Characteristics of Seismic Waves Propagation. Can We Accept the "Mexico City Effect" as Responsible for the Collapse of Buildings during Strong Earthquakes?

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SUMMARY

Physical processes associated to the occurrence of strong motions may be grouped into three basic categories: source, site and path effects. The first two account for phenomena that occur locally at the source or the observation site, while the third is related to the wave propagation between these two regions. Extensive research on seismic source and site response has been done. From an engineering point of view it's important to understand how the seismic energy is propagated from a hypocenter to a certain site. The effects of site conditions on seismic motions are usually interpreted to mean how seismic waves from the lithosphere are affected by the geometrical and geological structure of the softer sedimentary deposit during wave transmission to the surface. The present paper intends to be a signal for an interdisciplinary approach for improving knowledge for understanding the causes of distant earthquake damage and amplification at regional distances.

Keywords: seismic waves, Mexico City effect, Vrancea earthquake

1. INTRODUCTION

In the recent history of earthquake engineering (the last 35 years), several cases of seismic strong motions have been qualified as "*surprises*". For the purpose of the present paper two of them were selected: the 1977 Vrancea earthquake (Romania) and the 1985 Michoacan earthquake (Mexico). The word "*surprises*" refers to the very unfavourable effects of these strong earthquakes on buildings, in cities located at large epicentral distances. The paper is intended mainly to discuss the weight of the influence of seismic wave propagation phenomenon upon long distances versus that of local site conditions. The main event occurred on September 19, 1985 consisted of two subevents with an interval of 26 s between them. The peak acceleration at 20 km from the epicenter was about 0.2 g and there was little damage. However, in Mexico City, nearly 420 km away, the maximum accelerations exceeded those in the epicentral area. The city has been influenced by the *long distance effects of the earthquake* and, about 412 buildings collapsed. It was stated that a major factor of damage was the presence of lacustrine clays in the Lake Zone area (highly compressible soil). Eight years before, a strong earthquake has caused in Romania similar "*long distance effects*" but, due to its peculiarities, that seismic event hasn't drowned much interest to the international scientific community. However, after the processing of the only accelerographic record during the March 4, 1977 earthquake ($M_{G\text{-}R}$ = 7.2), foreign researchers have been so "surprised" by the configuration of the earthquake response spectra, as one of them stated "*such a motion doesn't exist*". Located about 160 km epicentral distance, the city of Bucharest sustained by far the worst damage: 32 high-rise reinforced concrete buildings (28 old and 4 new) partially or totally collapsed.

The paper is focused on a "*general theory*" which tries to explain the *long distance effects* of earthquakes on buildings and it is based on the following concepts: *the seismic wave concept*; *the magnification factor concept in the process of seismic motion transmission*; *the partial and total resonance concept*. Within this theory, the dynamic phenomena that are present in the seismic motion propagation process from the focus, passing through the lithospheric strata and the sedimentary geological deposit, and reaching the existing structures in a location, will be presented. The "*surprises*" related to the "*performances of the buildings*" during strong earthquakes, with many collapses and severe damage will be also demystified.

2. THE CONCEPT OF SEISMIC WAVE

Any reference to the concept of "seismic wave" should have as starting point the name of the French mathematician Siméon-Denis Poisson (1781-1840), who has established theoretically, in 1828, that a perturbation in an elastic solid body generates two (and only two!) types of waves: compressional waves, involving volumetric disturbances, and shear waves, involving only shearing deformations and no volume change (Lay and Wallace, 1995). Generally, the term "*wave*" is found in the discipline "Physics" and refers to the "*way of propagation of an effect produced by a certain phenomenon*". If we refer to the "*phenomenon*" generated by the incidence of an earthquake, named "*seismic vibration*", we should have in view the propagation of "*cycles of deformation*", through which the associated seismic energy of this phenomenon is radially propagated from the focus into the whole lithosphere. Having in mind that the lithosphere is present all over the surface of the Earth, it will be understood that the phenomenon of propagation of vibrations from focus through lithosphere is both complex and complicated. However, for a better understanding of the seismic phenomenon, we will refer to a "*simplified model*" according to which the seismic vibration, as "*deformation cycles*", is radially transmitted from the focus through "*elements of lithosphere*", whose dimensions cannot be defined. Much of the energy released by a rupture along a fault or by a subduction process takes the form of "*stress waves*". The amount of energy released in a seismic event is strongly related to its magnitude. Thus it is obvious that the characteristics of the stress waves will also be strongly related to seismic magnitude. As stress waves travel away from the source of an earthquake, they spread out and are partially absorbed by the materials they travel through. As a result, the energy per unit volume decreases with increasing distance from the source. Since the characteristics of stress waves are strongly related to their energy they will also be strongly related to epicentral distance. To understand the phenomenon of wave spatial spreading during a vibration generated by a tectonic process in the hypocenter, the following properties must be kept in view:

- the propagation of a seismic vibration means the propagation of a sequence of cycles of deformation;
- assuming a basically linear performance, the time history of ground motion at a given site can be represented as a superposition of spectral (sinusoidal) components; as a result of spatial spreading, the amplitude of higher frequency components tends to decrease faster with increasing distance than that of lower frequency ones, so the dominant period of ground motion tends to increase with increasing source distance.

3. THE CONCEPT OF RESONANCE

3.1. Definition

In the majority of the publications where the forced response of structural systems to dynamic loads is studied, the *resonance phenomenon* is definite for periodic motions (in a broader sense), respectively for motions produced by harmonic excitations (in a more strictly sense), described by the trigonometric function "sinus" depending on time. In case of forced vibrations of a linear dynamic system, *the resonance* is the phenomenon of "*unlimited increasing*" or of "*in time limited growth*" of their amplitudes, as an effect of the equality of one of the excitation frequencies and one of the eigenfrequencies of the excited dynamic system.

3.2. Some considerations on the definition of resonance

Resonance phenomena can be basically investigated for linear dynamic systems, considering two reference cases. One case is that, when the sinusoidal disturbance upon a linear dynamic system,

„$a \sin \omega t$", acts upon the whole time axis, $(-\infty, \infty)$. The other is that, when the sinusoidal disturbance „$a \sin \omega t$" is multiplied by a Heaviside function $\varepsilon(t)$ (having values 0 for $t < 0$, ½ for $t = 0$ and 1 for $t > 0$ respectively) and acts only for $t > 0$. In the first case there is pure resonance and the motion amplitude is determined exclusively by the damping capacity of the dynamic system. In the second case there is a gradual increase of amplitudes, starting from zero and tending asymptotically to the value that is proper to the first case. Traditionally, resonance phenomena are studied in literature assuming implicitly a Kelvin – Voigt constitutive law for the connection components of dynamic systems. The shortcomings of this constitutive law type should raise the interest for considering also alternative assumptions (e.g. Poynting, or generalized Maxwell, constitutive laws). Phenomena of amplification of some spectral components that are qualitatively similar to resonance often occur even in case of non-stationary (transient) motions. This fact lies at the basis of (approximately and conventionally) extending the terminology referred to the case of earthquake generated ground motions. Moreover, extensions may be considered even for various non-linear dynamic systems.

3.3. The concept of total resonance

For an accurate understanding of the resonance effects, the following four remarks are of great importance (paper in Vlad et al., 2008).

a) *First remark*. In case of a regular pattern forced vibration (for example, a harmonic forced vibration), it has been ascertained the fact that for each new applied cycle of excitation, the response of a dynamic system, expressed in fundamental kinematic quantities, is amplified. The repetition of the cycles of motion with the same intensity and its consequence (the increase of the number of cycles of motion) have as effect a gradual increasing of the values of the kinematic characteristics of the excited dynamic system response. The relation between the value of the dynamic system response after "n" cycles of motion and the value of its response after the first cycle of motion is known as the "*dynamic amplification factor*", and is noted with the Greek letter "β". The values of the dynamic amplification factor increase with the growing of the number of cycles of motion.

b) *Second remark*. As an approaching between a frequency of the exciter and one of the eigenfrequencies of the excited dynamic system is produced, the values of the kinematic characteristics of the motion (of the response expressed in displacements, velocities and accelerations) will be amplified.

c) *Third remark*. The value of the dynamic amplification factor of the excited dynamic system response is even greater as its damping capacity is more reduced.

c) *Fourth remark*. In the case of the repeating of the cycles of motion with the same intensity, in the stage when a frequency of the excitation matches an eigenfrequency of the excited dynamic system or element, the amplification of the motion kinematic characteristics arrives practically at a maximum value after a certain number of repeated cycles of motion; this situation is influenced by the salient feature of damping, respectively by the damping ratio (an asymptotical approaching of the pure resonance amplitude is produced); then, however many cycles of motion will follow, the amplification practically remains at the same extreme limit.

For the above four remarks, the following comments are considered necessary to be done.

a. The presented remarks maintain their availability for any types of loading of a dynamic system with linear elastic behaviour. The dynamic action can have a sinusoidal variation in time (of harmonic type), a more general periodic variation, or a random variation (namely of seismic type). In case of the sinusoidal type dynamic action (harmonic) or of the periodical type (more general), the situation is more simple, but rather imaginary, as in reality all dynamic actions have a transient character. In case of some more general non-periodical dynamic actions, expressions of approximate or of qualitative character are present, which refer to dynamic amplification phenomenon close to theoretical resonance. In conclusion, one can speak of the resonance phenomenon in the case of any type of dynamic action, being necessary some explanations function of the nature of the cycle of the considered dynamic load.

b. In case of a dynamic system with linear elastic behaviour, after applying a finite number of cycles of motion, a maximum value of the dynamic amplification factor (DAF) is practically reached. The existing relations between the structural material damping characteristic (damping ratio, "ξ") and the number of applied cycles of motion for which the maximum value of the dynamic amplification factor "β" is reached, are presented in Fig. 3.1: *for reinforced concrete structural elements and structural systems ($\xi \cong 5\%$), the maximum value of DAF is practically reached after approximately ten cycles of motion ($\beta_{max} = 10$)*; *for steel structural elements, or for steel moment resisting structural frames ($\xi = 2\%$), the maximum value of DAF is practically reached after approximately 30 cycles of motion ($\beta_{max}=25$)*; *the applied forces on the structural system must be multiplied with the value of the DAF, as appropriate $\beta_{max} = 10$, respectively $\beta_{max} = 30$.*

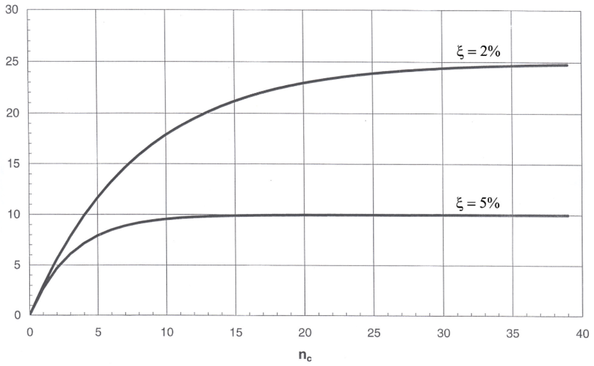


Figure 3.1. Dynamic amplification factor versus number of cycles of motion.

c. In case of structural systems, reinforced concrete structural walls type, their stiffness has an important role from the damping characteristic point of view, and the damping associated to the resting on deformable foundation medium is important, being quite possible to become prevailing. For other categories of structural systems (especially for the rigid ones), the damping associated to the foundation medium can have a significant influence.

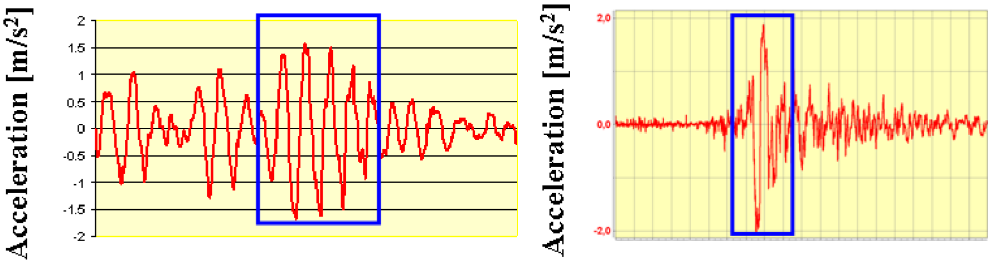
d. It must be mentioned the fact that the damping values that were specified correspond to a moderate level of loading, to stronger loadings the values of the damping characteristic is bigger.

e. The stages to which the dynamic amplification factor has maximal values (β_{max}) are called "*total resonance*" stages, and these have the property that after the value "β_{max}" is reached, no matter how much cycles of motion are to be applied (practically an infinity), the value of factor "β_{max}" remains unmodified (it does not increase). In conclusion, "*the concept of total resonance*" is based on two conditions:
   - the first among these refers to the *equality between one of the excitation frequencies and one of the eigenfrequencies of the structural elements, or of the excited dynamic system*;
   - the second condition refers to the *number of cycles of motion which is applied until the maximum amplification effect is reached* (the repeating of cycles of motion increases the amplification effect from a cycle to another).

   In the case in which the number of cycles of motion applied on the dynamic system is smaller compared with the number of cycles of motion corresponding to the total resonance stage, the dynamic amplification factor "β" has a value more reduced than that of "β_{max}", and the reached stage is called "*partial resonance stage*". The study of the resonance phenomenon is the only possibility by which the amplification of a dynamic action by the repeating of the number of cycles of motion can be explained.

3.4. The concept of resonance in case of seismic action

In the case of seismic action, *the resonance phenomenon* presents some peculiarities as a result that this type of excitation generates a *transient vibration state*. However, it is also obvious that in the case of an earthquake the concept of resonance can be defined on the two criteria already presented: the approaching or the equality between a frequency of the seismic excitation and of an eigenfrequency of a structure and the achievement of a certain number of repetitions of the seismic motion cycle of maximum intensity. First of all, it has to be mentioned the fact extremely important that, during an earthquake, the number of repetitions of the cycle of maximum intensity of acceleration in a recorded accelerogram at the superior part of the sedimentary geological deposit, or eventually at the superior part of the lithosphere, is very reduced (1÷6 cycles). As a result, the values of the dynamic amplification factor "β_{max}" of the elastic response spectra expressed in accelerations are limited. In consequence, in the case of an earthquake motion, the effects of the "*total resonance*" cannot be accomplished, but only the effects of the "*partial resonance*". This phenomenon occurs when only one of the two criteria is fulfilled: usually only the equality between the frequency of excitation and the fundamental eigenfrequency of the dynamic system (and the second criterion is only partially fulfilled). In other words, instead of accomplishing a number of repetitions of the seismic motion cycles which lead to a maximum dynamic amplification factor, after which however many cycles of motion will follow this would not increase, a smaller number of repetitions without arriving to the maximum value of the dynamic amplification factor is accomplished. During the significant duration of an earthquake there are not cycles of the same intensity, but cycles of close intensities are always present. In case of the March 4, 1977 earthquake, the cycle with maximum acceleration was practically 1.5 times repeated (and the dynamic amplification ratio for 5% critical damping approached to 3), while for the September 19, 1985 Mexico City earthquake, the cycle of motion with maximum acceleration was 4 to 5 times repeated (and the dynamic amplification ratio was approximately equal to 8). In relation to the seismic energy quantity released by the 1977 earthquake, the most important aspect that must be taken into account is the following: what would have happened if the seismic motion had one, ore more, supplementary cycles and the quantity of seismic energy released would have been greater? Is it possible an accumulation of a bigger quantity of energy in the Vrancea seismic zone, region in Romania where the strongest earthquakes occur? From this point of view, the new design code P100-1/2006 is not covering enough and does not specify how many times the cycle with maximal acceleration can be repeated (Fig. 3.2).



(a) 4 to 5 cycles

(b) 1.5 cycles

Figure 3.2. The 1985 Mexico City (a) and 1977 Vrancea (b) earthquakes accelerograms.

4. THE THEORY OF VIBRATION TRANSMISSION

4.1. The concept of "mechanical vibration"

A "*mechanical vibration*" is one which needs a material medium in order to be propagated. The aspects that will follow refer exclusively to mechanical vibrations produced by strong earthquakes. During an earthquake, which is primarily a mechanical process, the potential energy from a stressed geological medium is released, being converted into heat, into mechanical work moving the crustal blocks and crushing material in the fault zone, and into energy, E_S, associated with the generated seismic waves. In short, when a geological medium breaks, waves of energy are released and sent out through the Earth. During the short span of this process, the whole Earth, except in the earthquake source, behave as an elastic body. When the upper part of the Earth – the lithosphere – is displaced during a strong earthquake, it is the subject of some back and forth mechanical vibrations in respect with its relative equilibrium position. As a result of the elastic properties of the propagation medium, the seismic perturbation is transmitted from a zone of a medium to the other, starting with the one in the nearest vicinity of the "point" where the seismic event has originated.

4.2. The principal components of the vibration transmission system

The incidence of a "*mechanical vibration*" implies the existence of an "*exciter*" and of one or more "*excited objects*". A mechanical vibration generated by an exciter and transmitted to a dynamic system can have the character of a "*regular pattern vibration*" (as a periodic or harmonic one), or of an "*irregular pattern vibration*" (as one generated by the incidence of seismic waves during an earthquake). In the process of transmitting the seismic vibrations from the seismic source (focus) to structures in a given location at the surface of the Earth, three principal subsystems should be considered: *the subsystem represented by the lithosphere*; *the subsystem represented by the geological sedimentary deposit*; *the subsystem represented by the existing structures at the surface of the Earth in a given location*.

In case of an earthquake incidence, the "*exciter*" is the "*tectonic phenomenon*" associated to a seismic source, and the three subsystems are the "*excited entities*". The first "*excited subsystem*" is the lithosphere, then the lithosphere itself becomes "*exciter*" for the "sedimentary geological deposit" and, finally, the latter becomes "*exciter*" for the existing constructions in specific location. Clarifying the existing relationships between the seismic source and the three entities above mentioned will contribute to a comprehensive understanding of the seismic phenomenon. In the process of transmission of vibrations from a seismic source to a building, or to an engineering structure, *a first* important aspect is that the mechanical characteristics of the waves at the level of the excited subsystem will be *amplified* in comparison with their values at the level of the exciting subsystem; the level of amplification is put into evidence by a "*dynamic magnification factor*". *A second* very important aspect which must be mentioned is the following one: as a result of the existing connection between the "*exciter*" and the "*excited subsystem*", the period of vibration of the excited subsystem is identical with the period of the exciter. *A third very important aspect* which must be mentioned is that the period of vibration of the subsystem "1" (exciting subsystem) is *identical* to the period of vibration of the subsystem "2" (excited system), and further on with the period of vibration of the subsystem "3" (excited system as well). It should be mentioned that the previous considerations correspond to ideal cases where there are not feed back effects from excited components to source of excitation, i.e. in case one neglects dynamic interaction phenomena, which often can be significant at their turn.

4.3. Transmission of seismic vibration through lithosphere

The uppermost mantle, together with the crust, forms the lithosphere, the outer shell of the Earth, which is relatively strong and brittle. The lithosphere averages about 70 km thick beneath oceans and may be 125 to 250 km thick beneath continents. Starting from an earthquake focus the cycles of deformation are propagated through lithosphere, as we have already seen, with the velocity of primary waves "*P*" and with the velocity of secondary waves "*S*", respectively. These seismic "*deformation waves*" draw in vibration motions increasingly higher volumes of rock of the lithosphere. The immediate result of this physic phenomenon is, on one hand, the attenuation tendency of the seismic wave intensity (the reduction of peak values of acceleration and velocity and of the displacement amplitudes) and, on the other hand, the unquestionable fact that in the propagation path of a seismic wave both the period of the cycle of *seismic deformation* and the period of the seismic wave lengthen (the lengthening of the vibration propagation period). In the direction of propagation of seismic waves their periods lengthen as the distance between the focus and different locations is greater. In consequence it can be concluded that an important characteristic of the propagation phenomenon of the seismic waves is: *at a certain location, the period of a seismic wave that is propagated from the focus will correspond to the distance between the focus and the location* (one can talk of *the seismic wave period* in lithosphere corresponding to that location).

4.4. Transmission of seismic vibration from lithosphere to the geological sedimentary deposit

Generally, the sedimentary deposit (the ground) is considered a one-dimensional shear vibrational model, as shear vibration is predominant inside the ground during an earthquake. Thus, the ground can be converted into an appropriate number of layers of discrete masses connected by springs. The adopted structural model of analysis for the sedimentary deposit with nDOF has "*n*" vibration eigenmodes. The seismic waves that are propagated through the lithosphere can generate, in a considered seismic zone, a phenomenon of "*partial resonance*", as a result of the identity or the approaching of one of the frequencies of these waves with one of the eigenfrequencies of the sedimentary geological deposit. In other words, the sedimentary geological deposit *next to a given location* will be excited by the arrived seismic wave having the same frequency as the sedimentary deposit's fundamental eigenfrequency. That's why it can be concluded that the transmission of the seismic vibrations from the lithosphere to the sedimentary geological deposit corresponds to an effect of *a partial resonance*.

4.5. Transmission of seismic vibration from the geological sedimentary deposit to the structures

The equality of the frequency value of a cycle of the seismic motion propagated through the lithosphere with one of the eigenfrequencies of the sedimentary geological deposit, the intensity of the motion cycle and its number of repetitions having the same frequency, have a powerful influence on the dynamic amplification factor of the seismic motion that finally arrives at the surface, where it reaches different structures. The component of the seismic motion which has generated in the sedimentary geological deposit a first "*partial resonance*" produces, in the transmission process of seismic vibrations from the sedimentary geological deposit to the structures placed above it, a second "*partial resonance*". This new "*partial resonance*" is present as a result of the vibration of the sedimentary geological deposit and the structures, or group of structures having equal eigenfrequencies with the eigenfrequency of the sedimentary geological deposit (or with the eigenfrequency of the cycle of deformation in lithosphere next to a given location).

4.6. Some comments and partial conclusions

a) The transmission of the *cycles of deformation* from the hypocenter to a location is made by seismic waves which travel through lithosphere (subsystem resistant, rigid, with behaviour in the elastic range). When the seismic waves reach a location, the lithosphere transfers the seismic motion to the sedimentary deposit; as there are two coupled geological subsystems "*lithosphere-sedimentary deposit*", the exciter (acting as base rock), which is the lithosphere, transfers the same vibration to the driven subsystem, the sedimentary deposit. Due to refraction phenomena, the wave path tends to become vertical when approaching free surface. This phenomenon is characterized by two important features: (1) whatever nature of the sedimentary geological deposit, it has to move with the same period that the cycle of deformation has in the lithosphere, when the seismic waves reach the location; (2) the dynamic magnification of the acceleration from the lithosphere to the sedimentary deposit depends only on the number of identical cycles of deformation in the lithosphere; *the exciter* (the lithosphere) imparts a motion with the same period to the *driven subsystem* (the sedimentary geological deposit); whatever its nature, the role of the sedimentary geological deposit is to transfer only the "*dynamic amplification*" of the acceleration from the lithosphere to the bases of structures (so only a role of transfer, without any influence on the periods of the cycles of deformation); the sedimentary geological deposit transfers at the bases of structures the lithosphere accelerations that it amplifies; this amplification doesn't depend on the thickness and on the nature of the sedimentary deposit, but only on the number of identical cycles of deformation in the lithosphere; thus, at the base of a structure "*arrives*" the amplified accelerogram of the lithosphere and the manner in which it is transferred from the sedimentary deposit to the structure is revealed by the response spectrum.

b) The transmission of vibrations from the lithosphere to the sedimentary geological deposit next to a given location is performed based on the "*partial resonance phenomenon*" as follows:
   - the deformation cycle that is propagated by the seismic wave in the lithosphere arrives next to a given location with a certain value of its period, depending on the distance "focus – location" and with a peak value of its acceleration;
   - the sedimentary geological deposit is considered as a dynamic system with an infinity of eigenmodes; in consequence, the vibration transmitted from the lithosphere to the sedimentary geological deposit will excite that eigenmode of vibration of this subsystem whose eigenperiod is identical (or close) with the *period of the seismic wave* (T_{SW});

- the vibration transmitted to the sedimentary geological deposit is amplified by a dynamic magnification factor "β"; the value of this factor depends on the repeating number of identical cycles of motion having the same period and intensity; as a result, the acceleration in the sedimentary geological deposit will result amplified by a factor "β";
- the sedimentary geological deposit vibrations are transmitted to the surface existing stock of structures; within this ensemble there are groups of structures which are differentiated by the values of their fundamental eigenperiods;
- the transmission of vibrations from the sedimentary geological deposit to the surface existing ensemble of structures is also performed relying on the "*partial resonance phenomenon*".

5. THE MEXICO-CITY EFFECT

In this paragraph some aspects about the behaviour of buildings in Mexico City during the September 19, 1985 earthquake will be in brief presented. Of interest to engineers was the so-called "*local amplification*" of ground motion imparted by Mexico City's soft lake-bed subsoil.

Analytical developments and factual experience at hand have led to a consensus concerning the importance of influence of local conditions upon the spectral content of ground motion. The influence of local conditions is strong and stable for sites where the ratio of S-wave propagation speeds in base rock versus upper geological package is at least 5:1. If so, the dominant period of ground motion tends to coincide usually (and repeatedly) with the fundamental period of the upper geological package. This statement was strongly confirmed by the strong motion records of 1985.09.19 at sites of Mexico City (SCT, with dominant period > 2 s and Central de Abastos, with dominant period > 3 s) and for those of 1986.08.30, 1990.05.30 and 1990.05.31 of Romania (prototype: Cernavoda Town Hall, with dominant period $\approx$ 0.4 s), for which the S-wave condition mentioned previously is fulfilled. On the contrary, for sites of Romania for which such a condition is not fulfilled, the spectral contents of ground motions changed considerably from one event to the other. The destruction caused by the earthquake of 19 September 1985 in Mexico City showed the fact that this earthquake, characterized by a big epicentral distance, caused so much destruction in the lake-bed zone of Mexico City; three remarkable features were showed: *first*, a concentration of damage in the former lake-bed; *second*, a peculiar distribution of high- and low- damage areas alternating within a few city blocks, and *third*, a selectivity for buildings in the 5-20-storey range; while the last point is understood by civil engineers and the first one confirms the relevance of the soft ground, the second feature is most puzzling.

6. IS NEHPR SITE CLASSIFICATION A FALLACY IN EARTHQUAKE ENGINEERING?

The NEHRP (1994) ground classification (with some minor modifications) was adopted in the Eurocode 8 (2003) and in 2005 in the National Building Code of Canada (NBCC). In Eurocode 8, it is clearly stated: "*the values of the periods T_B,, T_C and T_D and of the soil factor S describing the shape of the elastic response spectrum depend on the ground type*". The conclusion of all these official documents is the concept according to which the "*sedimentary layer*" modifies the characteristics of the seismic action in a given location. On February 12, 2011, at the EERI Annual Meeting, a session entitled "*Is $V_{S,30}$ an effective parameter for site characterization?*" was held. Professor Izzat M. Idriss stated: "*$V_{S,30}$ is neither a fundamental nor a unique geotechnical parameter; sites with "identical" $V_{S,30}$, but different layering within the upper 30 m can have significantly different response; site effects do not appear to be well constrained or represented $V_{S,30}$; hence, $V_{S,30}$ is not an adequate continuous independent parameter in earthquake ground motions attenuation relationships*". Professor Ellen M. Rathje stated: "*although $V_{S,30}$ is a useful parameter for identifying general site conditions, it suffers from various deficiencies; for example it does not adequately capture the effects of the lowest velocity layers and it does not capture the deeper velocity structure because it ignores the velocity profiles below 30 m*". Norman Abrahamson stated: "*$V_{S,30}$ is not a fundamental physical parameter for determining the site amplification; the main question about the use of $V_{S,30}$ as a site parameter is: does it work? If $V_{S,30}$ by itself is not enough, then additional parameters can be considered*". Professor

Jonathan P. Stewart asking himself rhetorically: "*Is* $V_{S,30}$ *an effective parameter for site characterization?*", gave the following response: "*The* $V_{S,30}$ *parameter provide an incomplete representation of site condition for quantification of site response*". Having in mind these aspects all we have to do is to think about the existing codes in force. In the Romanian code, the Eurocode 8 ground classification scheme, is not applicable. For the design, the local ground conditions are classified in three categories (Z_1, Z_2, Z_3) based on the available seismic records of the 1977, 1986 and 1990 intermediate earthquakes. The values of the corner periods for the three local ground conditions of the Romanian territory are 0.7 s, 1.0 s, and 1.6 s. What is important to specify is the fact that these zones are also in agreement with the thicknesses and nature of the sedimentary geological deposits. In the author's opinion the sedimentary layer is not the cause which modifies the main characteristic of a seismic wave arriving at the base of a building in a certain location. To sustain this statement it is necessary to refer to the 1977 and 1986 Vrancea earthquakes. The whole area influenced by these seismic events, which includes Bucharest, is covered by a sedimentary geological deposit with variable thickness (for example, in Bucharest the thickness is about 1.5 km, while in a small locality called Cheia (MLR) the lithosphere is found practically at the surface of the Earth, so no sedimentary deposit exists). In Fig. 6.1 and Fig. 6.2 the corresponding absolute acceleration spectra for 5% critical damping for the two mentioned locations are presented.

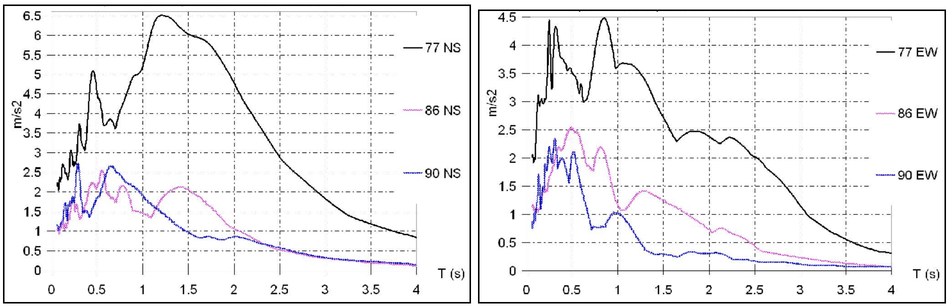


Figure 6.1. Absolute acceleration response spectra – INCERC Bucharest (1977, 1986 and 1990)

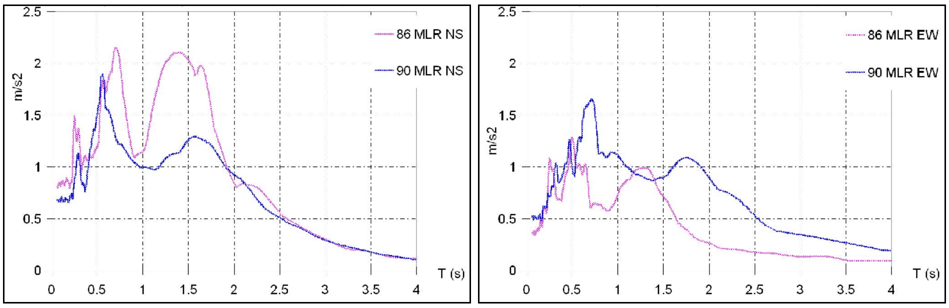


Figure 6.2. Absolute acceleration response spectra – Cheia (1986 and 1990)

The computed response spectra for Bucharest-INCERC station, for the 1977 and 1986 earthquakes, have similar shapes and the maximum seismic energy is centred in the long period zone corresponding to 1.5 s (Fig. 6.1). During the 1986 earthquake, the computed response spectra for MLR location (Cheia) put also to evidence peaks situated near periods of about 1.5 s. A very important conclusion that can be formulated is the following: for epicentral distances of the same order, periods of motion around the same values were obtained. This aspect shows that in Bucharest, the sedimentary geological deposit of 1.5 km thickness had no influence on the peaks of the response spectra, having in mind the MLR location where practically no sedimentary geological deposit exists (Fig. 6.2).

8. FINAL REMARKS

1. The examination of a huge amount of papers dealing with the propagation of seismic waves and with effects that local site conditions have on distribution of earthquake damage led to a

conclusion excellently exposed in 2003 by Professor Mihailo Trifunac: "*many published interpretations of damage are imprecise, and often they follow the consensus rather than the trends indicated by the data*" (Trifunac, 2003). Nothing can be added to this, but I dare to declare that in other topics, including the propagation of seismic waves, things get worse.

2. The complexity of earthquake ground motion is due to three factors: *source*, *path* and *local site effects.*
3. Next to a given location, along the propagation path of a seismic wave, a cycle of deformation arrives with a certain value of its period "T_{SW}"; the motion with this period value is transmitted to the sedimentary geological deposit which will further generate the maximum dynamic effects to some of the civil engineering works above it; in consequence, the maximum surface effects will be signalled to those structures for which $T_{1,S} = T_{SD} = T_{SW}$ (Sing et al, 1988).
4. The value of the period of the cycle of deformation in the lithosphere, T_{SW}, next to a given location, depends on the distance "*hypocenter – location*", on the severity of the earthquake (the seismic magnitude), on the nature of rocks in lithosphere, and more likely on other unknown factors.
5. The value of the period of the seismic wave (T_{SW}) for which a "β_{max}" dynamic magnification factor results is the same with the value of the corner period of the response spectra in the design codes.
6. The seismic waves arrived through the lithosphere next to a location are transmitted to the surface of the Earth almost vertically (due to refraction phenomenon). From a dynamic point of view, the seismic action arrived through lithosphere will be transmitted at the Earth's surface with the same period. Each stratum will move identically as the lithosphere moves.
7. In the design codes in force is found the concept according to which the nature of the sedimentary geological deposit modifies the dynamic characteristics of the seismic action in a given location. Based on this concept, in both American codes as well as the European ones there is a dynamic "*classification*" of the sedimentary layer effects on the characteristics of the accelerograms in a given location. The opening of a scientific debate on this subject is necessary as the concept above mentioned is tributary to the actual mode of propagation of seismic action from the hypocenter to a certain location. As it was previously shown, the first step was made by EERI, in 2011.
8. It is obvious that the difference in behaviour of buildings to seismic actions in Mexico City is given by their structures of foundation and, of course, by the "*characteristics*" of the sedimentary deposit. In conclusion, the past, present, and future behaviour of buildings (especially tall ones) must be studied having in mind the concept of the "*total structural system*", which comprises the superstructure, the substructure, the structure of foundation, and the foundation medium.
9. The "*predominant period*" of the sedimentary geological deposit "*doesn't exist*", being a false concept; the dominant period refers to the period of the cycle of deformation in the lithosphere in a given location.

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