Laboratório de Dinâmica Estrutural e Confiabilidade
Universidade Federal do Rio Grande do Sul
Porto Alegre, Brazil

Model Uncertainty and Analyst Qualification in Soil-Structure Interaction Analysis

Jorge Daniel Riera
UFRGS, Porto Alegre, RS, Brazil

Introduction

- The influence of model uncertainty was largely neglected in early stages of development of the Theory of Structural Reliability and as a direct consequence it remains virtually ignored in structural design codes and in engineering practice in general.

- By *model uncertainty* we mean the variability of the predictions of the response of a fully defined structural system subjected to an equally completely defined excitation, by the particular model, computer program and assumptions adopted by the designer.

Introduction

- Model uncertainty may be quantified, in the absence of other uncertainties, by the coefficient of variation (CV) of the design estimate.

- It has been observed in Round Robin experiments that in linear systems subjected to static loads this CV is of the order of 5%, but increases for dynamic loading and non-linear systems, reaching values that may exceed 20%.

Introduction

- Thus, model uncertainty *may be more relevant* in the decision making process than the uncertainties concerning the excitation or the system properties.

- The assertion above will be illustrated by examples. One additional difficulty is posed by the sources of uncertainty: excitation, system properties and model employed, are not truly uncoupled.

A case study

- The specification of a smoothed, broad-band seismic spectrum at rock outcrop has been a standard procedure in seismic design of NPP structures.

- When soil deposits are found overlying the base rock, the seismic waves propagating to the site are filtered through the soil layers, resulting in a modified spectrum at the free surface or at intermediate depths.

A case study

- Studies conducted at Angra 2 NPP in Brazil that illustrate the relevence of model uncertainty will be described in this section.

- Next Figure shows the future location of Angra 3 NPP, presently under design. The containment dome of Angra 2 may be seen below at right, while the containment of Angra 1 is further right.

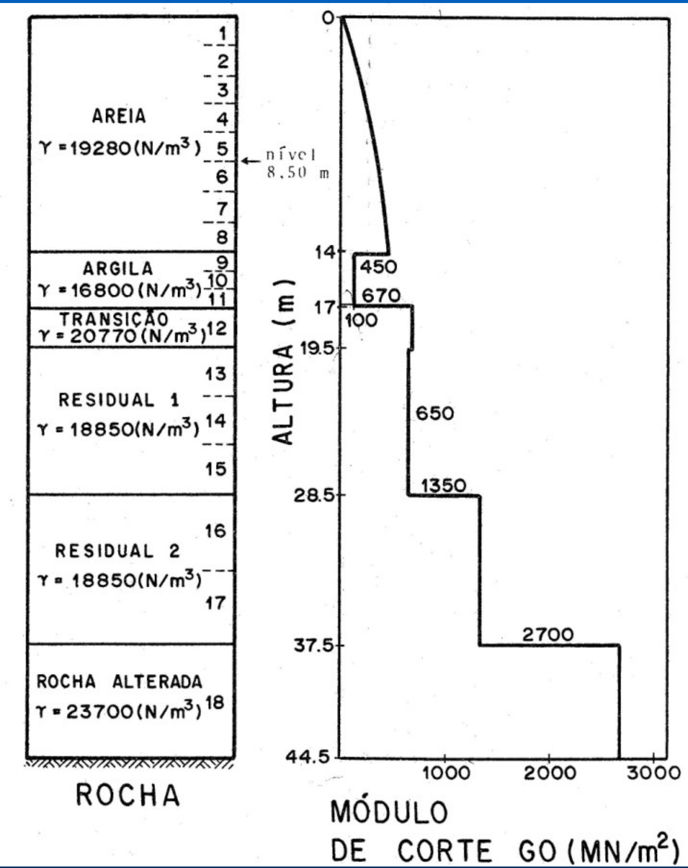
Angra NPP site (Rio de Janeiro, Brazil)

A case study

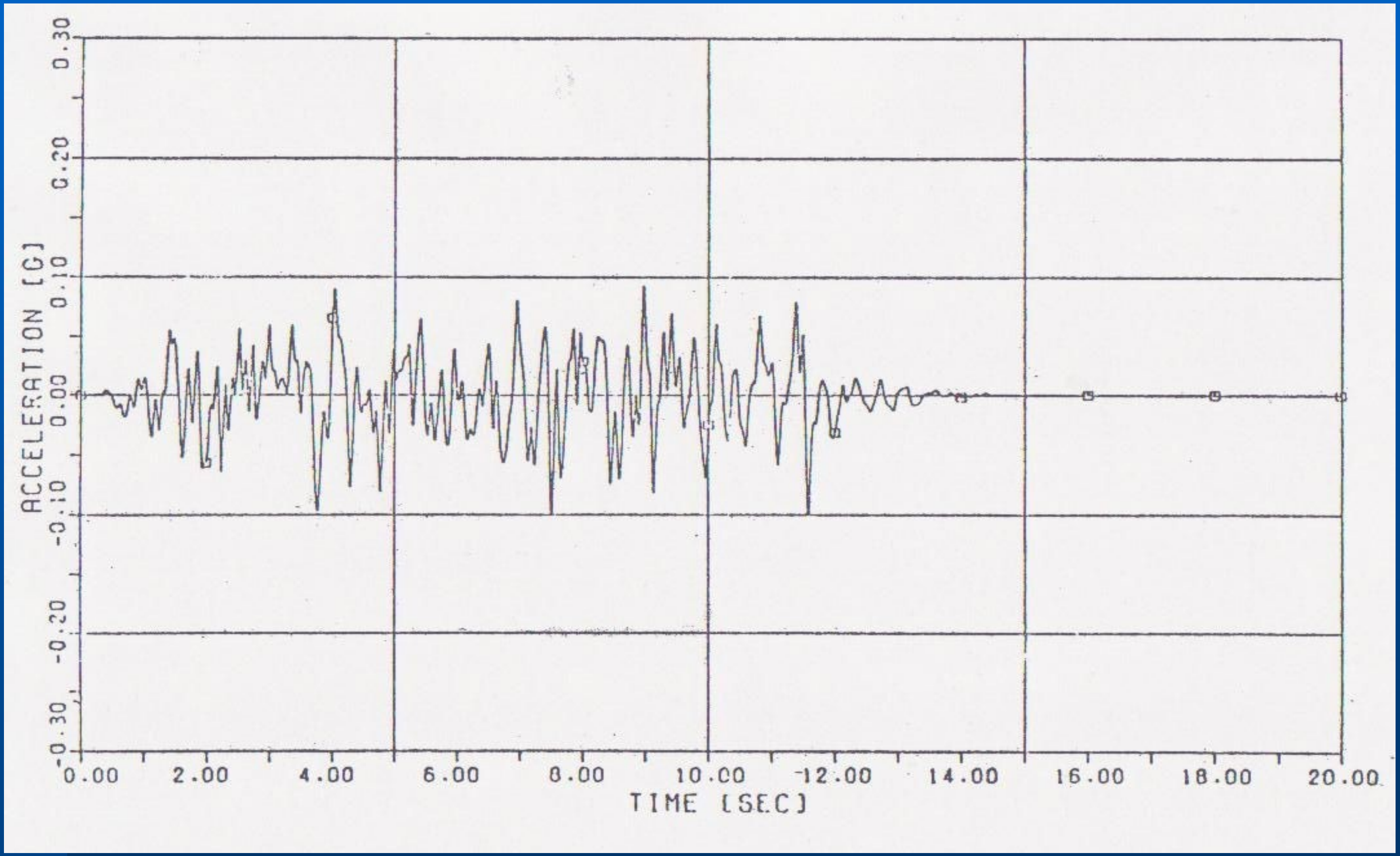
- Units 1 and 3 are located on rock outcrops, while Unit 2 is above roughly 50m of soft and intermediate soil layers.

- Due to this particular circumstance, the nuclear island of Angra 2 was founded on piles. The types and properties of the soil above unweathered rock surface at the site are indicated next.

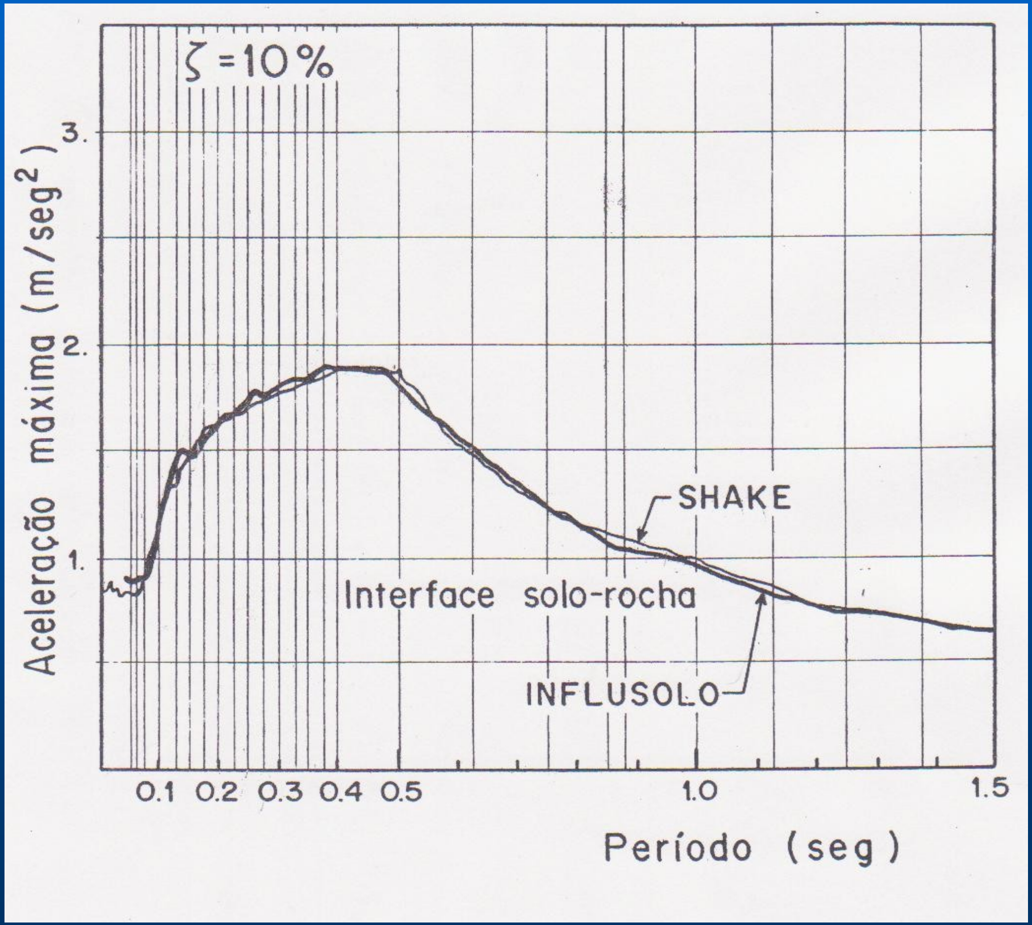
Soil Profile at the site of Angra 2 NPP



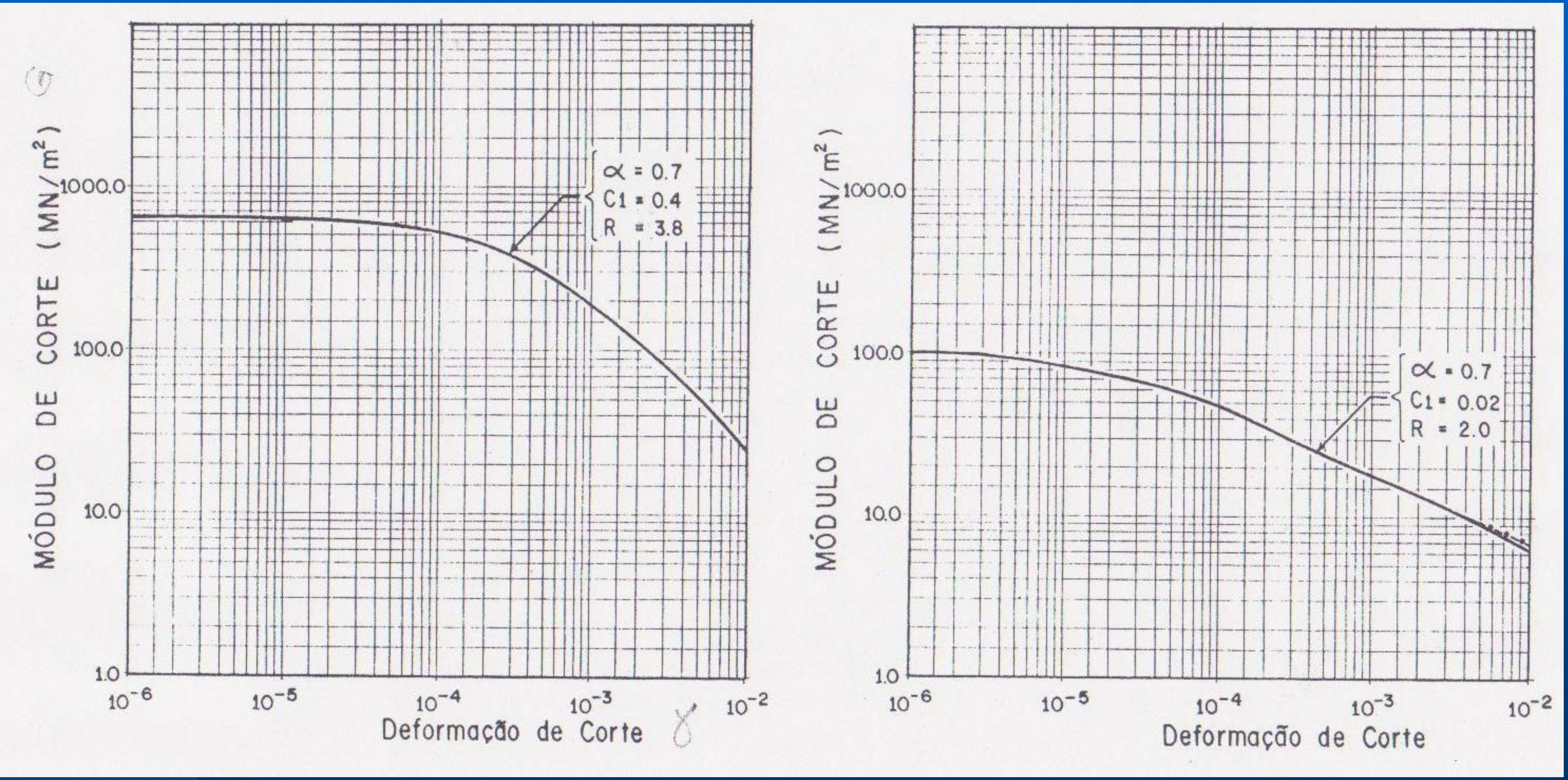
Acceleration time history at rock surface



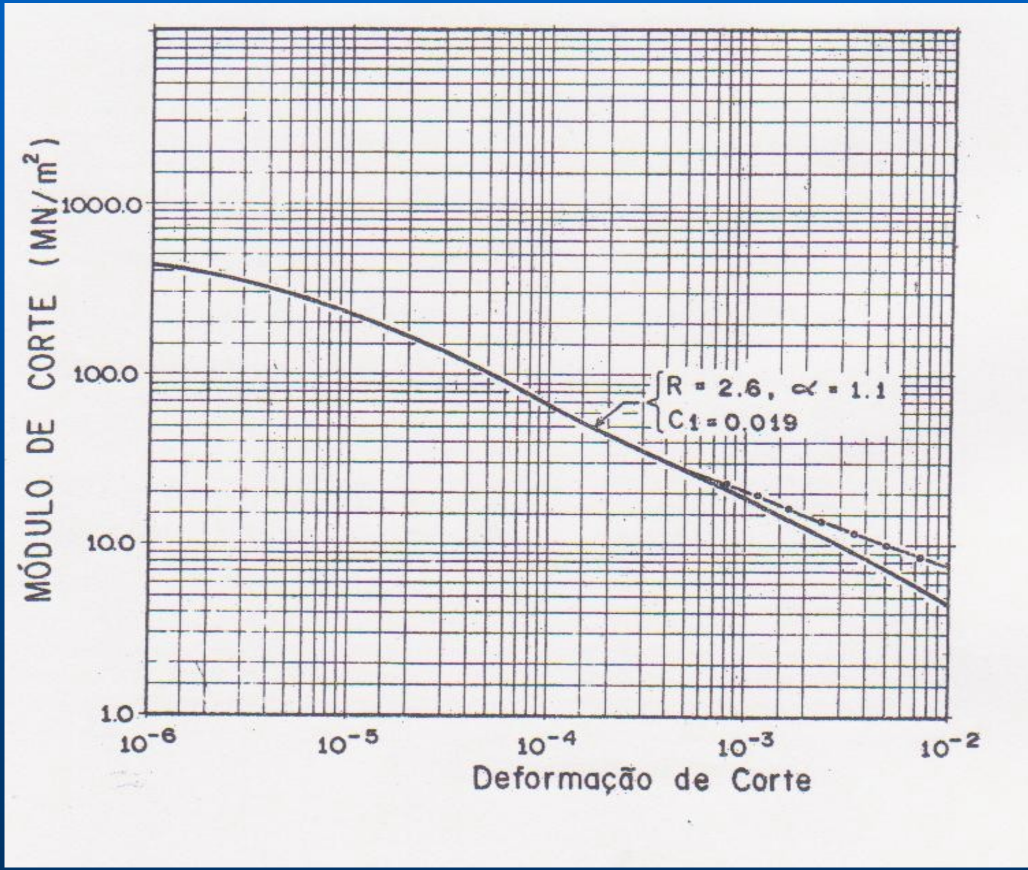
Response spectrum at rock-soil interface



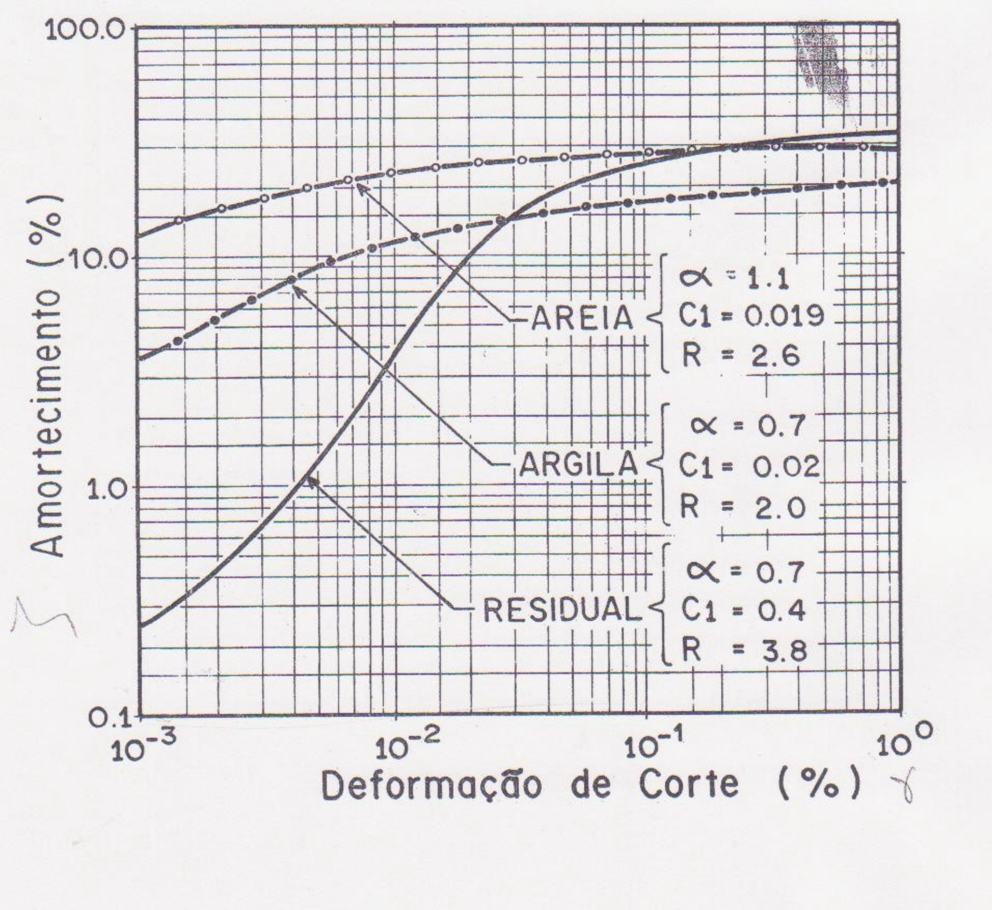
Soil Properties vs. Strain Amplitude



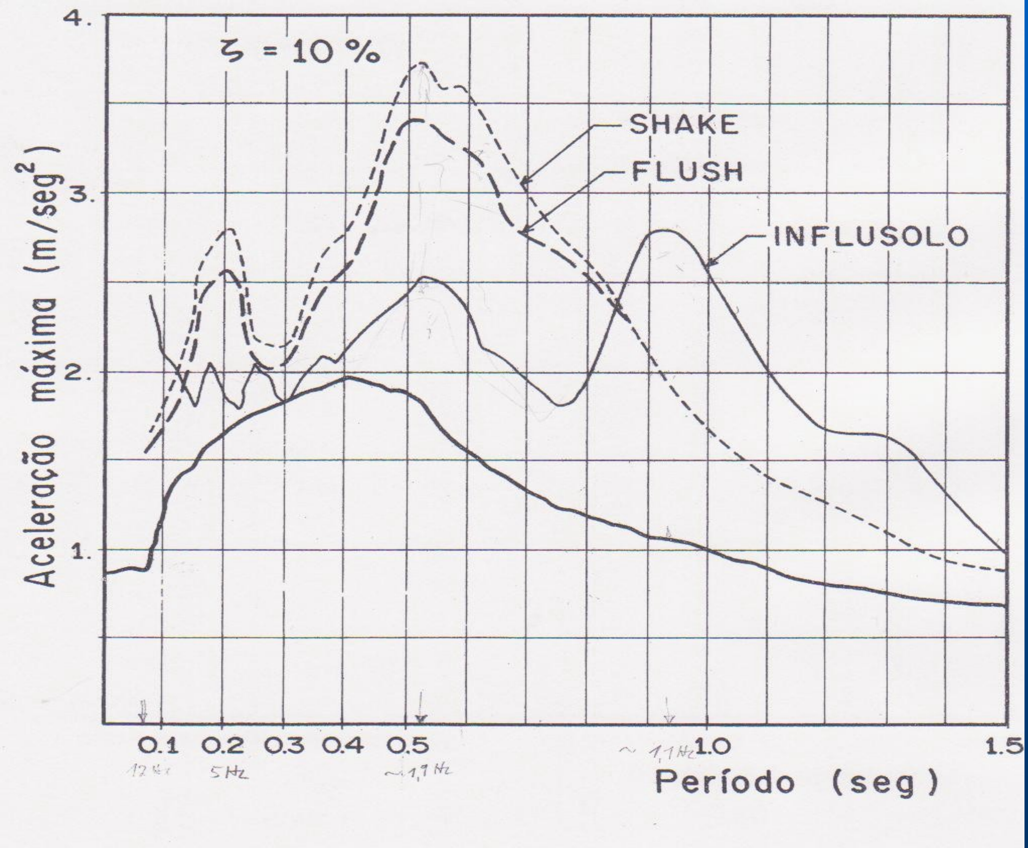
Soil Properties vs. Strain Amplitude



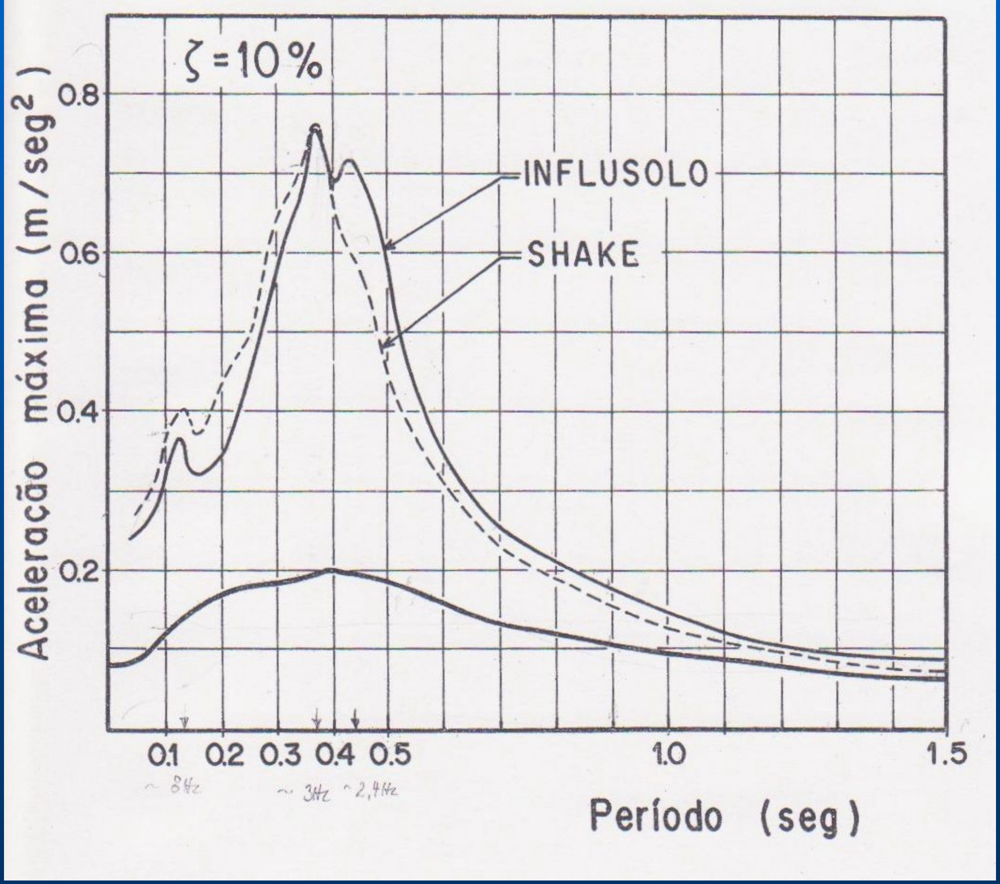
Soil Properties vs. Strain Amplitude



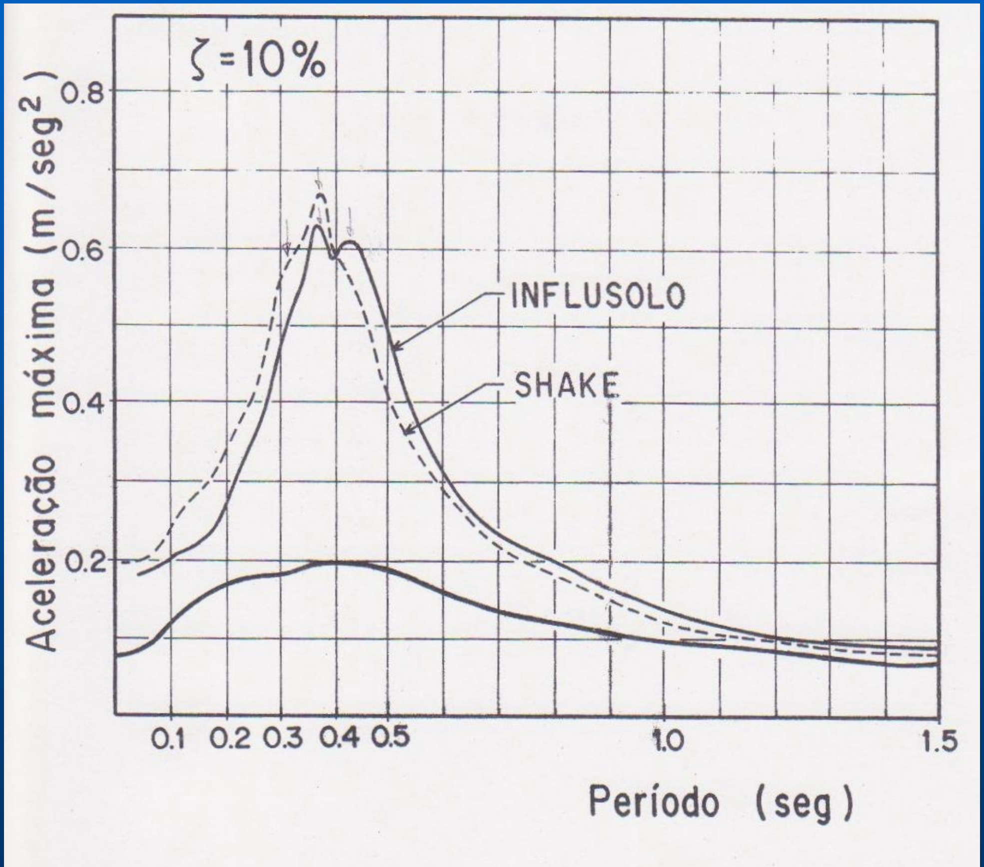
Seismic Response Spectra at surface



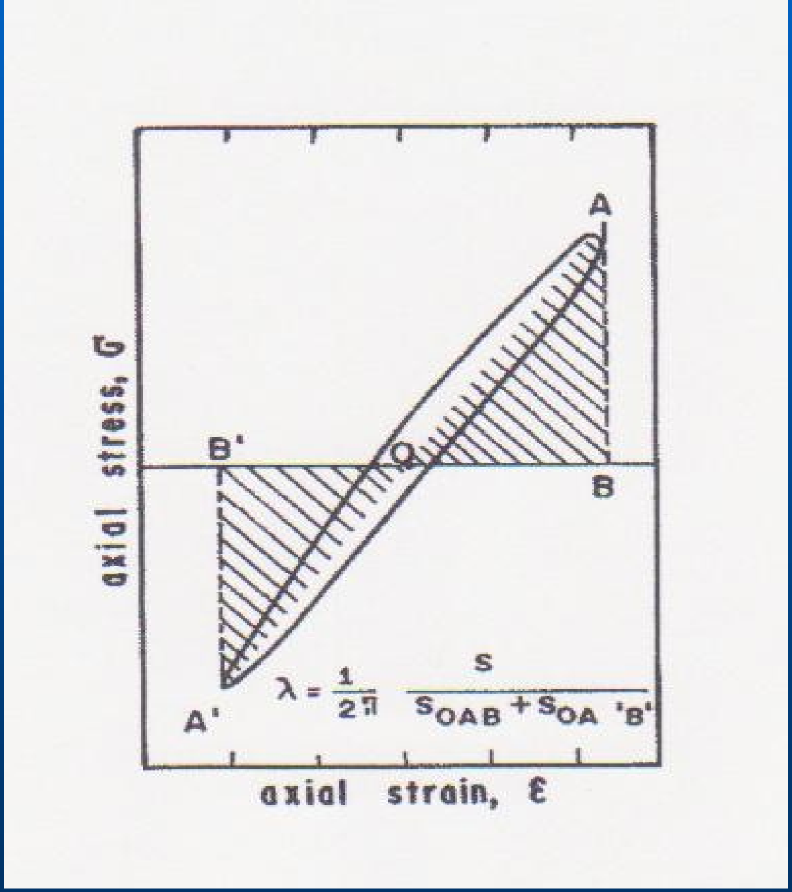
Seismic Response Spectra at surface



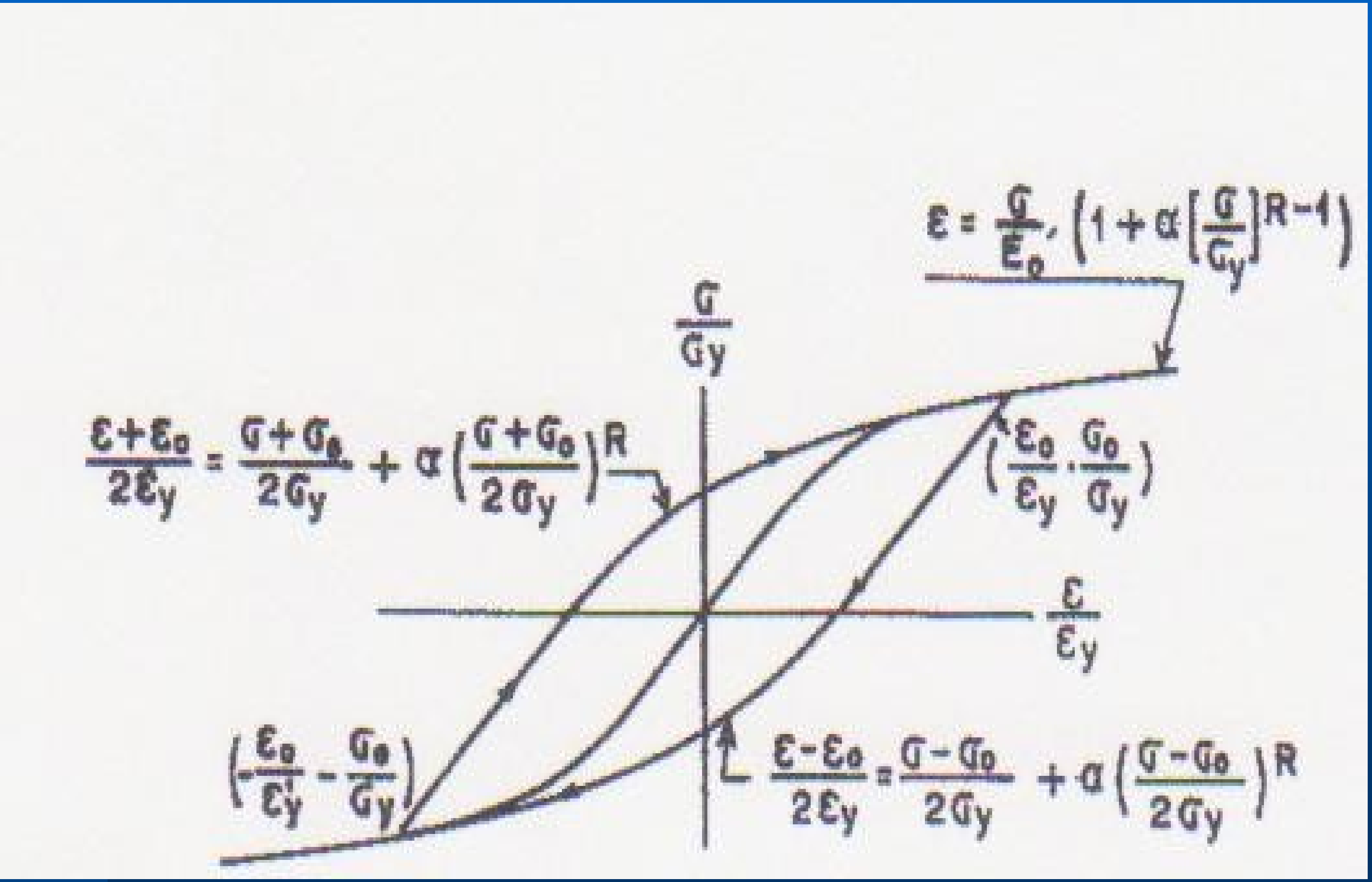
Seismic Response Spectra at surface



On effective stiffness and damping 18

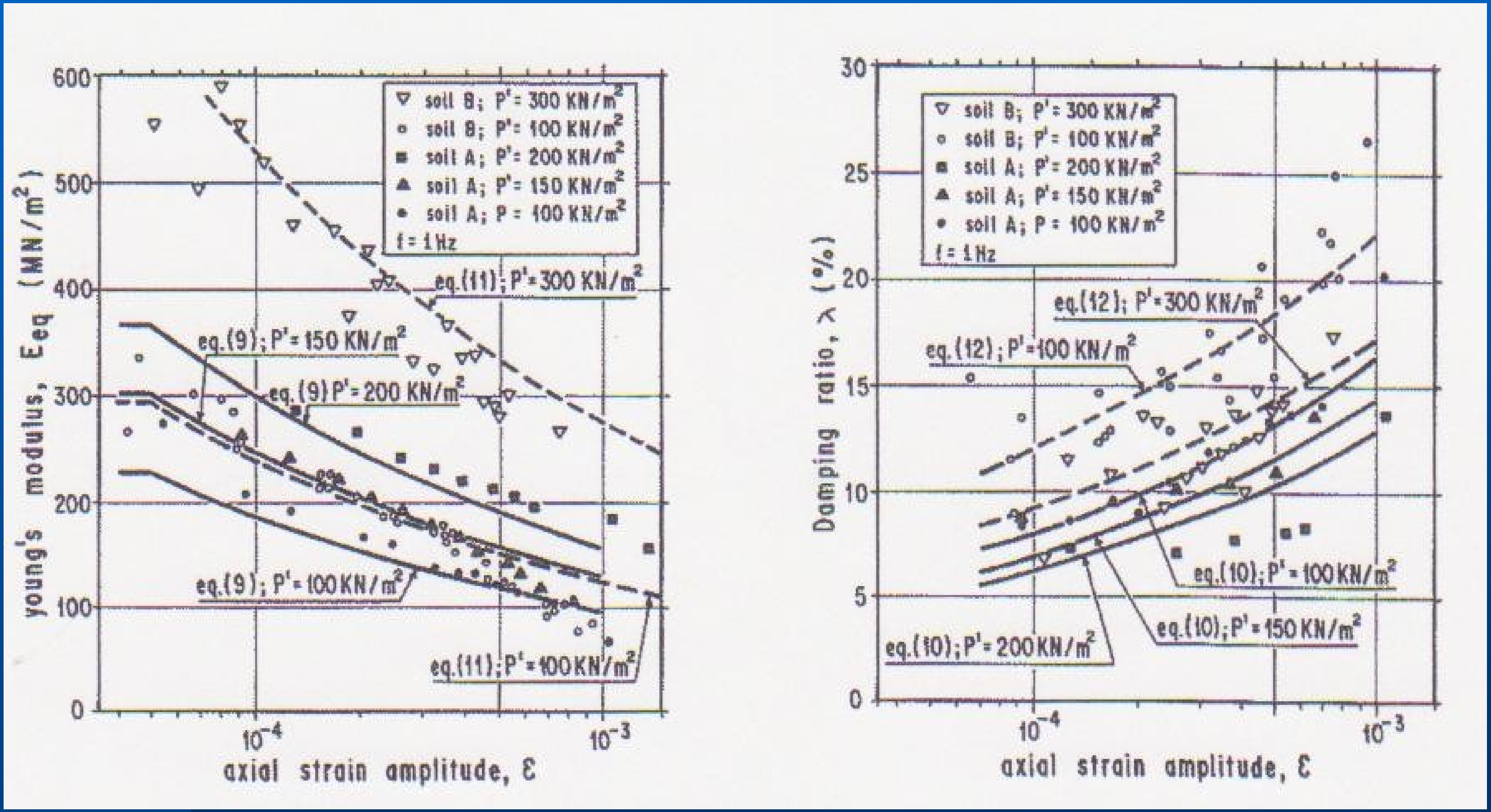


On effective stiffness and damping 19



On effective stiffness and damping

Empirical equations (Bica, Riera & Nanni, 1993)



Model uncertainty in soil amplification studies

- In applications 1-D models are often employed to account for the influence of soil layers above the rock surface, which implies accepting the hypothesis of uni-directional motion of the base, as implemented in both SHAKE and CHARSOIL programs.
- This implies neglecting the influence of the other horizontal and the vertical components of the base rock acceleration.

Model uncertainty in soil amplification studies

- In case of linearly elastic isotropic materials and horizontally stratified deposits, the resulting motions in the three coordinate directions are uncoupled. Thus, the response in each direction can be determined independently and the principle of superposition holds.

- If the material is nonlinear, a 3D analysis would be required.

Model uncertainty in soil amplification studies

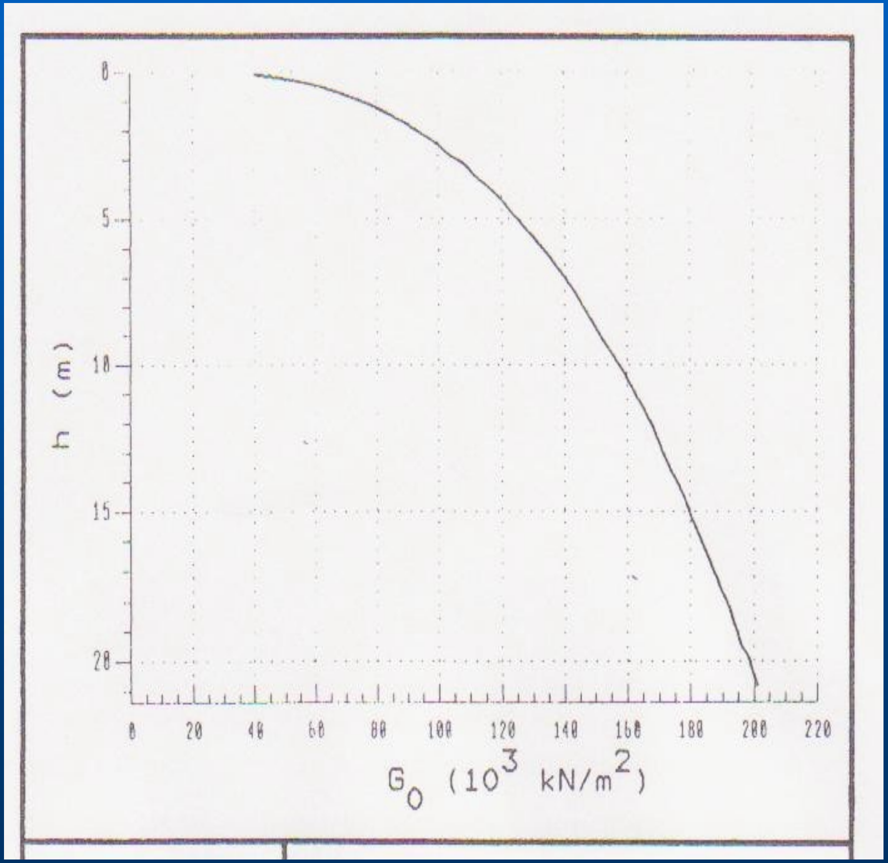
- For various reasons, a 3D analysis is rarely performed. The model error implicit in a 1D model was examined by Capelli and Riera (1993).

- The behavior of the soil subjected to cyclic loading was modelled employing the hyperbolic relations proposed by Kodner (1963) for the stress difference ($\sigma_1 - \sigma_3$) vs. strain relation. Duncan & Chang (1970) and Duncan (1981) presented the formulation adopted herein, which neglects the influence of the intermediate principal stress σ_2.

Model uncertainty in soil amplification studies

- A 22m thick sand deposit above the rock interface was considered in the example. The discretization for the numerical analysis and the parameters of Duncan-s model (1981) for the variouis layers may be found in Capelli (1990).
- The motion corresponding to the three components of the Port Hueneme earthquake of March 18, 1957 was applied as input at the base rock interface. The PGA for the horizontal components was slighly larger than 0.2g, while the vertical component had a PGA equal to 0.06g.

Model uncertainty in soil amplification studies 22



Model uncertainty in soil amplification studies 23

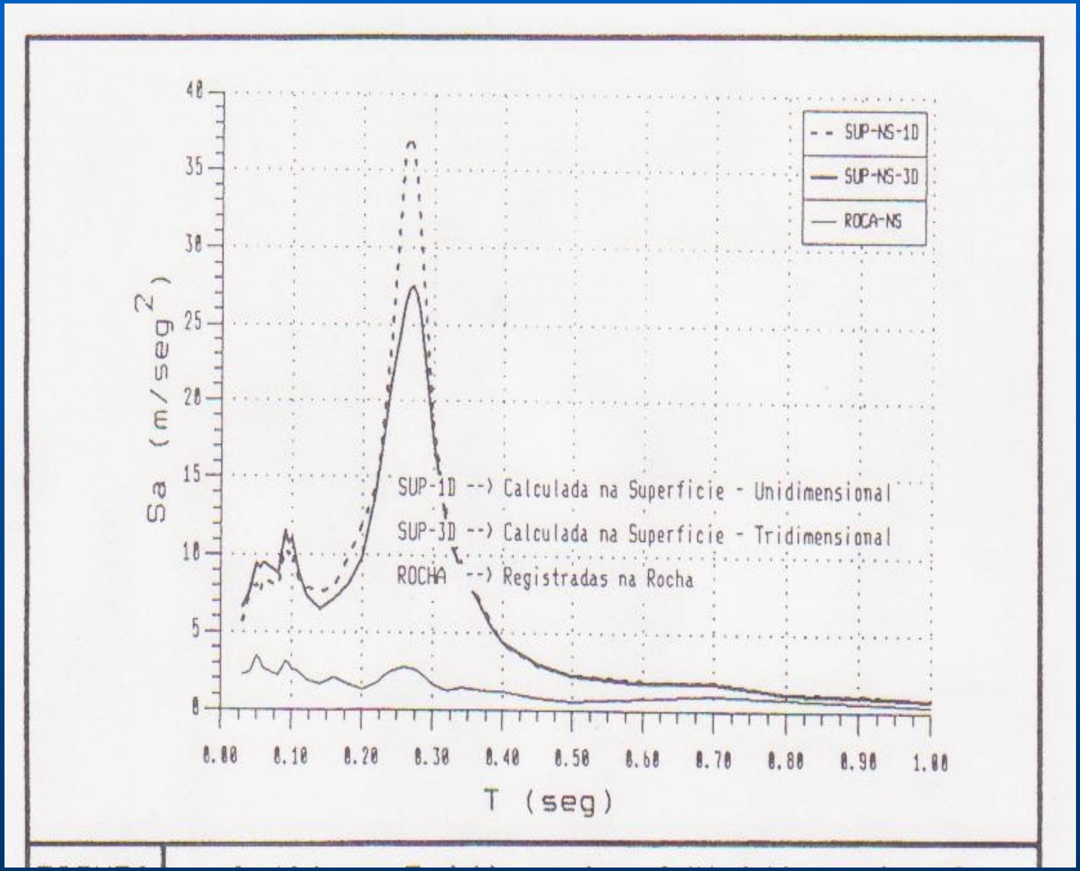
- The response spectra at the surface for the 1-D analysis (one component acting at a time) differed from the spectra computed for the three components acting simultaneously by less than 2% of the mean values, thus confirming the premise that *for linear or almost linear material behavior the acceleration time-histories in the three orthogonal directions are uncoupled.*

Model uncertainty in soil amplification studies

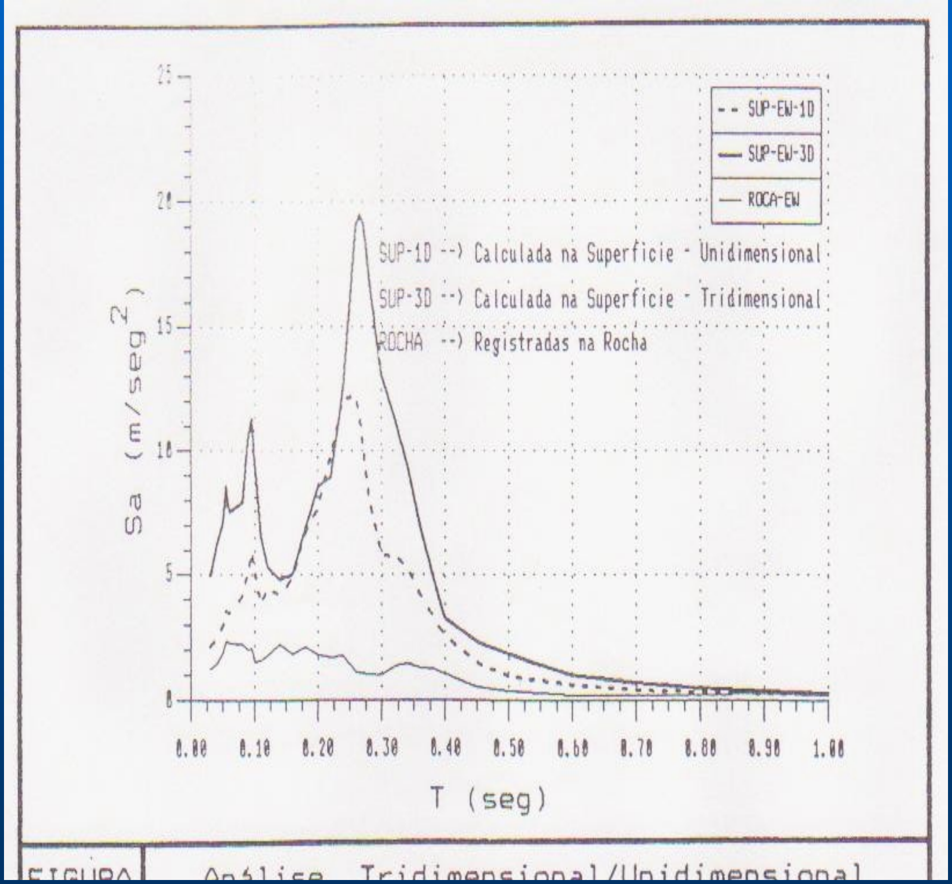
- On the other hand, when the base motion is amplified three times, reaching PGA values of 0.6g, the spectra shown next result. Significant differences in the peak values of the response spectra at the surface predicted by the 1-D and the 3-D models can be seen.

- Also large differences were detected, in the reported case as well as in other examples, in the high frequency range (above 5 Hz), although the latter have marginal importance for design or in reliability studies.

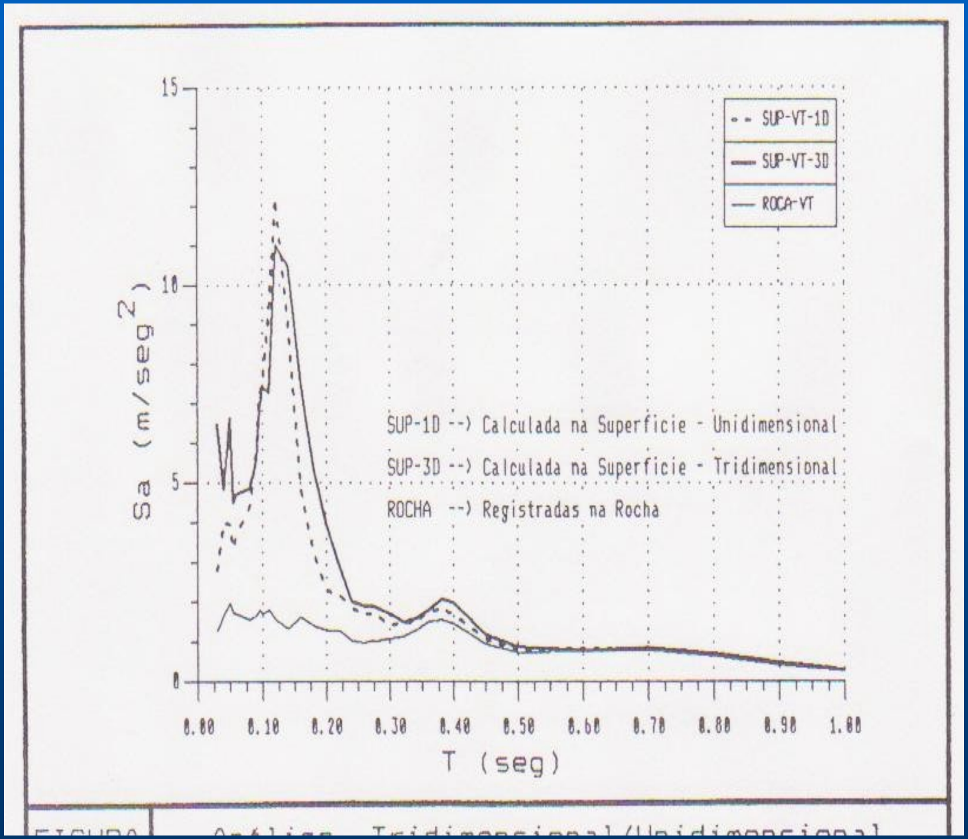
Model uncertainty in soil amplification studies 26



Model uncertainty in soil amplification studies



Model uncertainty in soil amplification studies 28



Preliminary assessment of model uncertainty in SSI studies 29

- Seismic response spectra constitute widely used tools in seismic engineering analysis and design and therefore attention will be initially paid to the assessment of model uncertainty in connection with the determination of site specific spectra considering local soil properties.

- Let $S_{a\,i}(T)$ designate the seismic acceleration spectrum determined employing model i, $i = 1, N$, in which T denotes the period and N the number of models available.

Preliminary assessment of model uncertainty in SSI studies 30

- For any period T, the best estimate of the spectral acceleration would be the mean $E\,[S_a\,(T)]$ of the various models:

$$E\,[S_a\,(T)] = \mu_{Sa} = [\,\Sigma\, S_{a\,i}(T)\,]\,/\,N$$

While the variance σ_{Sa}^{2} and the coefficient of variation CV may be estimated by:

$$\sigma_{Sa}^{2} = \{\,\Sigma\,[S_{a\,i}(T) - \mu_{Sa}]^2\,\}\ /\ (N\text{-}1)$$

$$CV\,(T) = \sigma_{Sa}\,/\,\mu_{Sa}$$

Preliminary assessment of model uncertainty in SSI studies 31

- A global coefficient of variation μ_{CV} *due to model uncertainty* of the seismic response spectrum under consideration may be computed as:

  $$\mu_{CV} = \int CV\,(T)\; dT \,/\, T_c$$

  In which the integral is calculated between 0 and a cut-off frequency T_c

  A simpler and perhaps more useful measure of the response variability due to model uncertainty would be the *range*, that is the difference between the largest and smallest amplitudes of the predicted spectra.

- In the following, a measure of the variability will be defined as the range divided by the mean (*normalized range)*:

$$Y\,(T) = [S_{a\,max}\,(T) - S_{a\,min}(T)]\;/\;E\,[S_a\;(T)]$$

In which $S_{a\,max}\,(T)$ and $S_{a\,min}(T)$ denote the highest and lowest spectral accelerations predicted by the various models at period T. The largest value of the normalized range is defined as:

$$Y_{max} = \max \mid Y\,(T) \mid , \qquad 0 < T < T_c$$

- For the case study described in Section 2, the following global coefficients of variation and largest value of the normalized range obtained with T_c = 1.5s are the following:

(a) Free surface, PGA= 0.01g, μ_{CV} = 0.070, Y_{max} = 0.19
(b) Level –8.50m , PGA = 0.01g, μ_{CV} = 0.068, Y_{max} = 0.20
(c) Free surface, PGA= 0.10g, μ_{CV} = 0.193, Y_{max} = 0.38

Preliminary assessment of model uncertainty in SSI studies

- It may be seen that the CV may be estimated as roughly half the normalized range. On the other hand, for the case study described in Section 3, the largest values of the normalized range obtained with T_c= 1.0 s are the following:

(a)	Free surface, PGA = .06g,	all cases,	$Y_{max} < 0.04$
(b)	Free surface, PGA = 0.2g,	NS orientation	$Y_{max} = 0.38$
(c)	Free surface, PGA = 0.2g,	EW orientation	$Y_{max} = 0.60$
(d)	Free surface, PGA = 0.2g,	VT orientation	$Y_{max} = 0.40$

- For Gaussian random variables the normalized range in the case of just two observations differs marginally from one coefficient of variation, which means that the CV appear to be non-Gaussian. The following simple relation was obtained by linear regression for the expected value of the coefficient of variation of the spectral amplitudes at the surface of *soft soil sites* in terms of the PGA at the underlying rock interface:

$$\mu_{CV} = 0.05 + \ (PGA/g) \qquad\qquad (PGA/g) < 0.5$$

Equation (4.7) provides an estimate of model error in the numerical determination of seismic response spectra for soil deposits overlying rock outcrops.

Conclusions

- With the objective of calling attention to the relevance of model error in engineering analysis and design, seismic soil amplification studies were described. In agreement with evidence already available in other areas, it is shown that uncertainty increases with the degree of nonlinearity of the structural model and a tentative empirical expression is proposed for the specific case of acceleration response spectra on soil deposits.

- The potential effects or influence of phenomenological uncertainty and human error were also mentioned, because both subjects deserve a more consistent treatment in reliability assessments as well as in design recommendations.