Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol II, 2013
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, ISSN-L 2285-6064

ASSESSMENT OF STRUCTURAL DAMAGES USING NON-DESTRUCTIVE AND SEISMIC INSTRUMENTATION METHODS. CASE STUDY OF AN EDUCATIONAL BUILDING IN BUCHAREST

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Abstract

All European countries are rich of pre-code buildings and there is also a considerable number of residential masonry buildings in the rural areas. In Romania, where over 60% of the territory and population are exposed to the Vrancea earthquakes, there are many pre-code reinforced concrete and masonry buildings. This type of buildings should be strengthened in accordance with the European and National Codes in force (EC8-Part 3 and P100- Part 3). According to paragraph 2.2.4., the "additional measures" of the Code of Building Seismic Design, indicative P100-1:2006, it is recommended to investigate the buildings with recording equipment for the seismic action parameters. The objective of the paper is to present a series of non-destructive methods used to assess damages of an educational building in Bucharest. The non-destructive testing of the concrete structures yields valuable information for the engineers when investigating problems and can reveal unanticipated or hidden damages. The repair of the structure is guided by the results of the testing. The building presented in the paper was designed as masonry structure with reinforced concrete cores and erected during 1950s with BS+GF+3storey height regime. In accordance with the technical report, building damages were evaluated. For this purpose, non-destructive and seismic instrumentation methods were used. Non-destructive methods are based on auscultation, ultrasound and percussion with Schmidt hammer, and the seismic instrumentation methods are based on the GEODAS-12USB equipment with adequate software. Evaluations are useful for both the seismic risk analysis of the inspected building and the design of the strengthening interventions. The prevention or determination of the earthquake effects was done by practical measures. It was understood that the increase in mass and stiffness was not always beneficial. The role of geometry was equally important in earthquake engineering and there were cases when reshaping might prove advantageous, especially when using advanced technologies available on the European market.

Keywords: *educational building, non-destructive tests, seismic instrumentation, structural assessment.*

INTRODUCTION

Earthquakes are the only unpredictable and the most destructive actions of all the natural catastrophes that can change the fate of people and their goods in a few seconds. In Romania, where over 60% of the territory and population are exposed to the Vrancea earthquakes, as there are many pre-code reinforced concrete and masonry buildings.

This type of buildings should be strengthened in accordance with the European and National Codes in force as EC8-Part 3 and P100-Part 3. According to paragraph 2.2.4.,"additional measures" in the Code of Building Seismic Design, indicative P100-1:2006, it is recommended to investigate the buildings with recording equipment of seismic action parameters.

The objective of the paper is to present a series of non-destructive methods used to assess damages of an educational building in Bucharest which is presented in Fig. 1. The non-destructive testing of the concrete structures yields valuable information for the engineers when investigating problems and can reveal unanticipated or hidden damages. The repair of the structure is guided by the results of the testing.

The old masonry and RC buildings, most of them with irregular plan and elevation, have suffered damage from the past seismic actions.

Making them safe is an important requirement for the owners and certainly urgent for the authorities.

The paper presents the authors‘ research on old building structures and proposes an original concept of evaluation for this type of building. The results on dynamic characteristics of these buildings obtained by seismic instrumentation with seismic data acquisition system are presented.

According to the Code P100-1:2006, asymmetric structures have no appropriate seismic shape; they have disadvantageous distribution of volumes, masses and stiffness.

Figure 1. Horticulture Faculty building within UASVM Bucharest, *BS+GF+2storeys+A*, located on 59 Mărăsti Blvd.

The irregularities and asymmetry of the structures cannot be avoided. They evolve from functional reasons in plan and technologic ones in height. This type of structures is also mentioned in the Eurocode 8 by the Principles of conceptual design, as follows: structural simplicity, uniformity and symmetry, redundancy, strength and bidirectional stiffness, strength and torsion stiffness, the effects of horizontal shear walls of the adequate floors and foundations.

According to the modern approach of preparedness, post-seismic interventions should be clearly foreseen and properly planned in order to avoid additional damages and fatalities, as well as save what has remained worth for further use. Post-seismic interventions should be designed and organised according to the provisions of the ISO13822:2001 (Dragomir and Calin, 2012). The clause 7.4 regarding the plausibility of interventions should be carefully considered.

General data on the building

The Horticulture Faculty is located in the complex of U.A.S.V.M. Bucharest. Its design and building were carried out in 1951-1952, which means that the building is approximately 60 years old. The Faculty building, shown in Figure 2, includes study spaces for education (lecture halls, classrooms, and laboratories), circulation spaces (corridors, stairways), faculty offices for the teaching staff, toilets and a terrace in the attic.

Access to the building is made through the main entrance located on the north facade or the secondary located in the western end of the building. The upper landings of the building can be reached by the central staircase next to the main entrance or the south-west wing of the building. Subsequently, the project for the external metal staircase was implemented in 2001; it is located in the southeast wing of the building that provides access to the attic through an outside terrace.

Figure 2. Main facade of Horticulture Faculty building

The plans show a building with five functional levels, BS+GF+3S+A, roughly rectangular in shape with dimensions 82.90 x 14.38 m; adjacent to these forms, on the south side there is a building which houses the largest lecture hall (Bpa), also with a basement and ground floor level of approximately 20.00 x 30,00 m in size. The built area is approximately 1625 m^2 and the surface area about 6840 m^2. The floor height is as follows: basement - 3.00 m, ground floor - 4.64 m, 1st floor - 4.64 m, 2nd floor - 4.84 m and the toilet walls in the attic - 2.40 m. The upper cornice height is 15.26 m, and 16.30 m from the average land height.

Given the irregular shape and size of the building plan, the building was divided into two distinct wings through an expansion joint of 2.00 cm. The section of the main entrance and lecture hall area was named B1, and the other was called B2.

Data on the construction system

The two sections, B1 and B2, differ structurally as follows:

- Section B1 has a structure consisting partly of load-bearing brick walls and partly of concrete pillars supporting the monolithic reinforced concrete floors;
- Section B2 has a structure consisting of load-bearing brick walls supporting the monolithic reinforced concrete slabs.

The masonry walls are at least 37.50 cm in thickness and may reach 50.00 cm in the lower levels or the structural elements of high loads, although normally the load-bearing walls have been reinforced with monolithic reinforced concrete.

Masonry is made of solid red, C100 double pressed bricks and lime-cement mortar equivalent to class M10. The separating walls are made of brick, being 12.5 cm or 25.00 cm in thickness, and mostly coincide with the positions of the floor beams made of monolithic reinforced concrete.

According to the expertise of PRINCER Ltd registered under no. 1131/1993, the following characteristics were similar to the building materials used: C100 bricks, M10 mortar cement, R28 Concrete (120 daN/cm2), current class C12/15 according to NE012-2007 and OB37concrete steel.

Data on the foundation system

A geotechnical study was conducted together with the technical expertise of Building A – Rector‘s Office. As the Horticulture Faculty is close to this building, it shares the same data on the soil foundation characteristics.

The geotechnical study states that the foundation ground is based on clayey sand. This layer is lower in quality than the active clay layer that has contractile properties specific to the area, which resulted in the past damage in some buildings (e.g., the students‘ bedrooms required expertise and consolidation, performed by Prof. Aurel Beles).

The carrying capacity of the soil at the standard depth of 2.00 m is 280 kPa. Groundwater has been found at a depth of -9.20 m, with no wide variations as to affect the building foundation. The geotechnical study does not mention water damage to the concrete.

From experience we can say that this type of structure foundations, made between 1950 and 1952, consists in continuous soles of simple and reinforced concrete under the structural brick walls and insulated foundations under the reinforced concrete pillars (Dragomir, 2010).

Structural damages

The two wings of the building show cracks and fissures caused by the earthquake on March 4, 1977 and reactivated by the 1986 and 1990 earthquakes. There have been no interventions in the building structure during its approximately 60 years of service.

The following images present both the wrong reinforcement, even for the 50s, and the rusty spots on the reinforcement surface of the pillar located in the semi-basement. The picture below shows that the central pillar has the behaviour of simple concrete.

The two wings of the building are irregular in shape and their eccentricities between CG and CR highly exceed the standard values. The effects of their eccentricities are worsened by the geometric irregularities.

Figure 3. Western facade damaged outside load-bearing brick wall

a. Damage to the expansion joint b. Joint damage between the projection hall and Bpa lecture hall

c. Damaged concrete pillar in the semi-basement d. Plaster-stripped areas for non-destructive testing

Figure 4. Main structural damages of the Horticulture Faculty building

Figure 4a shows that the 2.00 cm expansion joint plays no role as a seismic point since the two wings collided with each other, probably due to their different rigidity (different structural systems) particularly since the two wings have large heights (approx. 16.00 m). It was found that the metal bars supporting the outer load-bearing walls and the roof of the Bpa lecture hall were not protected against corrosion.

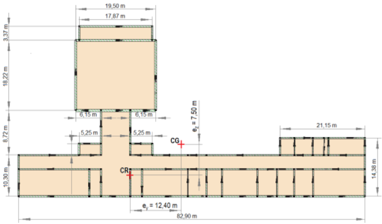


Figure 5. General plan of Horticulture Faculty (wings B1 and B2 with no expansion joint)

The plan shape of the wings is irregular, showing symmetrical discontinuities, ins and outs, resulting in additional pressure. The values presented in the figure above, and detailed in Appendix A, show that the Horticulture Faculty building plan does not comply with the regularly conditions imposed by both P100-1: 2006 Code and SR EN 1998.

The major structural damages of the building are shown in Figure 4.

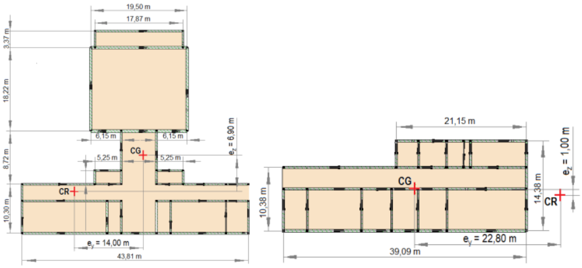
MATERIALS AND METHODS

The clause 4.4.3 of the P100-1/2006 Code establishes conditions for assessing structural regularity both in plan and vertically. To calculate the relative position of the two intrinsic centres, centre of gravity - CG and centre of rotation – CR, calculations have been performed using the computer program AUTODESK ROBOT (Figure 5 and 6). In order to solve this problem, one of the consolidation solutions is to divide the building into sections building by a seismic joint that separates the large lecture hall. This results in two buildings with approximately rectangular shapes. The design will focus on each wing separately, and the spatial computing models validated by micro-seismic measurements will aim to achieve the safety level required by the codes.

RESULTS AND DISCUSSIONS

The recording of the dynamic parameters was performed in September 2012, with the micro-seismic data acquisition equipment, GeoDAS 12-USB, BUTTAN SERVICE, Japan, endowed with 12 channels. Spatial structure speed was recorded in different locations, in the three main directions NS, EW and vertical Z, measured in mm/s. The processing of the recording by using specialized software resulted in the Fourier spectra. From these spectra we extracted the values corresponding to the fundamental period of vibration for the two transverse and longitudinal directions of the building.

For temporary seismic instrumentation, we used four tri-axial sensors placed in different directions. The resulting values indicated approximately the same values of their own periods, a shown in the table below.



a. B1 wing shape

b. B2 wing shape

Figure 6. Eccentricities according to the two orthogonal directions

Table 1. Natural oscillation periods measured for the building on two horizontal directions

Data	**Event**	**Direction**	
		T	**L**
24.09.2012	Micro-seismic	034.0.40	0.28

Comments:

1. The fundamental oscillation periods for the two horizontal directions ranged between 0.28 and 0.40 s, thus defining average rigidity structures. Analysing the response spectra recorded for the four earthquakes: March 1977, August 1986, May 1990 and October 2004 (see annex C), amplification peaks can be observed between 0.30 and 0.40 s (0.40 s in 1986 and 0.30 s in 1990). This dynamic amplification can be one of the causes for the recorded damages.
2. All the speed values were much lower than the threshold required, i.e. 5 mm / s as the vibration standard in the buildings, which means that there are no comfort-related problems.

In order to validate the results obtained by temporary seismic instrumentation, we present the fundamental periods of some existing buildings with a reinforced concrete frame (Figure 7) or load-bearing walls of masonry (Figure 8) analysed by the INCERC Bucharest researchers in Bucharest at different time periods (Dragomir, 2013).

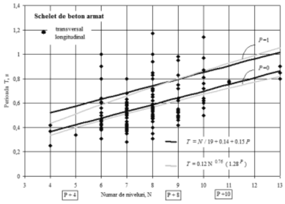


Figure 7. Values of own vibration periods for reinforced-concrete framed structures

Based on the results obtained were calibrated two regression models: linear and nonlinear (UBC format, Eurocode). The exponent 0.76 determined for the reinforced concrete frame structures was close to the value specified by the UBC 0.75 and Eurocode EC8.

For the Horticulture Faculty, the calculation formula for the fundamental vibration period of the two wings led to the following values:

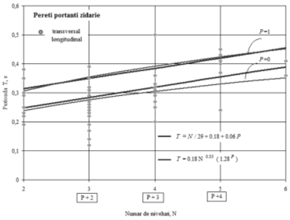


Figure 8. Values of own vibration periods for load-bearing brick wall structures

- for reinforced-concrete framed buildings, as wing B1:

$$T = 0,12N^{0.76} => T_{N=4} = 0,34 \text{ s si } T_{N=5} = 0,40 \text{ s} \quad (1)$$

- for brick-wall structured buildings, as wing B2:

$$T = 0,18N^{0.35} => T_{N=4} = 0,29\ s\ si\ T_{N=5} = 0,31\ s \qquad (2)$$

The values obtained by the formulae determined by INCERC ranged from 0.29 to 0.40 s. In conclusion, we can state that the values were validated for the vibration periods recorded in the Horticulture Faculty, as determined by the temporary seismic investigation conducted in September 2012.

CONCLUSIONS

Following the analysis of the existing plans and the technical expertise performed until the present, and as the result of the visual inspection and calculations carried out for this study on the overall behaviour of the Horticulture Faculty, we have identified some deficiencies in the design and structure of the building.

The two wings separated by the expansion joint have different strength structures and there are no reinforced concrete pillars at the intersection of the load-bearing brick walls for strengthening these areas;

The building has an irregular shape in plan and elevation and the expansion joint is damaged, which means that the two buildings clashed in the earthquakes that occurred over the past 60 years. Therefore, the expansion joint has failed to fulfil the function of seismic joint;

There are no double walls or double poles in the expansion joint and covering the area of the largest lecture hall (Bpa) with metal trusses of approximately 20.00 m in opening and the absence of a rigid washer element in the roof structure, which would uniformly distribute the seismic action to all the structural elements if an earthquake occurs.

Under these circumstances, the failure to comply with the provisions of the code P100-1:2006 is evident for the seismic design of the buildings. The safety levels deriving from the new requirements are lower than the ones that were previously recorded by the 1993 expertise (cf. P-100-92, Standard for the seismic design of houses, social and cultural, agricultural and industrial buildings) because the different definitions of the seismic hazard: IMR = 50 years for P-100-92, and IMR = 100 years for P100-3/2008, which leads to higher values in the latter requirement and hence the lower values of the safety level.

In addition, the requirements imposed by the Standard P100-3/2008 for calculating the indicator (R3) (R_{3i}>0.5). These restrictions eliminate the capacity contribution of the active structural walls, while the standard P-100-92 is unconditionally considered the contribution of all walls.

To conclude, it is considered imperative to consolidate the building of the Horticulture Faculty. In addition to the building solutions presented in Expertise no. 1131/1993, building systems based on composite materials can be adopted in various forms which can be applied on one or on both sides of the wall. The solution is present among the consolidation measures included in P100-3:2008. In this case, the shear force capacity of the masonry wall plated with composite materials is given by the contribution of the composite material and the masonry.

The advantages of this type of intervention for the Horticulture Faculty are the following: good mechanical properties of the composite materials; the light weight composite materials generate permanently low loads on the structure; reduced thickness of the plating layers; structural intervention does not alter the original appearance; intervention is reversible as the materials can be removed from the structure if they fail to comply with the long-term performance levels that have been initially established.

ACKNOWLEDGEMENTS

The authors would like to thank the staff of the Seismic Risk Assessment Laboratory, INCERC Bucharest Branch of the National Institute for Research and Development for Constructions, Urban Planning and Sustainable Spatial Development.

REFERENCES

***Technical Report no. 1131/1993 developed by PRINCER SA.

Dragomir C.S., 2013. Damage assessment of buildings. Case study of an educational building, International Conference on Urban Earthquake Engineering, March, 2013, Japan

Dragomir, C.S. Calin, M.C., 2012. Dynamic response parameters and damage assessment of educational building located in earthquake prone area, Proceedings of the 15th World Civil Earthquake Engineeering in Lisbon, Portugal.

Dragomir, C.S., 2010. Seismic monitoring of architectural heritage building rehabilitation, Proceedings of the 14th European Conference on Earthquake Engineering, Ohrid, Republic of Macedonia.