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STUDY ON NONLINEAR DYNAMIC ANALYSIS METHOD OF PILE SUBJECTED TO GROUND MOTION
PART 2 : COMPARISON BETWEEN THEORY AND EXPERIMENT

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ABSTRACT

First purpose of this study is to make clear the characteristics of the response of a pile with one mass on its head subjected to ground motion through experimental studies. Model experiments with ground-pile-mass systems were carried out and the influence on the response by frequencies of input wave and weights of mass were discussed. Second purpose is to confirm validity of our analysis method proposed in part 1. Comparisons between theoretical values and experimental results show applicability and efficiency of this analysis method with good agreement.

KEYWORDS

Ground-pile-mass system; lateral ground motion; model experiment; sand; non-linear numerical analysis.

INTRODUCTION

Characteristics of response of a pile with one mass on its head subjected to ground motion are influenced by frequencies of input wave, stiffnesses of pile, soil characteristics of, weights of mass, and so on.
The authors conducted two kinds of laboratory experiments regarding a single pile installed in dry sand as described below and grasped characteristics of the response.

1. Seismic sin wave tests
2. Earthquake motion tests

These results of experiments are compared with theoretical values proposed in part 1 in order to confirm validity of this analysis method.

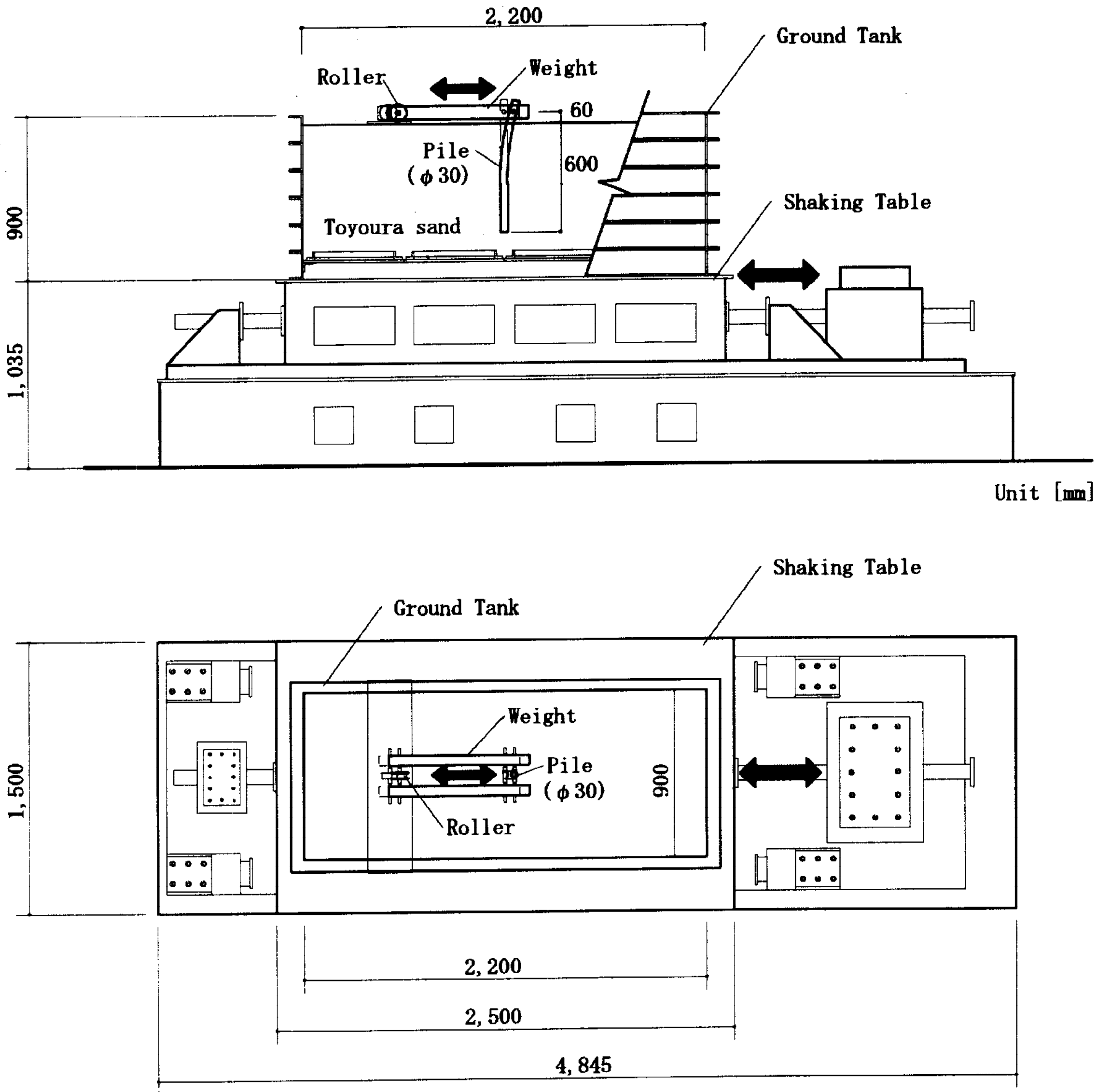


Fig.1 Laboratory Equipment

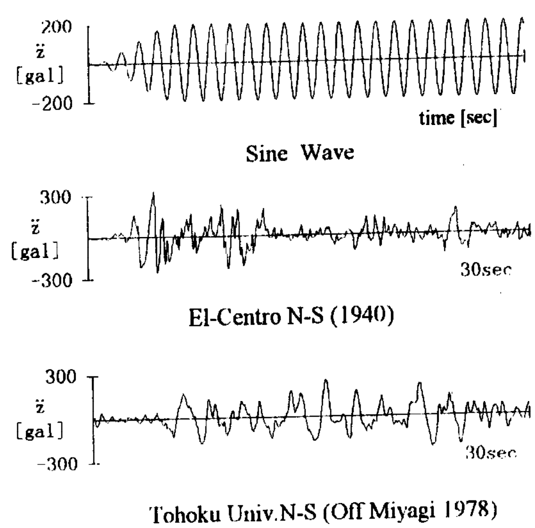


Fig.2 Input Motion of Acceleration

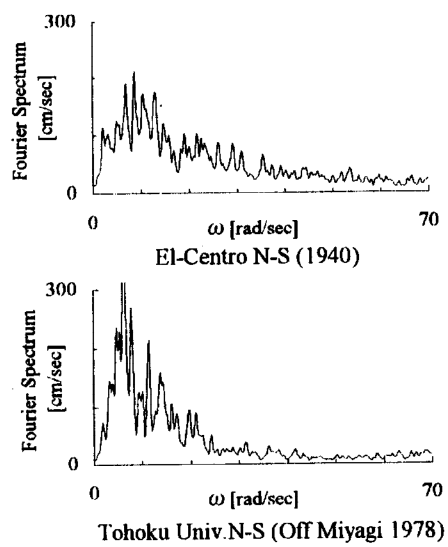


Fig.3 Fourier Spectra of Earthquake Motions

Table 1 Parameters of Experiments

weight of mass W[kgf]	circular frequency ω [rad/sec]
30	10,20,25,26,27.5,30,40,50,60
50	10,15,16,17.5,20,30,40,50,60

Table 2 Model Soil

internal friction angle ϕ_{max} [deg]	46	pile diameter D [mm]	30
ϕ_{min} [deg]	35	thickness t [mm]	2.173
cohesion C_{max} [kg/cm²]	0.02	bending stiffness EI [kg/cm²]	7.1×10^4
C_{min} [kg/cm²]	0.01	height of eccentricity e [mm]	60
unit weight γ [g/cm³]	1.63	pile depth H [mm]	600
		coefficient of soil reaction k_h[kg/cm³]	20

EXPERIMENT METHOD

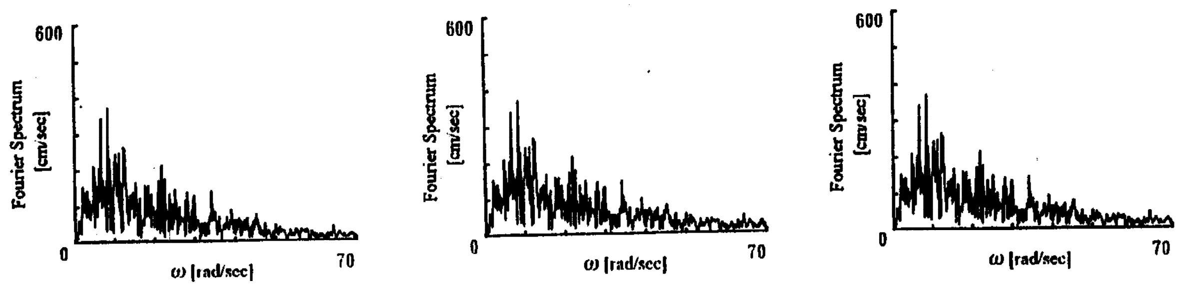
The laboratory equipment is shown in fig.1 The area of shaking table is length × width=2.5m × 1.5m, and volume of ground tank is length × width × depth=2.2m × 0.9m × 0.8m. Test soil is prepared using air-dry Toyoura sand. A pile is made of an acrylic resin pipe that is 3.0cm in diameter and 0.2cm in thickness. Combined iron plates are used as a weight on pile head. One of edges of the plates is supported by pin to the pile head and another is supported by roller in order to act only horizontal inertia force to pile head. The shaking table is driven seismic sine wave with maximum acceleration($\ddot{z}_{max}$) 200gal and circular frequencies(ω) ranging from 10rad/sec to 60rad/sec in Test 1. The table is also shaken by recording earthquake motions of El-Centro N-S (Imperial Valley ,1940) or Tohoku University N-S (Off Miyagi, 1978) in Test 2.

Weights of mass (30kgf, 50kgf) are chosen as the parameter. These input waves are shown in fig.2 and Fourier spectra of acceleration of the earthquakes are shown in Fig.3 Table 1 presents the parameters of experiments.

The test ground is prepared as follows:

1) After setting a pile, dry sands are put into the tank in each 10cm-thichness depth and tightened up by vibrator. Total depth of the ground is 70cm.
2) The ground tank is put and fixed on the shaking table. The Shaking table is vibrated during 20 minutes with maximum acceleration 500gal and frequency 35Hz in order to tighten up and make the ground homogeous.
3) Before each measurement of test series, the model ground is remade by shaking during 3 minutes with the same acceleration and frequency mentioned above.
4) The unit weight of sand is 1.63g/cm³. Table 2 presents the characteristics of the test ground . When the shaking table is motioned in the range of frequencies chosen in these tests, the whole sands are moved uniformly because of high stiffness of the ground tank.

Acceleration and displacement of input wave, response acceleration of surface and underground (±0cm,-15cm,-30cm, -60cm), response acceleration and deflection of the weight(mass) are measured.



a. Input (Shaking Table) b. G.L. ±0cm (Free Surface) c. G.L. -30cm

Fig.4 Fourier Spectra of Response Acceleration of Test Ground

RESPONSE OF GROUND

Fig.4 presents Fourier spectra of response acceleration of the ground at G.L.±0cm(free surface), G.L.-30cm when El-Centro earthquake motion is inputted. From these results, we conform that the hole sands are motioned uniformly as we planed because these spectrums show the same shape.

NUMERICAL ANALYSIS METHOD

Theoretical values which are compared with experimental results are calculated by using numerical analysis method proposed in part 1. The analysis model is shown in fig.5. Distribution of ultimate soil reactions p_{max0} and p_{min0} are shown Fig.6. Distribution of family of initial p-y curves applied from p_{max0} and p_{min0} are shown in Fig.7. Table 2 presents conditions of soil and calculations.

COMPARISONS EXPERIMENTAL AND THEORETICAL VALUE

1. Seismic Sine Wave Tests

Fig.8 and fig.9 show same of comparisons between theoretical values and experimental results, that is, relationship between relative displacement (y) and acceleration ($\ddot{y} + \ddot{z}$), time histories of acceleration and displacement at pile head (weight). Fig.10 and fig.11 present amplification factors of acceleration and displacement.

In these figures, ys means displacement of pile head subjected to the static lateral force ($P = m\ \ddot{z}_{max}$).

Through these comparisons, below mentions are found:

1) Displacement-acceleration response curves shape such as a reversed "S" character. The more circular frequency of input sine wave is close to predominant frequency of ground-pile-mass system, the more an area of spindle-shape increases, and the more non linear characteristic of response of ground is emphasized. On the contrary, the more frequency of input wave is far away from predominant frequency, the more the displacement-acceleration response curve shapes linearly, and the more non linear characteristic of ground disappears.

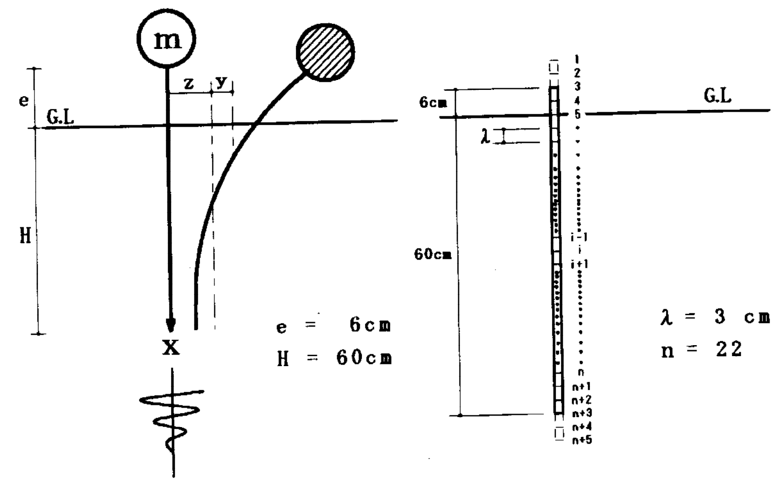


Fig.5 Numerical Analysis Model

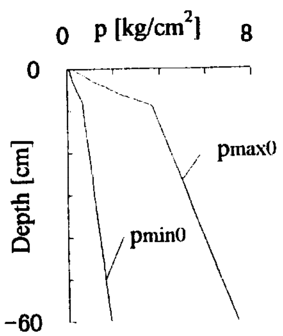


Fig.6 Distribution of p_{max0} and p_{min0}

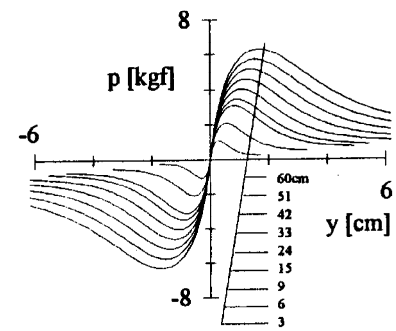


Fig.7 Family of Initial p-y Curve

2) In the case of 50kgf of weight, the predominant circular frequency is larger than in the case of 30kgf. The heavier the weight of mass becomes, the more amplification factors of acceleration at the predominant circular frequency increase. On the other hand, the amplification factors of displacement decrease with increasing on the mass weight.
3) The values of numerical calculations reflect nonlinear characteristic of soil, and comparisons with experimental results show good agreement in the shapes of response curve, maximum response value and predominant circular frequency.

2. Earthquake Motion Tests

Fig.12 and fig.13 show comparisons between theoretical values and experimental results, that is, relationship between relative displacement (y) and acceleration ($\ddot{y} + \ddot{z}$), time histories of acceleration and displacement at pile head. Fig.14 and fig.15 show the Fourier spectra about response of acceleration.

Below mentions are discussed through these comparisons:
1) Comparisons with theoretical and experimental results about out-line of displacement-acceleration response curves show good agreement comparatively.
2) Fourier spectra about acceleration response have two peeks around the predominant circular frequency of input and around predominant frequency of ground-pile-mass system. The spectra of calculations are as the same values as experiments' in lower frequency range but in higher frequency range, theoretical values are less than experimental ones.

CONCLUSIONS

Through experimental studies, the response characteristics of the ground-pile-mass system emphasize the nonlinear characteristic of ground. And from comparisons between this nonlinear numerical analysis values and experimental results, it is found out that good solutions are obtained by this method and that the method can be calculated easily in short time even if micro computer is used.

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2) Kouda,M., Yamashita,T, Sato, H., & Enami,A. 1990. A study on the passive earth pressure of a pile, Proceeding of the ICSEC, Beijing, China

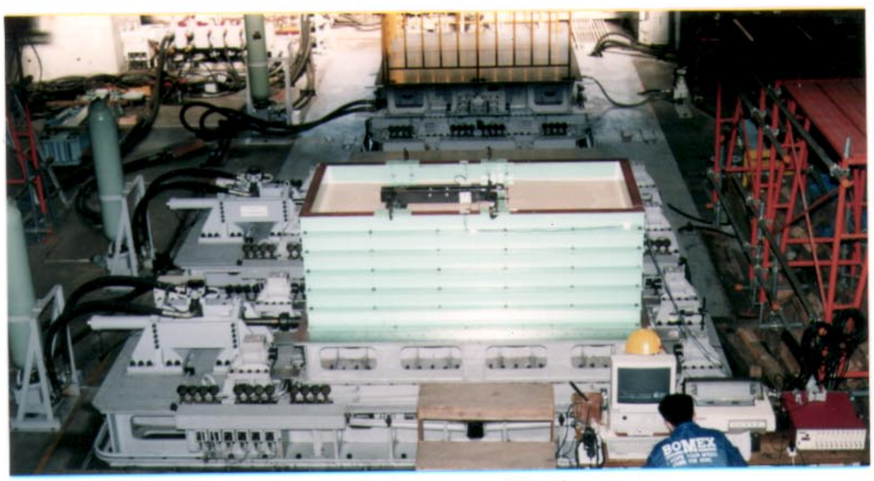


Photo 1 Laboratory Equipment

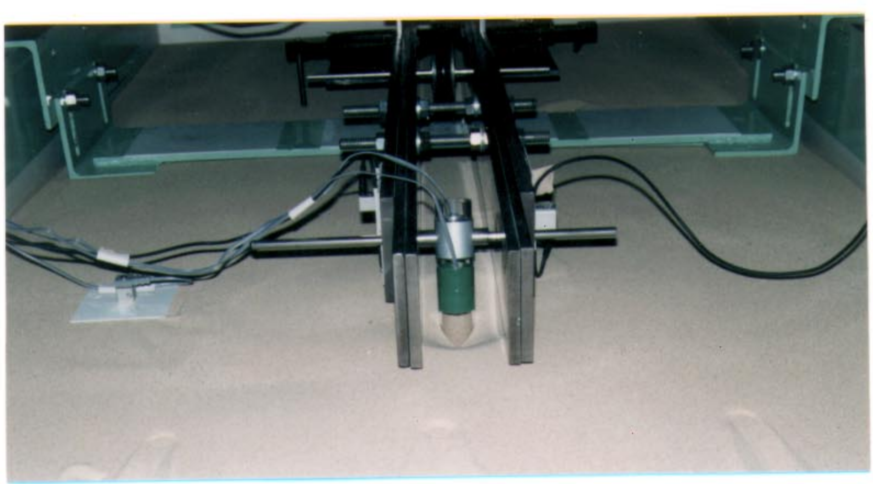


Photo 2 Test Pile and Weight (mass)

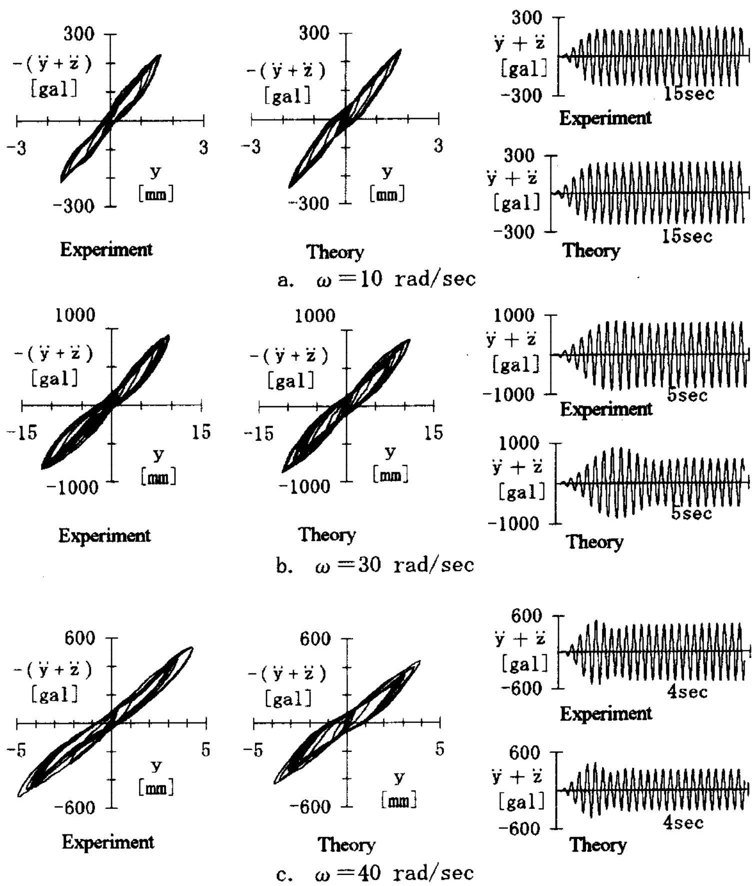


Fig.8 Comparisons Experimental and Theoretical Values
(Seismic Sine Wave Tests : W=30kgf)

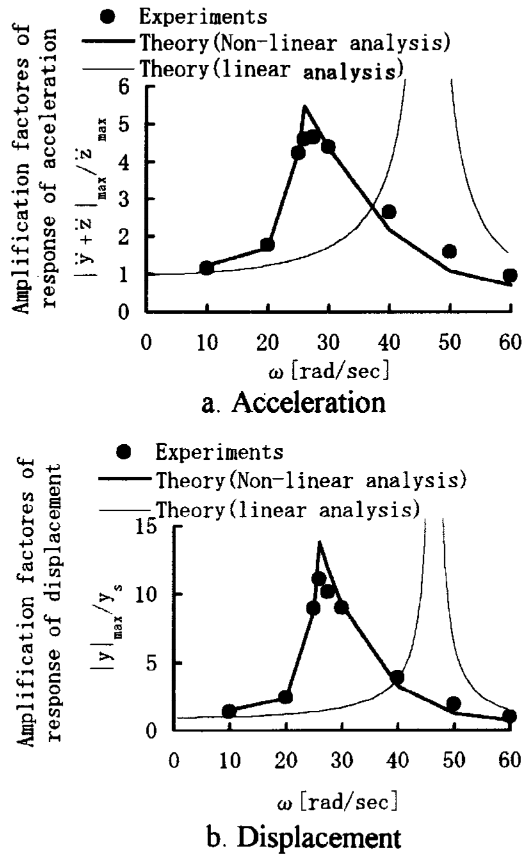


Fig.10 Amplification Factors
(Seismic Sine Wave Tests : W=30kgf)

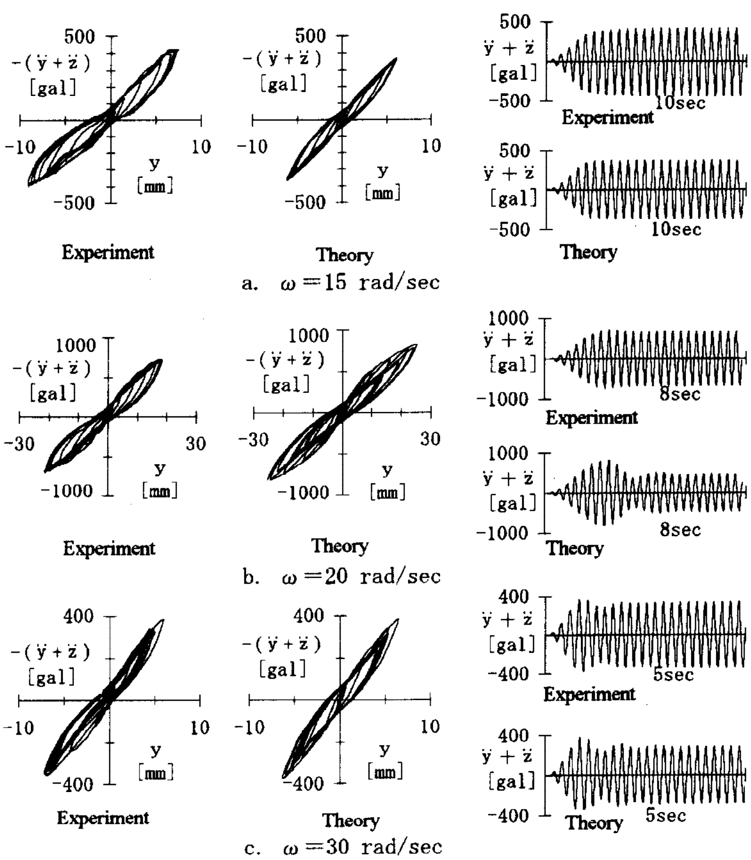


Fig.9 Comparisons Experimental and Theoretical Values
(Seismic Sine Wave Tests : W=50kgf)

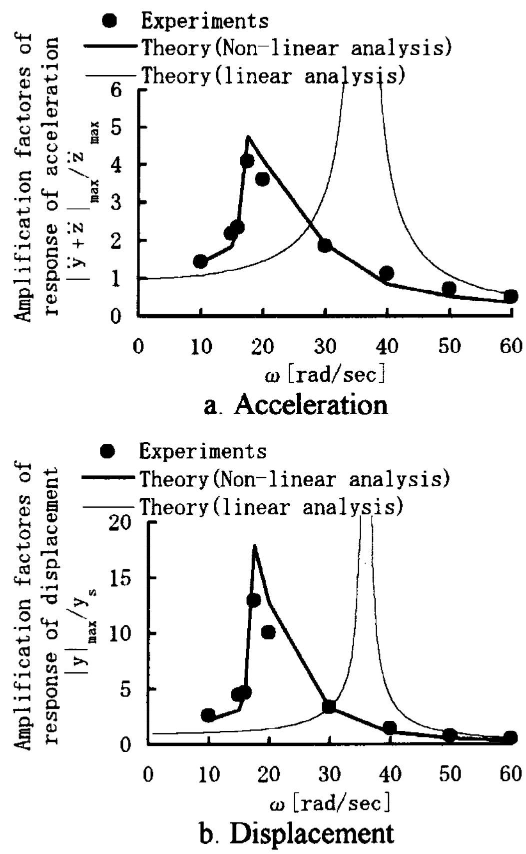


Fig.11 Amplification Factors
(Seismic Sine Wave Tests : W=50kgf)

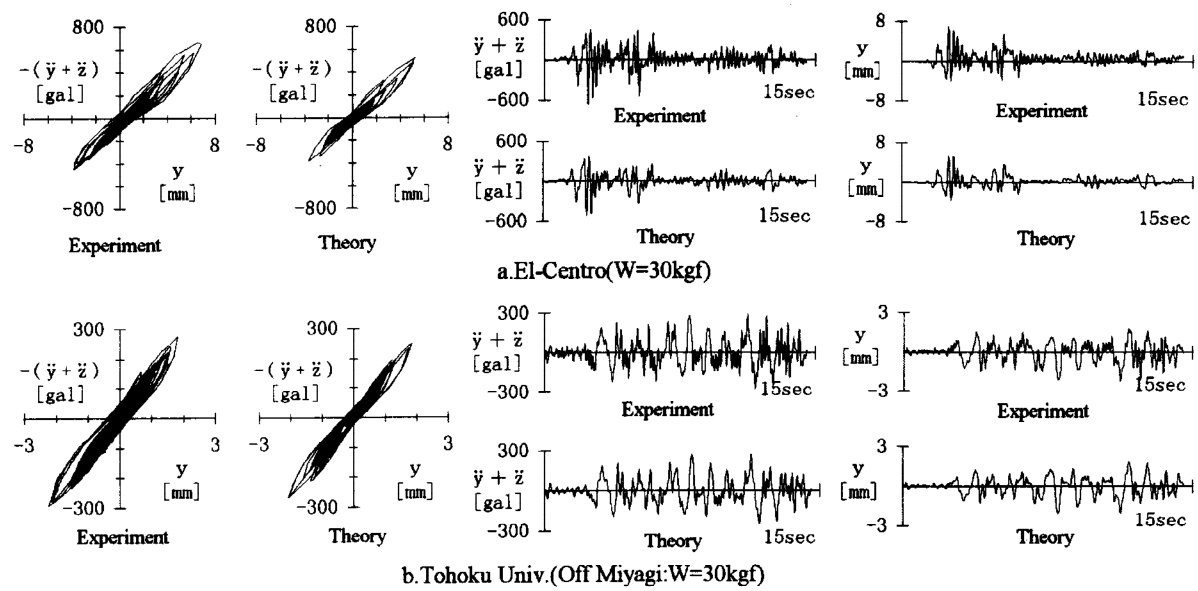


Fig. 12 Comparisons Experimental and Theoretical Values (Earthquake Motion Tests : W=30kgf)

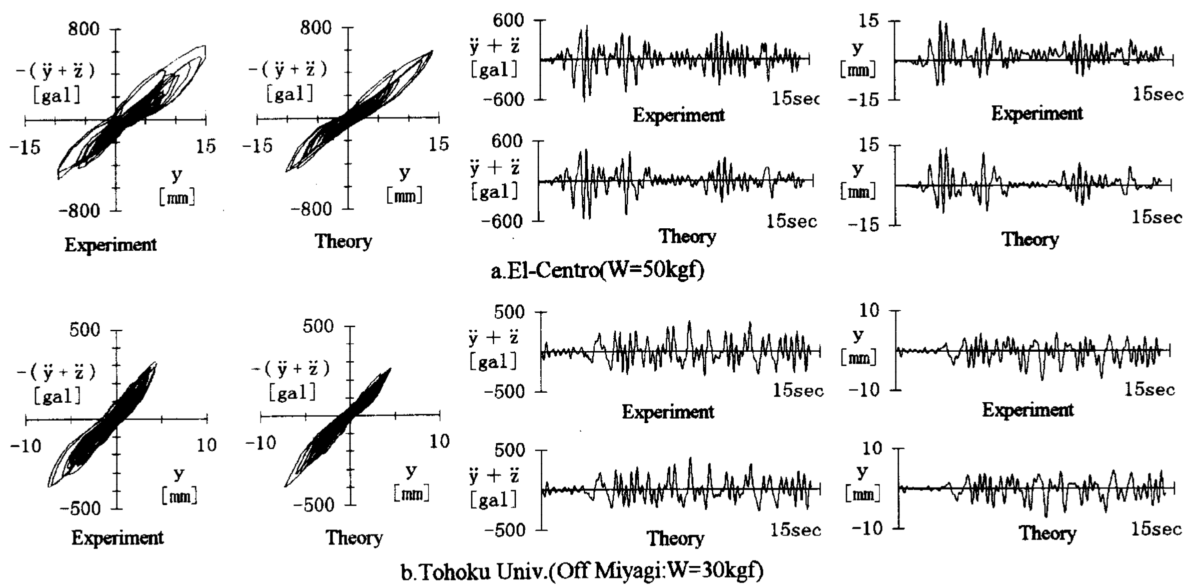
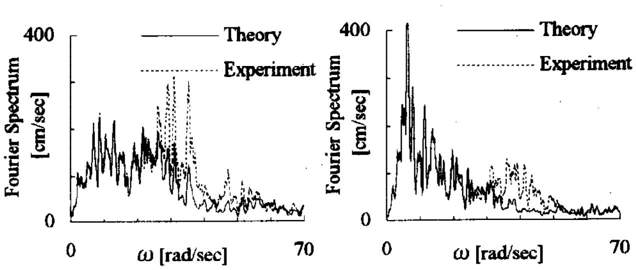
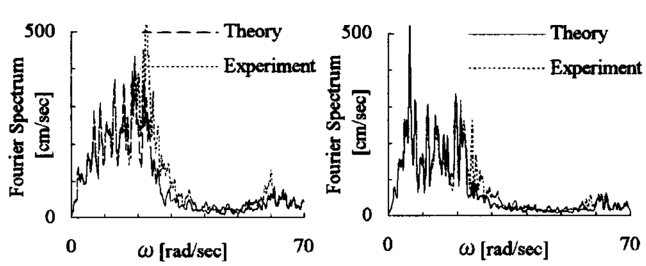


Fig. 13 Comparisons Experimental and Theoretical Values (Earthquake Motion Tests : W=50kgf)



a. W=30kgf b. W=50kgf

Fig. 14 Fourier Spectra (El-Centro)



a. W=30kgf b. W=50kgf

Fig. 15 Fourier Spectra(Tohoku Univ.)