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A SUMMARY LOOK AT THE PERFORMANCE OFA LARGE SIZE STRUCTURE

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Abstract: The main objective of the paper is to present the results of the monitoring of the dynamic characteristics of the reinforced concrete infrastructure of the great hall of ROMEXPO, the main exhibition building in Bucharest. The monitoring included the initial stage and, thereafter, the stages post-earthquake and post-rehabilitation intervention, for the events of 1977.03.04, 1986.08.30, 1990.05.30 and 1990.05.31. The axial symmetry of the structure made it appropriate to use Fourier expansion techniques.

Keywords: dynamic characteristics, spectral densities, Fourier expansion, stages of performance

INTRODUCTION

The paper is concerned with a presentation of the main features and of the performance of a large size structure, namely the main hall of ROMEXPO in Bucharest, Romania. This paper includes:

- a brief presentation of some main characteristics of the structure dealt with;
- a brief presentation of the studies carried out;
- main results on the monitoring of the dynamic characteristics of the structure, at successive stages of the structural performances, before and after the earthquakes having occurred during the service period of the structure;
- references to the additional studies performed.

Other aspects dealt with, just briefly referred to due to the length restrictions of the paper, are mentioned in the references. The paper summarizes analytical and full scale experimental work carried out during two different periods:

- the period of analog recording (July 1976 to July 1993)during which Ioan Sorin Borcia (†), Mihail Stancu and Olga Stancu (†) had significant contributions;
- the period of digital recording (September 2011 to September 2012), during which Patricia Murzea (doctoral thesis [3] advised by the first author), Ion Vlad and Nausica Vlad (management and use of digital recording instrumentation, processing of records)had important contributions.

The first author developed and coordinated the analytical work and coordinated the experimental work and processing of records.

DATA OF THE PROBLEM AND APPROACH ADOPTED

The structure (lateral view: Figure 1, vertical section Figure 2) has an almost perfect axi-symmetrical layout and consists of a reinforced concrete infrastructure (mainly: 32 couples of 25m tall columns) and a steel dome. The initial network dome solution collapsed during the winter of 1963, due to strong non-symmetrical snow loading. The new solution adopted for the dome relies on 32 radial arches.

The diameter of the steel dome is 95 m and the altitude of the dome apex is 30 m. The external structure, which bears the dome, is separated from the internal structure, which bears the live loads determined by the service. An internal view of the dome is given in Figure 3, while a scheme of placing the instruments at the level at the main bearing ring in a horizontal plane view is given in Figure 4.

The earthquake of 1977.03.04 (which produced more than 30 cases of collapse of buildings in Bucharest [1]) damaged severely the structure. Some of the natural periods were seriously lengthened and the axial symmetry was obviously affected. The lateral glazing of the infrastructure was destroyed to more than 50%.

Figure 1: Lateral view from East. Main entrance

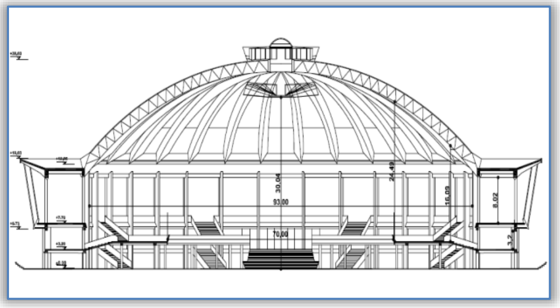

Figure 2: Vertical, central, section

Figure 3. Internal view of the dome

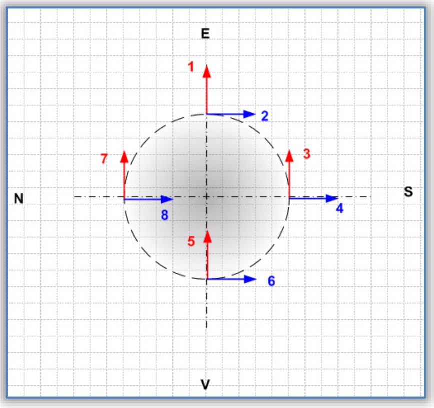

Figure 4. Degrees of freedom of condensed model

A first post-earthquake intervention was undertaken promptly and was adapted thereafter soon to more severe conditions, as required in order to increase the capacity of resistance of the structure to a level appropriate to the intensity of seismic hazard, as made obviously necessary by the experience of the 1977 event. A new rehabilitation and strengthening solution was developed after the occurrence of the subsequent events. Among other, the dynamic axial symmetry was thus rehabilitated. Note that the main reinforced concrete members were strengthened in comparison with their initial sizes.

The signals provided by the pickups used had to be combined in order to obtain the desired information on the deformation of the structure. During the period of analog recording the cables connected to the pickups were alternatively combined in field, in order to directly obtain the information of interest, namely time histories of the combinations referred to. During the period of digital recording just simple records of the reference variables were stored and the combinations of interest were obtained from the computer.

The reference model used for structural analysis is quite simple, due to the features of symmetry referred to. At the scale of the structure as a whole, it derives from a vertical macro-cantilever, placed at the central axis of the dome. Attention is paid to the horizontal local displacements at recording locations only, namely at the points of intersection of the EW and NS ring diameters with the (circular) axis of the main dome bearing ring (Figure. 4). The deformation of the structure is characterized on this basis by the horizontal components of displacements.

The systems of displacements corresponding to the natural oscillation shapes are ordered in principle as double sequences, depending on two variables. A first, basic variable corresponds to the order of natural macro-shape in the overall system. A second variable, representing the order of macro-shape in the detailed sequence of macro-shapes characterizing the deformation of the vertical bearing members, is not explicitly used in this frame. It is implicitly assumed that, in relation to this second variable, only the fundamental natural shape is considered. Two terms form a couple of identification symbols for the displacements of each order. In fact, only the fundamental term of the sequence corresponding to a term of the first sequence is used. The first sequence order concerning the infrastructure as a whole corresponds to following successive couples of terms:

- 0: ring dilatation and ring rotation around main structural axis;
- 1: rigid ring translation along a horizontal direction and along a direction orthogonal ($\pi/2$) to it;
- 2: basic (2nd order) ovalization. oriented along the axes of coordinates and a couple of systems of displacements oriented at $\pi/4$ to it;
- 3rd(3rd order) ovalization oriented along the axes of coordinates and a couple oriented at $\pi/6$ to it etc.

To each of the coordinates referred to a couple of systems of displacements thus corresponds.

EXPERIMENTAL RESULTS

Monitoring at successive stages, analog results

A summary of results of analog recording is presented in Table 1.

Table 1. Dominant periods (s) revealed by ambient vibrations (analog recording)

Oscillation direction (DoF)	Recording moment Before 1977.03.04 'quake (July '76)	After 1977.03.04 'quake (Mar.'77)	After provisional strengthening (steel bracing) (April '77)
In plane ring rotation	.41	.94	.59
E-W ring translation	.60	.98	.74
N-S ring translation	.60	1.08	.78
Ring ovalization	.35	.36	.36

Oscillation direction (DoF)	Recording moment After final strengthening (r.c. spatial frame) (July '84)	After 1986.08.30 'quake (Sept. '86)	After 1990.05 'quakes (July '93)
In plane ring rotation	.43	.52	.52
E-W ring translation	.52	.65	.72
N-S ring translation	.55	.65	.66
Ring ovalization	.34	.39	.41

The peak frequency of oscillations along several (generalized) degrees of freedom of the structure is given. The cases, or moments, of loss of axial dynamic symmetry and of its recovery are made obvious. Some main remarks:

- the main dome bearing ring appears not to have been damaged by bending in the horizontal plane (the ovalization periods of the last row are practically unchanged), so it may be concluded that damage was practically confined to the vertical bearing members;
- the event of 1977 produced a strong loss of dynamic symmetry and, most obvious, a lengthening of the in plane ring rotation period corresponding to a loss of stiffness of about 80% (this led the first author to conclude and impose that the vertical bearing system of the structure is to be strengthened especially in the vertical tangent plane of the macro-cylindrical system built by the vertical bearing members);
- the strengthening intervention of 1984 brought the dynamic characteristics back close to the values of 1976 (pre-earthquake), but the subsequent earthquakes (1986, 1990) produced again a lengthening of natural periods that reveals some non-negligible damage.

Characteristics of the current stage of the structure, digital results

Segments of time histories of basic variables are given for illustration in Figures 5 (for displacements) and 6 (for velocities). The plots correspond respectively to the degrees of freedom defined in Figure 4. The plots reveal considerable differences between the various channels, from the points of view of spectral contents and amplitudes. These differences are on the other hand totally changed in case one looks at the plots corresponding to the various subspaces/ combinations of degrees of freedom involved by the structural dynamic symmetry characteristics. Some comments relying on the features of following combinations are presented subsequently.

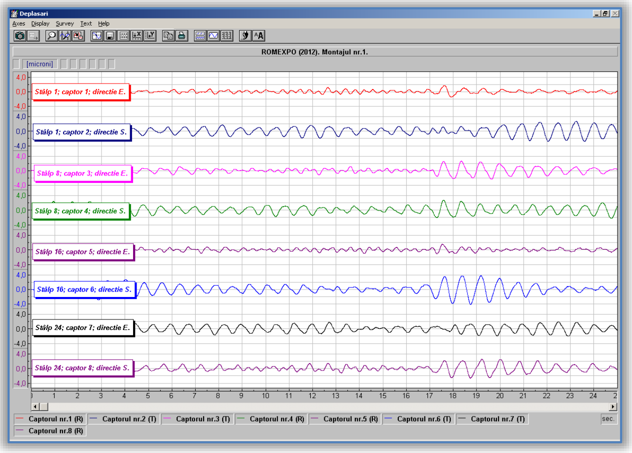

Figure 5: Time histories of displacements along condensed degrees of freedom

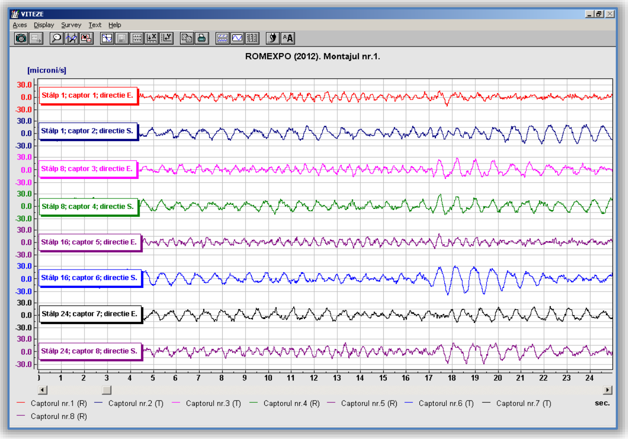

Figure 6: Time histories of velocities along condensed degrees of freedom

A first combination,

$$u_{rad} = (u_1 + u_4 - u_5 - u_8) / 4, \qquad (1)$$

is dealt with in Figures 7… 10. This corresponds to a superposition of symmetrical dilatation with values of a sequence of radial displacements corresponding to the 4-th, 8-th etc. normal mode. By difference to the other combinations dealt with, the sum thus defined does not reveal a clear spectral selectivity.

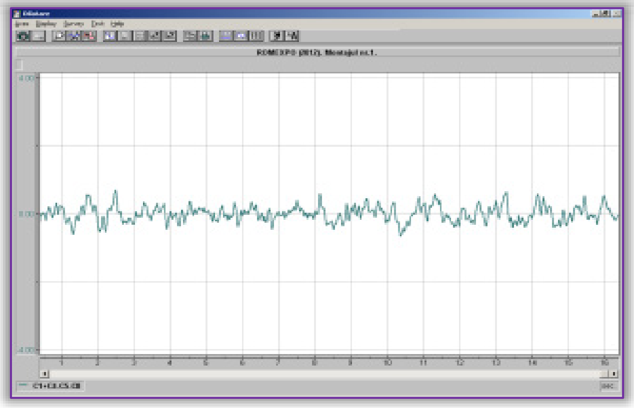

Figure 7: Time history of ring dilatation superposed with condensed coordinates of 4th, 8th etc. orders (displacements)

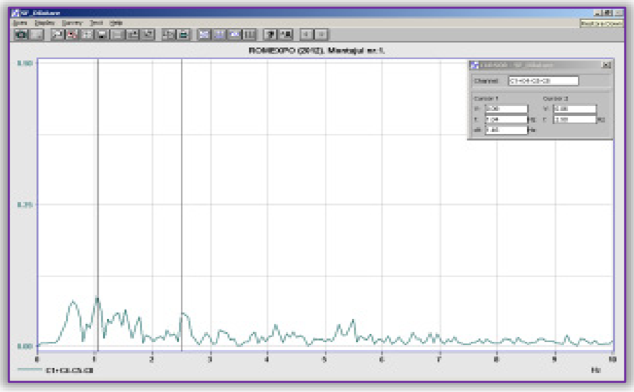

Figure 8: Fourier amplitude spectrum of time history of Figure 7

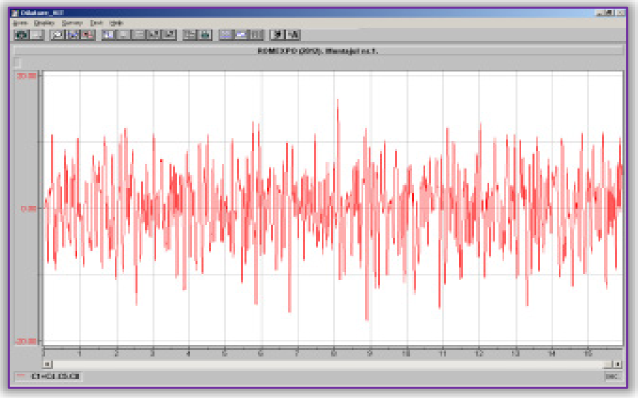

Figure 9: Time history of ring dilatation superposed with condensed coordinates of 4th, 8th etc. orders (velocities)

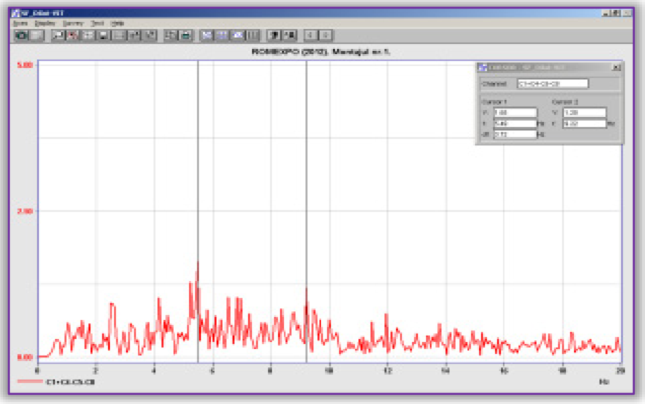

Figure 10: Fourier amplitude of time history of Figure 9

The combination corresponding to rigid rotation of the dome bearing ring around the axis of symmetry of the structure

$$u_{rot} = (u_3 - u_2 - u_7 + u_6) / 4 \qquad (2)$$

is dealt with in Figures 11… 14. This combination reveals a high spectral selectivity, as determined by the sharp peaks of the Fourier spectra.

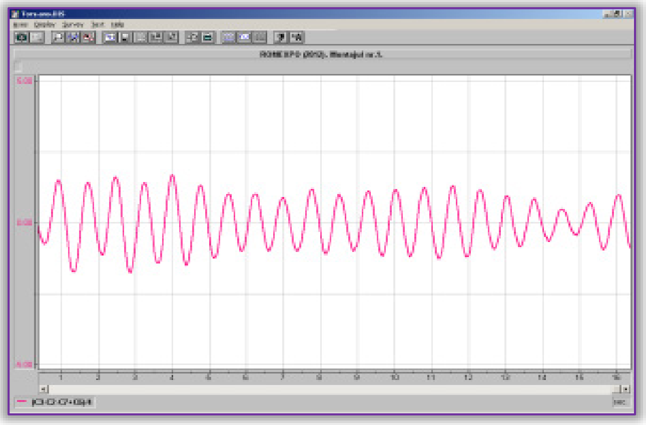

Figure 11: Time history of ring rotation around axis of symmetry of the structure (displacements)

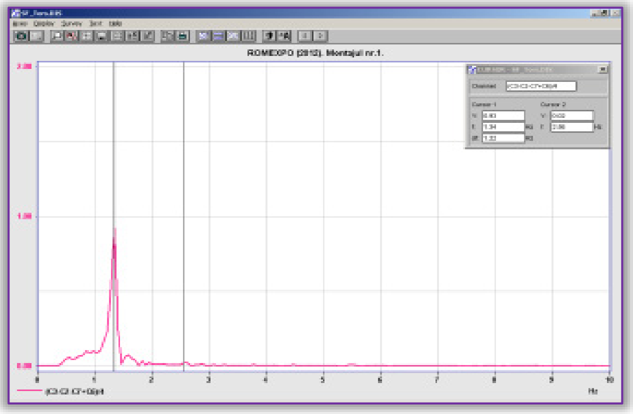

Figure 12: Fourier amplitude spectrum of time history of Figure 11

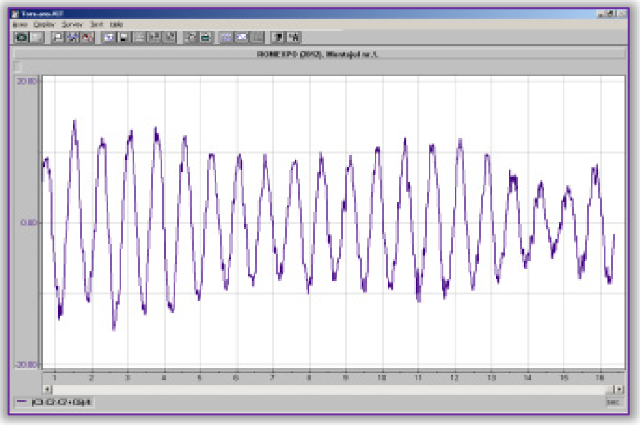

Figure 13: Time history of ring rotation around axis of symmetry of the structure (velocities)

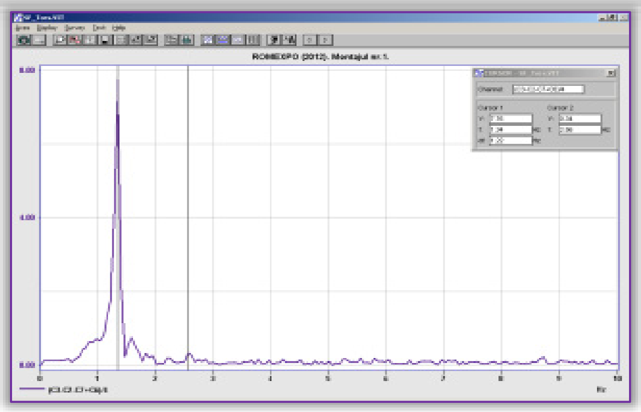

Figure 14: Fourier amplitude spectrum of time history of Figure13

The combination corresponding to rigid translation of the dome bearing ring along the E-W direction,

$$u_{EW} = (u_1 + u_3 + u_7 + u_8) / 4 \qquad (3)$$

is dealt with in Figures 15...18. Here, also, the combination reveals a high selectivity (which is nevertheless lower than in case of the rotation motion).

The combination corresponding to rigid translation of the dome bearing ring along the N-S direction,

$$u_{NS} = (u_2 + u_4 + u_6 + u_8) / 4 \qquad (4)$$

(see Figures 19 to 22) is comparable to the combination corresponding to the E-W combination.

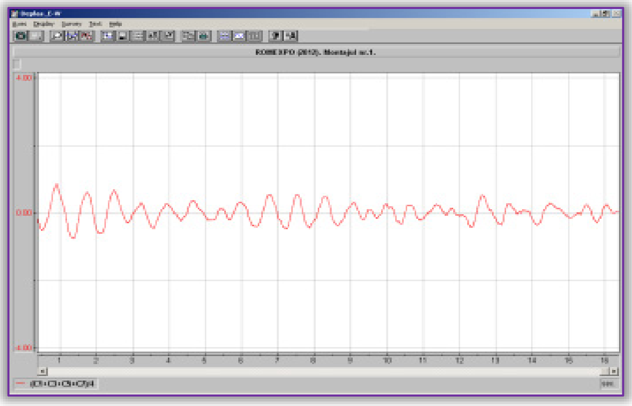

Figure 15: Time history of E-W ring translation (displacements)

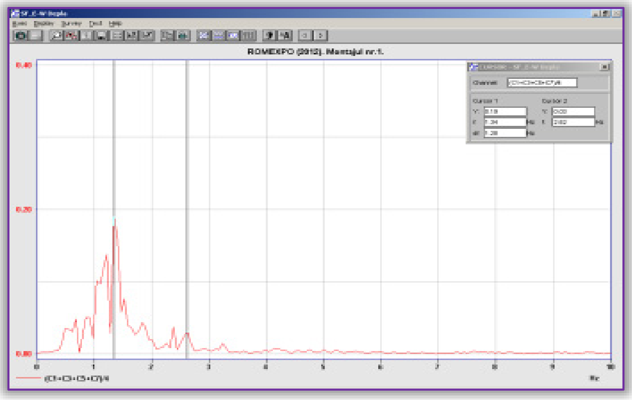

Figure 16: Fourier amplitude spectrum of time history of Figure15

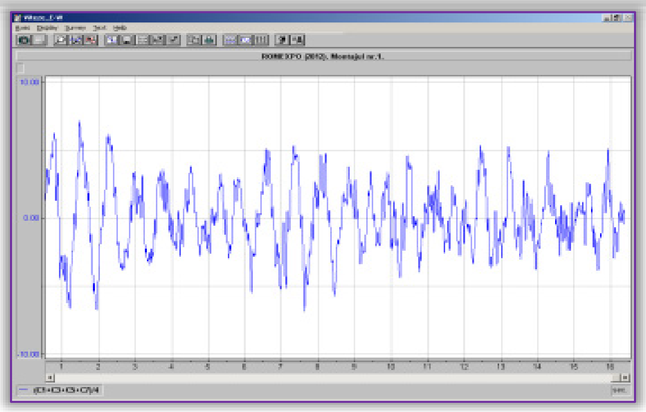

Figure 17: Time history of E-W ring translation (velocities)

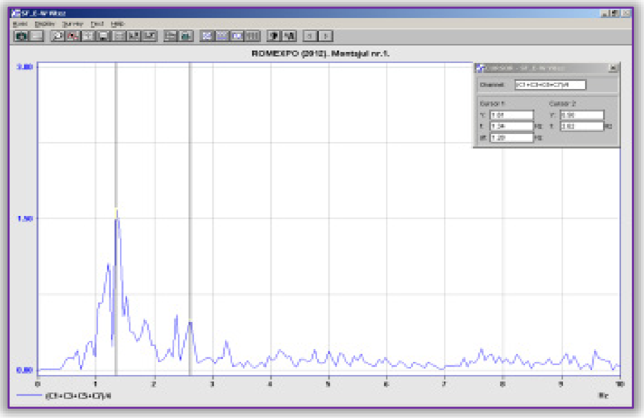

Figure 18: Fourier amplitude spectrum of time history of Figure17

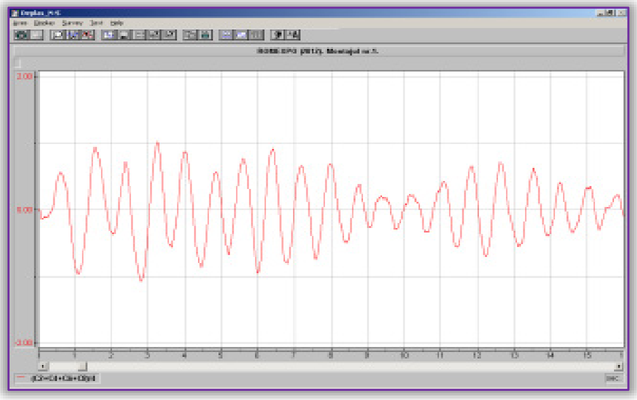

Figure 19: Time history of N-S ring translation (displacements)

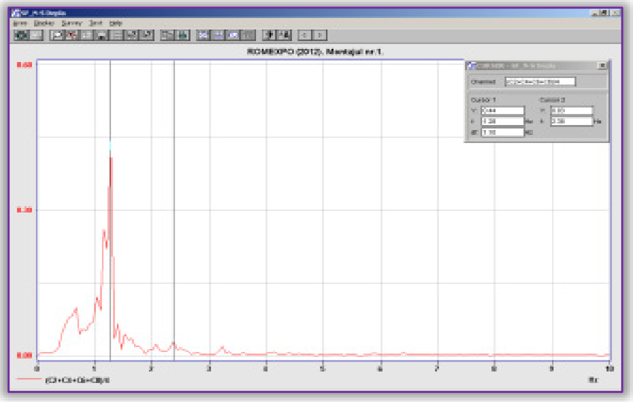

Figure 20: Fourier amplitude spectrum of time history of Figure 19

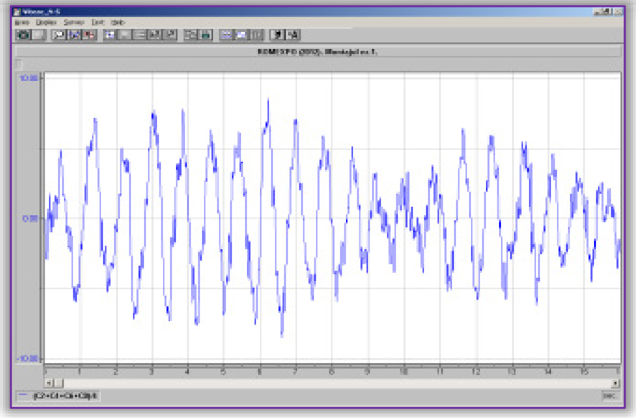

Figure 21: Time history of N-S ring translation (velocities)

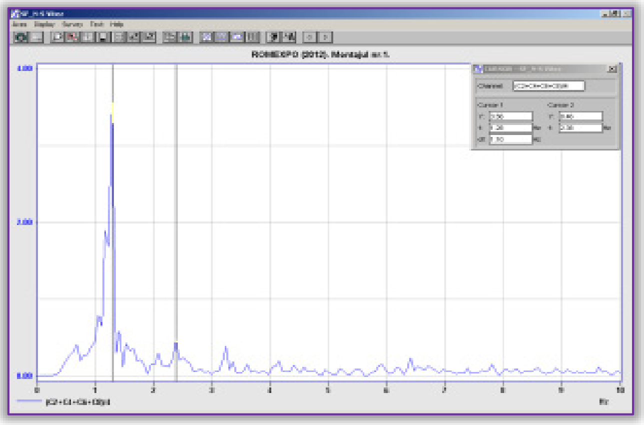

Figure 22: Fourier amplitude spectrum of time history of Figure21

The combination

$$u_{ov2} = (u_4 - u_1 - u_8 + u_5)/4 \qquad (5)$$

corresponding to ovalization along the horizontal reference axes, is dealt with in Figures 23...26. The motion amplitude along this degree of freedom is high, as the spectral selectivity too.

The combination

$$u_{ov2'} = (u_1 - u_3 - u_7 - u_6) / 4 \qquad (6)$$

(see Figures 27 to 30) corresponding to ovalization along directions oriented at 45⁰ with respect to horizontal axes, has characteristics that are quite similar to the previous ones.

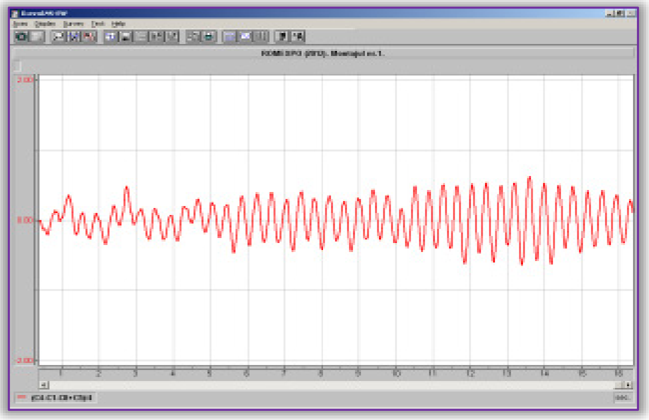

Figure 23: Time history of 2nd order ovalization along coordinate axes (displacements)

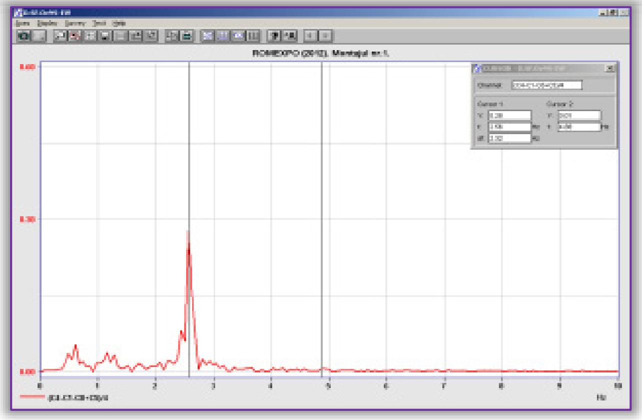

Figure 24: Fourier amplitude spectrum of time history of Figure 23

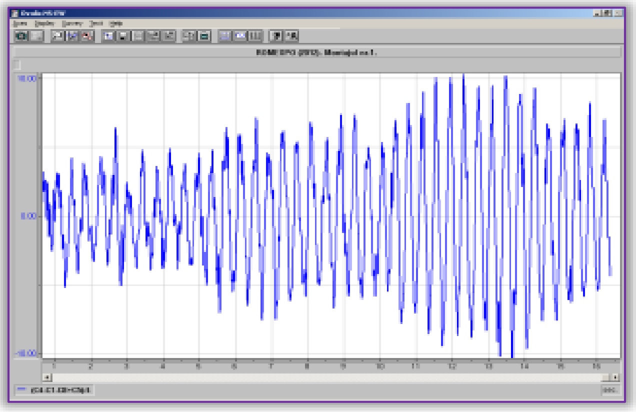

Figure 25: Time history of 2nd order ovalization along coordinate axes (velocities)

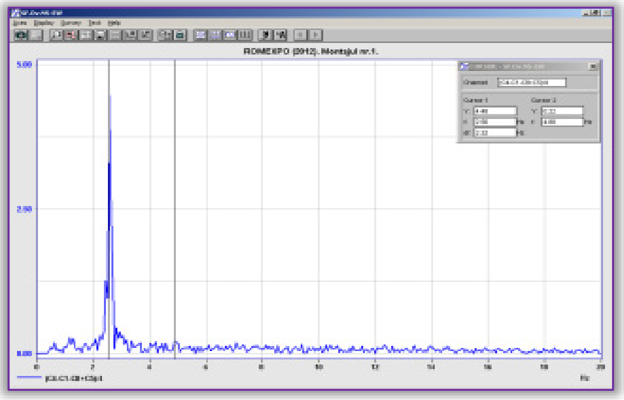

Figure 26: Fourier amplitude spectrum of time history of Figure 25

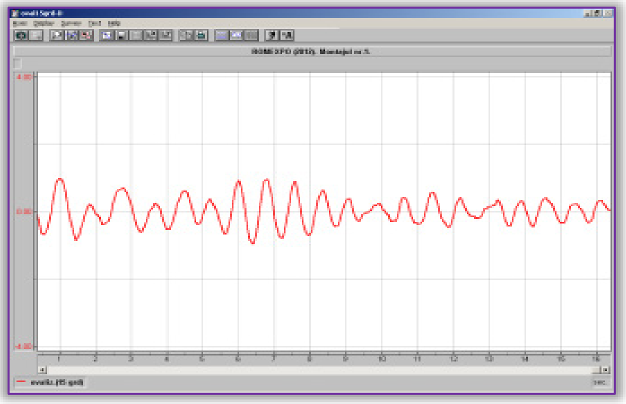

Figure 27: Time history of 2nd order ovalization 45⁰ from coordinate axes (displacements)

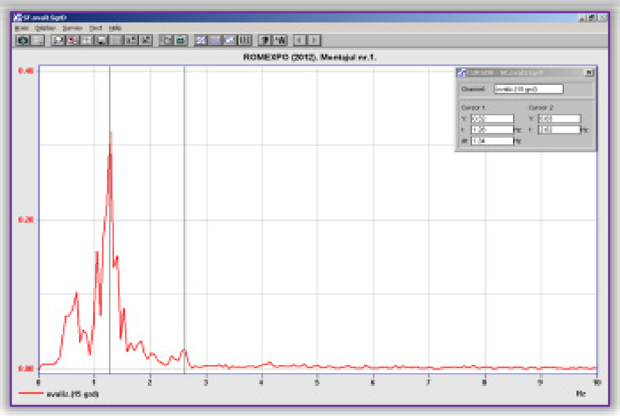

Figure 28: Fourier amplitude spectrum
of time history of Figure 31

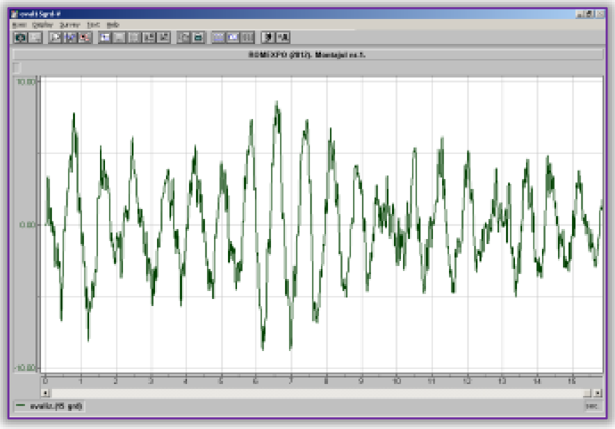

Figure 29: Time history 2nd order ovalization 45º from coordinate axes (velocities)

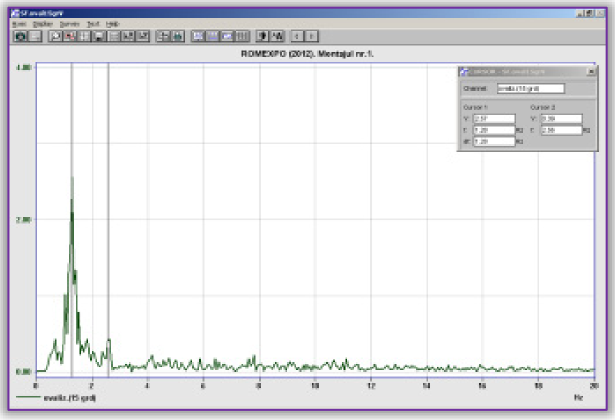

Figure 30: Fourier spectrum of time history of Figure 33

FINAL CONSIDERATIONS

The records obtained during the analog recording period (1976…1993) made it posible to determine a time history of occurrence of damage and of consequences of repair & rehabilitation interventions. They made it possible also to derive conclusions on the appropriate way to intervene.

The outcome of processing the digital basic information provided more detailed information about the features of dynamic deformation, including data on the dynamic seleectivity for the various deformation types.

The availability of the ROMEXPO structure and of the history of its performance offered a rare opportunity of obvious technical interest to combine the possibilities of joint analytical and experimental work in order to examine in depth the features of performance of a highly important structure and, moreover, to add to the knowledge and know how specific to the field of structural dynamics.

Given the currrent state of the art, it is desirable at present to use digital recording and processing techniques. This offers wide possibilities of investigation of various aspects of interest, as speciffic to the tasks dealt with.

This case study confirmed once more the possibilities offered by the combination of analytical and experimental work. A qualitative analytical grasping of the features of structural performance is necessary in order to adopt an efficient way to perform experimental work. On the other hand, the availability of appropriate experimental information offers the possibility of refining the analytical approach adopted.

The case study presented provided information about the influence of overloading upon the dynamic characteristics of the structure dealt with.It turns out that, even in the case in which the structure was not on the brink of collapse, some of the dynamic characteristics were quite strongly modified.

A look at the time histories of rigid risk translation, rigid risk rotation and (basic, second order) ovalization, given in previous figures, which are of comparable amplitudes, raises a problem of fundamental interest concerning the characterization of ground micro-tremors lying at the origin of ambient oscillations presented in the figures referred to. Given the strong dynamic symmetry of the structure dealt with, it turns out that the three categories of ambient oscillations referred to pertain to different, dynamically orthogonal, subspaces of the structure. This means that these three categories of oscillations must be due to different kinds of input ground motions. Consequently, the micro-tremors must consist basically of three corresponding homologous categories of components. This requires a revision of the usual approach to ground motion, which would take into account just rigid translation micro-tremors (and ground-structure interface motions). An approach proposed in this connection, [4], [6], [7], is to adopt a (stationary) random spatial model of micro-tremors and to consequently calibrate the correlation/coherence characteristics.

References

[1.] Şt. Bălan, V. Crisescu, I. Cornea (editors): ”Cutremurul de pământ din Vrancea, de la 4 martie 1977” (The Vrancea earthquake of 4

March 1977). Editura Academiei, Bucharest, 1982.

[2.] G. Danci, D. Rădulescu, H. Sandi, M. Stancu: “Some first data on the Romania, 30/31 August 1986, earthquake”. Proc. 8-th European Conf. on Earthquake Engineering, Lisbon, 1986.

[3.] P. Murzea: Studiu asupra specificării mărimilor de intrare privind acțiunea seismică asupra construcțiilor (Study on the specification of input on the seismic action upon structures). Doctoral Thesis. UTCB, 2012.

[4.] S. V. Pugachov: “Teoria sluchaynykh funktsiy” (Theory of random functions), GIFML, Moscow, 1960.

[5.] H. Sandi: “Siguranţa clădirilor de locuit. Invăţăminte rezultate din comportarea la cutremurul din 4 martie 1977”. (Safety of residential buildings. Lessons from the performance during the 4 March 1977 earthquake). Construcţii, 12, 1981.

[6.] H. Sandi: “Stochastic models of spatial ground motions”. Proc. 7-th European Conf. on Earthquake Engineering, Athens, 1982.

[7.] H. Sandi: “On the seismic input for the analysis of irregular structures”. Proc. 4-th European Workshop on Irregular and Complex Structures, Thessaloniki, September 2005.

[8.] H. Sandi, M. Stancu, O. Stancu, I. S. Borcia: “A biography of a large-span structure, pre- and post- earthquake, after the provisional and final strengthening”. Proc. 8-th European Conf. on Earthquake Engineering, Lisbon, 1986.

[9.] H. Sandi, G. Şerbănescu, T. Zorapapel: “Lessons from the Romania earthquake of 4 March 1977”. Proc. 6-th European Conf. on Earthquake Engineering, Dubrovnik, 1978.

[10.] I. Vlad, H. Sandi, P. Murzea, O. Păucescu, N. Vlad: ”An updated history of the earthquake performance of a large span structure” Proc. 15-th European Conference on Earthquake Engineering, Istanbul, 2014.

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