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RELATIONSHIP SOIL-STRUCTURE UPON FUNDAMENTAL DYNAMICS PROPERTIES OF ORDINARY BUILDINGS

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ABSTRACT

This paper deals briefly with the results of a wide parametric analysis of the relationship between soil-structure to determine fundamental dynamic properties of ordinary buildings.

The parametric analysis has been developed on a broad set of ideal buildings in which characteristics are representative of actual structure. The evaluation was based on Prof. Jacobo Bielak`s simple methodology. Results clearly show a reduction the frecuencies proper of the system vibration, a variation of global damping factor and a change of the modal vibrating forms, as compared to those obtained for a structure with a base condition.

KEYWORDS

Soil-structure interaction; interaction effects; dynamics properties; fundamental period; flexible base; parametric evaluation; regular buildings; ordinary building; impedance functions; histeretic damping.

PARAMETRIC EVALUATION

Using as a basis the simple methodology proposed by the Professor J. Bielak (Bielak, 1975), it was proceed to make a parametric evaluation about an ideal family of buildings, to study the influence that different factors have on the soil-structure interaction effects.

For the definition of the characteristics of each system, were taken into account some hypothesis oriented to describe representatives qualities of the structures so the foundation system. Among the most important parameters that were employed, can be pointed out; number of levels N, story height hi, total height of the building h, building radius r, slenderness relationship h/r, weight of each level Wi, building total weight W, fundamental period of the structure on stiff base T, structure damping ξ, foundation radius base ro, radius relationship R = ro/r, shear wave propagation speed Vs, poisson coefficient ν, histeretic soil damping factor D, among others.

Forward to simplify the parametric evaluation without taking it out generality, it were adopted constant values for some parameters that present little variation. Besides, it was established before some practical relationships among some of these parameters, proper of regular buildings, it worth to mention:

1. Were studied five (5) slenderness relationships, established before like h/r = 1-2-3-4-5, which ones can be linked to ideal buildings of 4-8-12-16 and 20 levels respectively, if it is considered a constant story height of hi = 3.00 meters and a building radius of r = 12.00 meters.

2. The story stiffness values have been defined, that for a pre-fixed fundamental period (**T**) and a constant mass distribution and story heights, the fundamental vibration mode will be linear. In particular, 3 possibilities were considered for each condition:

Flexible Building: $T_1 = 0.10$ N
Intermediate Building: T_2 (Average Value of T_1 and T_3)
Rigid Building: $T_3 = 0.061\ h^{3/4}$

The structure damping was supposed as a constant value: ξ=5%.

3. The base level it is conformed by a rigid disc of radius ro, mass mo, inertia Jo, supported on the surface of a half-space that represents the foundation medium.

The evaluation of dynamic impedance functions use as a basis the Veletsos and Verbic proposal (Veletsos and Verbic, 1973)) for the rigid disc vibration on a viscous-elastic medium.

The base radius is a parameter that shows the stiffness level of the building foundation system, and it is introduced through a no-dimensional parameter defined as Radius Relationship R = ro/r. In a particular were evaluated R values between 0.80 and 1.20.

4. With the purpose of describing the foundation medium, were adopted the following characteristic values; soil specific weight γs = 2 T/m^3, Poisson Modulus between 0.33 and 0.45 and it were considered four representatives values of Vs for the foundation medium:

Vs = 100 m/s .... Very soft soils
Vs = 150 m/s .... Soft soils
Vs = 300 m/s .... Intermediate soils
Vs = 600 m/s .... Hard soils

The histeretic damping factor represents the soil capacity to dissipate energy by histeretic action or by inelastic capacity of the material, it was adopted 3 representatives values for D according to strain levels induced on the medium during a seismic effect:

D = 0.0 - Strain low levels (elastic).
D = 0.2 - Strain intermediate levels.
D = 0.4 - Strain high levels.

RESULTS

The results that were obtained from the parametric evaluation have been organized in a way that permit to show the main effects of the soil-structure interaction, on the ideal building response supported on the surface of a flexible foundation medium.

It can be proved that the vibration fundamental mode is the most influenced by the soil-structure interaction effects. Now, considering the great influence of the first mode in the structure response under the seismic effects, it was employed the linked parameter in order to quantify the interaction effects in buildings.

In particular, it is emphasized the variations of the fundamental period of the system, the modal damping factor and vibration shape linked to the fundamental mode, to those obtained for the structure with rigid base condition.

Following this, it is defined the next parameters to quantify the interaction effects:

$\tilde{T} / T$....... Relationship between the system fundamental period on flexible base, regarding to fundamental period of the structure with rigid base.

$\tilde{\xi}$........... Critical damping factor, corresponding to system vibration fundamental mode on flexible base.

Therefore, it is proved that the main parameters that control the system response are :

- The relative stiffness parameter soil-structure, which it has been defined as $\phi = h / Vs\, T$
- Slenderness relationship: h/r
- Radius relationship: R = ro/r
- Soil histeretic damping factor: D

In particular, ϕ is a no-dimensional parameter that value for conventional buildings varies between 0.0 and 0.50. The adopted values in the evaluation are summarized in the table 1, independent of the considered height.

Table 1. Adopted values for the parameter ϕ = h/VsT

ϕ = h/VsT		Vs (m/s)			
Description	T	100	150	300	600
Flexible Building	T_1	0.30	0.20	0.10	0.05
Intermediate Building	T_2	0.369	0.246	0.123	0.062
Rigid Building	T_3	0.48	0.32	0.16	0.08

As it can be seen, these values apply to situations from low slenderness and very stiff buildings, to very slender and flexible ones, supported on ground with different levels of stiffness.

The results of $\tilde{T} / T$ and $\tilde{\xi}$ are presented through a whole of graphics due to no-dimensional parameters that control the system response (figures 1, 2 and 3).

The fact that the soil could show an inelastic behavior or histeretic has a remarked influence in modal damping factor of the system, so it can be shown in the figure 4.

If it is considered that the system total damping is composed by structural damping by one side, and by soil damping by the other, which are responsible of the dissipated energy in the foundation medium not only for the wave radiation but for the histeretic action or inelastic behavior of the material, then:

$$\tilde{\xi} = \xi_{est} + \xi_o \qquad (1)$$

The figure 5 shows the structural damping variation ξest with the period relationship $\tilde{T}/T$. Such variation can be fitted through the relationship:

$$\xi_{est} = \frac{0.05}{(\tilde{T}/T)^3} \qquad (2)$$

The soil damping ξ_o depends not only of the period relationship but of the soil histeretic damping factor, the slenderness relationship and radius relationship, as it can be noticed in the figure 6.

ONE D.O.F. EQUIVALENT OSCILLATOR ANALOGY

Based in the fact that the fundamental vibration mode is the most influenced by the soil-structure interaction effects and considering that it is important in the structure response under the seismic action, it has been employed a method to estimate the response of the system soil-structure fundamental vibration mode through a 1 freedom degree equivalent oscillator (Jennings and Bielak, 1973).

Such equivalent oscillator is conformed by a simple elastic system of one degree of freedom, which under the condition of rigid base it is characterized by a mass M_1, stiffness K_1, viscous damping ξ_1, and a height H_1, supported by a circular rigid base with mass mo and an approximated to zero thickness, supported on the viscous-elastic half-space surface.

Using as a basis the same ideal building family, that were pointed out before, it is verified that the values $\tilde{T}_1/T$ and the approximated ξ_1, fitted to those obtained with the model analysis application, previously employed to all the evaluated cases where the parameters were changed as ϕ, h/r, R, D, etc.

SIMPLIFIED MODEL IMPLEMENTATION

Because the excellent results obtained with the approximate methodology, and in order to quantify the result sensibility to the stiffness dependent coefficients (Kvv and $K_{\theta\theta}$) with the system frequency ω, it was included the results obtained with a simplified alternative of the approximated method, in which it has been adopted the static stiffness of a rigid disc resting on elastic medium, expressed as:

$$K_\theta = \frac{8 \cdot G \cdot r_\theta^3}{3 \cdot (1-\nu)} \qquad K_x = \frac{8 \cdot G \cdot r_x}{2-\nu} \qquad (3)$$

Begining with the same hypothesis employed in the ideal building family definition and introducing as variables X_1 and X_2, defined as weight effective proportions and total building height linked to the fundamental vibration mode on rigid base, it is easy to prove that it is possible to write a period relationship, just as:

$$\frac{\tilde{T}}{T} = \left[1 + (\alpha + \beta) \cdot \phi^2\right]^{1/2} \qquad (4)$$

$$\alpha = \frac{3}{2} \cdot \pi^3 \cdot (1 - \nu) \cdot X_1 \cdot X_2{}^2 \cdot \left(\frac{w}{h_i \gamma_s}\right) \cdot \left(\frac{h}{r}\right) \cdot \left(\frac{r}{r_\theta}\right)^3 \qquad (4.1)$$

$$\beta = \frac{1}{2} \cdot \pi^3 \cdot (2 - \nu) \cdot X_1 \cdot \left(\frac{w}{h_i \gamma_s}\right) \cdot \left(\frac{r}{h}\right) \cdot \left(\frac{r}{r_x}\right) \qquad (4.2)$$

In this definition, α and β are no-dimensional parameters that represent the contribution to soil-structure interaction effects of the rotation components and translational, respectively.

The figures 7 and 8 show the $\tilde{T} / T$ and $\tilde{\xi}$ results, obtained for the different analysis methods that were employed (the "exact", the approximated and the simplified).

CONCLUSIONS.

The results obtained from the parametric evaluation allow to conclude that the main soil-structure interaction effect in the ideal buildings response supported on the surface of a flexible foundation medium, are:

1. The reduction of system own frequencies of vibration, in order to those evaluated for the structure with rigid base condition.

2. The variation of the modal damping factor of the system, in respect with the one that was supposed, for the structure on rigid base.

3. The vibration modal shapes change of the system according to those which were obtained for the structure with rigid base.

Thus, it can be proved that the vibration fundamental mode is the one that get most influence due to soil-structure interaction effects.

About the different methods of analysis that were employed, it can be conclude:

1. Both methodologies (approximated and simplified models) allow to reproduce properly the reductions of the fundamental frequency of the system, according to those which were evaluated for structures on rigid base.

2. The approximated method allows to estimate the system damping factor variations associatedto the vibration fundamental mode in order to the supposed one for the structure on rigid base.

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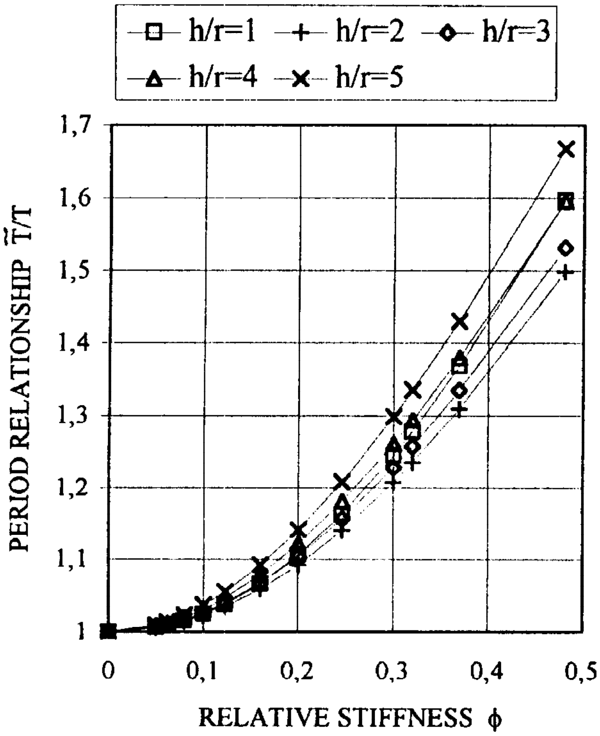

Fig. 1. RELATIONSHIP T̃/T vs ϕ, h/r
R=1,00 D=0 (Elastic)

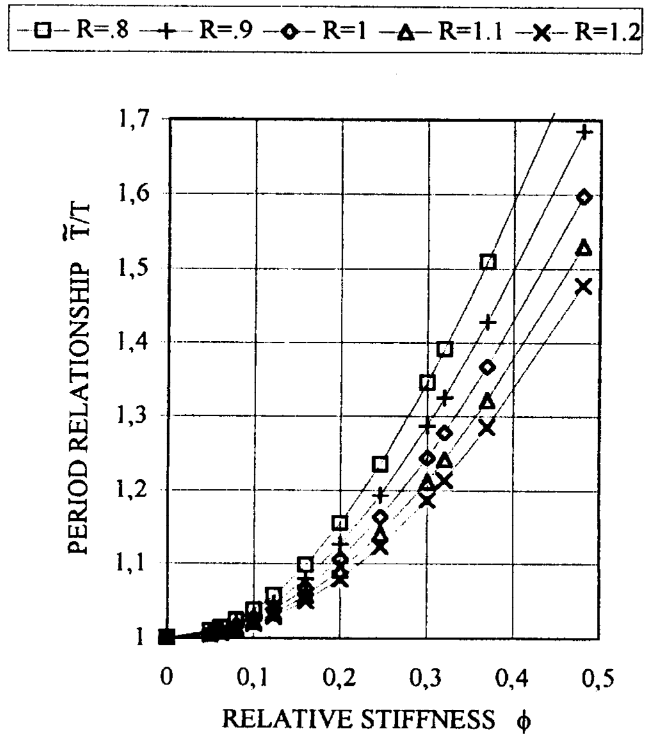

Fig. 2. RELATIONSHIP T̃/T vs ϕ, R
H/R=1 D=0 (Elastic)

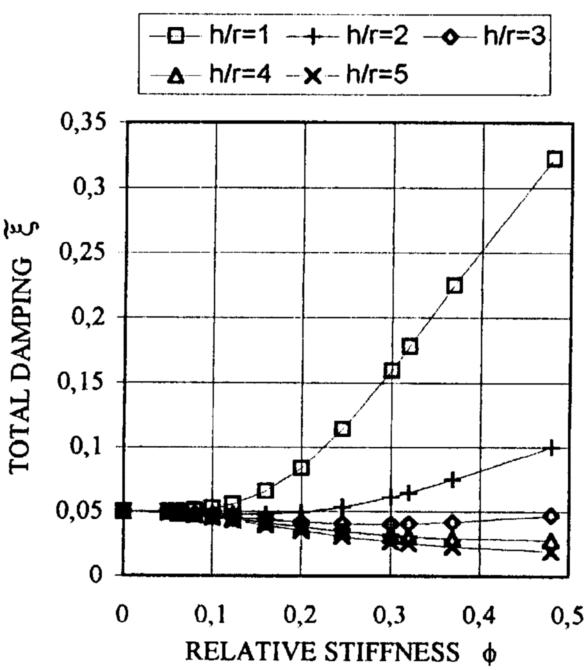

Fig. 3. TOTAL DAMPING vs ϕ, h/r
R=1,00 D=0 (Elastic)

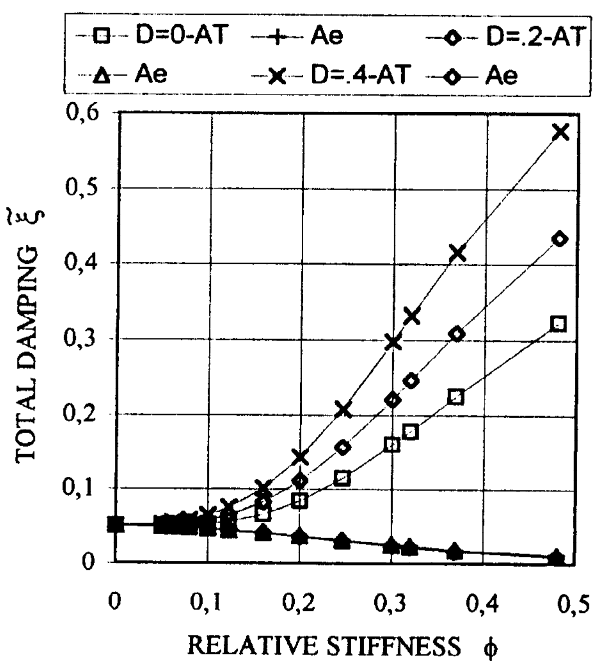

Fig. 4. TOTAL DAMPING vs ϕ, D
R=1,0 H/R=1

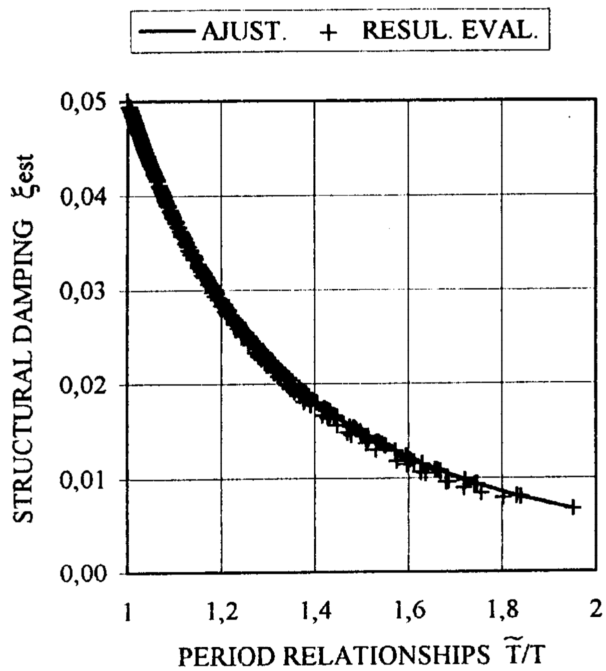

Fig. 5. STRUCT. DAMPING vs $\tilde{T}/T$
Adjustament curve: $\xi est = 0.05/(\tilde{T}/T)^3$

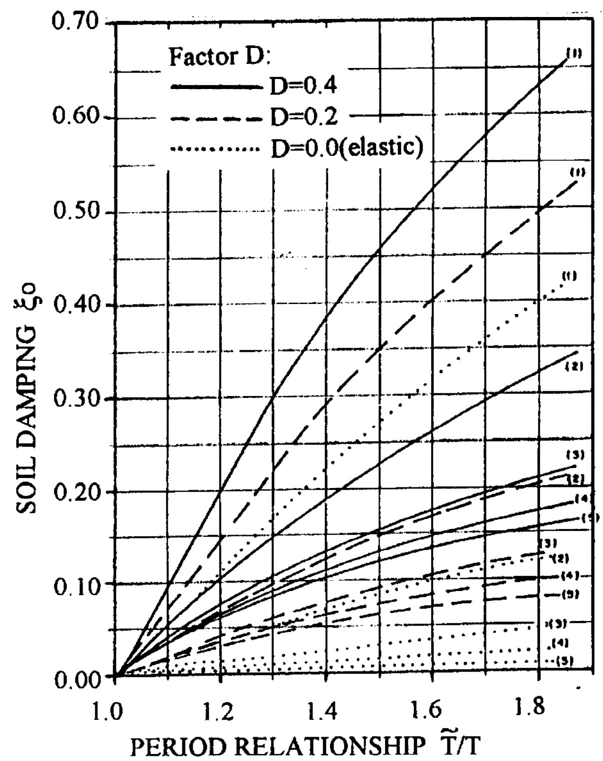

Fig. 6. FACTOR ξo vs $\tilde{T}/T$, D, h/r
R=1,0 (Relationship h/r)

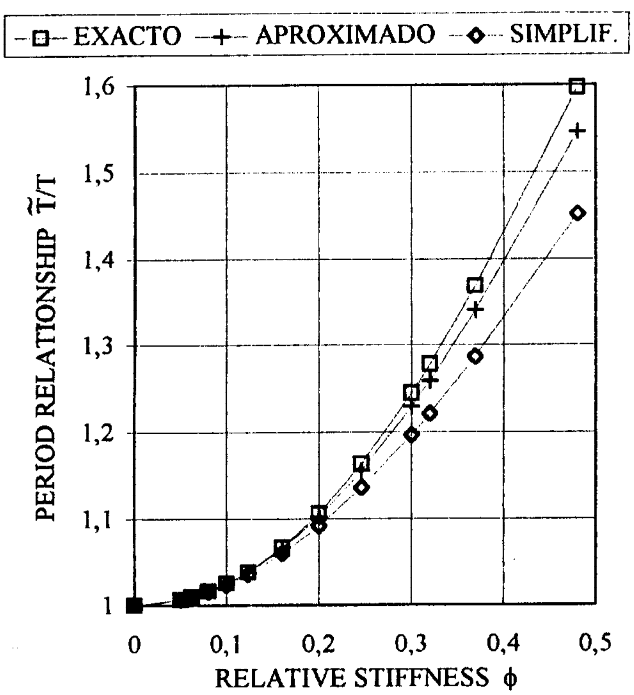

Fig. 7. ANALYSIS METHODS
R=1 D=0 (Elastic)

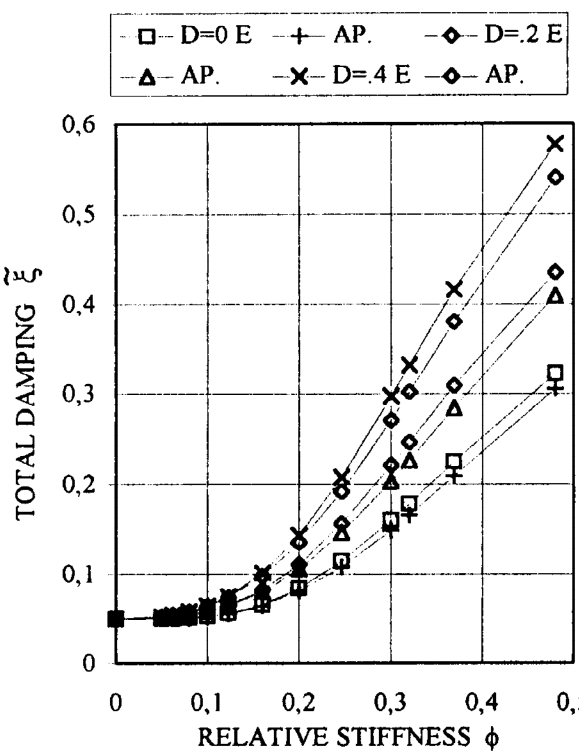

Fig. 8. ANALYSIS METHODS
R=1 D=0 (Elastic)