INCREASING SUSTAINABILITY OF THE HOUSING STOCK BY AVOIDING DAMAGE CAUSED BY THE SOIL-STRUCTURE RESONANCE

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Abstract: In any dynamic system, the coincidence between natural period and excitation period (***the resonance***) lead to extremely large dynamic amplification. For example a linear system with damping of order $\zeta = 2 \rightarrow 5\%$ the dynamic amplification factor has values between $\Phi = x_{\mathrm{d}inamic} / x_{static} = 25 \rightarrow 10$ [4, 6]. The amplifications of this order can also occur in the building structures loaded in the resonant regime. And it is unlikely that a structure can support such a demand without major damages. The essence of the strategy of avoiding site – structure resonance consists in the correct evaluation of the both structural T_s and site natural periods T_g followed by the imposed condition $T_s \neq T_g$. However, the site natural period T_g has no a unique value. The site materials have a mechanical behavior strongly dependent on strain, stress or loading level (manifested by dynamic stiffness degradation and increasing damping) [2, 4, 5, 6, 8, 11]. As a result, T_g becomes dependent on earthquakes amplitude, and this dependence can be observed in the seismic records [12, 13]. In the current practice for site natural period determination is usually used the "quarter length formula" $T_g = 4H / v_s$ where H is the site depth and v_s is the shear wave velocity [8, 13]. This method assumes the site as linear elastic space in contradiction with mechanical reality and gives a unique natural period value in contradiction with earthquake recordings. This paper proposes an evaluation method of the natural period nonlinear dependence assuming site materials as nonlinear viscoelastic materials modeled with a nonlinear Kelvin-Voigt model (which includes dynamic stiffness degradation and increasing damping) [3, 4, 6]. By using resonant column tests we can quantify the nonlinear dependence of the site natural period in the normalized form $T_n = T_n(\bullet)$ where $T_n = T_g / T_0$ and $\bullet = PGA$ sau M_{GR}. Then, from "in situ" information we can obtain the normalization value T_0 and finally, the nonlinear site natural function result in the form: $T_g(\bullet) = T_0 \cdot T_n(\bullet)$. Validation of this method is provided by comparison between the function T_g^{calc} evaluated by nonlinear calculus for a site with sufficient seismic records and the function T_g^{rec} obtained directly from these records.

Key words: Soil dynamic degradation, Nonlinear site natural period, Nonlinear oscillating soil-structure system, Soil-structure resonance.

1. NATURAL SITE PERIODS OBTAINED FROM SEISMIC RECORDINGS

The seismic data recording during Vrancea earthquakes with different magnitudes shows a doubtless dependence of the natural periods and maximum accelerations on earthquake magnitude as is illustrated by the examples from figures 2.1, 2.2 and 2.3, where the data recorded at some Bucharest seismic station is presented and where the estimation of the maximum predicted event was added [12].

One can see from these examples the obvious nonlinear increase of the site natural period T_g and of maximum acceleration PGA versus the increasing earthquake magnitude. Certainly, the different local conditions from the seismic station sites lead to a large dispersion of the recorded natural period values. But, using only data recorded at the same seismic station this dispersion become acceptable (fig. 2.3).

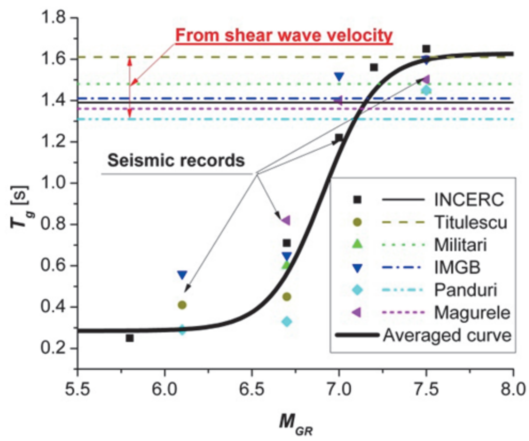

Fig. 2.1. Nonlinear tendency of site natural periods.

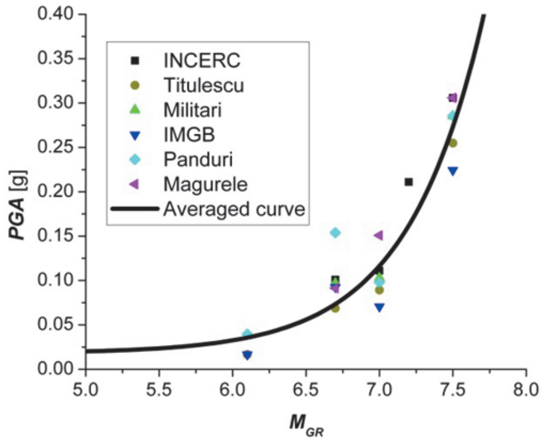

Fig. 2.2. Nonlinear tendency of maximum accelerations.

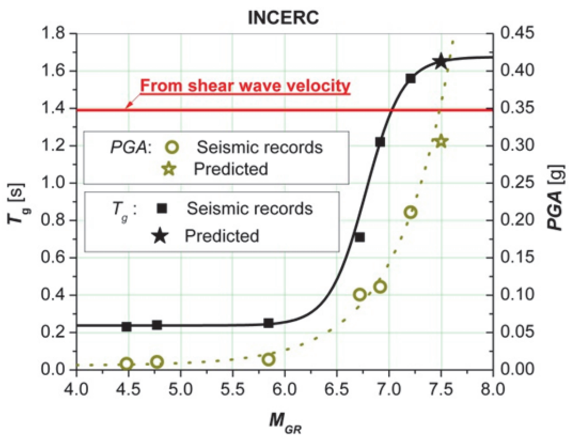

Fig. 2.3. Seismic records at INCERC site.

The direct evaluation of the nonlinear natural period functions in the form $T_g = T_g(M_{GR})$ or $T_g = T_g(PGA)$ is an adequate method but is not always possible. The seismic station network is not so expanded and only in a few stations the recorded events are appropriate for determination of natural period functions with a reasonable precision. Only for the INCERC station there are multiple seismic recorded values with different magnitudes beginning with low events until the strong March 4, 1977 earthquake.

For this reason, the usual method for site natural period determination is based on the "quarter length formula" $T_g = 4H/v_s$ where H is the site depth and v_s is the shear wave velocity. This formula treats the site as semi-infinite linear elastic space in contradiction with mechanical reality and gives a unique natural period value in contradiction with earthquake recordings (figs. 2.1 and 2.3).

2. NONLINEAR BEHAVIOR OF THE SITE MATERIALS

As known, the site materials, soils and rocks, are nonlinear materials with a dynamic behavior strongly dependent of loading level and this behavior affects the whole dynamic response including the site natural period values [2, 4, 6, 8].

Assuming that the geological site materials are nonlinear viscoelastic materials in the previous author's papers [2, 3, 4] this nonlinear behavior was modeled by using a nonlinear Kelvin-Voigt model which describes the variation of material mechanical parameters (shear modulus G and damping ratio ζ) in terms of shear strain invariant γ: $G = G(\gamma)$, $\zeta = \zeta(\gamma)$. Both these material function can be complete quantify by resonant column tests data [2, 3, 14]. As it can be seen from figures 3.1 and 3.2 the rigidity of the site materials may display during the strong events an important dynamic strength degradation associated with a substantial increase of the damping capacity.

Due to these nonlinear characteristics of the site materials, every site oscillating system becomes a nonlinear system and for every site instead of a unique linear natural period value T_g a function $T_g = T_g(\bullet)$ (in terms of strain, stress or loading input) must be evaluated [5, 6]. For full quantification of such function we will prove in the next that the resonant column data can have an important contribution.

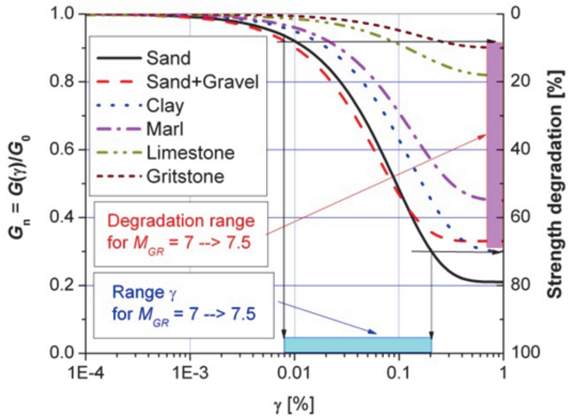

Fig. 3.1. Strength degradation

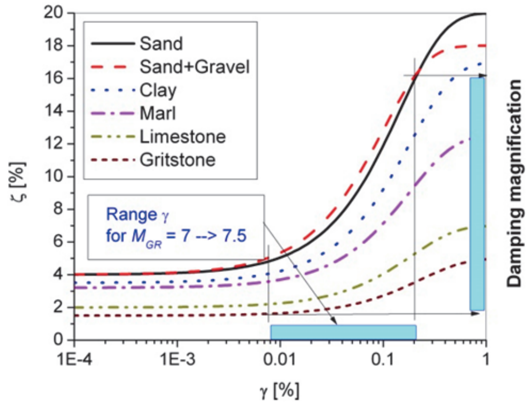

Fig. 3.2. Damping magnification

3. NATURAL PERIOD OF THE RESONANT COLUMN SAMPLE

From resonant column test under harmonic torsional inputs with different amplitudes $M^i = M_0^i \sin \omega t$ we can obtain the corresponding strain level γ_i, the modulus-function value G^i and damping value ζ^i [4, 14]. The shear-modulus value G^i is obtained using the relationship:

$$G^i = \rho\left(v_s^i\right)^2 = \rho\left(\frac{\omega_0^i h}{\Psi}\right)^2 \quad \text{with} \quad \Psi = \sqrt{R - \frac{1}{3}R^2 + \frac{4}{45}R^3} \tag{4.1}$$

where ρ is the mass density of specimen, v_s^i and ω_0^i are the shear wave velocity and the sample natural frequency at level *i*, *h* is the sample height and Ψ is the root of torsional frequency equation with analytical form in terms of the ratio *R* between torsional inertia of the sample and the torsional inertia of the top cap system: $R = J / J_{top}$.

After several tests with different strain level γ_i $\left(i = 1,2...n\right)$ the shear-modulus function $G = G\left(\gamma\right)$ and the damping function $\zeta = \zeta\left(\gamma\right)$ can be obtained in the normalized forms:

$$G\left(\gamma\right) = G_0 \cdot G_n\left(\gamma\right) \quad \text{with : } G_0 = G\left(\gamma\right)\Big|_{\gamma=0} \text{ and } G_n\left(\gamma\right) = G\left(\gamma\right)/G_0 \tag{4.2}$$

$$\zeta = \zeta\left(\gamma\right) = \zeta_0 \cdot \zeta_n\left(\gamma\right) \quad \text{with : } \zeta_0 = \zeta\left(\gamma\right)\Big|_{\gamma=0} \text{ and } \zeta_n\left(\gamma\right) = \zeta\left(\gamma\right)/\zeta_0 \tag{4.3}$$

where G_0 is the initial value of the shear modulus-function, $G_n\left(\gamma\right)$ is the normalized shear-modulus function ζ_0 is the initial damping value and $\zeta_n\left(\gamma\right)$ is the normalized damping function.

The natural period of the sample for a level γ_i is:

$$T^i = \frac{2\pi}{\omega_0^i} = \frac{2\pi h\sqrt{\rho}}{\Psi} \cdot \frac{1}{\sqrt{G^i}} \tag{4.4}$$

and using eq. (4.2), *the nonlinear natural period function* of the soil sample results:

$$T_{sample}\left(\gamma\right) = T_0 \cdot T_n\left(\gamma\right) \text{ with: } T_0 = T_{sample}\left(\gamma\right)\Big|_{\gamma=0} = \frac{2\pi h\sqrt{\rho}}{\Psi} \cdot \frac{1}{\sqrt{G_0}} \text{ and } T_n\left(\gamma\right) = \frac{T_{sample}\left(\gamma\right)}{T_0} = \frac{1}{\sqrt{G_n\left(\gamma\right)}} \tag{4.5}$$

We mention that the natural periods obtained by resonant column test in the form (4.5) is the natural periods of the single degree of freedom oscillating system composed by a single mass (the vibration device) supported by a spring and a damper represented by the sample. This system is much different in comparison with site-structure system. But, as can see from eq. (4.5) the physical and geometrical sample properties (h, ρ, J, J_{top}) are included only in the initial value T_0. Thus, the resonant column test can offer accurate data for obtaining only the nonlinear dependence of the normalized natural period $T_n = T_n(\gamma)$.

4. NORMALIZED NATURAL PERIODS DEPENDING ON LOADING

For practical applications it is necessary to determine the normalized natural period in function of loading amplitude usually described by *peak ground acceleration* (*PGA*). For this conversion - $T_n = T_n(\gamma)$ into $T_n = T_n(PGA)$ - we used the numerical simulation of the resonant column sample behavior, modeled as nonlinear Kelvin-Voigt model subjected to abutment motion $\ddot{x}_g(t) = \ddot{x}_g^0 \sin\omega t$ with different acceleration amplitude $\ddot{x}_g^0$. In this loading case, the motion equation reads as [4]:

$$\ddot{x} + 2\omega_0\zeta(x)\cdot\dot{x} + \omega_0^2 G_n(x)\cdot x = -\ddot{x}_g^0 \sin\omega t \tag{5.1}$$

Using the change of variable $\tau = \omega_0 t$ and introducing a new time function $\varphi(\tau) = x(t) = x(\tau/\omega_0)$ we can obtain the dimensionless form eq. (5.1) [3]:

$$\varphi'' + C(\varphi)\cdot\varphi' + K(\varphi)\cdot\varphi = \mu \sin\upsilon\tau \tag{5.2}$$

where the superscript accent denotes the time derivative with respect to □, and:

$$C(\varphi) = \frac{c(x)}{m\omega_0} = 2\zeta(x) \quad ; \quad K(\varphi) = \frac{k(x)}{m\omega_0^2} = G_n(x) \quad ; \quad \mu = \frac{\ddot{x}_g^0}{\omega_0^2} = x_{static} \quad ; \quad \upsilon = \frac{\omega}{\omega_0} \tag{5.3}$$

The steady-state solution of the equation (5.2) can be numerically obtained using a computer program based on Newmark algorithm [3, 7, 9]. The solution can be written in the form: $\varphi(\tau,\upsilon,\mu) = \mu\Phi(\upsilon,\mu)\sin(\upsilon\tau-\psi)$, where $\Phi(\upsilon,\mu)$ is *the nonlinear magnification function:*

$$\Phi(\upsilon,\mu) = \frac{\max_{\tau}\left[\varphi(\tau,\upsilon,\mu)\right]}{\mu} = \frac{x_{dynamic}}{x_{static}} \tag{5.4}$$

a ratio of maximum dynamic amplitude $\varphi_{\max} \equiv x_{dynamic}$ to static displacement $\mu = x_{static}$.

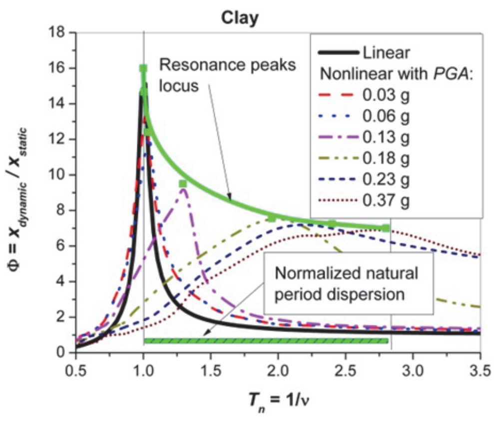

Fig. 5.1. Nonlinear magnification functions in terms of normalized periods (for a clay specimen).

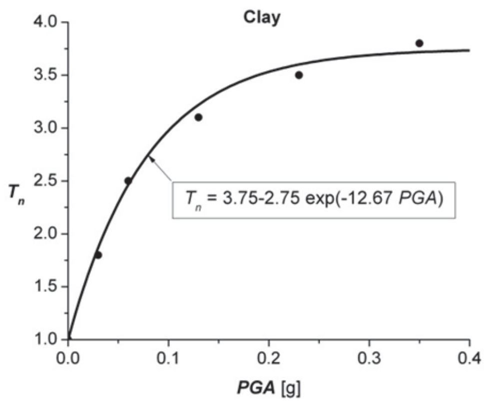

Fig. 5.2. Relationship $T_n = T_n(PGA)$.

By numerical simulations with different values of normalized loading amplitudes μ we can obtain a set of nonlinear magnification functions $\Phi(\upsilon) = \Phi(\upsilon;\mu)\big|_{\mu=ct.}$ [2]. Because $\upsilon = \omega/\omega_0 = T_0/T = 1/T_n$ one can obtain the magnification functions Φ in terms of normalized period T_n (fig. 5.1) and because $\mu = \ddot{x}_g^0/\omega_0^2 = (g\cdot PGA)/\omega_0^2$ a relationship $T_n = T_n(PGA)$ results (fig. 5.2).

5. NONLINEAR NORMALIZED NATURAL PERIOD OF THE SITE

For the evaluation of the entire site normalized natural periods first one must determine by resonant column tests the nonlinear variation T_n^i for each site stratum, and then one can obtain the average natural period variation for the entire site layers T_n^{av} as the average of the strata normalized natural period T_n^i weighted with its thickness h_i [6, 13]:

$$T_n^{av} = \left(\sum T_n^i \times h_i\right) / \sum h_i \tag{5.5}$$

This method was validated using the site emplacement of the seismic station INCERC with known stratification [1]. First, for each constituent layer the material functions $G = G(\gamma)$ and $\zeta = \zeta(\gamma)$ were estimated and by numerical simulation, some functions $T_n^i = T_n^i(PGA)$ one for each stratum *i* was obtained.

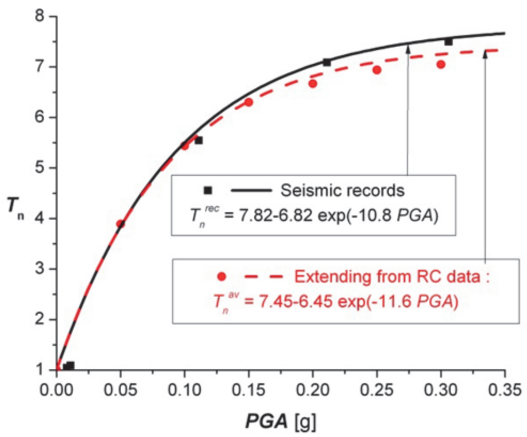

Fig. 6.1. Dependence $T_n - PGA$ provided both resonant column data and seismic records.

Then, for some *PGA* values (0.05, 0.10, 0.15, 0.20, 0.25 and 0.30 g) using eq. (6.1) the site natural period values $T_n^{av}\big|_{PGA=ct.}$ was obtained and by statistical fit from these period values a normalized averaged natural period function $T_n^{av} = T_n^{av}(PGA)$ results.

This method was validated using the necessary data (material functions and seismic records) from seismic station INCERC site.

In figure 6.1 the validation result is given, by comparison between nonlinear function $T_n^{av} = T_n^{av}(PGA)$ obtained with the aid of resonant column data and the same function directly obtained from seismic measurements $T_n^{rec} = T_n^{rec}(PGA)$ [22]. As can see from this figure the differences between seismic records and resonant column simulations are acceptable.

6. T_0 ESTIMATION FROM SEISMIC RECORDS

We remember that only resonant column data are not enough for complete determination of the natural period function $T_g(PGA) = T_0 \cdot T_n(PGA)$ and besides of the normalized function $T_n^{av} = T_n^{av}(PGA)$ given by the resonant column data, the initial value T_0 obtained from seismic measurements it is necessary.

When T_0 value is not available or is to difficult to obtain from processing of seismic records one can use any known pair of values $\left(T_g^{kn}, PGA^{kn}\right)$. In this case, the T_0 is obtained by moving of the normalized resonant column curve $T_n^{av} = T_n^{av}(PGA)$ in any known "point" $\left(T_g^{kn}, PGA^{kn}\right)$ of the $\left(T_g, PGA\right)$ space:

$$T_0 = \frac{T_g^{kn}\big|_{PGA=PGA^{kn}}}{T_n^{av}\big|_{PGA=PGA^{kn}}} \tag{5.6}$$

Finally, the calculated form of the site natural period function becomes:

$$T_g^{calc}(PGA) = T_0 \cdot T_n^{av}(PGA) \tag{5.7}$$

The validation of this method can be done by comparison between T_g^{calc} and T_g^{rec} curves both obtained from the same site. Thus, in figure 7.1 such comparison is given using the laboratory and in situ data for INCERC site. The calculated curve $T_g^{calc} = T_g^{calc}(PGA)$ was obtained by translation of the normalized curve $T_n^{av} = T_n^{av}\left(PGA\right)$ into the 1977 earthquake "point" $\left(PGA = 0.21\text{g} \ ; \ T_g = 1.56\text{s}\right)$ and the recorded curve $T_g^{rec} = T_g^{rec}\left(PGA\right)$ was obtained directly from seismic measurements processing.

Also, the translation can be done and in another measurement points. Thus, in figure 7.2 the normalized curve $T_n^{av} = T_n^{av}\left(PGA\right)$ was translated in three known points of the strong events: 1977 point $\left(PGA = 0.21\text{g} \ ; \ T_g = 1.56\text{s}\right)$, 1986 point $\left(PGA = 0.11\text{g} \ ; \ T_g = 1.22\text{s}\right)$ and in the point $\left(PGA = 0.306\text{g} \ ; \ T_g = 1.65\text{s}\right)$ corresponding to maximum predicted event. In all these cases the differences between calculated and measured curves was reasonable: $\Delta T_g = \left|T_g^{rec} - T_g^{calc}\right| \leq 0.1 \text{ s}$.

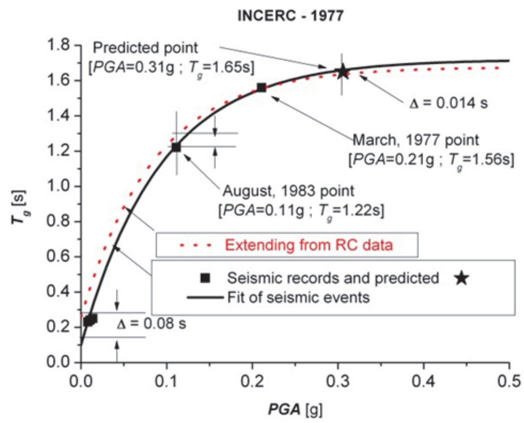

Fig. 7.1. Translation in the 1977 point.

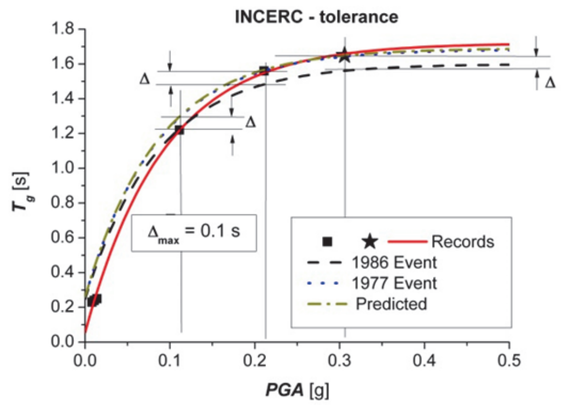

Fig. 7.2. Translation in some strong seismic points.

7. SOME ADDITIONAL APPLICATIONS OF THE COMBINED SITE-RC APPROACH

The method presented in the previous chapters is primarily useful to determine the loading dependence of the site natural period $T_g = T_g\left(PGA\right)$, dependence necessary to avoid soil-structure resonance. Next, we will briefly present some aspects concerning the same purpose - to avoid resonance.

7.1 Prediction of natural periods for strong earthquakes

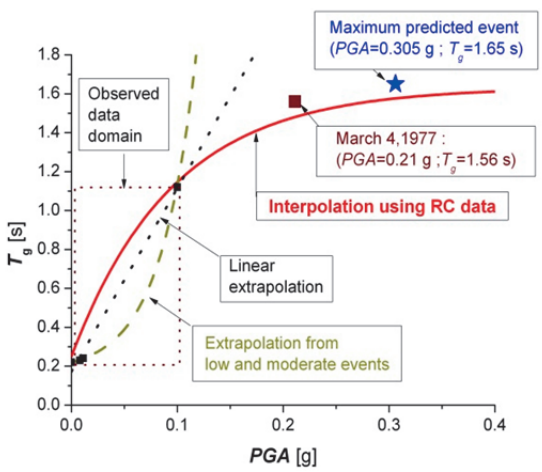

Fig. 8.1. Predicted large natural periods of the strong earthquakes (example).

For a large majority of the usual sites only seismic recording of the low and moderate events are available. In these cases, the evaluation of the dominant period for strong earthquakes using only seismic low and moderate data presume an extrapolation procedure with inherent large errors [4, 7, 9].

The resonant column device can charge the soil specimen to a loading range equivalent to low until strong earthquakes [4, 14] and the nonlinear natural period dependence $T_n = T_n\left(PGA\right)$ can be obtained by means of an interpolation process with an upper accuracy.

In this case, when only low and moderate seismic data are available, the resonant column determination by the interpolation of the nonlinear variations in normalized form: $T_n = T_n\left(PGA\right)$

together with the determination of the normalization value T_0 from seismic recording can leads to a better approximation of the natural periods for large *PGA* values (fig. 8.1).

7.2. Trap of overestimation

Treating the site as linear oscillator means a unique natural period as provided the low loading methods (the wave velocity, H/V method, or else [12]). Even if this value is overestimated the site-structure resonance avoidance cannot be assured. In the usual strength design the overvaluation of the external loadings assures a safe structural response to inferior loadings. But, in the resonance case, the overestimations of the natural site period values do not assure the resonance avoidance.

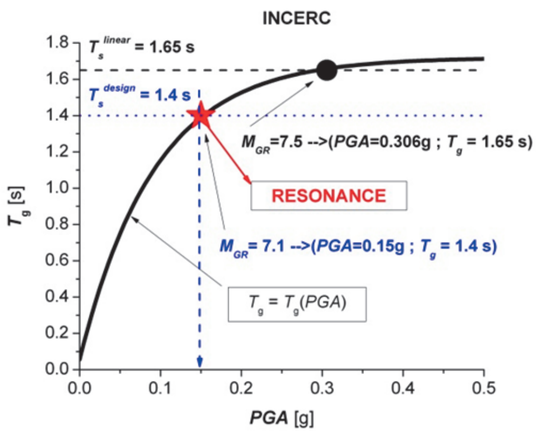

Fig. 8.1. Overestimation trap (site INCERC).

Thus, for example, if for INCERC site it is considered only a unique site natural period with the maximum predicted values $T_g = 1.56$ s, it seems that for this site the resonance danger arises only for buildings with the same natural period. Therefore, for a building designed with an inferior natural period $T_s = 1.4$ s, placed on this site the occurrence of resonance is unlikely. But, if we take into account the loading dependence, the natural site period of $T_g = 1.4$ s can be reach under inferior earthquake loading as $M_{GR} = 7.1$ and the resonant magnifications becomes quite possible (fig. 8.2).

7.3. Range periods with the possibility of resonance

The post-earthquake observations show that seismic loading level (magnitude, *PGA*) play an important role in the resonance consequences because only strong events (over $M_{GR} \geq 7$) may lead to an important structural damages which can growth until structural collapse [12]. Thus, for safe avoidance of resonance is necessary to define for each site a natural period value range corresponding to strong earthquakes.

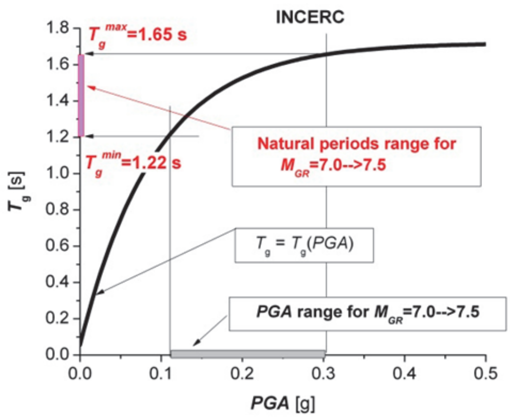

Fig. 8.3. Dangerous resonant zone (site INCERC).

As example, for seismic site INCERC the seismic recordings show that for magnitudes between $M_{GR} = 7$ and maximum expected magnitude $M_{GR} = 7.5$ correspond an acceleration range $PGA \simeq 0.1 \rightarrow 0.3$ g and a dangerous natural period range $T_g \simeq 1.22 \rightarrow 1.65$ s (fig. 8.3). So, it is not recommended to use this site for buildings with natural periods T_s included in the same range.

CONCLUDING REMARKS

● The seismic data recording during Vrancea earthquakes with different magnitudes shows a doubtless dependence of the site natural periods and maximum accelerations on earthquake magnitude.

● The "quarter length formula" ($T_g = 4H / v_s$) treats the site as linear elastic space in contradiction with mechanical reality and gives a unique natural period value in contradiction with earthquake recordings.

● The nonlinear natural site period - $T_g\left(PGA\right) = T_0 \cdot T_n\left(PGA\right)$ - can be obtained from recorded seismic data if these data cover the entire expected *PGA* value range.

● In default of complete and reliable site information, the site nonlinear natural period can be done by a combination of *in situ* data - T_0 - and resonant column data - $T_n\left(PGA\right)$.

REFERENCES

[1] BĂLAN Stefan, CRISTESCU Valeriu, CORNEA Ion (Editors), *Romanian earthquakes from March 4, 1977*(in Romanian), Publishing House of the Romanian Academy, 1982.

[2] BRATOSIN Dinu, A *dynamic constitutive law for soils,* Proceedings of the Romanian Academy – Series A: Mathematics, Physics, Technical Sciences, Information Science (ProcRoAcad), **1-2**, pp.37-44, 2002.

[3] BRATOSIN Dinu, SIRETEANU Tudor, *Hysteretic damping modelling by nonlinear Kelvin-Voigt model,* ProcRoAcad, **3**, pp.99-104, 2002.

[4] BRATOSIN Dinu, *Soil dynamics elements* (in Romanian)*,* Publishing House of the Romanian Academy, 2002.

[5] BRATOSIN Dinu, Florin-Stefan BĂLAN, Carmen-Ortanza CIOFLAN, *Soils nonlinearity effects on dominant site period evaluation,* ProcRoAcad, **10**, 3, pp.261-268, 2009.

[6] BRATOSIN Dinu, *Loading dependence of the site natural period,* ProcRoAcad, **12**, 4, pp.339-346, 2011.

[7] CARNAHAN, B., LUTHER, H.A., WILKES, J.O., *Applied numerical methods*, J. Willey, New York, 1969.

[8] ISHIHARA K., *Soil Behavior in Earthquake Geotechnics,* Clarendon Press, Oxford, 1996.

[9] LEVY S., WILKINSON J.P.D., *The Component Element Method in Dynamics*, McGraw-Hill Book Company, 1976.

[10] MALVERN, L.E., *Introduction to the mechanics of a continuous medium*, Prentince Hall, New Jersey, 1969.

[11] MĂRMUREANU Gh., MĂRMUREANU Al., CIOFLAN C.O., BĂLAN S.F., *Assessment of Vrancea earthquake risk in a real/nonlinear seismology,* Proc.of the 3rd Conf. on Structural Control, Vienna, pp.29-32, 12-15 July, 2004.

[12] MĂRMUREANU Gheorghe, CIOFLAN Carmen-Ortanza, MĂRMUREANU Alex., *Research on local seismic hazard (*zoning) *of the Bucharest metropolitan area. Seismic zoning map,* (in Romanian), Ed. Tehnopress, 2010.

[13] MÂNDRESCU Nicolae, RADULIAN Mircea, MĂRMUREANU Gheorghe, *Geological, geophysical and seismological criteria for local response evaluation in Bucharest area,* Soil Dynamics and Earthquake Engineering 27, pp.367–393, 2007.

[14] * * * *Drnevich Long-Tor Resonant Column Apparatus*, Operating Manual, Soil Dynamics Instruments Inc. (1979).

CREŞTEREA DURABILITĂŢII FONDULUI CONSTRUIT PRIN EVITAREA DISTRUGERILOR PROVOCATE DE REZONANŢA TEREN – STRUCTURĂ

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Rezumat. In orice sistem dinamic, coincidenta dintre perioada proprie si perioada excitatiei (**rezonanta**) provoaca amplificari mari. De exemplu, in cazul unui sistem liniar cu o amortizare de ordinul $\zeta = 2 \rightarrow 5\%$, facorul de amplificare ia valori intre $\Phi = x_{\mathrm{d}inamic} / x_{static} = 25 \rightarrow 10$ [4, 6].

Amplificari de acest ordin de marime pot apare si in structurile de rezistenta solicitate in regim de rezonanta. Si este putin probabil ca structura sa le poata prelua fara distrugeri majore. Esenta strategiei de evitare a rezonantei teren-structura consta in evaluarea corecta a perioadei proprii a structurii T_s si a amplasamentului T_g, urmata de impunerea conditiei $T_s \neq T_g$. Insa, perioada proprie a amplasamentului T_g nu are o valoare unica. Materialele din amplasament au o comportare mecanica puternic dependenta de nivelul de solicitare, comportare manifestata prin degradarea dinamica a rigiditatii si cresterea amortizarii [2, 4, 5, 6, 8, 11]. Ca urmare T_g devine dependent de magnitudinea cutremurului, dependenta aparuta si in inregistrarile seismice [12, 13].
In practica curenta, pentru determinarea perioadei proprii a amplasamentului este utilizata formula $T_g = 4H / v_s$, unde H este adancimea depozitului iar v_s viteza undelor de forfecare [8, 13]. Metoda considera amplasamentul ca un spatiu elastic liniar in contradictie cu realitatea mecanica si furnizeaza o valoare unica a perioadei proprii a amplasamentului in contradictie cu inregistrarile seismice. Aceasta lucrare propune o medoda de determinare a dependentei neliniare a perioadei proprii a amplasamentului considerand materialele din amplasament drept materiale vascoelastic neliniare modelate cu un model Kelvin-Voigt neliniar care include degradarea dinamica si cresterea amortizarii [3, 4, 6]. Cuantificarea acestui model este realizata prin combinarea informatiilor obtinute prin teste in coloana rezonanta cu cele obtinute in situ. Prin teste in coloana rezonanta se obtine dependenta neliniara in forma normalizata $T_n = T_n(\bullet)$, unde $T_n = T_g / T_0$ iar $\bullet = PGA$ sau M_{GR} Apoi, din informatiile "in situ" se obtine valoarea de normalizare T_0 iar in final perioada proprie a amplasamentului rezulta in forma : $T_g(\bullet) = T_0 \cdot T_n(\bullet)$. Validarea metodei este realizata prin compararea functiei T_g^{calc} evaluata prin calcul neliniar pentru un amplasament cu suficiente inregistrari seismice cu functia T_g^{rec} obtinuta direct din aceste inregistrari.

Cuvinte cheie: Degradare dinamica, Perioada proprie neliniara, Sistem neliniar teren-structura, Rezonanta teren-structura.