Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Seismic earth response considering various mechanical models

Gh. Mărmureanu, S. F. Bălan & I. Vasile
Center of Earth Physics, Romania

ABSTRACT: The paper summarizes the results obtained by authors regarding the influence of the soil mechanical modelling on seismic earth massive response. There were used constitutive models (nonlinear viscoelastic, linear viscoelastic, nonlinear elastic and linear elastic model) and finally it was computed the response values, that is, maximum accelerations, fundamental periods, amplification spectrum, acceleration and velocity response spectra.

1 INTRODUCTION

The characteristics of the soil at the site play a significant role in defining both the free field ground motion and the soil behaviour during soil structure interaction. Soils are seldom homogenous and they seldom lie in clearly defined horizontal layers. Selecting a mathematical model (constitutive models) to represent the stress-strain behaviour of the soil is a difficult problem. In general, the stress-strain behaviour of the soil is strongly nonlinear, anisotropic, elasto-plastic, loading-path dependent and also depends on the water constant and possible flow conditions in the soil. The role of the constitutive models is to compress the data into a form which is efficient for computations.

2 NONLINEAR VISCOELASTIC MODEL FOR SOILS

The analytic forms of the constitutive equations of soils can be evaluated by means of experimental data obtained from creep triaxial tests. (Bratosin 1986). From this data by polynomial regression method at each time t_j we can obtain m constitutive relationships in the form (Bratosin 1983):

$$\tau(\gamma,t)=G_j(\gamma).\gamma=\sum_{K}^{0,2} g_{kj}(-\gamma)^k \quad (1)$$

$t=t_j$; $j=1,2...m$

or in integral form:

$$\tau(t)=\int_0^t G(\gamma,t-\lambda)\dot{\gamma}(\lambda)d\lambda \quad (2)$$

where τ and γ are the tensor invariants of the stress σ_{ij} and strain ϵ_{ij} :

$$\tau=\left\{\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]/3\right\}^{1/2} \quad (3)$$

$$\gamma=\left\{\left[(\epsilon_1-\epsilon_2)^2+(\epsilon_2-\epsilon_3)^2+(\epsilon_3-\epsilon_1)^2\right]/3\right\}^{1/2} \quad (4)$$

and $G(\gamma,t)$ is the nonlinear relaxation functions:

$$G(\gamma,t)=\sum_{i}^{0,2}\left[g_i^o+(g_i^o-g_i^{\infty})\exp(-\beta_i t)\right]\cdot(-\gamma)^i \quad (5)$$

g_i^o, g_i^{∞} and β_i are material constants. Functions (5) is in compliance with three-relaxation model. This model has sufficient accuracy for practical purposes and satisfies the reduction condition to the nonlinear form (Bratosin 1986).

The values of the constants g_{ij} ($i=o,1,2$; $j=1,2...m$) from equation (5) are the values obtained at time t_j for the corresponding exponentials $G_i(t)$ from eq. (1). For each of these exponentials G_i ($i=o,1,2$) we have m pairs (g_{ij},t_j) formed by the values of the argument $t=t_j$ and the values of this function at time t_j: $G_i(t_j)=g_{ij}$. Statistical analyses of these pairs (logarithmic transformation and linear regression) can give the parameters $g_i^o, g_i^\infty, \beta_i$ of the nonlinear relaxation function $G(\gamma,t)$. If the strain history is in the form:

$$\gamma(t)= \gamma_o \exp(i\omega t) \qquad (6)$$

where γ_o is the strain amplitude and ω is the excitation frequency and from eq. (2),(5) and (6) and after integration we obtain the dynamic shear constitutive equation in the form (Bratosin 1986):

$$\tau(\gamma_o,t)=G^*(\gamma_o,i\omega)\gamma(t) \qquad (7)$$

where $G^*(\gamma_o,i\omega)$ is the complex modulus function:

$$G^*(\gamma_o,i\omega)=G_r(\gamma_o,\omega) + iG_i(\gamma_o,\omega) \qquad (8)$$

The real part $G_r(\gamma_o,\omega)$ is the storage modulus function and the imaginary part $G_i(\gamma_o,\omega)$ is the loss modulus function and they have the following forms:

$$G_r(\gamma_o,\omega)=\sum_i^{0,2} g_i^o(-\gamma)^i + \sum_i^{0,2} (g_i^o - g_i^\infty)(-\gamma)^i\omega^2/(\omega^2 + \beta_i^2) \qquad (9)$$

$$G_i(\gamma_o,\omega)=\sum_i^{0,2} (g_i^o - g_i^\infty)(-\gamma)^i\omega\beta_i /(\omega^2 + \beta_i^2) \qquad (1o)$$

The complex modulus function can have the form:

$$G^*(\gamma_o,i\omega)=G(\gamma_o,\omega) \exp\left[i \tan^{-1}G(\gamma_o,\omega)\right] \qquad (11)$$

where:

$$G(\gamma_o,\omega)=\left[G(\gamma_o,i\omega)\right]=\left[G_r^2(\gamma_o,\omega) + G_i^2(\gamma_o,\omega)\right]^{1/2} \qquad (12)$$

$$D(\gamma_o,\omega)=G_i(\gamma_o,\omega)/G_r(\gamma_o,\omega) \qquad (13)$$

The first function (eq.12) is called dynamic torsional modulus and the second function (13) is called torsional damping function. From equations 9,1o,11,12 and 13 we can obtain another forms of the dynamic torsional modulus function and damping functions:

$$G(\gamma_o,\omega)=\sum_i^{0,2} G_i(\omega)(-\gamma_o)^i \qquad (14)$$

$$D(\gamma_o,\omega)=\sum_i^{0,2} D_i(\omega)\ (\gamma_o)^i \qquad (15)$$

where G_i and D_i, i=o,1,2 are function only of frequency ω and contain only material parameters : g_i^o, g_i^∞, β_i, i=o,1,2 which are found from resonant column data by polinomial regression method. On the other hand, the analysis of several resonant column tests shown a major weight of the strain level on modulus and damping values and a minor influence of the frequency values above 1 Hz on frequency functions $G_i(\omega)$ and $D_i(\omega)$, i=o,1,2. Then from practical point of view, we can consider G_i and D_i as constants over the frequency range which is of main interest in the analysis and in the case, the complex modulus function becomes:

$$G^*(\gamma_o)=G(\gamma_o)\exp(i \ \tan^{-1}D(\gamma_o)) \qquad (16)$$

or

$$G^*(\gamma_o)=\sum_i^{0,2} G_i(-\gamma_o)^i \qquad (17)$$

where G_i^* are complex constants of form:

$$G_i^* = G_i' + i\,G_i'' \quad , i=o,1,2 \qquad (18)$$

where G_i' and G_i'' are combinations of the constants G_i and D_i, i=o,1,2 obtained from resonant column data, (Bratosin 1986):

$$G_o'=G_o(1 - o.5D_o^2) \ ; \ G_o''= G_oD_o;$$
$$G_1'=G_1(1 - o.5D_o^2) + G_oD_oD_1 \ ;$$
$$G_1''=G_1D_o- G_oD_1 \qquad (19)$$
$$G_2'=G_2(1-o.5D_o^2) + G_1D_oD_1 - G_o(o.5D_1^2 + D_oD_2); \ G_2''=G_2D_o-G_1D_1+G_oD_2$$

The data from resonant column tests are very usefull for checking the behaviour of the nonlinear viscoelastic model under dynamic conditions. As is shown in Fig. 1 a good agreement is obtained between dynamic shear modulus (14) and damping

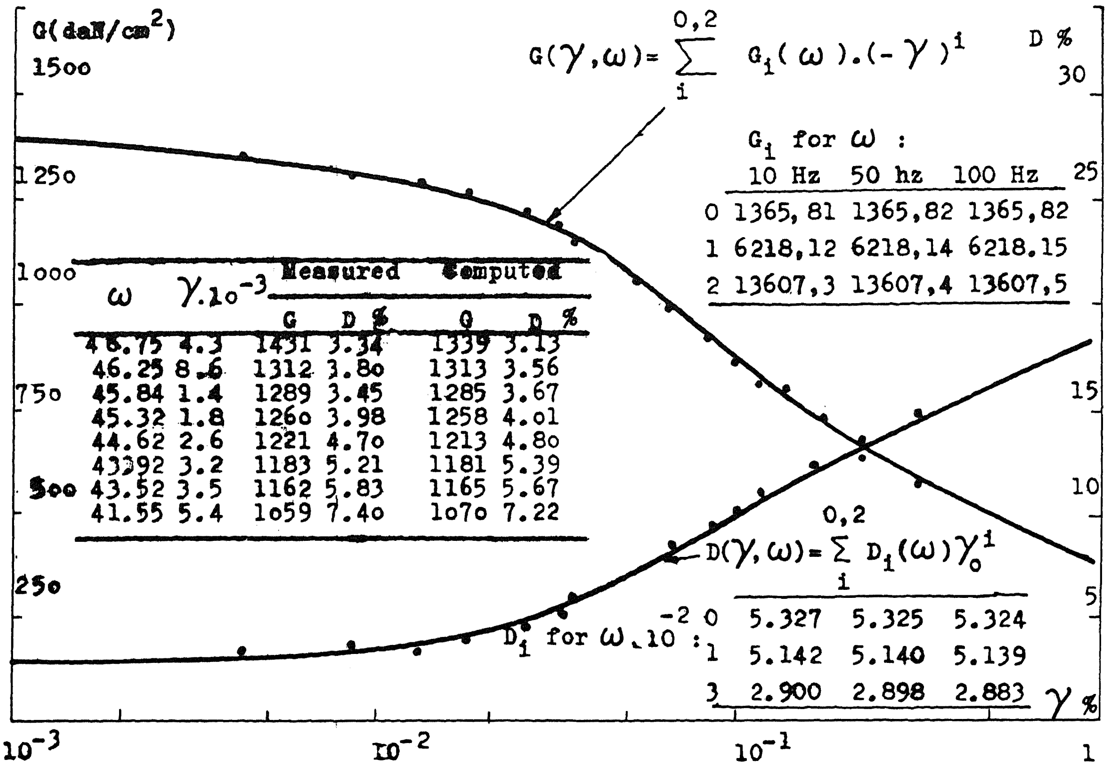

Fig. 1

(15) functions and resonant Hardin and Drnevich column data from our laboratory for diluvian clay from layer number two (Fig. 2).The same data are obtained for layers number 1,3 and 4.

3 THE INFLUENCE OF MODELLING

The theory considers the responses associated with vertical propagation of shear waves through the linear viscoelastic (G_i=constant and D_i=constant) or linear elastic (G_i=constant and D_i=0%) system.

The system (Fig.2) consists of 4 horizontal layers extended to infinity in the horizontal direction and has an elastic halfspace as the bottom layer.Each layer is homogeneous and isotropic and is characterized by the thickness h,mass density ρ, dynamic torsional modulus function, $G_i=G_i(\gamma)$ and torsional damping function, $D_i=D_i(\omega)$.If $G_i=G_i(\gamma)$ and D_i=0% then we have a nonlinear elastic model.The nonlinearity of the shear modulus and damping ratio is accounted for by the use of equivalent linear soil properties using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer.

The input base motion is the same in all cases and the maximum acceleration at the base rock is 0.041 g. The response values,that is,maximum accelerations,fundamental periods, amplification spectrum,acceleration and velocity spectra (0% and 5% damping values)are given in Tables 1 to 4 and Figures 3 and 4.

All values were obtained by using AMPLOC (St. Bălan 1987) and SHAKE (Schnabel 1972) programs which are based on the continuous solution to the wave equation adapted for use with transient motions through the Fast Fourier Transform algorithm.

4 CONCLUSIONS

The analytic forms of the constitutive equations of soils can be evaluated by means of experimental data. The resonant column sample is subjected to harmonic longitudinal or/ and torsional vibrations and for a given excitation level it can give

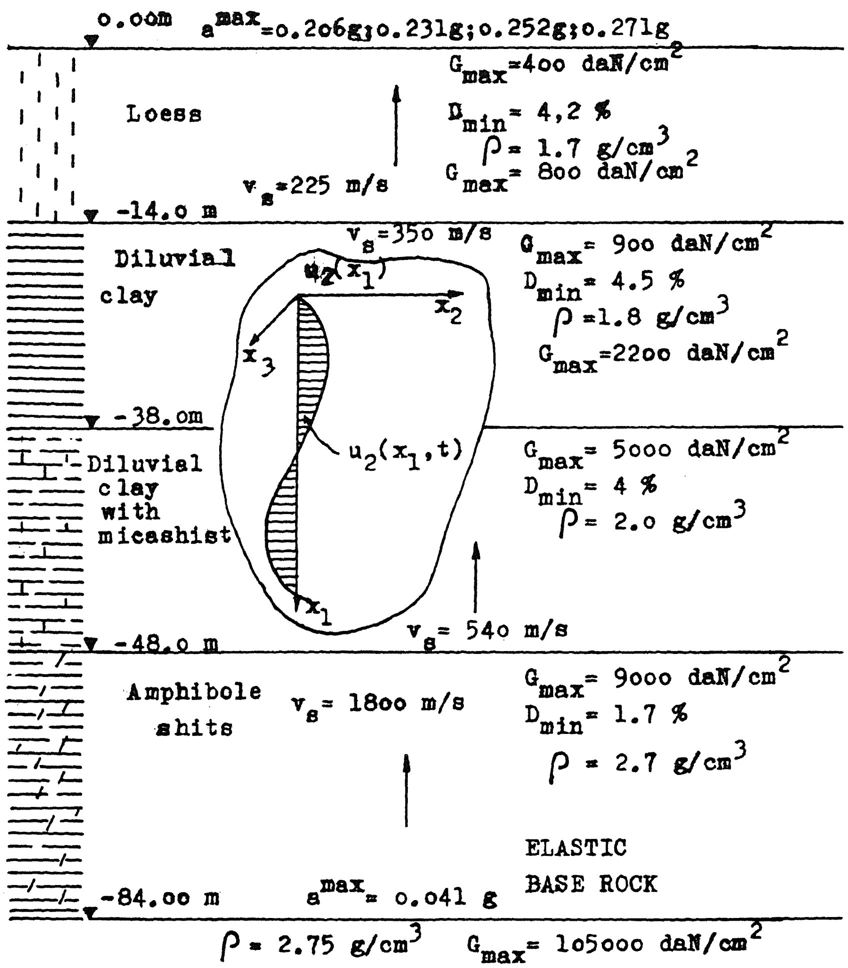

Fig. 2

one value of the dynamic shear modulus function (G_i) and one value of the damping function (D_i). The dynamic torsional modulus function and damping function become polynomials in terms of strain and can be entirely determined from resonant column data by polynomial regression method. An example is shown in Fig. 1.

Vertically propagating shear waves show that different constitutive models for the same site and the same seismic input lead to different results. The difference between a nonlinear viscoelastic model and a linear elastic one is often as great as a factor of 1.32 in peak surface acceleration (Table 1), of 1.7 in maximum amplification spectrum (Tabel 2), of 2.7 and 1.13 in maximum absolute acceleration spectra for damping 0%, respectively, 5%. There are some shifts in the fundamental periods of the site due to softening of soil layers (Fig. 2 and 3, Tabel 2). While these effects may be relatively unimportant in the special case of vertically propagating shear waves in the free field, they may be significant when more ground shaking is considered and are definitely important to the complex stress states associated with seismic soil structure interaction.

REFERENCES

Bălan St., (coordinating), Gh. Mărmureanu, M. Oncescu, I. Cornea, St. F. Bălan, 1987, Introduction to the mechanics of seismic phenomena and seismic engineering. (in romanian). Academy Printing House.

Bratosin D., 1986, Mechanical models for dynamic behaviour of soils,

Table 1

Maximum Accelarations Values in g				
Level (m)	Nonlinear viscoelastic model	Linear viscoelastic model	Nonlinear elastic model	Linear elastic model
0,00m	0.20695 g	0.2310 g	0.2525 g	0.2710 g
-14.00m	0.08904 g	0.1191 g	0.1150 g	0.1402 g
-38.00m	0.08761 g	0.0742 g	0.1025 g	0.0905 g
-48.00m	0.08284 g	0.0673 g	0.0941 g	0.0772 g
Amplification Spectrum,	|H(iω)|/10			TABEL 2
|H(iω)|	3.55	4.72	5.40	6.93
Period, T	0.206 s	0.201 s	0.252 s	0.201 s
Maximum Absolute Acceleration Spectra (in g) at T=0,2 s; TABEL 3				
D=0%	4.295 g	7.880 g	4.550 g	11.770 g
D=5%	0.980 g	0.905 g	1.289 g	1.1070 g
Maximum Relative Velocity Spectra (m/s) at T=0.2 s ; TABEL 4				
D=0%	1.330 m/s	2.45 m/s	1.440 m/s	3.650 m/s
D=5%	0.306 m/s	0.298 m/s	0.374 m/s	0.359 m/s

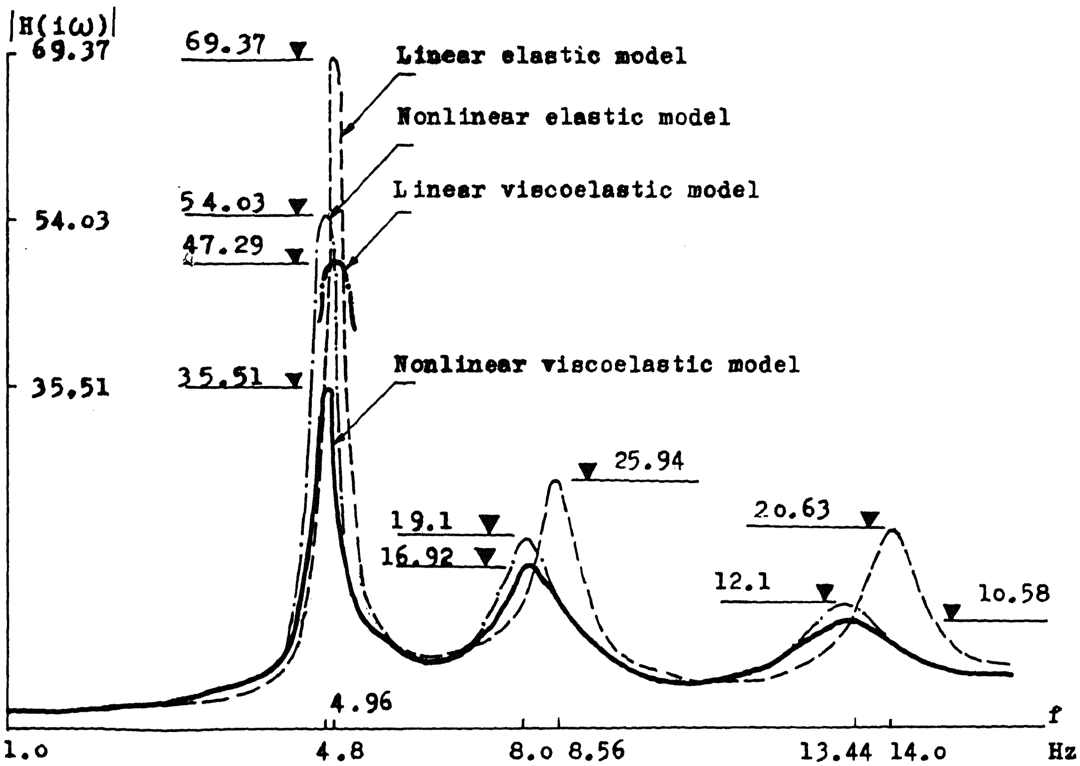

Fig. 3

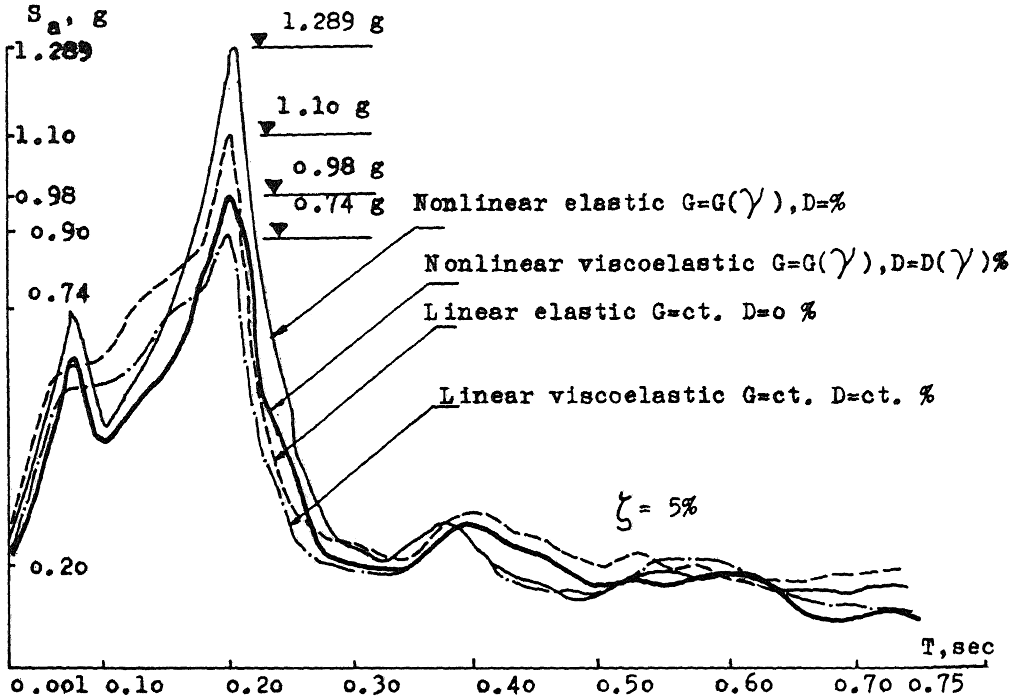

Fig. 4

Preprint EP-3o ICEFIZ,Buch.R.

Bratosin D.,1983,Contributions to stress and strain analysis of soils by considering the nonlinear and rheological properties (in romanian) Ph.D. Dissertation, ICEFIZ, Bucharest.

Isenberg I.,D.K.Vaugham,G.L.Wojcik F.S.Wong,J.P.Wright,198o,A review of structure medium interaction analysis methods with application to SSMRP, Weidlinger Associates Menlo Park, California.

Schnabel Per B.,J.Lysmer,H.Bolton Seed, SHAKE a computer program for earthquake response analysis of horizontally layered sites. Report No. EERC 72-12,University of California.