Bulletin of the *Transilvania* University of Braşov • Vol. 5 (54) - 2012
Series 1: Special Issue No. 1

ASSESSING CUMULATIVE DAMAGE ON RC STRUCTURES BY TEMPORARY SEISMIC INSTRUMENTATION

C.S. DRAGOMIR[1,2], D. DOBRE[2,3], E.S. GEORGESCU[2]

Abstract: *When the earthquake is produced, there are many cases when the buildings are badly damaged. Overall, the measurement of the own vibration period may reveal a number of structural damage, endured by the structure until the moment of measurement; measuring this size, before and after the earthquake, is a comprehensive method for assessing changes in the rigidity of a construction due to seismic stress, noting that rigidity such highlighted corresponds to low levels of stress. According to the modern approach of the post-seismic investigation the damage building assessment should be clearly foreseen and properly planned in order to obtain dynamic parameters for the analysis. The objectives of the paper are to present both a concept for building performances assessment and his applicability for an RC structure.*

Key words: *seismic action, structural analysis, dynamic parameters.*

1. Introduction

Overall, the measurement of the own vibration period may reveal a number of structural damage, endured by the structure until the moment of measurement; measuring this size, before and after the earthquake, is a comprehensive method for assessing changes in the rigidity of a construction due to seismic stress, noting that rigidity such highlighted corresponds to low levels of stress.

Instrumental monitoring of structures under microtremors, industrial and urban vibrations was promoted in Romania by INCERC. Structural health monitoring using measurements of dynamic parameters under microtremors or forced excitation has a rather long history in Romania, starting with the 1960's INCERC records.

The Romanian experience of INCERC after 1977 [1] proved that low damage was associated to increases of natural periods under 20...25%.

Multiple, but relatively light damage may rise periods up to 25...50%, while systematic damages or local and significant ones raised periods by more than 50%. Spectral content was a major issue, since buildings having natural periods closer to high spectral values have

1 University of Agronomical Science and Veterinary Medicine, Faculty of Land Reclamation and Environmental Engineering, Department of Environment and Land Improvement, Sector 1, Bucharest.
2 The National Research and Development Institute URBAN-INCERC & European Center for Buildings Rehabilitation, Sector 2, Bucharest.
3 Technical University of Civil Engineering Bucharest, Mechanics Department.

been heavily damaged.

A data base of measured natural periods for some 50 high-rise buildings existed prior to Vrancea, March 4, 1977 earthquake and it was possible to compare the pre- and post-earthquake natural periods, i. e. to correlate them with the damage and further on with the effect of strengthening.

Other measurements were performed after the 1977 earthquake for over 100 standard design condominia [2, 3]. Several valuable records were possible in buildings during Vrancea earthquakes of 1986 and 1990 [4, 5].

In Romania, the seismic design code, index P100-1/2006, states, in Annex A, the following regarding the future seismic instrumentation for buildings:

- in seismic areas where the design acceleration value ag, with IMR (average recurrence) = 100 years is ag ≥ 0.24 g, buildings with a height of more than 50 m or more than 16 stories high or with a surface area of over 7500m^2, will be instrumented with a digital acquisition system and minimum 4 (four) triaxial acceleration sensors.
- this minimal instrumentation will be located as follows: 1 sensor in the open field, near the construction, 1 sensor in the basement and 2 sensors on the top floor. Instruments will be placed so that access to equipment could be possible at any time.
- Instrumentation, maintenance and operation is funded by the building owner and undertaken by approved organizations.
- Records obtained during strong earthquakes must be made available to the competent authorities and specialized institutions in 24 hours from the earthquake occurrence.

2. Concept of assessing cumulative damage

The experimental model presented here was conducted in 1990-1991 in the seismic Hall of INCERC Bucharest, in view of full-scale tests.

The construction is based on a modular square grid 3.90 x 3.90 m and a floor height of 2.75 m, consisting of two openings and two bays, which comprises a single structural wall.

At the intersection of axes, constant cross-section poles are placed, 500 x 500 mm, covering the entire height of the building. Pillars are prefabricated for two-story height, with a non-concrete portion in the middle of 350 mm, which includes reinforcement of strips of plate. Full-scale tests were conducted as three different times (1995, 1996 and 1997) [6].

To simulate the behaviour of a future earthquake damaged building, the following steps were followed:

- Determination of the own vibration periods by microseism measurements and their processing;
- Modelling a spatial structure identical to that found in seismic Hall; noting that the model was created with five levels unlike the existing one that had four levels (being tested at the top- -floor - terrace to simulate the loading of an extra floor).
- The time-history analysis to determine the structure response spectrum using accelerograms recorded in the earthquakes in from the '77, '86 and '90.

Following the above steps, microseism measurements were made on the experimental model, following two sensor placement schemes presented in Fig. 1. Measurements were made both by applying shocks in the centre of the 2nd floor and the microseism movement from the site.

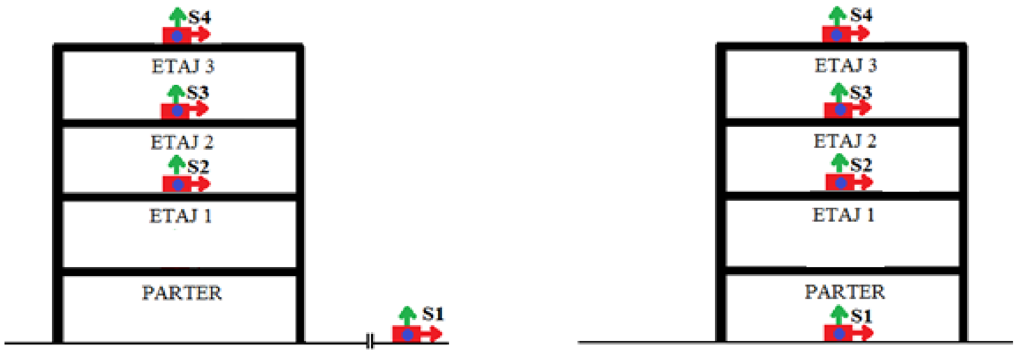
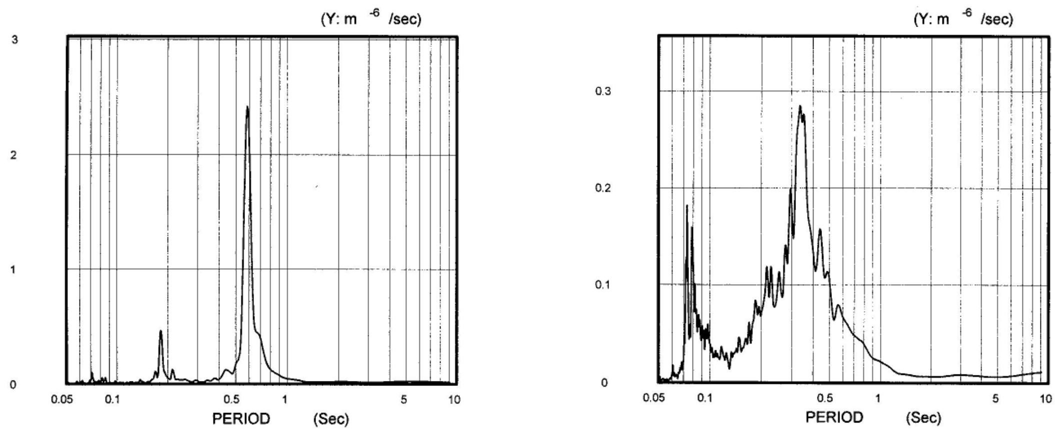


Fig. 1. *Sensor placement schemes*

Microseism measurement results obtained in the case of the full-scale experimental model, with GF+3 floors are presented in Table 1. These values of own periods of vibration are determined from the Fourier spectrums. Processing the records made at this stage of cracking of the model is presented in Fig. 2 [8].



a) *X direction* b) *Y direction*

Fig. 2. *The response spectrums obtained by processing the microseism records*

Dynamic characteristics of the experimental model in the present state of cracking Table 1

Equipment / Program used	**T** dir. x **(s)**	**T** dir. y **(s)**
GEODAS 12-USB, Japonia /Microwave tremor observation	0.60	0.32

The linear modal time-history analysis provides the results as graphs and comprises, for the structural system studied, the movement and acceleration variations versus time, in a node at the top level and at the level 1.

Regarding the movements, the results are shown on Fig. 3 and Fig. 4.

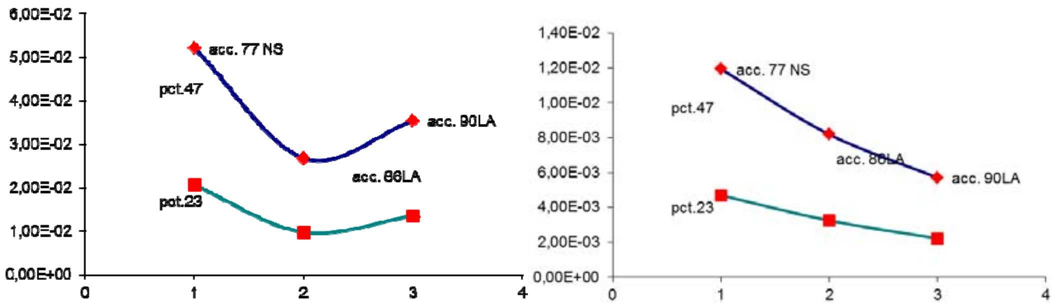
It can be seen that the maximum values presented in Figure 5 are exceeded only in SLS as P100-1 Code: 2006:

SLS

$$d_{r\,adm} = 0.005\ h = 1.38{*}10^{-2}\ m \qquad (1)$$

ULS

$$d_{r\,adm} = 0.025\ h = 6.88{*}10^{-2}\ m \qquad (2)$$



a. *X direction* b. *Y direction*

Fig. 3. *Maximum values of displacements in the y direction, corresponding to nodes 47 and 23 at different earthquakes ('77, '86 and '90)*

3. Applicability of concept on real RC - structure

Part of the building of the Faculty of Land Reclamation and Environmental Engineering has resistance structure of reinforced concrete frames designed in the '70s, according to the Code P13-70 (see Fig. 4).

Fig. 4. *The Faculty of Land Reclamation and Environmental Engineering in Bucharest*

Although the height is low (H = 20.33 m) and the shape in plane is regular, the earthquake of 4 March 1977 have caused damage, especially to non-structural elements due to insufficient stiffness for the protection of subdivision elements.

In Figure 5 is shown the time evolution of part A's own periods of F.L.R.E.E. in Bucharest, with records made available by INCERC Bucharest between 1986-1998.

By determining the dynamic characteristics of part A of the Faculty of Land Reclamation and Environmental Engineering, from December 2009, and then in 2012, it was found that the period of oscillation of the building was reduced by approximately 19% compared to values determined in 1998.

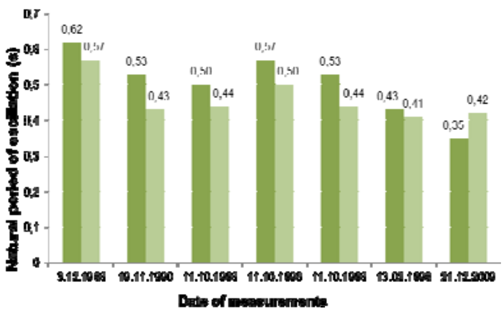


Fig. 5. *Time evolution of own periods of part A of F.L.R.E.E.*

The recordings made after the entry into force of the new design code P100-1: 2006 are presented. Recordings were made on the 4th floor of part A of building F.L.R.E.E.

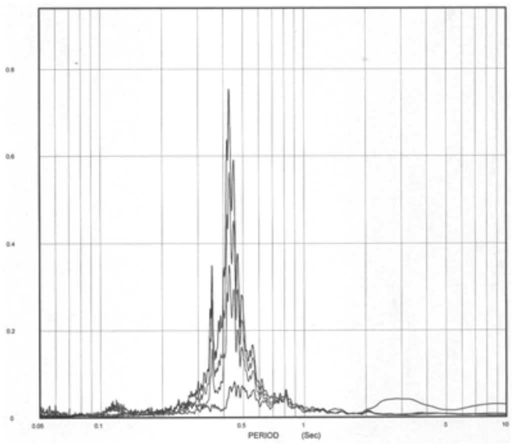


Fig. 6. *Fourier Spectra obtained from processing of recorded data*

It is estimated that this reduction is due to the collaboration processes of the various parts of old and the new structure and to earthquake of magnitude Mw = 6.0, which took place on October 27, 2004, in Vrancea seismic zone, which may contributed to structural transfer efforts from the four concrete caissons to the structure.

Following the changes made in the composition of the building, either to the structural or non-structural elements, through the interventions to strengthen the building from damage caused by earthquake or other causes, the building suffered significant changes both in terms of both mass and own periods.

All those three types of calculation for that comparative study was performed (initial structure before the 1977 earthquake; structure after consolidation in 1986; structure after consolidation in 1996.) are shown in Figure 7.

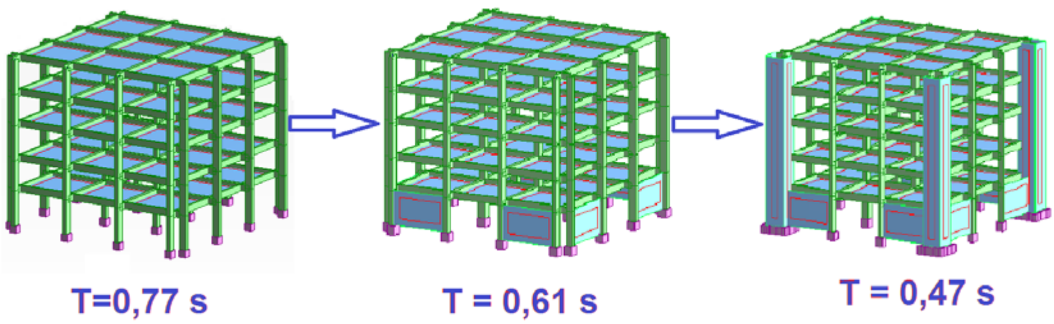


Fig. 7. *Oscillation periods of F.L.R.E.E. determined by dynamic analysis*

From the image shown in Fig. 8, it can be seen that the two consolidations have brought an decreases in the period of fundamental mode of oscillation (39% compared to initial version). This demonstrates the effectiveness of interventions to strengthen applied throughout the period of life of the structure, but they have become inadequate because of changes occurring over time with the introduction of new design codes.

Basically, the building interventions to strengthen were designed to increase the rigidity of structure that is obtained by increasing the size of structural elements and/or adding other structural elements.

However, while reducing their periods of oscillation for the T…Tc of the spectrum (Tc is in this case under the Code P100-1/2006 equal with 1.6s) not reduces the design forces due to the covering adoption of a constant value (landing) for spectral acceleration in this area, removal of the resonance conditions T = Tc is a goal of always watching.

Based on the results of the presented structural calculations, can be made the following comments:

- In any of the situations, permissible value of the relative displacement at the service limit state has not been exceeded and the allowable amount of relative displacement at ultimate limit state has been exceeded in a single statement in the version I of calculation; this would have contributed to serious damage to the building in the earthquake of 1977 (according to the P100-1/2006, the value of SLU d = 0.025 h and SLS d = 0.008h).
- After the first consolidation, the relative displacement was decreased by 38% and after the second by 40% compared to the previous consolidation, representing 63% compared to the relative displacement in the initial situation. In this way, the structure fulfils the conditions imposed by the current seismic design code P100-1/2006 from the point of view of the relative displacement.

Although, despite the increased rigidity of the building after the building interventions, the bending and twisting ratio remained less than 1.5, which means that the danger of coupling between the three modes of oscillation remained.

Thus, the results of calculation in ROBOT program were validated through the dynamic parameters of the structure, i.e. the periods and the frequencies determined by measurements.

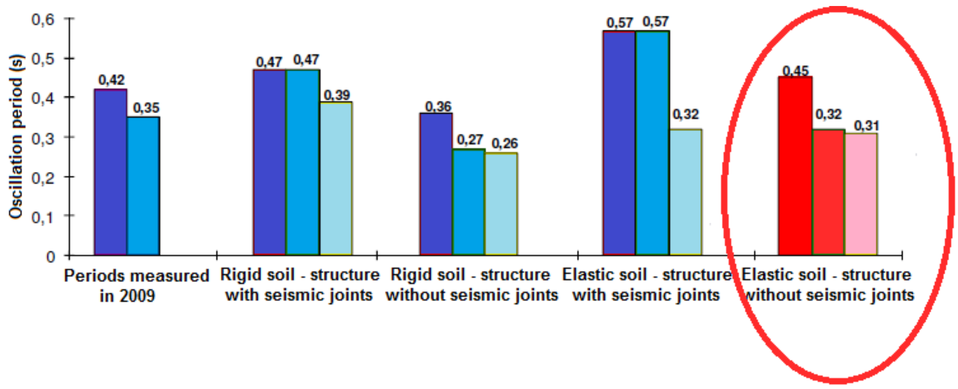


Fig. 8. *Oscillation periods of the first three modes obtained from analysis performed in the 4 assumptions compared with recently measured oscillation periods*

In comparison calculation were taken into account the two structural assumptions: 1. the parts were separated by virtual seismic joints, and, 2. the parts were linked together without seismic gaps. These assumptions were applied to both rigid and elastic soil.

From the point of view of their periods of oscillation, the comparative analysis shows (Fig. 8) that the real behaviour of the structure corresponds to the elastic structure hypothesis (there is a ground-structure interaction) without seismic joints, which is the real situation at this moment [7].

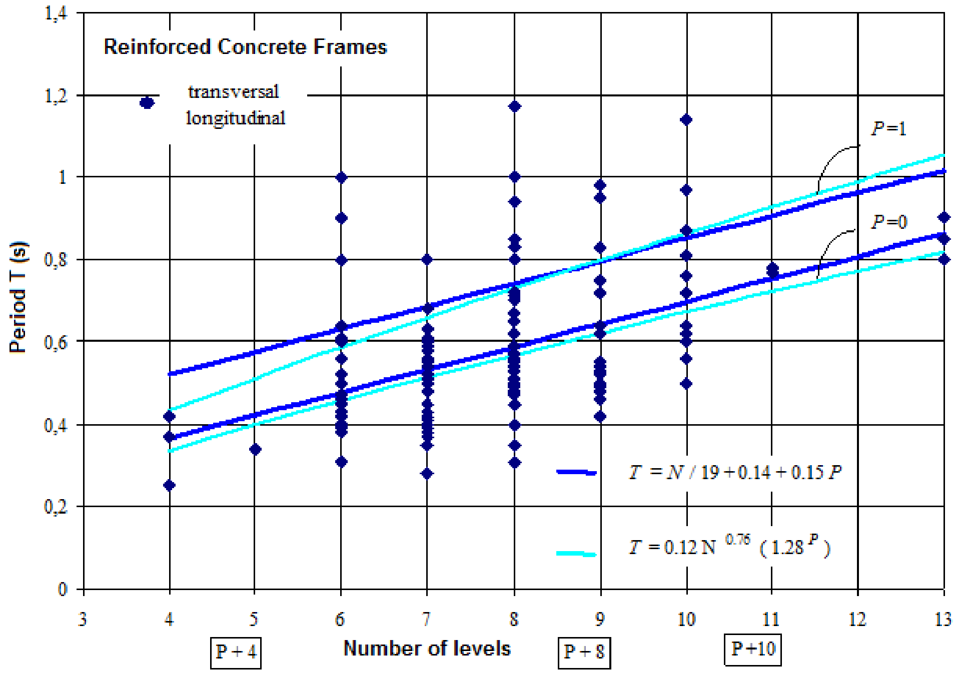


Fig. 9. *Periods measured by INCERC for RC structures*

In Fig. 9 are shown the periods measured by INCERC for some specimens of the existing buildings of reinforced concrete frame made in Bucharest in different periods.

Two regression models (other than those presented in previous sections): linear and nonlinear (UBC format, Eurocode) are sized. The exponent of 0.76 determined for the reinforced concrete frame structures is closed to value 0.75 specified in UBC and Eurocode8.

Based on the formulas established by INCERC, the value of the period of vibration of the fundamental mode, obtained by temporary seismic instrumentation is:

$$T = 0{,}12N^{0{,}76} => T = 0{,}41\ s \qquad (3)$$

4. Conclusion

The concept of investigating the performance of a building proposes the validation of calculations with a program dedicated to structural analysis using instrumental data processing techniques.

Based on the results obtained on site with through temporary seismic instrumentation, a structural model with identical dynamic characteristics can be modelled and thus the behaviour of the existing structure to strong earthquakes in Romania can be studied.

It can say that in this way one can predict how certain structures that have experienced earthquakes in the last century will respond to future earthquakes.

References

1. Balan, St., Cristescu, V., Cornea, I: *The Romania Earthquake of 4 March 1977* (in Romanian). Editura Academiei, Bucharest, Romania, 1982.
2. Sandi, H., Cazacu, D., Constantinescu, C., Stancu, M.: *A Summary of Studies on the Seismic Vulnerability of Buildings,*

Carried out in Bucharest Subsequent to the March 4, 1977, Earthquake. Proc. Joint US-Romania Seminar on Earthquakes and Energy, Vol. 2. Earthquakes, Bucuresti,1985.
3. Constantinescu, C., Stancu, M.: *Statistical Studies for the Prediction of Seismic Damage of Reinforced Concrete Structures.* Proc. Joint US-Romania Seminar on Earthquakes and Energy,. Vol. 2 . Earthquakes, Bucuresti, 1985.
4. Lungu, D.: *Earthquake Mitigation in Romania: Synergy from International Projects*, in Review of the Collaborative Research Center 461 *Strong Earthquakes: A Challenge for Geosciences and Civil Engineering*, Karlsruhe, September, 28 - 29, 2004.
5. Borcia, I. S.: *Processing of strong motion records specific for the territory of Romania*, Ph D Thesis, Technical University of Civil Engineering, Bucharest, 2006.
6. Vlaicu G.: *Contributions to the improvement of seismic design methods of the mixed structures with prefabricated diaphragms and reinforced concrete frames*. PhD Thesis, University of Civil Engineering, Bucharest, 1999.
7. Calin, M.C.: *Anti-seismic rehabilitation of space structures by genetic algorithm*, PhD Thesis, Technical University of Civil Engineering in Bucharest, 2011.
8. Dragomir, C.S., Dobre, D., Croicu, N.C., Georgescu, E.S.: *Integrated investigation of building performance*. Proceedings of the third edition of the National Conference on Research in Construction, Construction Economics, Architecture, Urbanism and Territorial Development with international participation, Architecture Urbanism Construction Magazine, vol.3, nr. 4, Bucharest, 2012.