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SYNOPSIS: It is known that not only local soil conditions but also seismic wave, used in analysis, together with its input conditions had a major effect on the intensity and characteristics of ground motion. In this paper the ground motions to different input depths of base motion under the near epicentre or far epicentre conditions, using EL CENTRO record after adjusting as base motion input, for two representative sites in Shanghai were reviewd and the results of analytical studies were presented to explore the site dependent design spectra suited to local conditions

INTRODUCTION

Shanghai is located on an alluvial plain filling the former sea where the soil conditions consist essentially of a thin surface layer of mixed silty clay, clay and fill, followed by a 20-40m thick soft clayey soil layer with interbedded seams of silt, fine sand or silty sand. Underneath this layer are a series of intercalated or interbedded strata of clay, silty clay, silty sand and sand, which extends to hard formations at a depth of about 300m in centre of the city. It is investigated that the bedrock surface in urban districts of the city is essentially horizontal. Since overburdened layer is so deep and interface between soft and hard strata is so uncertain that it is necessary to probe the effect of the different input depths of base motion on the ground motion. In addition, the studies show that Shanghai Area may be affected by far epicentre earthquake besides near epicentre earthquake. Thus two sites in Shanghai city, as shown in Fig. 1, were selected to analyse the ground motions to a series of assumed input depths of base motion under near or far epicentre earthquake conditions in order to estimate the effects of various influence factors on the results.

To this end, the EL CENTRO record after adjusting was used as base motion input in consideration of: the lack of the strong motion record in Shanghai Area as well as its typical representative of its kind.

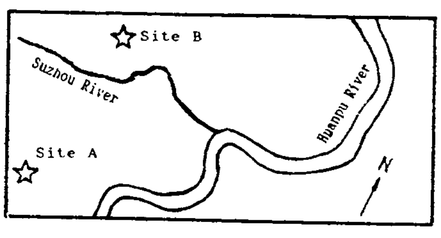

Fig. 1 Computed Site (in Shanghai)

ANALYTICAL STUDIES OF GROUND MOTION

In many cases the ground motions developed near the surface of soil deposit during an earthquake may attributed primarily to the upward propagation of shear waves from an underlying rock formation. The soil deposits related to Shanghai site are very thin compared with their lateral extent and thus the dynamic response can be evaluated by one dimensional wave propagation analysis.

A horizontal soil deposit may consist of m sublayers having different material characteristics. Such a deposit constitutes a semi-infinite body and may be idealized by a series of lumped masses. Each sublayer, j, is divided into n_j levels and the entire deposit is divided into N levels in which $N=\sum_{j=1}^{m} n_j$.

The response of the deposit to a horizontal seismic base excitation may then be evaluated from a solution of the following equation of motion:

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{R(t)\} \qquad (1)$$

in which [M], [C] and [K] are respectively the mass, damping and stiffness matrices of the system; {u} is the relative displacement vector (dots represent differentiation with respect to time) and {R(t)} is the earthquake load vector. Once the mass, damping and stiffness matrices of the system and the earthquake motion at base are known, Eq. 1 may be solved by appropriate numrerical procedure. The step-by-step procedure was adopted in the computer program which was written in FORTRAN 77 language.

The soil spring stiffness constant, K, and viscous damping coefficient, C, can be expressed respectively as: $K_i = G_i/h_i$ and $C_i = 2m_i\omega_i\lambda_i$, in which K_i, G_i, h_i, c_i, m_i, ω_i and λ_i are respctively the spring constants, shear modulus, thinkness, viscous damping coefficient, lumped-mass, natural circular frequency and viscous damping ratio of i th level.

The accuracy of the solution depends on the number of division, N, used, and the fundamental period, T_1, of the layer. Its stability depends on the time interval, Δt, used in integrating the normal equation and the value of vibration period, T, included in the analysis. The values of N used actually in the analyses are listed in Table 1 and from that it may be seen that the total values of N for the four assumed seismic wave input depths of 50m, 100m, 200m and 300m are respectively 25, 35, 45 and 50. The Wilson's θ method was introduced in integrating the normal equations and the equivalent linear system was used for computing the response of a nonlinear system.

Table 1

Embedded Depth of Natural Soil Strata (m)	0-10	10-20	20-50	50-100	100-200	200-300
Segment Thickness (m)	1	2	3	5	10	20
Number of Segment	10	5	10	10	10	5

The solution of Eq.1 provides the values of acceleration, velocity, displacement, shear strain and shear stress throughout the deposit for the entire duration of the applied base motion. Thus equivalent linear moduli and equivalent linear damping ratios for each segment of the deposit can be incorporated in the solution based on the computed values of the developed shear strain in these segments. In analysis the time interval Δt was estimated based on $\Delta t/T<0.02$ (where T is vibration period) and the values of Δt used actually were 0.005-0.01 second.

The study was made for the following conditions at the sites of the city:

1. Assuming that strain dependent shear modulus, G, and damping ratio, λ, can be prescribed respectively by

$$\frac{G}{G_0} = \frac{1}{1+\gamma/\gamma_r} \qquad (2)$$

and

$$\frac{\lambda}{\lambda_{max}} = \left(\frac{\gamma/\gamma_r}{1+\gamma/\gamma_r}\right)^{0.5} \qquad (3)$$

where γ is shear strain; γ_r, G_0 and λ_{max} are parameters, refered to as the reference shear strain, initial shear modulus and maximum damping ratio respectively.

2. The subsoil conditions at the sites mostly consist of a 3-5m thick surface layer of mixed silty clay, clay and fill, followed by a about 20-40m thick soft clayey soil layer with interbedded seams of silty sand, silt and fine sand; the water content, w, in soft clayey materials ranges from about 40% to 60% and the shear wave velocity, V_s, varies from about 100m/s to 140m/s. Underneath this layer are a series of intercalated strata of clay, silty clay, silty sand and sand about 150m in thickness, with a value of V_s ranging from about 150m/s to 200m/s, followed by a about 120m thick layer of plastic clay and clayey soil with intercalated strata of silt, sand and gravel sand in medium density, with a value of V_s ranging from about 200m/s to 400m/s which overlies the 300m deep hard formations.

In view of the preliminary nature of the studies, a simplified representation of the actual soil profiles, as shown in Fig.3 as well as Fig.4, was used in analyses. The values of G_0 varing with depth in these figures are formed in such a way that for the upper parts they are based on investigation of shear wave velocity, V_s, thereby the values of G_0 can be calculated by the expression of $G_0 = \rho V_s^2$ where ρ is mass density of soil; and for the lower parts they are evaluated by soil properties and their relativity, and the fitting relation may be expressed as $V_s = a + bz^p$ where z represents the depth ordinate from the depth of 50m, the value of parameter p was taken as 1/6 since soil conditions in lower parts mainly involve clayey soils. The values of parameters a and b are 230 and 78 respectively for site A and 380 and 96 respectively for site B. Assume that the soils at these sites have a overall average λ_{max} value of 25% or 30%, where the former is for clayey soils and the latter for sandy soils. Analyses show that the parameters and soil characteristic indexes abovementioned had only a less effect on the results except for shear modulus G.

The EL CENTRO seismic wave record after adjusting was used as input base motion in order to explore the effect of soil conditions together with different base inputs on the characteristics of ground motion. The peak acceleration of original record was about 340 galls occurred at 2.12 seconds. As it is used as an input source the peak acceleration value has been adjusted to 100 galls according to ground intensity of seven degrees (Seismic background in Shanghai). The original record seismic wave was near epicentre one and its sampling time interval was 0.02 second, which was unchanged to be used as input base motion in the case of near epicentre. If magnitude is 5, the duration of the strong motion will be 5 second (According to H.B.Seed). For input base motion in the case of far epicentre, the sampling time interval of the original record was increased to 0.03 second which corresponds to the earthquake of magnitude 6.5 occurred as far as 150-200km. Thus its predominant period would be 5/3 times as large as that of original record and the duration was elongated to 15 second. The spectral accelerations of input base motion used in the analyses are shown in Fig. 2, in which the solid line is used for near epicentre input and the dotted line for far epicentre input. The characteristics of input base motion was summarized in Table 2.

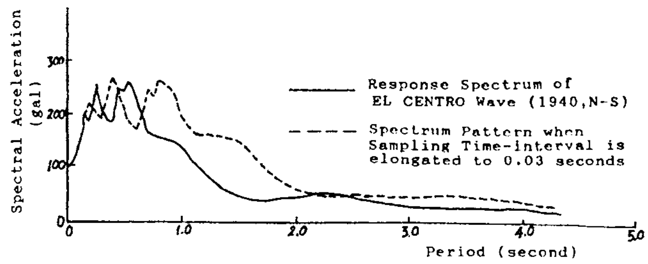

Fig.2 Response Spectra of Seismic Wave (EL-CENTRO) used as Near or Far Earthquake Input

Table 2

Input Condition	Max. Acceleration (gal)	Duration (second)	Sampling Time Interval (sec.)
Near Earthquake	100	5	0.02
Far Earthquake	.100	15	0.03

The results of analyses are shown in Figs. 4, 5 and 6. Fig.4, for a representative example, shows the resulting time histories of accelerations at ground surface for site A to 300m deep input base motion in the both cases of near and far epicentre. For another representative example, the maximum values of shear strain, shear stress, acceleration and velocity within 50m in depth to 300m deep input in the case of near epicentre for both sites are presented in Fig.5. It may be seen that the response curves for the two sites are similar in form except that the response at site B are stronger than those at site A. Besides, for both sites the maximum shear stress was approximately increased in proportion to depth (<50m) and the peak of the maximum shear strain as well as that of the maximum acceleration occurred at a depth of about 10m which is obviously related to local soil conditions.

The results of acceleration response spectra at ground surface are summarized in Fig. 6. Fig. 6 (a) shows a comparison of response spectra for site A for different base motion input depths such as 50m, 100m, 200m and 300m in the case of near epicentre. It may be seen that these response spectra to different depths of base motion input are quite similar to each other, with a predominant period of about 1.0 second, i.e., the difference in base input depths has only a minor effect on results for site A in the case of near epicentre input.

The results shown in Fig. 6 (b) is also for site A but for far epicentre earthquake input. It may be noted that it is different greatly from those shown in Figure 6(a), showing the characteristics that the former peak is depressed and the latter peak is prominent, and the the position of the peak moves toward the direction of long period so much that the predominant period is elongated to such a degree as 1.5-4.0 seconds dependent on the base motion input depth.

The Corresponding results for site B are presented in Fig. 6 (c) and (d) where the former is for the case of near epicentre and the latter for the case of far epicentre. It is worthy to note that the results for site B are essentionally similar to those for site A except that the response at site B is much stronger than those at

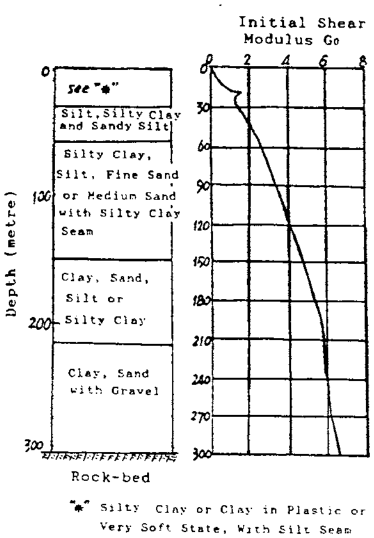

Fig.3 Soil Profile at Site B

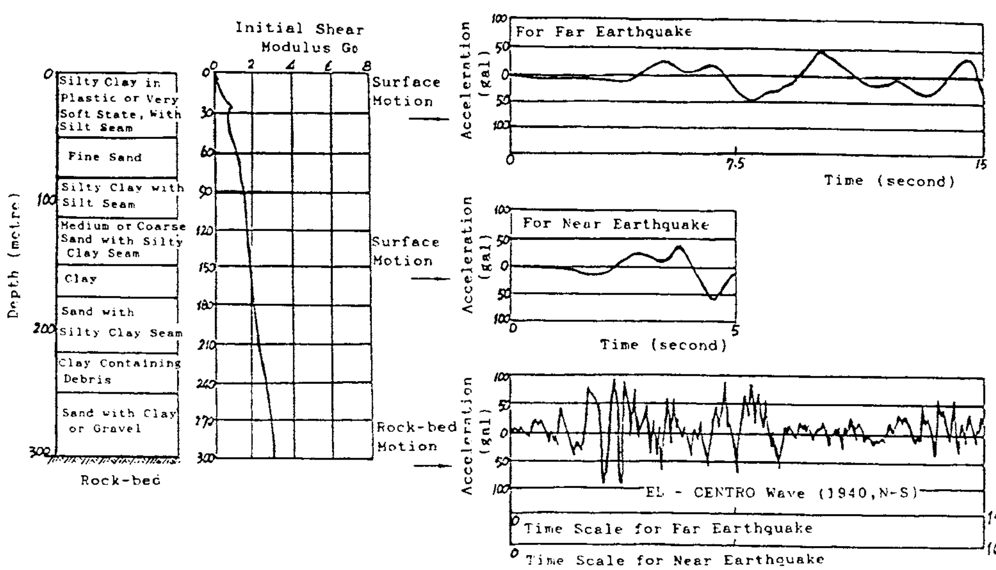

Fig.4 Computed Surface Response at Site A for Far and Near Earthquake Input at a Depth of 300 m (Rock-bed Surface)

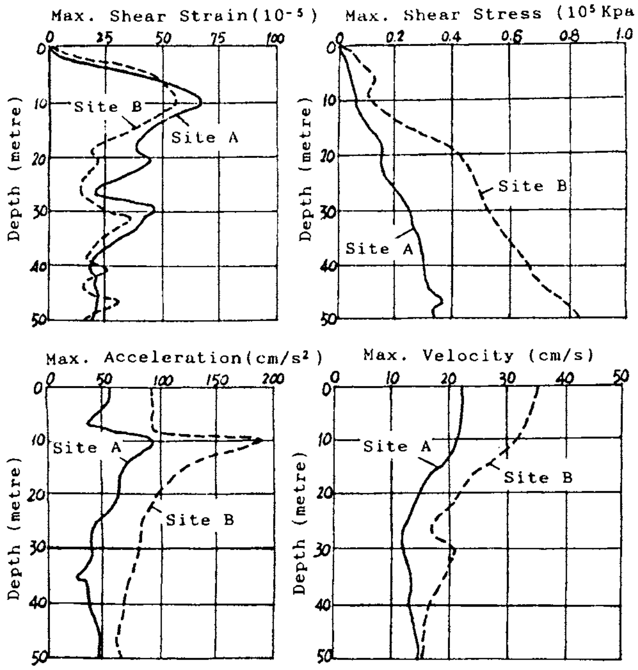

Fig. 5 Max. Shear Strain, Shear Stress, Acceleration and Velocity within the Depth of 50 m for Computed Motion on the Condition of Near Earthquake

site A. Fig.6 (e) shows the acceleration response spectra for both sites and both of near and far epicentre input conditions to 300m deep base motion input, which is listed alone for the sake of eye-catching only.

CONCLUSIONS

In the preceding pages have been presented the results of some analytical studies of ground response for two sites in Shanghai. It seems clear that the input conditions of near or far epicentre have a major effect on the frequency characteristics of response spectra of ground surface. In the case of the near epicentre input the results of response spectra to different depths of base motion input are in less diversification or rather stable, with a predominant period of about 0.9-1.0 seconds for site A and a predominant period of about 0.9-1.1 seconds for site B. Whereas, in the case of the far epicentre input the results to different depths of base motion input are diverse, with a predominant period, enhanced greatly, ranging from 1.3 to 4.2 seconds dependent on the input depth of base motion. The peak of acceleration response spectra at ground surface, as compared to that of input wave, has a decrease of about 30%-40% for site A and an increase of about 20% for site B. The floating of soil property parameters in actually available range has only a less effect on the results except for shear modulus. The results of such analyses may provide a useful basis for assessing the ground motion characteristics in Shanghai Area and for developing seismic risk maps and site dependent design spectra for this city.

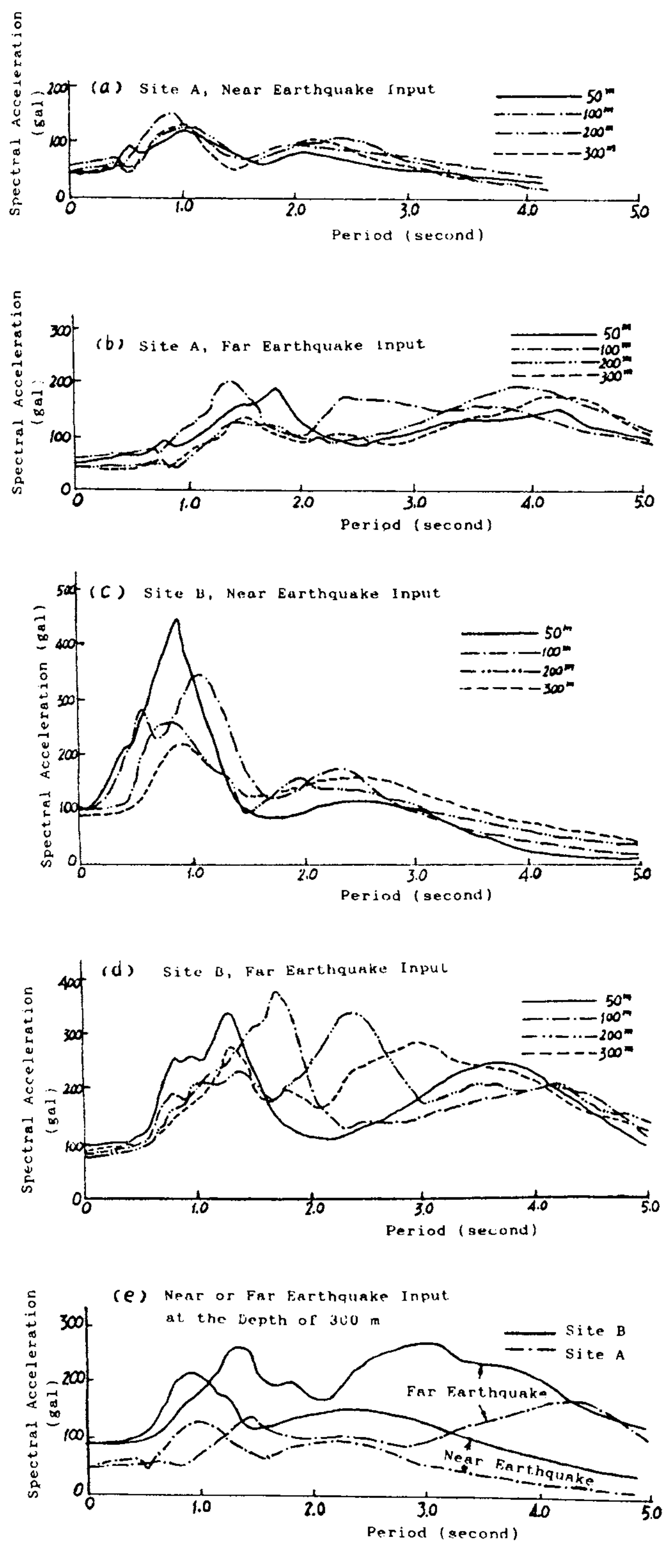

Fig. 6 Acceleration Response Spectra for Computed Motions in Differnt Site and Input Conditions

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