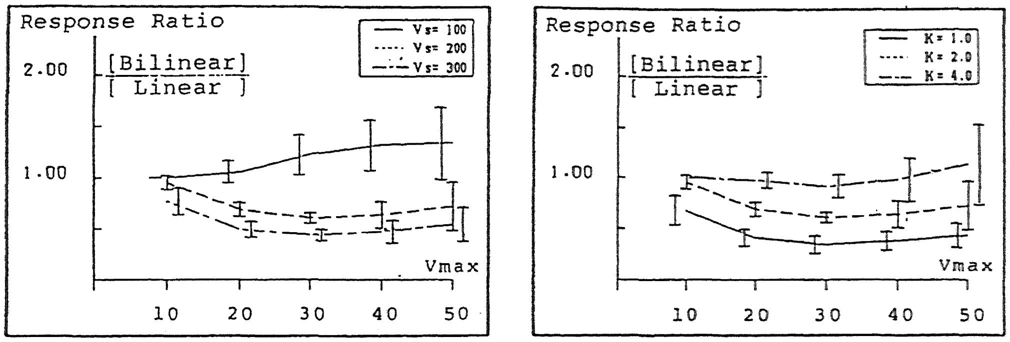
(b) column III

Fig.4 Ductility Factor of Column:El Centro, Vs=200m/s, Rex=0.0



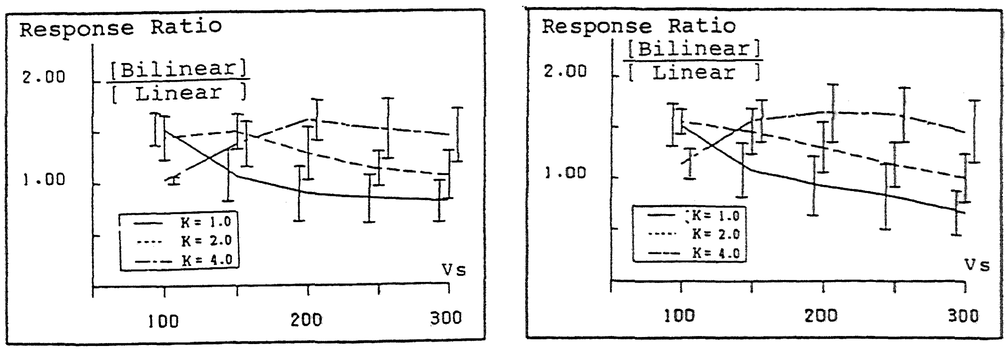
(a) K=2.0 (b) Vs=200m/s

Fig.5 Response Ratio of Horizontal Displacement of Structure, Rex=0.3



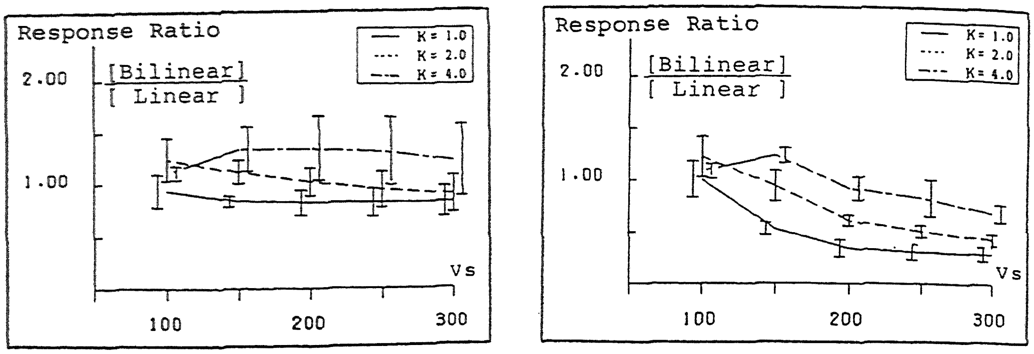
(a) K=2.0 (b) Vs=200m/s

Fig.6 Response Ratio of Torsion of Structure, Rex=0.3



(a) Rex=0.0 (b) Rex=0.3

Fig.7 Response Ratio of Horizontal Displacement of Structure, Vmax=30cm/s



(a) Rex=0.0 (b) Rex=0.3

Fig.8 Response Ratio of Torsion of Structure, Vmax=30cm/s

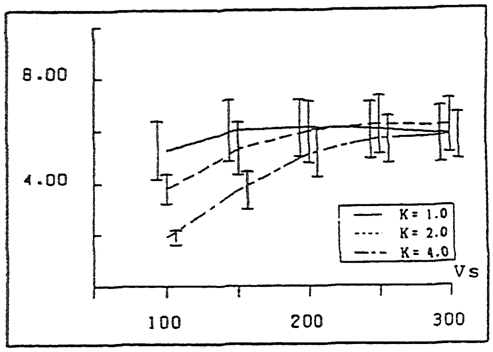


Fig.9 Ductility Factor of Column III, Vmax=30cm/s, Rex=0.3

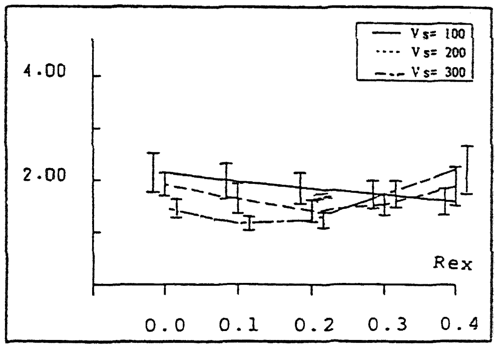
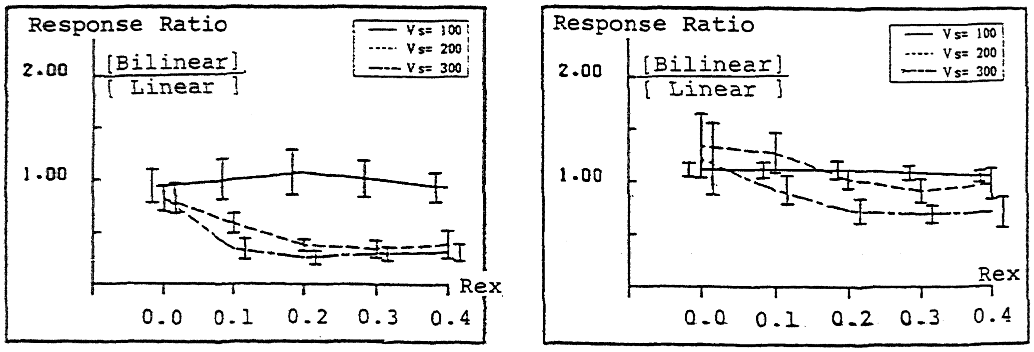


Fig.10 Torsion of Structure, Vmax=30cm/s, K=2.0



(a) K=1.0 (b) K=4.0

Fig.11 Response Ratio of Torsion of Structure, Vmax=30cm/s