Paper No. 1419. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

THE INFLUENCE OF THE SOIL MODELING UPON THE DYNAMIC (SEISMIC) RESPONSE OF THE SOIL-STRUCTURE SYSTEM

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ABSTRACT

The paper presents how two hard and soft soil deposits, for each considering three soil models, can influence the soil-structure system. As for structures there are studied two types, one flexible (steel tower) and the other stiff (industrial hall) on these soil deposits.

There are calculated : maximum accelerations, local amplification spectra, response spectra for accelerations and velocities in different points of the soil-structure system and stresses in some structure beams.

The paper emphasizes the interaction effect between different structures on different soil deposits, the influence of local conditions, soil models used and as a whole the interaction design for mitigation of seismic risk at important structures.

KEYWORDS

soil-structure interaction; soil non linearity; constitutive law; soil model; structural model;

INTRODUCTION

The object of this paper is to present a study of the influence of soil models (with their constitutive laws) of the foundation soil in the design of structures when taking into account the soil-structure seismic interaction.

The way we model soil is of great importance for the results obtained in the calculus of soil-structure interaction (stresses, spectra, accelerations, etc. in the soil deposit, foundation and structure).

The design of structures using soil-structure interaction gives us more real data about all elements needed in a safe design to mitigate the seismic risk.

SOIL-STRUCTURE SYSTEM MODELLING

For this experiment were chosen two types of soils and two types of structures to see the effect of different structures on different soils.

Soil Profiles and their Modelling

A soft soil deposit of loesses and marls is chosen for type 1 of soil, Fig. 1.
A hard soil deposit of limestone and grits stone is chosen for type 2 of soil, Fig. 2.

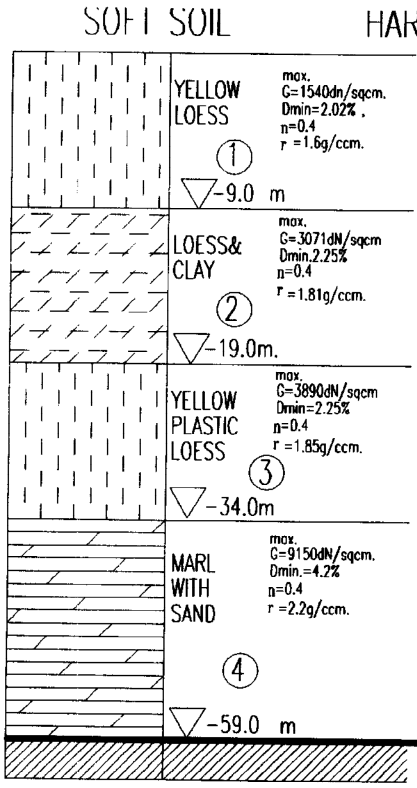

Fig. 1. Soft soil profile

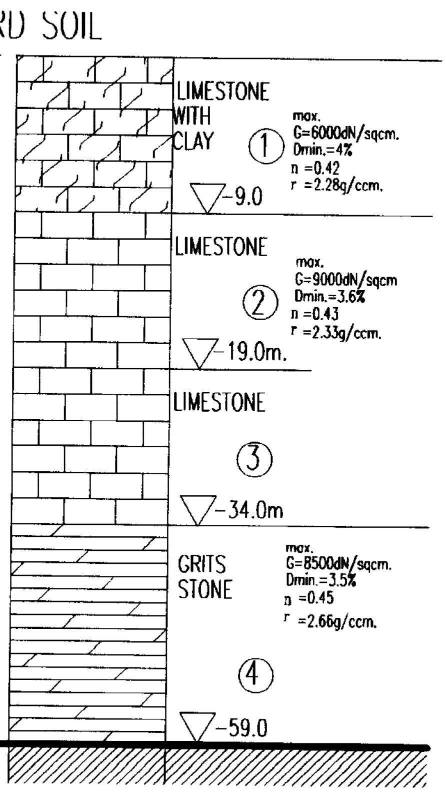

Fig. 2. Hard soil profile

It was determined the standard geotechnical data for the soil deposits and because the soil-structure interaction calculus takes into account the non linearity of the soil it was necessary to find the dependence of the shear modulus (G) and transversal damping (D) with shear strain (γ) during strong earthquakes.
This soil non linearity can be expressed in the functions G=G(γ) and D=D(γ).

For modelling of the soil it were used three constitutive laws :

- nonlinear viscoelastic model G=G(γ) and D=D(γ);
- linear viscoelastic model G=ct.(constant) and D=ct.;
- linear elastic model G=G(γ) and D=0.

Shear modulus functions G(γ) and damping functions D(γ) curves for every strata are found experimentally in the "Department of Seismology Engineering" (from N.I. E.P.) with the resonant columns Drnevich and Hardin.

Modelling of the Structures

For this experiment were chosen two types of structures: one stiff and one flexible to see the effect of different soils on different structures.

For the flexible, structure it was chosen a steel tower, Fig. 3., H=40.0m (height). With stiff base it has the characteristics :

- fundamental period 0.65 s;
- at top of the structure (node 71), horizontal displacement is 0.101m and horizontal acceleration is 1.04 g;
- horizontal acceleration of node 85 is 0.35g and at node 89 is 0.22 g;

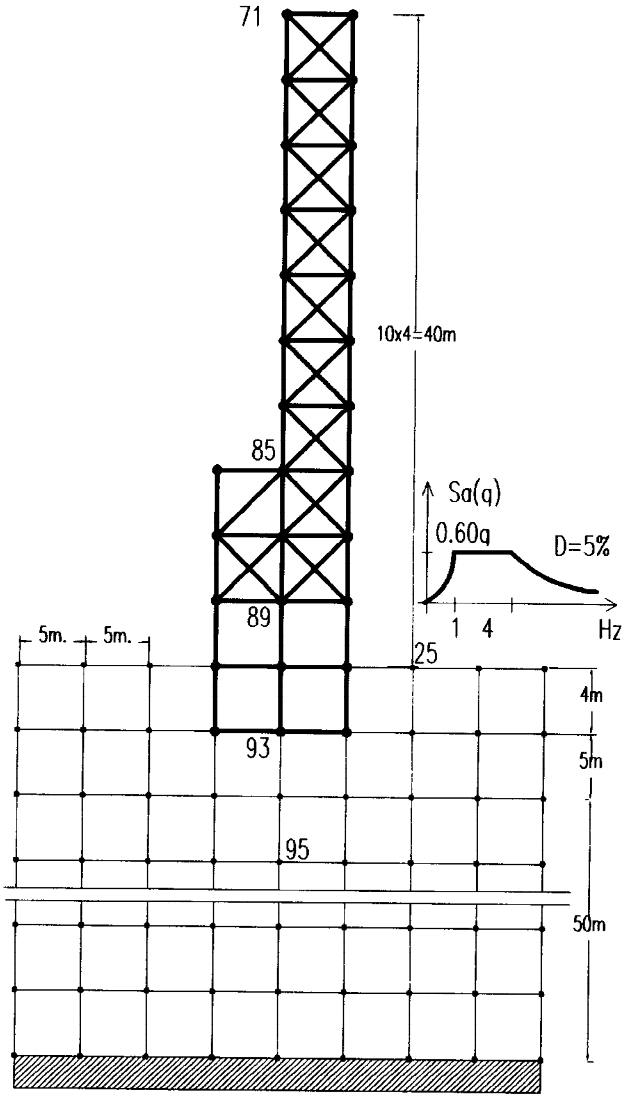

Fig. 3. Flexible structure.

For the stiff structure, it was chosen an industrial hall, Fig. 4., H=14 m. With stiff base it has the characteristics :

- fundamental period 0.31 s;
- maximum acceleration in node 55 is 1.602 g, in node 57 is 0.66 g and in node 59 is 0.18 g;
- maximum displacement in node 55 is 0.022m.

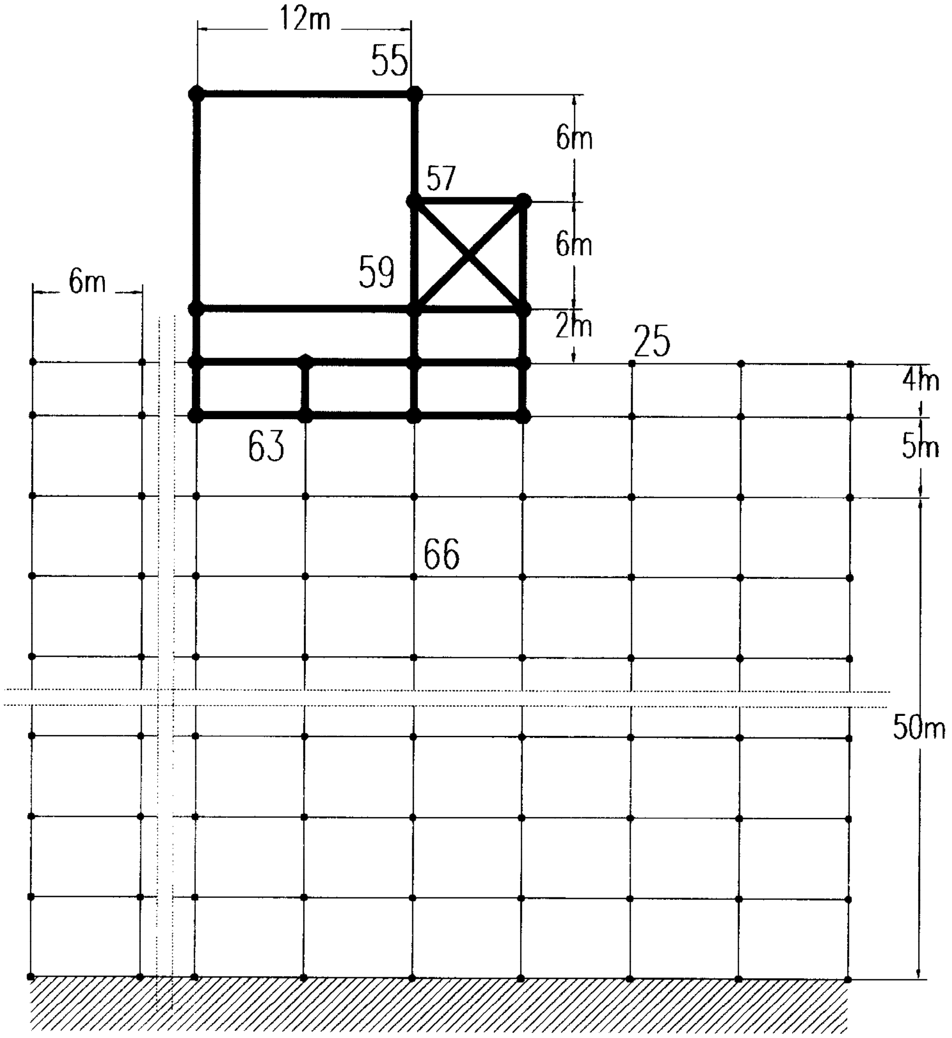

Fig. 4. Stiff structure.

The calculus of interaction soil-structure for both structures was made using the programs FLUSH and SAPLI 5, using each time the same seismic input in free field under the form of a design spectrum with 5% damping.
The influence of soil modelling will be emphasized by the response of the soil deposit and the structure in the assemble of soil-structure interaction.
These responses would be materialized through: accelerations, spectral values of absolute accelerations and relative velocities in different points of the system. Also it would be calculated shear forces, axial forces, and bending moments in some important beams of the structures.

RESULTS

Local Amplification Spectrum in Free Field

In Table 1. are presented the values of local amplification spectrum $|H(i\gamma)|$ between the 5-th layer and the surface of the first and second layer, with the frequencies where maximum amplification occurs. From Table 1 it can be seen the differences which appear due to the constitutive law used and also in function of the soil.

Table 1. Values of Fourier amplification functions in free field |H(iγ)|

Model (Constitutive law)	Hard Soil		Soft Soil	
	|H(iγ)|	f, Hz	|H(i γ)|	f, Hz
LAYER 1				
Nonlinear viscoelastic	0.054	2.44	0.063	1.27
Linear viscoelastic	0.060	2.19	0.132	1.46
Nonlinear elastic	0.263	2.44	0.733	1.31
LAYER 2				
Nonlinear viscoelastic	0.053	2.44	0.062	1.27
Linear Viscoelastic	0.059	2.19	0.130	1.46
Nonlinear elastic	0.260	2.44	0.722	1.31

Maximum Accelerations and Response Spectrum in Free Field

Having the Fourier amplification functions, we computed the accelerations at the upper level of layer 1 (0.00m) and 2 (-9.00m). The response spectra of absolute acceleration S_a (in g) and relative velocities, S_v (in m/s) for critical damping D=5% and the values of maximum accelerations, spectral accelerations and velocities are those in Table 2, all the values are function of the constitutive law and type of soil. Because we are in free field, there is no influence of the structure .

Table 2. Maximum accelerations and spectral values in free field (D=5%)

Constitutive Law	HARD SOIL			SOFT SOIL		
	a_{max}	S_a(g)	S_v(m/s)	a_{max}	S_a(g)	S_v(m/s)
LAYER 1						
Nonlinear viscoelastic	0.1993	0.668 T=0.51 s	0.948 T=1.01 s	0.214	0.621 T=0.51 s	0.960 T=1.01 s
Linear viscoelastic	0.1991	0.675 T=0.51 s	0.948 T=1.01 s	0.213	0.627 T=0.78 s	0.960 T=1.01 s
Nonlinear elastic	0.3035	1.1 T=0.08 s	0.948 T=1.01 s	0.381	1.91 T=0.13 s	0.960 m/s T=1.01 s
LAYER 2						
Nonlinear viscoelastic	0.1977	0.660 T=o.51 s	0.955 T=1.01 s	0.204	0.610 T=0.51 s	0.940 T=1.01 s
Linear viscoelastic	0.1960	0.670 T=0.51 s	0.955 T=1.01 s	0.202	0.621 T=0.78 s	0.940 T=1.01 s
Nonlinear elastic	0.2054	0.669 T=o.51 s	0.955 T=1.01 s	0.268	1.11 T=0.16 s	0.94o T=1.01 s

Dynamic amplification factor between spectral acceleration (S_a) and maximum acceleration (a_{max}) is between 3.35 and 3.62 at a hard soil and around 2.90 in the case of a soft soil, data in concordance with speciality literature.

Maximum Accelerations and Response Spectra in the Soil-Structure System

Both soil-structure systems were analyzed with the computer program FLUSH (Lysmer et al.,1975) in the assumption of modeling each soil layer through a model previously presented.
Values of maximum accelerations are presented in Table 3 and spectral values of absolute accelerations and relative velocities are presented in Table 4.

Table 3. Maximum accelerations (g) in some points of the soil-structure system

Constitutive Law	FLEXIBLE STRUCTURE			STIFF STRUCTURE		
	Node	Hard Soil	Soft Soil	Node	Hard Soil	Soft Soil
Nonlinear Viscoelastic	71	0.8700	0.6251	55	1.2151	1.0658
	85	0.2647	0.2390	57	0.4911	0.3941
	89	0.2266	0.2168	59	0.2827	0.3270
	93	0.2127	0.1976	63	0.2481	0.2837
	95	0.2107	0.2162	66	0.1960	0.2287
	25	0.2122	0.1993	25	0.2426	0.2574
Linear Viscoelastic	71	0.4797	0.5682	55	1.4806	1.0907
	85	0.2104	0.2345	57	0.4726	0.5305
	89	0.2017	0.2156	59	0.3283	0.3179
	93	0.1912	0.1963	63	0.2726	0.2812
	95	0.1962	0.2140	66	0.2134	0.2207
	25	0.1953	0.2000	25	0.2811	0.2632
Nonlinear Elastic	71	0.9431	0.7061	55	1.5920	1.4776
	85	0.2622	0.3045	57	0.5606	0.5674
	89	0.2289	0.2920	59	0.2925	0.3382
	93	0.2261	0.3923	63	0.2513	0.3007
	95	0.2156	0.2130	66	0.1968	0.2493
	25	0.2290	0.2679	25	0.2472	0.2672

Table 4. Response spectra of absolute accelerations and relative velocities (D=5%)

Constitutive Law	HARD SOIL			SOFT SOIL		
	NODE	S_a(g)	S_v(m/s)	NODE	S_a(g)	S_v(m/s)
FLEXIBLE STRUCTURE						
Nonlinear viscoelastic	71	4.430 T=0.219 s	1.72 T=0.259 s	71	2.57 T=0.308 s	1.34 T=1.01 s
Linear viscoelastic	71	1.958 T=0.259 s	1.13 T=1.01 s	71	2.17 T=308 s	1.34 T=854 s
Nonlinear elastic	71	4.90 T=0.219 s	1.91 T=0.259 s	71	3.27 T=0.308 s	1.32 T=0.854 s
STIFF STRUCTURE						
Nonlinear viscoelastic	55	3.99 T=0.201 s	1.80 T=0.201	55	3.18 T=0.282 s	1.40 T=0.282 s
Linear viscoelastic	55	4.88 T=0.201 s	1.85 T=0.201 s	55	3.27 T=0.219	1.88 T=0.219 s
Nonlinear elastic	55	5.27 T=0.201 s	1.95 T=0.201 s	55	2.16 T=0.219 s	1.70 T=0.219 s

The values of maximum accelerations in all points of interest of the flexible structure are less than those calculated in the assumption of a stiff base, for example in node 71 -stiff base case assumption- horizontal maximum acceleration is 1.044g than 0.87g in the nonlinear viscoelastic case assumption with a hard soil and is 0.4797g and 0.9431g (Table 3.) with the linear viscoelastic, respectively nonlinear elastic model.
With a soft soil, also with the flexible structure, maximum accelerations are less for nonlinear viscoelastic model (0.6251g) than for the nonlinear elastic model (0.7061g). It is observed a slightly grow of the maximum acceleration for the flexible structure, soft soil, linear viscoelastic model, (0.5682g), compared with hard soil (0.4797g). Using the nonlinear elastic model leads to the greatest acceleration compared with the other models.

For the stiff structure Fig. 3. -node 59, Table 3.- the situation is different, the values of maximum accelerations are greater than those obtained in the case of the stiff base.

The result, is very interesting, because it confirms some assumptions made by Yeh (Yeh,1971) and then by Velestos and Nair (Velestos and Nair, 1975). Yeh in conclusion -d- of the paper (Yeh,1971) at page 333 says:"The dynamic responses for the model disregarding the soil-structure interaction are lower than the responses for the model including the soil-structure interaction. This means that a design disregarding the soil-structure interaction can be non conservative"

The response spectral values (Table 4.) for a hard soil are greater then for a soft soil, with the exception of the linear viscoelastic model. The result is normal and if we compare the results obtained by all three constitutive laws used, than the smalest response values are obtained in the case of the nonlinear viscoelastic model.

From all data seen till here it was seen important differences in all analysed responses (accelerations, response spectra of accelerations and velocities), this being due to the three constitutive laws used, type of structure and soil.

Stresses in the Structures Beams

Another aspect of the seismic soil-structure interaction is the variance of the stresses (shear forces,T, axial forces,N, and bending moments,M,) in the principal beams of the structures, function of the soil type and constitutive law.

In the case of the flexible structure, it can be seen clearly the interaction effects, axial forces (N) and shear forces (T) are much less than those computed in the hypothesis of the structure with stiff base. Stresses N, T, and M computed in the case of hard soil for the nonlinear viscoelastic and nonlinear elastic model are greater than those obtained in the same conditions for a soft soil.

With the linear viscoelastic model (G=ct. and D=ct.) of the soil deposit, one of the classical design methods, stresses: N,M and T are less when the soil is hard.

In the case of the rigid structure it was made the same analysis as before (2 types of soils and 3 constitutive laws). The stresses in the beams of the stiff structure on a hard soil with a nonlinear viscoelastic and nonlinear elastic are in general smaller than those computed in the hypothesis of the structure on a soft soil, an opposite situation than that obtained before for the flexible structure.
For the linear viscoelastic model with hard soil, the stresses in the structure beams are in general greater than those computed in the hypothesis of a soft soil, opposite situation than that obtained for flexible structure.

From all these observations it is seen that the soil model used has also a great influence on the values of the stresses at the beam level in the structure.

CONCLUSIONS

The nonlinear response of the soil deposit, influences through the seismic input, the response of the structure. The stiffness and damping characteristics of every stratum generates "in detail" the way in which the local ground movements are modified.

The response spectra values in the case of a stiff ground are greater than those for a soft ground except for the soil modeled with a linear viscoelastic law, normal result and if we compare the results obtained with the three constitutive laws in modeling the ground, the smallest response values are obtained in the case of the nonlinear viscoelastic model.

Bending moments, shear and axial forces in the beams of the flexible structure of the soil-structure system are much less than these computed for the stiff base structure.

The soil-structure interaction is valid as well for the hard and soft ground in any case of constitutive law used.

For relatively large and important buildings it is worth the soil-structure interaction design to promote safe and economic buildings and to choose the right structure configuration for the site, considering local conditions to mitigate the seismic risk.

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