Dynamic Analysis of Ground Motion During Earthquake in the Bangkok Area

地震時 방콕지역의 地盤운동에 대한 動力學的 研究

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要 旨

SHAKE 프로그램을 이용하여 연약지반으로 분포되어 있는 방콕지역에 대한 地震應答을 지표면의 加速度應答 스펙트럼과 최대 加速度로서 分析하였다.

기초암반의 최대가속도와 卓越周期가 증가됨에 따라 지표면의 최대加速度는 증가되고 그 값은 0.3g로 收斂되었다. 아울러 지진應答 스펙트럼의 성질에 대해서도 설명되었다.

ABSTRACT

In this paper, earthquake response of the Bangkok area in Thailand was analyzed in terms of the acceleration response spectrum and maximum acceleration of the computed surface motions. The program SHAKE was employed to analyse the ground motion.

With increasing the maximum acceleration and predominant period of given base rock motion, the computed maximum ground surface acceleration increases, but converges on a maximum value of about 0.3g.

The characteristics of earthquake response spectrum in the Bangkok area are also discussed and illustrated.

1. Introduction

The most important parameters of ground motion during earthquake include the maximum ground acceleration and fundamental period of soil deposit. These parameters of ground motion during earthquake at any site are influenced by the maximum acceleration (Ab) and predominant period (Tp) of base rock motion. Response spectrum has been widely used for the purpose of differentiating signif-

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*Member · Daewoo Engineering Company, Civil Eng. Div. Formeny Asian Institute of Technology icant characteristics of accelerograph records. A response spectrum is a graphical representation of maximum dynamic responses(absolute acceleration, relative velocity and relative displacement) of a responding system against the fundamental period or frequency of a structure.

This study presents results of analyses of the ground motions (maximum ground surface acceleration, acceleration response spectrum) during design earthquake motions for typical subsoil profile in the Bangkok area. The computer program SHAKE(1) was used in this study for the analyses of the ground motion.

2. Earthquake Response Program-SHAKE

Program SHAKE computes the respones in a system of homogeneous visco-elastic, infinite horizontal layers subjected to vertically travelling shear waves. The program is based on the continuous solutions to the wave equation(2) adopted for use with transient motions through the FFT (Fast Fouvier Transform) algorithm(3).

The nonlinearity of the shear modulus and damping ratio is considered with the use of equivalent linear soil properties using an iterative procedure to obtain values for modulus and damping compatible with the effective strain in each layer. The theoretical background of program SHAKE is also discribed in this section.

The input data for SHAKE program consist of three parts, namely base rock motion data, soil layer model and initial dynamic soil properties. A brief description of the determination of input data is presented in the following section. Further details can be found in Ref(1).

2.1. Wave propagation method

The wave equation for the vertical propagation of shear waves through one-dimensional system shown in Fig. 1 is given as follows:

$$\rho\frac{\partial^2 u}{\partial t^2}=G\frac{\partial^2 u}{\partial x^2}+\eta\frac{\partial u^3}{\partial x^2\partial t} \qquad (1)$$

For a hamonic motion of frequency ω, the general solution of Eq. (1) is

$$U(x,t)=Ee^{i(kx+\omega t)}+Fe^{-i(kx-\omega t)} \qquad (2)$$

in which

$$K=\frac{\rho\omega^2}{G+i\omega\eta}=\frac{\rho\omega^2}{G^*}=\frac{\rho\omega^2}{G(1+2iD)} \qquad (3)$$

where; K=complex wave number
G=shear modulus
G^*=Complex shear modulus
D=Critical damping ratio
η=viscousity
ρ=mass density
$U(x,t)$=displacement
x=depth in each layer
t=time
E=Amplitude of Incident wave
F=Amplitude of Reflected wave

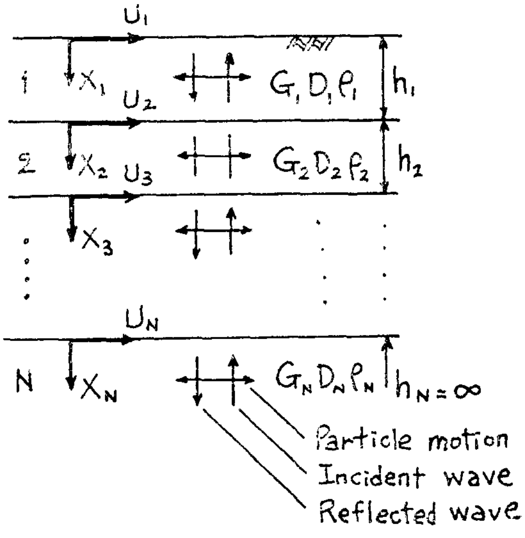

Fig. 1. One-dimensional System

This theory can be extended through the use of Fourier Transformation for vibration loading with transient motions such as earthquake, machine vibration, etc.

2.2. Equivalent Linear Analysis

The use of an equivalent linear system to compute the response of a non-linear system has been found to provide a reasonably satisfactory means of evaluating dynamic behavior of single-degree-of-freedom system.

A equivalent linearization procedure involves the determination of an equivalent linear modulus, Geq, and an equivalent damping ratio, Deq, in the SHAKE program. For a single hysteretic stress-strain cycle, the value of Geq may be taken as the chord modulus of the loop; i.e., the slope of the line joining the extreme points of the hysteresis loop as shown in Fig. 2. For a response involving a number of cycles of different stress and strain amplitude it would be appropriate to use the average value, Geq, of the values of Geq corresponding to the different cycles. Similarly an average value of the equivalent viscous damping ratio, Deq, corresponding to the hysteretic damping of the nonlinear system may be evaluated.

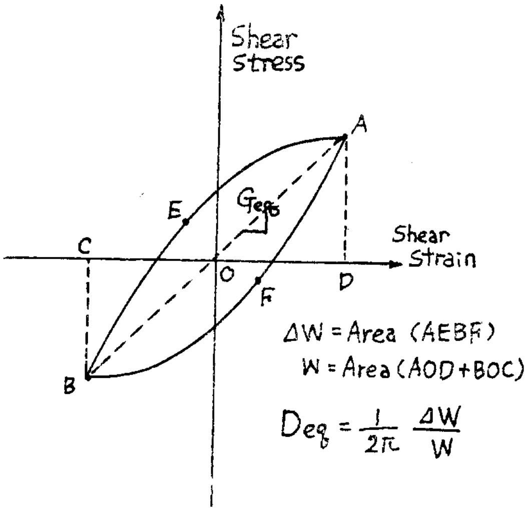

Fig. 2. Evaluation of Equivalent linear parameter

3. Design Earthquake

In order to carry out earthquake response analyses of a given soil deposit for design purposes, design seismic motion is needed at the base rock. Such motions are usually in the form of design accelerograms. When no local record is available for the region under study, the bed rock accelerogram can be chosen from the existing strong motion data or may be generated by means of statistic simulation models. This study was employed a method which is based on the modification of recorded accelerograms by applying a scaling factor to both ordinate and abscissa of the accelerogram. Since the Pasadena Earthquake motions (Fig. 3) is strong motion which resulted from the filtering of earthquake wave of the proceding types through layers of soft soil, this recorded motion was employed in the Bangkok area (soft soil deposit). The earthquake records are modified as follows;

i) Take any recorded accelerogram in which the predominant period (T_1) and maximum recorded acceleration (Amax) are known

ii) Estimate the desired predominant period (T_p) and the scaling factor, $\frac{T_p}{T_1}$, is used to change the time step of the recorded accelerogram (Δt_1), new time step (Δt_p) is

$$\Delta t_p = \frac{T_p}{T_1} \times \Delta t_1$$

iii) Estimate the maximum design base rock acceleration (Ab) and change the recorded motion by multification factor, Ab/Amax

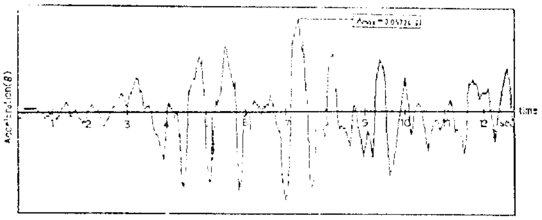

Fig. 3. Pasadena Earthquake Recorded Motion

4. Soil Profile and Dynamic Soil Properties

For analytical purposes, an idealized soil profile (or soil layer model) of the Bangkok area shown in Fig. 4 was employed in this study. The value of soil properties were decided as average values of existing data collected from various sources(4).

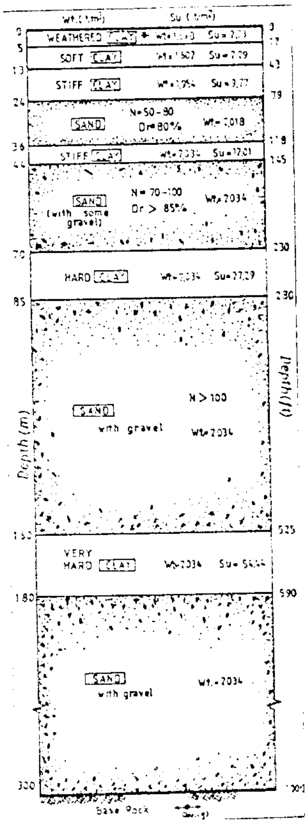

Fig. 4. Typical Soil profile of the Bangkok Area

when assigning dynamic properties, (i.e. shear modulus and damping ratio) to each layer, the initial values at low strain ($10^{-4}\%$) must be determined. Since the data of such initial dynamic properties are not available for the Bangkok soils, an empirical formula has to be used. It has been shown that in equivalent linear analysis the shear moduli and damping characteristics of the soil are strain-dependent with the modulus decreasing and the damping ratio increasing with magnitude of the cyclic strain. General relationships between shear modulus, damping ratio and strain for saturated clays and sands with relative density of about 75%, have been proposed by Seed and Idriss(5). These general relationships shown in Fig. 5(a) to 6(b) were used in this study. For other types of soil, the same general relationships will be used, but appropriate correction factors will be incorporated to allow for variations in soil characteristics. For example, silts, sandy silts and silty sands may be treated as sand but with modulus values modified by a factor ranging from 0.5 to 0.9 depending on the silt content. Gravels may be treated as

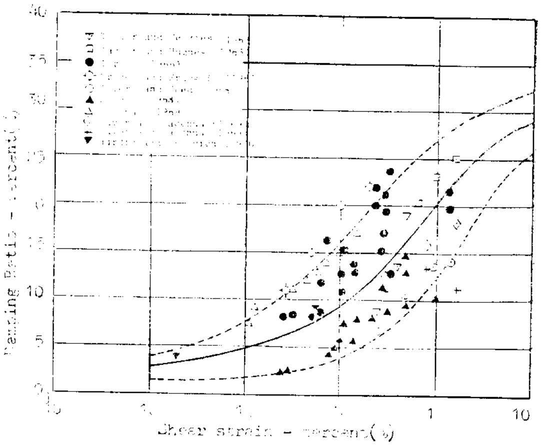

Fig. 5. (**a**) Damping Ratio For Saturated Clays(5).

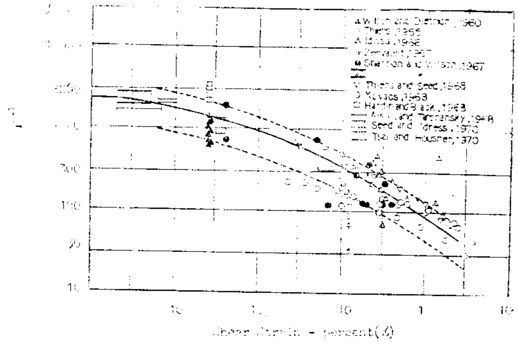

Fig. 5. (**b**) In-Site Shear Moduli For Saturated Clays(5).

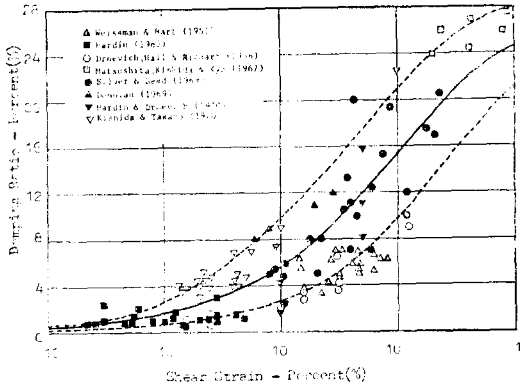

Fig. 6. **(a)** Damping Ratio For Sands(5).

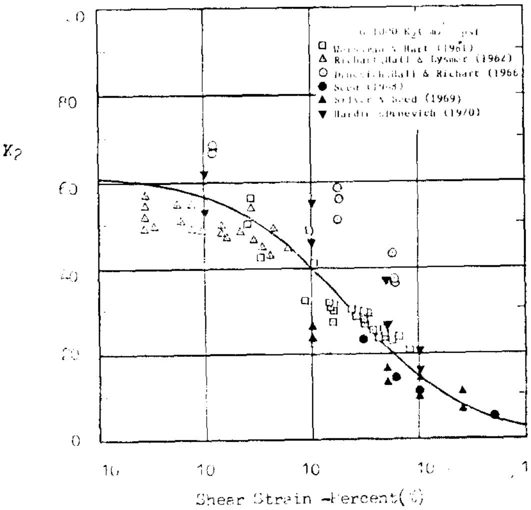

Fig. 6. **(b)** Shear Moduli of Sands at Dr=75%(5)

sand but with modulus values modified by a factor ranging from about 1.2 to 2.0 depending on the gravel content.

It is known the damping ratio of sands are essentially independent of relative density but that shear moduli vary with relative density as follows(5) :

$$G_{D_r}=G_{75}\left(1+\frac{D_r-75}{100}\right) \qquad (4)$$

where; G_{D_r}=shear modulus of sand at relative density (D_r)

G_{75}=Shear modulus of sand at D_r= 75% from Fig. 6(b)

Eq. (4) was used in all the dynamic analyses described in this study to define shear moduli of the sand layers.

For cohesive soils, the shear modulus at low strain can be related to the undrained shear strength, Su(5).

In this study, the ratio of Go at 10^{-4}% shear strain to the shear strength, Su, was fixed at Go/Su=2300 from the data shown in Fig. 5(b). The input parameters for the subsoil layers setected are summarized in Table. 1.

Table. 1. The Input. Data of Dynamic Response Analysis for Bangkok Area

Layer NO.	Soil Type	Sub-Layer	Thickness (m)	G_0(t/m^2) × 10^3	D	Wt. (t/m^3)	Factor
1	1	1	5	5.86	0.05	1,698	0.56
2	1	1	8	4.88	0.05	1,602	0.47
3	1	1	11	21.00	0.05	1,954	1.90
4	2	1	12	22.95	0.05	2,018	1.05
5	1	1	8	27.34	0.05	2,034	2.46
6	2	2	26	34.18	0.05	2,034	1.25
7	1	1	15	58.59	0.05	2,034	5.59
8	2	3	75	56.64	0.05	2,034	1.50
9	1	1	20	117.19	0.05	2,034	11.15
10	2	2	120	94.73	0.05	2,034	1.80
11		—	—	—	0.00	2,034	V_s= 2500ft/sec

1 : clay 2 : sand

5. Results of Ground Motion Analyses

The analytical procedures described above may be used to study the influence of the base rock motion and the predominant period of base rock motion on the response characteristics. To illustrate this, analyses were made on the response of the soil deposit in the Bangkok urban area to base rock accelerations having the same form but different amplitudes. The response of the soil deposit in the Bangkok urban area was calculated for 7 different maximum base rock accelerations (Ab) ranging from 0.001g (1 gal) to 0.5g (490 gals) with 3 different predominant periods of base rock motion (Tp=0.2, 0.4, and 0.65 seconds) using SHAKE program. The moduli and the

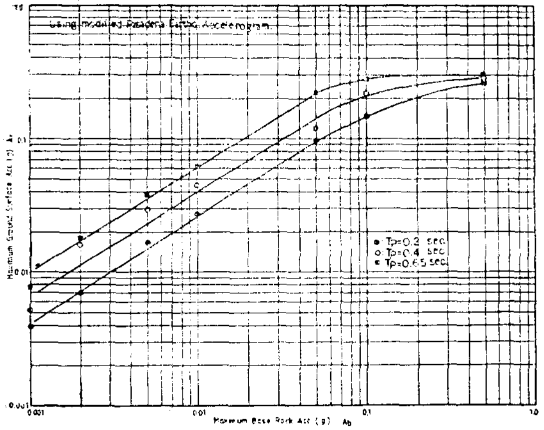

Fig. 7. Variation Between Max. Ground Surface Acc. (As) & Max. Base Rock Acc. (Ab).

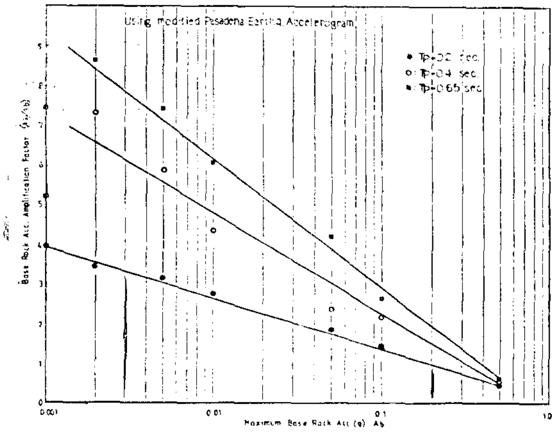

Fig. 8. Variation of Amplification Factor(As/Ab)

average damping ratios of the deposit were adjusted to be compatible with the strains developed during each base rock motion.

The variations of maximum ground surface acceleration (As) with the applied maximum base rock acceleration (Ab) and predominant period (Tp) are shown in Fig. 7. This figure shows that As increases with increasing amplitude of the base motion. This value also increase with increasing Tp. The results shown in Fig. 8 indicate that the amplification factor (As/Ab) decreases considerably as the value of Ab is increased; It is also shown the computed amplification factor decreased from about 8.6 to less than 1.0 with increase in amplitude of base rock acceleration from 1gal to 490 gals. The influence of the amplitude of base motions on structures built on the top of the deposit is best illustrated by considering the response spectrum of the resulting ground surface motions. The response spectrum computed for each base rock motions with the variation of Tp are shown in Fig. 9 to Fig. 11. As can be seen in these figures, each spectrum appears to have three major peaks. The first peak occurs at a period which is close to the predominant period of the base motion. And the second peak can be considered to the second order of natural period, that is one third of the fundamental period. The periods of occu-

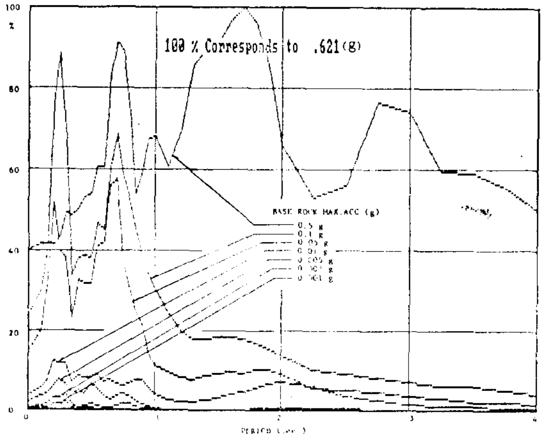

Fig. 9. Comparison of As Spectrum For Tp=0.2 sec.

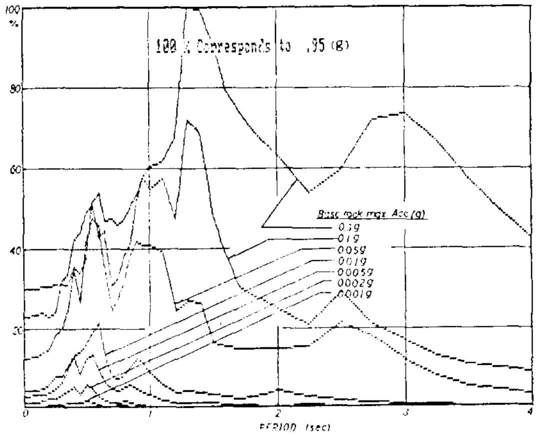

Fig. 10. Comparison of As Spectrum For Tp=0.4sec.

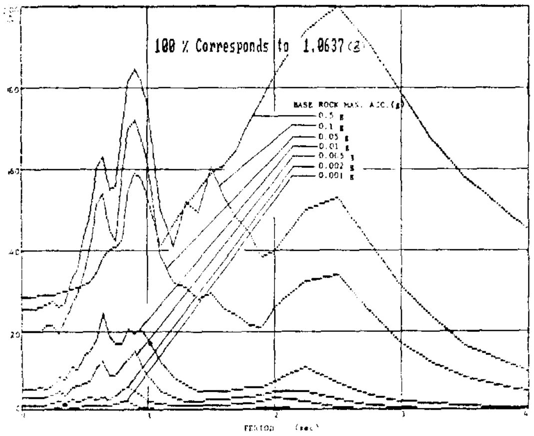

Fig. 11. Comparison of As Spectrum For Tp=0.65sec.

rrence of the first and peak are gradually governed by the nature of subsoils.

6. Conclusions

A series of dynamic response analysis of ground motions for a typical subsoil deposit found in the Bangkok area was carried out using SHAKE program. Accelerogram of the Pasadena Earthquake with modifications in the predominant (Tp) and the maximum acceleration (Ab) of base motion, was used as the input wave. The following conclusions were obtained:

(1) With increase in the applied base rock acceleration (Ab) and the predominant period of base motion (Tp), the computed ground surface acceleration (As) gradually increases and converges on maximum value of about 0.3g.

(2) The amplification factor for acceleration (As/Ab) decreases from about 8.6 to less than 1.0 with increase in Ab from 1 gal to 490 gals and Tp from 0.2 to 0.65 seconds.

(3) With increase in Ab, the effect of input motion on ground motion decreases and gradually becomes independent of Tp.

References

(1) Schnabel, P.B., Lysmer, J., and Seed, H.B., "SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," Report No. EERC 72-12, Univ. of California, Berkeley, Calif., Earthquake Engng. Research Center, Dec., 1972.

(2) Kanai, K., "Relations between the Nature of Surface Layer and the Amplitudes Earthquake Motions," *Bull.*, Earthq. Research Institute, Tokyo Univ., Vol. 30, pp. 31~37.

(3) Cooley, J.W. and Tukey., J.W. "An Algorithm for the Machine Calculation of Complex Fourier Series," *Mathematics of Computation*, Vol. 19, No. 90, 1965, pp. 297~301.

(4) AIT "Results of Laboratory Tests on Subsoils of Bangkok and Adjacent Areas, Investigation of Land Subsidence Cauced by Deep Well Pumping in the Bangkok Area," *GTE Report* Vol. 2, No. 91, AIT, Bangkok, Thailand, 1981.

(5) Seed, H.B. and Idriss, I.M., "Soil Moduli and Damping Factorsfor Dynamic Responss Analysis," *Report No. EERC* 70-10, Earthquake Engng. Research Center, Univ. of Calif., Berkeley, 1970.

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