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SOME IMPLICATIONS OF STRONG MOTION ACCELEROGRAMS OBTAINED IN ROMANIA

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Abstract: *The regulatory literature concerning the earthquake protection reveals the fact that the design parameters are prescribed assuming implicitly a linear performance of the ground – structure interface. Thereafter, the upper part of the ground – structure system may be eventually designed recognizing explicitly the post-elastic performance of the upper part referred to. On the contrary, the scientific concern during recent decades has shown that non-linear interaction during strong earthquakes is frequently unavoidable and, perhaps, even beneficial for the capacity of structures to withstand strong seismic action. The data at hand reveal the fact that non-linear dynamic interaction had to occur in some cases, at least in terms of partial uplift of foundations. The implications of potential occurrence of non-linear performance of ground – structure systems lead logically to the need to revise the philosophy of regulatory documents. This requires at its turn an examination of the topology of transfer to ground of the seismic forces.*

Key words: *soil – structure interaction, foundation uplift, transfer topology, code philosophy.*

1. Introduction

A look to the regulatory literature concerning the earthquake protection of buildings and other structures reveals the fact that the parameters concerning the specification of design loading are routinely prescribed assuming implicitly a linear performance of the ground – structure interface (or contact system). Thereafter, the upper part of the ground – structure system may be eventually designed recognizing explicitly the post-elastic performance of the upper part referred to. In agreement with the scientific impact of the modern philosophy of the New Zealand school on earthquake resistant design, the ground performance should be, implicitly, in a mandatory way, linear. On the contrary, the scientific concern during recent decades on ground – structure interaction (which has become feasible due to the progress of calculation capabilities), has shown that non-linear interaction during strong earthquakes is frequently unavoidable and, frequently, even beneficial for the capacity of structures to withstand strong seismic action. Note here some representative papers, [2], [3], as well as two early representative papers of Romania, [4], [1].

After some methodological

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considerations, the data at hand on structural performance of some buildings, as revealed by simultaneous accelerograms obtained at ground and at top level, reveal the fact that non-linear dynamic interaction had to occur, at least in terms of partial uplift of foundations.

The implications of potential occurrence of non-linear performance of ground – structure systems lead logically to the need to revise the philosophy of regulatory documents. Prior to specifying the seismic loading parameters, the weak links of ground – structure systems are to be identified, and this requires at its turn an examination of the topology of transfer to ground of the seismic forces.

2. Some methodological references

The references to the case studies presented in next section make use of some methodological developments that are to be briefly recalled. They are related to:

1. Ways of characterizing the seismic motion of ground and/or structures.
2. Ways of dealing in a simplified manner with the kinematics of dynamic systems analysed.

Some brief data on these developments are presented subsequently.

2.1. Ground motion characteristics used

The basic full characterization of actual ground motions is provided by the accelerograms recorded. Since we are interested in the spectral content as well as the destructive potential of ground motion, it is most useful to undertake some appropriate ways of processing referred to.

The most usual way to do that is to determine the response spectra for absolute or relative accelerations, velocities or displacements, depending upon the type of analysis performed. These functions refer usually to ground motions. They may be of interest even for some locations on structures, in case one installs there some valuable and vulnerable components of equipment.

Another way of high interest to analyse the features of ground motion, as well as of motion of various objects, is represented by the Fourier spectra, (complex or absolute). This approach makes it possible to analyse in a comprehensive way the features of seismic motion of ground or other objects and to derive in a reversible way the motion characteristics of various objects of interest in one sense of passage or in the opposite sense. It is usable as far as the systems dealt with present a linear performance.

Besides the ways widely known and used referred to, it may be interesting to use also the intensity spectra [9]. This approach makes it possible to get a condensed and flexible characterization of the severity of ground motion, providing a synthetic view capable to generalize in terms that are of interest for engineering activities, of the destructive potential of ground motion, for various spectral bands and also for various directions. This approach is not used in this paper, due to overall length limitation. Details on this subject can be read in [5], [7].

2.2. Dealing with the kinematics of the systems analysed

The systems analysed in this view are relatively tall residential buildings like those of Fig. 2. Some general data on their ambient oscillation were given in [10]. The structures dealt with are assumed to be dynamically symmetrical with respect to two (orthogonal) vertical planes (referred to as longitudinal and transversal main planes). The main components of their deformation analysed on the basis of full scale experimental results refer to the features of motion in a principal (longitudinal or transversal) vertical plane. The structures dealt with are considered vertical macro-cantilevers. The full scale experimental data at hand were referred to this basic model. The types of macro-deformation of these systems are:

a) Rigid tilting (due to ground deformation);

b) Pure bending;

c) Pure shear.

The full scale experimental data have shown that, for oscillations in the longitudinal plane, the pure shear contributes with around 50% of the amplitude of displacements at the top, while for oscillations in the transversal plane the contribution of tilting and or pure bending is usually more than 50%. In spite of accepting a quite crude idealization, the oscillations of these dynamic systems will be assumed to correspond purely to rigid tilting.

An exercise in dealing with the relationship between pure rigid tilting and vertical motions is presented for the simple case of a vertical macro-cantilever. The interface with the ground is a rectangle of dimensions a and b respectively and the height is h (from the centre of ground – structure interface to the top). The axes Ox and Oy have an origin located at the centre of the rectangle referred to, while the axis Oz with a coordinate (increasing upwards) corresponds to the intersection of the two main vertical planes mentioned. The (infinitesimal) rotations considered are φ (rotation from Ox to Oz) and ψ (rotation from Oy to Oz) respectively. The displacements along the axes Ox, Oy and Oz are u, v and w respectively. The angles of rotation are

$$\varphi = \partial w/\partial x = - u / h \qquad (1.a)$$

$$\psi = \partial w/\partial y = - v / h \qquad (1.b)$$

The vertical displacement at a current point of coordinates x and y (assuming no vertical displacement at the origin of axes) is

$$w (x, y) = \varphi x + \psi y \qquad (2)$$

The vertical displacements at the corners of the horizontal plane section are, under these assumptions,

$$w (\pm a /2, \pm b / 2, t) =$$

$$= \pm \varphi (t)\, a / 2 \pm \psi (t)\, b / 2 \qquad (2')$$

The equation (2') may be used for displacements, velocities or accelerations. The time variable during the seismic event, *t*, was explicitly introduced just in the equation (2'), but it is self-understood that it may be introduced already in former equations. The functions characterizing the variable position of the ground structure interface during an earthquake are the vertical displacements at the four corners, $w (\pm a /2, \pm b / 2, t)$. Due to the dynamic symmetry assumed for the dynamic system dealt with, the order of the interface corners is not significant.

3. Some case studies

The data referred to subsequently rely on the strong motion information at hand, obtained from the accelerographic network in operation during last decades. This network pertains to the Building Research Institute INCERC – Bucharest and consists of analog accelerographs (mainly SMA-1).

Romania was subjected during last decades to three strong Vrancea earthquakes, as shown in Table 1. While in 1977 the strong motion network of INCERC consisted of a very small number of accelerographs, the situation changed totally thereafter, mainly due to the generous aid provided in 1978 by the Agency of International Development of the State Department of USA.

Data on earthquakes referred to Table 1

No	Earthquake	*h* (km)	Date
1	$M_{GR} = 7.2$	109	1977.03.04
2	$M_{GR} = 7.0$	133	1986.08.30
3	$M_{GR} = 6.7$	91	1990.05.30

The strong motion network that provided records during the earthquakes referred to consists currently of analog instruments, most of them of SMA-1 type, produced by Kinemetrics (USA). The location of towns where instruments are installed is shown in Fig. 1. The results concerning the features of ground motion, obtained by the network referred to were presented and discussed in several papers, [6], etc., but less attention was paid to date to the performance of structures, as revealed by motion records obtained at the top level of several buildings. A recent publication on this subject was [8]. Since the main object of this paper is to identify some features of the non-linear performance of buildings, attention is paid to some cases concerning buildings like those of Fig. 2, subjected to some of the earthquakes mentioned in Table 1.

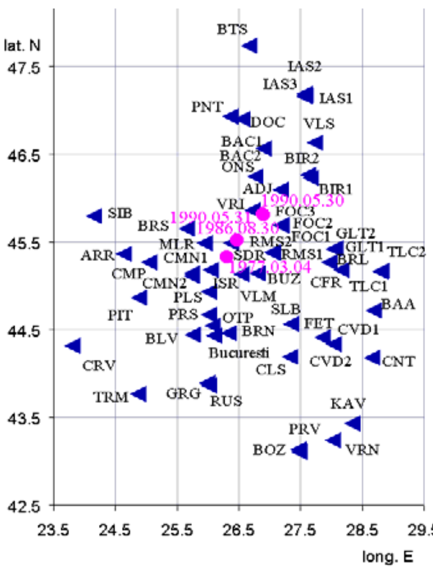

Fig. 1. *Analogical strong motion network of Romania*

The time histories of horizontal accelerations recorded are given in Fig. 3. for some cases, if possible together for ground and top levels of a same building dealt with, for the two horizontal directions. The Bucharest - INCERC and Bucharest – Balta Albă, data of 1977.03.04, are given together in Fig. 3.1, since accelerographic information at that date was available only for ground level at

Fig. 2.1. *BUCHAREST, Balta Albă, E.5, BLA*

Fig. 2.2. *BUCHAREST, Alexandria 114, OD1 Bldg., RAH*

Fig. 2.3. *PLOIEȘTI – WEST, 149 C Bldg., PLS*

Fig. 2. Buildings where non-linear performance apparently occurred during recent earthquakes

INCERC and top level at Balta Albă. This arbitrary latter combination was adopted because only these records were available for the event of 1977.003.03, while for other cases the accelerograms are given

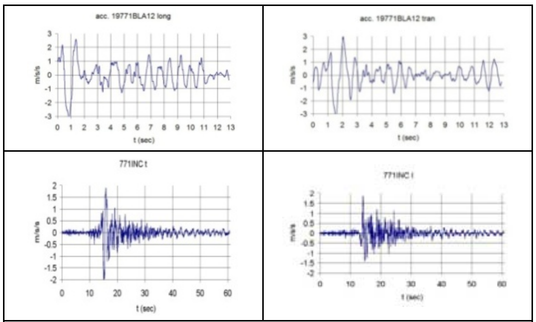

Fig. 3.1. *Accelerograms at top level of building of Fig. 2.1. and at ground level, at INCERC, on 1977.03.04*

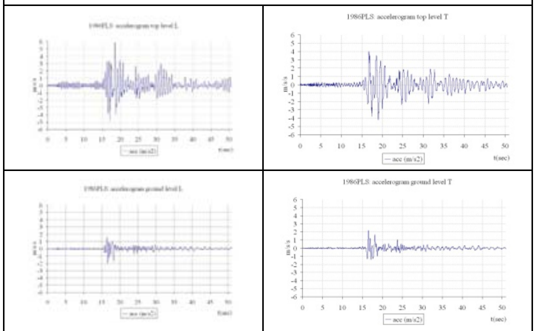

Fig. 3.2. *Accelerograms at top and ground levels of building of Fig. 2.3 on 1986.05.30*

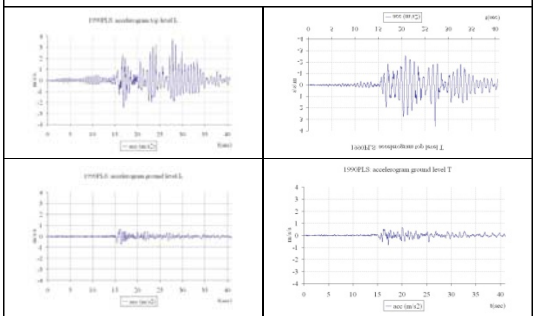

Fig. 3.3. *Accelerograms at top and ground levels of building of Fig. 2.2. on 1990.05.30*

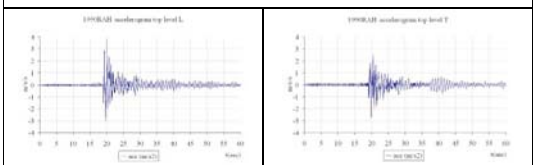

Fig. 3.4. *Accelerograms at top level of building of Fig. 2.2. on 1990.05.30*

Fig. 3. *Accelerogams referred to in the paper*

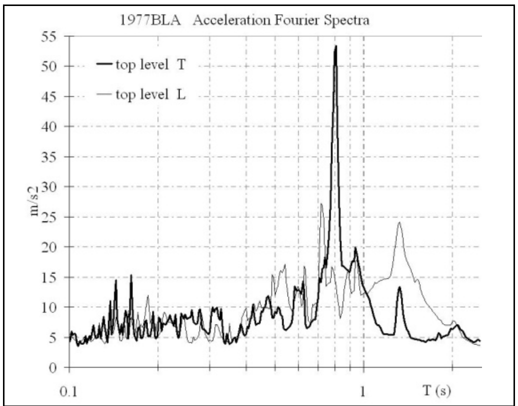

Fig. 4.1. *Fourier spectra of accelerograms at top level for building of Fig. 2.1, for both directions, for the event of 1977.03.04*

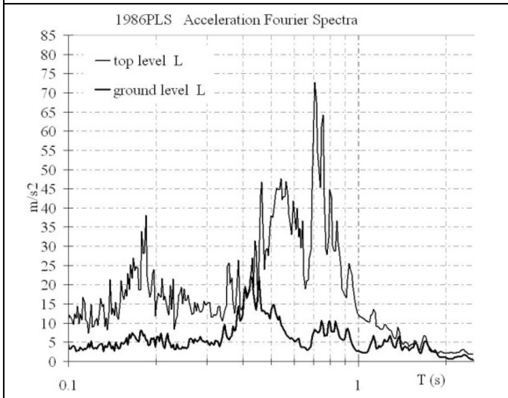

Fig. 4.2.a *Fourier spectra of accelerograms at top level for building of Fig. 2.3, for the longitudinal direction, for the event of 1986.08.30*

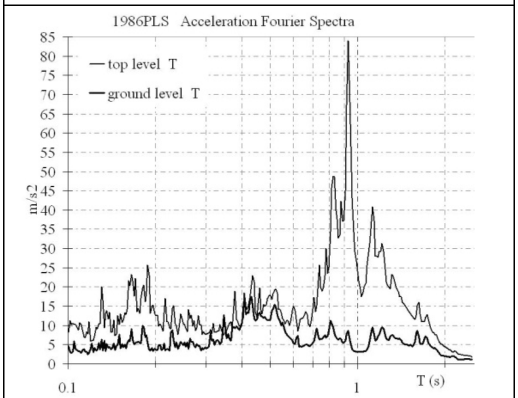

Fig. 4.2.b.*Fourier spectra of accelerograms at top level for building of Fig. 2.3, for the transversal direction, for the event of 1986.08.30*

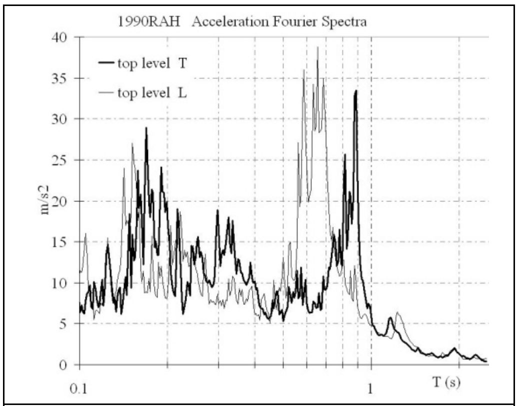

Fig. 4.3. *Fourier spectra of accelerograms at top level for building of Fig. 2.2, for both directions, for the event of 1990.05.30*

Fig. 4. *Fourier spectra for some buildings and events*

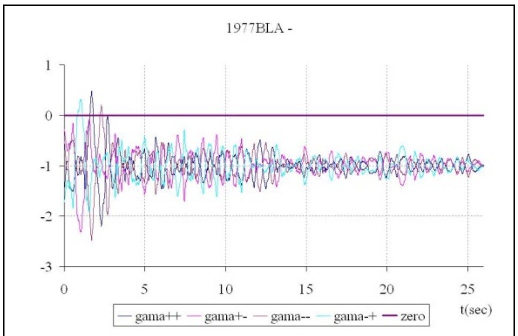

Fig. 5.1. *Vertical accelerograms derived for the corners of building of Fig. 2.1, for the event of 1977.03.04*

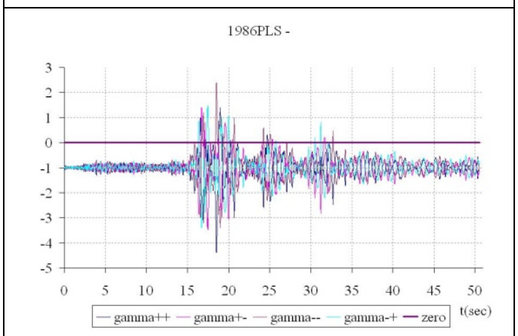

Fig. 5.2. *Vertical accelerograms derived for the corners of building of Fig. 2.3, for the event of 1986*

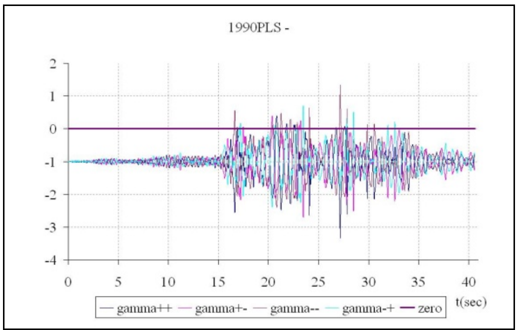

Fig. 5.3. *Vertical accelerograms derived for the corners of building of Fig. 2.3, for the event of 1990.05.30*

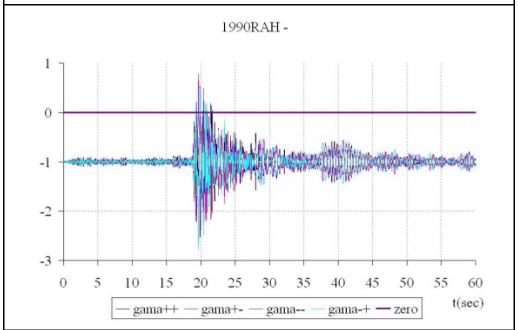

Fig. 5.4. *Vertical accelerograms derived for the corners of building of Fig. 2.2, for the event of 1990.05.30*

Fig. 5. *Vertical accelerograms derived assuming rigid body motion for the buildings and events referred to*

together for ground and top levels for the various cases. The accelerograms for the cases of Bucharest - INCERC and Bucharest – Balta Albă, on 1977.03.04, are given together, since accelerographic data and Fourier spectra were quite similar for other events [6].

The acceleration amplitude Fourier spectra are given in Fig. 4. It was estimated that, given the limited length of the paper, other characteristics of motion, like response spectra or intensity spectra, should not be presented here.

Some comments on the figures presented:

- The buildings dealt with are quite similar and are also representative for and important part of mass construction achieved in Romania, during three decades, from about 1960 to 1990;

- Data provided by accelerograms, available and used, characterize some of the most severe cases of earthquake effects obtained to date in Romania during the strong earthquakes and locations for which recording instruments were installed. While the earthquake of 1977 was destructive, having a magnitude return period of around 50 years, the other two events referred to were severe too, but not destructive, and had return periods in the range of 10 to 30 years. This means that the Vrancea sesimogenic zone is able to generate also more severe earthquakes, during which non-linear performance of the soil and ground – structure interface should be characterized by higher uplift amplitudes and, perhaps, by severe local deformation of soil, generated by compressive stresses.
- The graphs of Fig. 3.2 reveal the well known fact that, for a given building, the amplitude of seismic accelerations at the top level are much more severe than those of ground level.
- The graphs of Fig. 4.2 reveal a similar fact, that amplitudes of oscillations at the top level of a building are much more severe than those of ground level. Moreover, they reveal the fact that the dominant periods (or frequencies) of motion at top level do not coincide with those of ground level, while a paramount influence of the dynamic characteristics may be remarked, especially for the plots of Fig. 4.2 (especially Fig. 4.2.b).
- A look at Figures 5 shows that partial, transient, uplift should have occurred during the earthquakes and at the locations considered. It is most likely that the phenomenon of non-linear soil performance should have occurred in several cases.

4. Final considerations

1. A look at literature shows that, while about three to four decades ago, literature devoted to non-linear dynamic interaction was at its beginnings, by now the concern for non-linear dynamic ground – structure interaction during strong earthquakes has increasingly become a recognized, important, branch / component of earthquake engineering. In numerous cases, the concern for non-linear performance of ground – structure dynamic systems appears to be a key component of measures of earthquake protection of structures. Note here as representative the references [2] and [3].

2. The analysis of performance of structures in case of occurrence of phenomena of non-linear soil performance shows that there may be many situations for which the non-linearity of interaction turns out to be favorable. The non-linear performance of the interface of relatively tall buildings leads to a decrease of overturning stiffness as well as of overturning moments. A new problem is raised instead in case of relatively slender buildings: the risk of overturning of structures. This represents a problem of stability of position.

3. The concern for non-linear performance of ground – structure systems implies a need of methodological reconsiderations. In principle, the seismic design loading should no longer be prescribed assuming that it may be specified irrespective of possible non-linear ground – interaction. On the contrary, one should investigate the ground – structure interface, in order to determine weak links of the system.

4. It turns out that it would be correct and necessary to investigate the topology of ground – structure transfer of seismic effects. Moreover, in case the system dealt with includes also critical pieces of

equipment, the view on the topology referred to should be extended, by deciding which should be the most appropriate sequence of failure of parts of ground, structure, equipment etc. in case of overloading.

5. It is highest time to reconsider the philosophy of codes and, correspondingly, the procedures of design or of evaluation of vulnerability and risk of existing structures, adopting an appropriate methodology.

6. The problems raised by the methodological modifications required are quite complex and, in order to reach satisfactory solutions, research of analytical nature should be organized. Of course, in depth analysis of the actual performance of structures, paying special attention to instrumental information will be necessary.

References

1. Constantinescu, D., Dimitriu, D.: Efecte ale rotirii fundației pe teren asupra răspunsului dinamic al structurii. *Construcții,* 6, 1985.
2. Gazetas, G.: Apostolou, M.: Nonlinear Soil–Structure Interaction: Foundation Uplifting and Soil Yielding", *Proceedings Third UJNR Workshop on Soil-Structure Interaction*, March 29-30, 2004, Menlo Park, California, USA.
3. Pecker, A.: „Non-linear soil structure interaction: impact on the seismic response of structures".Gėodynamique et structure. *OECD / NEA IAGE IAEA ISCC Workshop on SSI*, Ottawa, 2010.
4. Sandi, H.: "Interacțiunea dinamică dintre structură şi terenul de fundare" (Dynamic interaction between structure and soil). *Construcții*, 4-5, 1985.
5. Sandi, H., Borcia, I. S.: "Intensity spectra versus response spectra. Basic concepts and applications." *Pure and Applied Geophysics*, Springer, 2011, Volume 168, Numbers 1-2, Pages 261-287, ISSN 0033-4553.
6. Sandi, H., Borcia, I. S.: "A summary view of instrumental data on recent strong Vrancea earthquakes and implications for seismic hazard". *Pure and Applied Geophysics*, 2011, Volume 168, Numbers 3-4, Pages 659-694, ISSN 0033-4553.
7. Sandi, H., Borcia, I. S.: "An attempt to recalibrate instrumental criteria for intensity assessmeent*". Proc. 15-th European Conference on Earthquake Engineering*, Istanbul, 2014
8. Sandi, H., Borcia, I. S.: Some implications of full scale data obtained during recent strong Vrancea earthquakes on the assessment of seismic risk. *Proc.Comportarea in situ a construcțiilor*, Braşov, 2014
9. Sandi, H., Floricel, I.: "Some alternative instrumental measures of ground motion severity". *Proc. 11-th European Conf. on Earthquake Engineering*, Paris, 1998
10. Sandi, H., Şerbănescu, Gh.: "Experimental results on the dynamic deformation of multi-story buildings". *Proc. 4-th World Conf. on Earthquake Engineering,* Santiago, 1969.