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STRUCTURAL VIBRATION AND FIRE RESISTANCE

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Abstract

The paper presents an assessment approach based on non-destructive and temporary vibration monitoring methods of a reinforced concrete building which is to be structurally and thermally rehabilitated. These methods are in according to the Romanian Code for Seismic Design of Building, Part 3 - Building Assessment, SR EN 1998-3:2008. The results related on dynamic characteristics of this building obtained by ambient vibration monitoring with a data acquisition system are presented. Also, a solution for the thermal insulation of the building is presented, as well as some results obtained from fire testing of this type of system. Where it is not possible to obtain correct information regarding the behaviour of a structural system, due to the lack of data needed to create a reliable model, the contribution of each presented method is consistent, using the advantages of non-destructive methods, ambient vibration monitoring and modal analysis. It is a current internationally practice, with a certain confidence.

Key words: *earthquake, ambient vibration, dynamic characteristics, building assessment.*

INTRODUCTION

In Romania, the seismicity of Vrancea source is very important (Figure 1), with a maximum instrumentally measured magnitude of 7.7, maximum possible magnitude of Mw = 8.0 (it was obtained for 1940, 1977, 1986, 1990 earthquakes), the frequency content showing significant differences in source mechanisms, with a directivity between events and, for soil conditions in Bucharest, a long predominant period of ground vibration of T = 1.4-1.6 s etc. (Lungu et al., 2004) (Radulian and Popa, 1996). In these conditions, reducing the seismic risk of buildings is a complex action, of national interest.

The paper presents an assessment approach based on non-destructive and temporary vibration monitoring methods of a reinforced concrete building from Bucharest, which is to be structurally and thermally rehabilitated. These methods are in according to the Seismic design code, P100-1/2013, Part I - Design prescriptions for buildings and the Code for the seismic design of buildings, P100-3/2008, Part III - Prescriptions for the seismic assessment of existing buildings, SR EN 1998-3:2008.

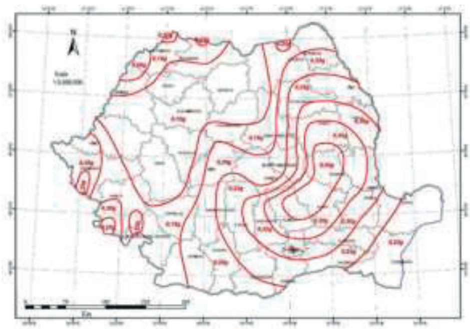

Figure 1. Peak ground acceleration map of the Romanian territory (P100-1/2013)

MATERIALS AND METHODS

1. Structural characteristics of the studied building: The Faculty of Horticulture from 59 Marasti Blvd, Bucharest (Dragomir et al., 2013)

It was built during 1950s with basement + ground floor + 3 storey height regime and two bodies (B1 and B2) separated by an expansion joint (no role as a seismic point) (Figure 2).

The two differ structurally: B1 has a structure consisting partly of structural walls of brick masonry and partly of reinforced concrete

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columns, on which the monolithic reinforced concrete floors are supported; B2 has a structure consisting of structural walls made of brick masonry on which the monolithic reinforced concrete floors are supported.

The thickness of the masonry walls is at least 37.50 cm and can reach up to 50.00 cm at lower levels or in structural elements with high code demands, although currently the supporting walls have been reinforced with reinforced concrete cores. The masonry is made of solid, red brick, double pressed C100 class and lime-cement mortar equivalent to the M10 class.

The partition walls are also made of brick masonry, having thicknesses of 12.5 cm or 25.00 cm and they coincide in most cases with the positions of the beams in the floor made of monolithic reinforced concrete.

The geotechnical study mentions that at the foundation level the ground consists of clay sand. This layer is inferior to the active clay layer with properties specific to the area contracts and due to which in the past certain buildings have suffered. The bearing capacity of the foundation ground at the standard depth of 2.00 m is 280 kPa.

From the accumulated experience it can be said that the foundations of this type of structure, realized between 1950 and 1952, consisted of continuous foundation of simple concrete and reinforced concrete under the structural walls of brick masonry and isolated foundations under the columns of reinforced concrete.

Figure 2. The building with the two sections, B1 and B2

2. Over time, several types of technical studies (approaches) have been developed related to:

- sonic auscultation, ultrasound and percussion with Schmidt hammer (Dragomir et al., 2013);
- evaluation of structural regularity both in plane and vertically (Dragomir et al., 2013), by calculations in order to determine the relative position between the two intrinsic centres (eccentricities e_x and e_y), the centre of gravity - CG and the centre of rotation - CR. Body B1, $e_x = 14.0$ m, $e_y = 6.9$ m; Body B2, $e_x = 22.8$ m, $e_y = 1.0$ m (Figures 3 and 4).
- determining the dynamic structural characteristics from micro vibrations/ microseisms/ ambiental vibrations instrumentation (Dragomir et al., 2013)

The plan shape of the buildings is irregular, asymmetrical, presenting discontinuities, which lead to the appearance of additional code demands. The values, shown in the above figures, indicate that the plan of the building does not comply with the regularity conditions.

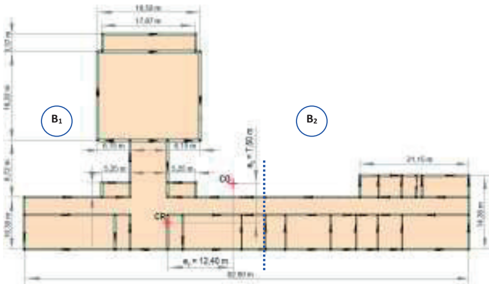

Figure 3. General plan of the Faculty of Horticulture (B1 and B2 bodies without expansion joint)

Figure 4. Eccentricities on the two orthogonal directions

The recording of the dynamic parameters was performed with the micro-seismic data acquisition equipment GeoDAS 12-USB, with 12 channels (Figure 5). Spatial structure velocity was recorded in different locations, in three main directions NS, EW and vertical Z, measured in mm/s.

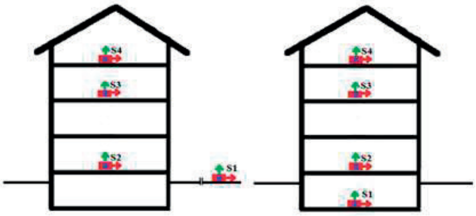

Figure 5. Location schemes of the 4 triaxial sensors. Scheme 1 (left): sensors located on the ground floor, 2nd floor, 3rd floor and near the building. Scheme 2 (right): sensors located on the basement, ground floor, 2nd floor and 3rd floor

The processing of the recording by using specialized software resulted in the Fourier spectra and response spectra. From these spectra, values corresponding to the fundamental period of vibration, for the two transverse and longitudinal directions of the building, were extracted T_{tr} = 0.40 s, T_{long} = 0.28 s (Figure 6). Also, all the velocities values are much lower than the threshold of 5 mm/s, imposed by the norms related to the vibrations in buildings, which means that there are no comfort problems.

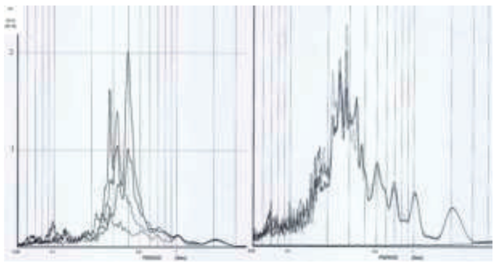

Figure 6. Response spectra on x and y direction (y-axis: maximum values of velocity, x-axis: natural vibration period)

- determining the structural dynamic characteristics from the modal analysis (Dobre et al., 2013). In the following, the dynamic characteristics of the two buildings, B1 and B2; B1 without walls, because the system is a frame structure, B2 with a structure consisting of load-bearing brick walls, mainly (Figure 7).
- determining the dynamic structural characteristics for the B1-B2 assembly (Figure 8), in order to investigate seismic pounding (Dobre et al., 2013); pounding is modelled through a contact element that is activated when the seismic gap between two buildings.

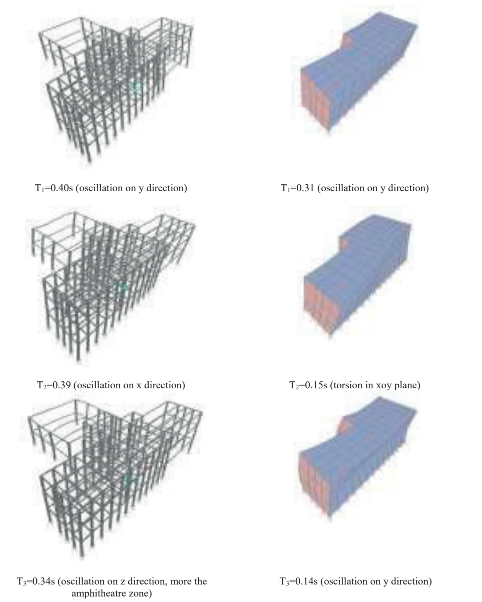

Figure 7. The dynamic characteristics of the two buildings, B1 and B2

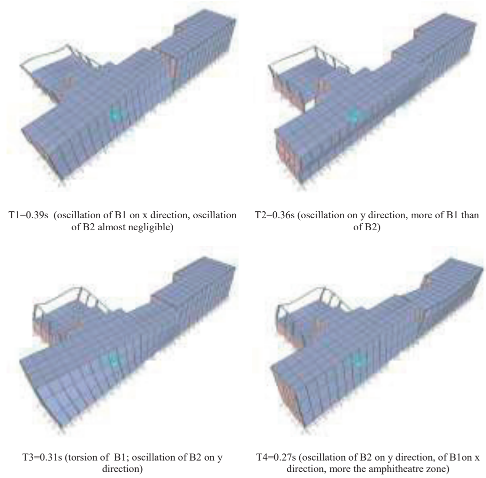

Figure 8. The dynamic characteristics of the system consisting of B1 and B2

- determining the fundamental vibration period, according to the simplified calculation formulas:

For buildings with reinforced concrete structural system (case of B1): T = 0.12N^0.76, thus T (N = 4) = 0.34 s and T (N = 5) = 0.40 s (where N is the number of levels). For buildings with structural brick walls (case of

B2): T = 0.18N^0.35, thus T (N = 4) = 0.29 s and T (N = 5) = 0.31 s.

The values obtained by applying the formulas and those from the modal analysis, or from vibration recordings are comparable.

- validation of the results obtained through temporary seismic instrumentation, by comparing with the fundamental periods of other existing buildings with reinforced concrete structural system or structural masonry walls (representation based on studies conducted within the INCD URBAN-INCERC, in different time periods) (Figures 9 and 10).

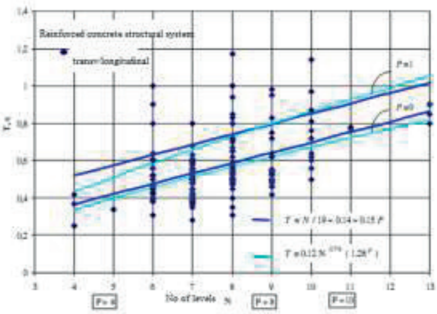

Figure 9. Fundamental periods values for buildings with reinforced concrete structural system.

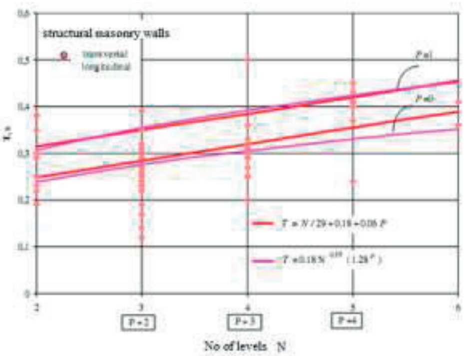

Figure 10. Fundamental periods values for buildings with structural masonry walls

Moreover, for the same building have been also addressed: determination of the response spectra, having represented the pseudo spectral-frequency acceleration, at points of interest, on levels; representations of displacements and accelerations in points of interest; pushover curve and capacity spectrum; the failure mechanism and the development of the plastic joints, with 2D view of one of the x Oz planes; lateral displacements, at service limit state and ultimate limit state; energy charts, taking into account also the control strategies for seismic energy dissipation (Luca et al., 2014; Luca et. al., 2015), establishing the level of structural degradation based on methods of estimating lateral displacements etc. On the other hand, the soil conditions were studied from the perspective of the possibility of consolidation using binders with ecological benefits based on parametric correlations (Dobrescu, 2017).

RESULTS AND DISCUSSIONS

Related to the dynamic characteristics of the two buildings, B1 and B2, as separate systems or in cooperation as a whole, the oscillation periods have close values in the case of modelling, applying a simplified formula, temporary seismic instrumentation, or comparing with the fundamental periods of other existing buildings with reinforced concrete structural system or structural masonry walls.

The presented building is proposed for structural and thermal consolidation, after this another measurement of these characteristics to be realized.

In this case, the capacity to the sheer force of the masonry wall, plated with composite materials, is given also by the contribution of the composite material in addition to the contribution of the masonry (Figure 11).

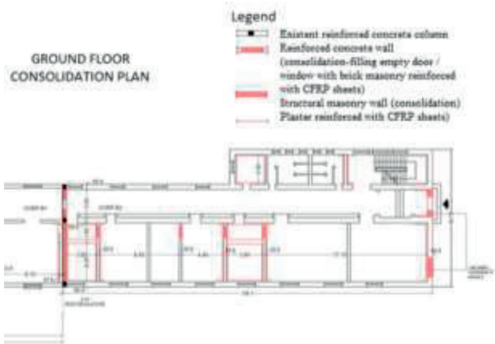

Figure 11. A part of consolidation plan for the ground floor (proposal). Existent reinforced concrete column; Reinforced concrete wall (consolidation-filling empty door / window with brick masonry reinforced with carbon fiber reinforced polymer/CFRP sheets); Structural masonry wall (consolidation); plaster reinforced with CFRP sheets)

The advantages of using this type of intervention are:
- good mechanical properties of composite materials;
- the reduced weight of the composite materials generates permanent loads on the structure; reduced thickness of the coating layers;
- the structural intervention does not alter the initial aesthetic aspect;
- the intervention has a reversible character, the materials can be dismantled from the structure, if the performance levels initially established are not met in the long term.

From the point of view of thermal rehabilitation, a thermal insulation system based on expanded polystyrene (ETICS) could be considered (Kotthoff, 2015) (Figures 12a, 12b), because it is easy to apply on load-bearing or non-bearing exterior walls from masonry or reinforced concrete, does not add loads to the structure, is energy efficient and has low costs compared to mineral dry wool (Simion et al., 2019).

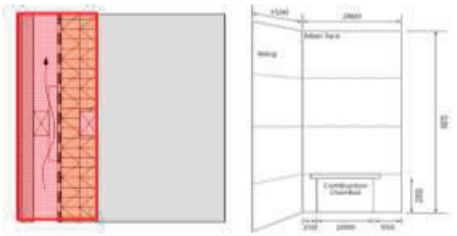

Figure 12a. Thermal insulation system based on expanded polystyrene (ETICS-wall) (Kotthoff, 2015). Large-scale cladding test facility-exposure level two (Simion et al., 2019)

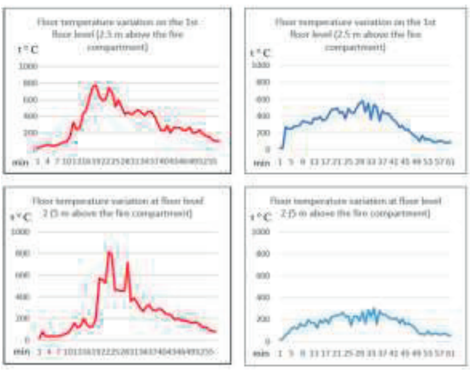

Figure 12b. Temperature-time behaviour on 2 vertical levels of test model (Simion et al., 2019)

The polystyrene sheets can be bonded to the masonry wall by adhesive mortar points or glued to the wall with adhesive mortar, both perimetral (all over the borders) and in the centre by three bonding points (a reinforcement layer consisting of a glass fiber mesh embedded in the glue mortar), with/without protective fire propagation barriers (from basalt mineral wool).

The choice of such a solution could be justified by the results of the tests carried out at the INCD URBAN-INCERC, which highlighted that the perimeter bonding to the support wall of polystyrene sheets with adhesive mortar together with the solution of planking the windows and doors with non-combustible barriers, having a width equal to of polystyrene, provides a high degree of fire safety for the used system in order to obtain the external thermal insulation of a building.

CONCLUSIONS

In the context of national seismicity, it is important to obtain more data on the performance of a structural system, its real resistance, as well as on how a structure behaves after exceeding the elastic limits of behaviour.

There have been presented several types of technical approaches related to an old building in the stage of structural consolidation and thermal rehabilitation, at present.

From the point of view of the dynamic actions, the natural period of vibration, determined experimentally, applying simplified calculation formulas, or from a modal analysis (after the commissioning of a building, before the earthquake, after the action of the earthquake that caused damage, or after carrying out the strengthening works), allows a determination of the rigidity and therefore a very useful assessment on the resistance capacity.

From the point of fire protection measure, some performance characteristics should be considered in the future: spread of fire, maximum flame heights, temperature-time behaviour, progressive smouldering, mechanical behaviour (damage, falling material, collapse of the parts of facade cladding system) etc. in fact, prevention of fire occurring in the insulation layer, or secure restriction of a fire in the insulation layer of every second floor.

Where it is not possible to obtain correct information regarding the behaviour of a structural system, due to the lack of data needed to create a reliable model, the contribution of each presented method is consistent, using the advantages of non-destructive methods, ambient vibration monitoring and modal analysis.

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