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DESIGN OF REINFORCED CONCRETE STRUCTURES LOCATED IN SEISMIC AREAS

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Abstract

In Romania there are yet many old buildings, who have suffered damage during earthquakes in the last century. Securing them is an important issue for the owners and of course for the authorities. The paper analyses the maximum displacements at the top of the structures under seismic actions at different heights. Maximum values are compared with allowable limits specified in current design codes. The study was conducted for RC frame structures with different heights. As a novelty authors used as entry data for structural modelling, the resulting values from the non-destructive tests on concrete and reinforced concrete samples. In the first part of this study relative positions of the two intrinsic centers, CG and CR, were calculated. Then, RC frame structures that have the same shape in plan, but different heights were modelled using Autodesk Robot structural analysis program. Because the maximum amplification was at the largest structure height, the second part of the study was to determine the displacement for structures with the same height but different shape in plan. In conclusion, the paper emphasises the influence of the height regime on the displacement at the top of the building and irregularities that influence on the same phenomenon. The results are conclusive and are discussed both on the charts and analytical results obtained. The activities of this research were conducted under the supervision of Mr. Claudiu-Sorin DRAGOMIR, Lecturer in the Department of Environment and Land Reclamation at the Faculty of Land Reclamation and Environmental Engineering of Bucharest.

Key words: *eccentricities, old irregular buildings, seismic action, structure response*

INTRODUCTION

The study presumes that in Bucharest many buildings were built after more permissive norms than the existing ones that follow the seismic design code P100-1:2006 (Dragomir, 2013). The study looks at the displacements caused by the earthquakes at the superior levels of buildings with different heights (GF+3Storeys, GF+7Storeys, GF+10Storeys) and various plan forms (L, T and +).

For exemplification it were chosen two buildings presented in Figure 1 because they are old, have an irregular shape and do not meet the rigors of today’s design codes.

a. Law Faculty

b. Romanian Opera

Figure 1. Irregular shapes of buildings

In order to determine the state of the buildings non-destructive test can be made using the following equipment: Digi Schmidt, which records the concrete's rebound index and Pundit Lab, which measures the speed and time needed for ultrasounds to transit the concrete block. In this manner the entry dates was obtained for the automatic structural calculation.

METHODS AND MATERIALS

Methods of structural analysis.

As methods of structural analysis the Autodesk Robot Structural Analysis Professional software used:

The method of equivalent static seismic forces.

This method can be applied to buildings for which the characteristics can be calculated through the consideration of two plane models on orthogonal directions and for which the total seismic response is not significantly altered by the higher oscillation Eigen modes. In this case, its fundamental mode of translation has a predominant influence in the total seismic response. The main shear force corresponds to the proper fundamental mode, for each of the primary horizontal directions considered in the building's calculations, is determined as followed:

$$F_b = \gamma_I S(T_1) m \qquad (1)$$

where:

$S(T_1)$ - is the design response spectrum ordinate correspondent to the fundamental period;

T_1 - is the primary fundamental period of oscillation for the building in the plan that contains the considered horizontal line;

m - is the building's total mass;

γ_I - is the importance (exposure) factor of building;

λ – is the correction factor that considers the proper fundamental mode through the effective modal mass associated to it, whose values are $\lambda = 0{,}85$ if $T_1 \leq T_C$ and the building has more than two floors and $\lambda = 1{,}0$ in the other cases.

The primary fundamental period T_1 is determined using a dynamic structural analysis.

For the structures considered in the calculation the following expression regarding the main shear force:

$$F_b = \gamma_I S(T_1) m\lambda \Rightarrow F_b = 0{,}14m \qquad (2)$$

The method of modal analysis with response spectra.

In the method of modal analysis, seismic actions evaluated based on response spectra corresponding to unidirectional translational movement of ground described by accelerograms. Horizontal seismic actions described by two horizontal components measured on the same design response spectrum. The vertical component of seismic actions was characterized by vertical response spectrum. This analysis method applies to buildings that do not meet the specified conditions for use of the simplified equivalent static lateral forces. For buildings that meet the principles of regularity in plan and vertical uniformity principle, the calculation can be done using two plane structural models corresponding to the main horizontal orthogonal directions. Buildings that do not meet the above principles will be calculated with spatial models. When using a spatial model, seismic action will apply to the relevant horizontal and orthogonal main directions. For buildings with structural elements located in two perpendicular directions can be considered as relevant. Usually, the main directions corresponding with the base shear force associated with the fundamental mode of translation oscillation and the normal force on this direction. The structures with linear behaviour are characterized by their own modes of oscillation (natural period, proper oscillation shapes, effective modal masses, and effective modal mass of participation factors). They are determined by dynamic calculation methods using dynamic inertial and deformation characteristics of structural systems resistant to seismic action. In calculating Eigen modes will consider a contribution to the total seismic response.

Dynamic aspect of seismic action and inelastic behaviour of structures affected by destructive earthquakes require specific design methods, governed by rules of seismic design. In Romania, these regulations are contained in the

"Seismic Design CodeP100 – part I –Design provisions for buildings" (P100-1:2006). P100 provisions contain two fundamental requirements, performance levels that constructions built in seismic areas must satisfy:

The life safety requirement – The buildings must be designed such that under the effect of the projected seismic action to possess enough margin of safety towards the local or global collapse of the buildings, so that the people's lives be protected. The level of the seismic action associated with this performance level corresponds to an average recurrence interval (Average Recurrence Interval = 100 years)

The degradation limit requirement – The buildings must be designed in such a way that for the earthquakes with a higher probability of occurrence than the projected seismic action, the buildings do not suffer degradations or these be taken out of use, so that the repairs cost would be exaggerated towards the initial cost of the building.

The level of the seismic action associated with this performance level corresponds to an average recurrence interval SLS (ARI=30 years).

Romanian territory is divided in seismic zones depending on local seismic chance, which is considered to be constant in each seismic area. The seismic chance for design is expressed by top value of the horizontal ground acceleration (a_g) determined for the appropriated Average Recurrence Interval ULS (ARI =100 years). The seismic motion in a point on the ground is described by elastic response spectra for absolute accelerations (two horizontal components and one vertical component).

The local ground conditions affect the form of the elastic response spectrums and change both peak acceleration amplification of the ground (a_g), as well the frequency content of the seismic motion. The peak acceleration amplification of the ground for the Bucharest is 0,24. The local ground conditions are described trough the values of the control interval (of corner), T_C, of the response spectrum for the regarded area, which is expressed in seconds. The value for this interval in Bucharest is 1.6 seconds. The code P100:2006 or the Eurocode 8 specifies tree values of the control interval T_C on a macro seismic map. Of a value of the control interval, T_C corresponds to a pair of values T_B and T_D. The control interval, T_C (s) of the response spectrum is the limit between the maximum values area from the absolute acceleration spectrum, the normalized forms of the elastic response spectrum for the horizontal components of the ground acceleration, β(T), for the fraction of critical damping (ξ =0,05- depending on the control interval T_B, T_C and T_D), and the area of maximum values in relative speed range.

$$0 \le T \le T_B, \beta(T) = 1 + \frac{(\beta_0 - 1)}{T_B} T \qquad (3)$$

$$T_B < T \le T_C,\ \beta(T) = \beta_0 \qquad (4)$$

$$T_C < T \le T_D, \beta(T) = \beta_0 \frac{T_C}{T} \qquad (5)$$

$$T > T_D, \beta(T) = \beta_0 \frac{T_C T_D}{T^2} \qquad (6)$$

where:

β0 – maximum dynamic amplification factor;

T – own period of oscillation of a system with one degree of dynamic elastic freedom response;

The graph in Figure 2 shows that dynamic amplification factor value of ground acceleration for Bucharest is 2.75.

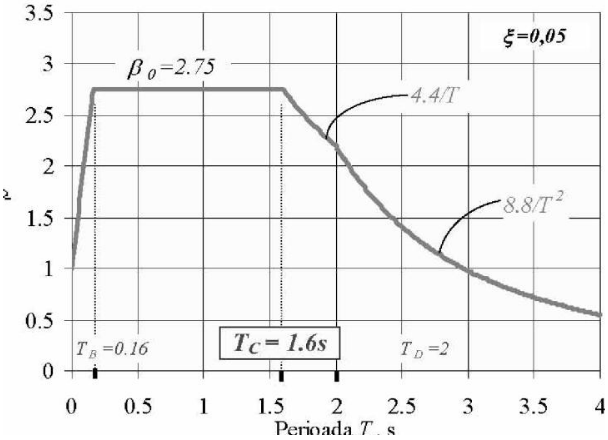

Figure 2. Normalized spectrum of elastic response of acceleration for horizontal components of ground motion in areas characterized by control period T_C = 1.6 s

A conceptual design of structures located in seismic areas that ensures adequate seismic behaviour is very important.

Simplicity of the structure assumes a continuous and strong enough structural system that can ensure a clear path, uninterrupted for the seismic forces directly to the foundation soil. An example of discontinuity of seismic actions is a big hole in the ceiling or a lack of reinforcement. Seismic design should aim producing a structure as regular and as uniform distributed in plan so that inertial forces are transmitted directly on the shortest way to the foundations. Therefore plans form shown in Figure 3 should be avoided in designing structures.

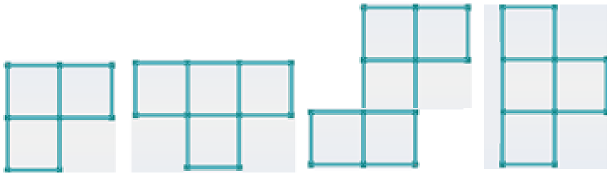

Figure 3. Examples of irregular shapes in plan

In Autodesk Robot Structural Analysis Professional software were simulated different types of structures that determined a system of axes with an opening and a span of 4.5 meters and 3 meters distance between levels. Concrete used is C16/20, section poles at ground level are 45x45 cm and at the top will be 30x30 cm; 25x50 cm section beams and reinforcement is done according to the standards in effect. It should be mentioned that in each case the structure were encased to the bottom.

RESULTS AND DISCUSSIONS

In the first part of the study we chose three simple structures with three different height regimens (GF+3Storeys, GF+7Storeys, GF+10Storeys). The three structures were modelled using Autodesk Robot Structural Analysis Professional software. It was simulated an earthquake and then it was determined their displacement values at the top of structure (Dragomir, 2011). Following the results it was observed, as expected, that the largest displacement was recorded at the highest structure height as shown in Figure 4.

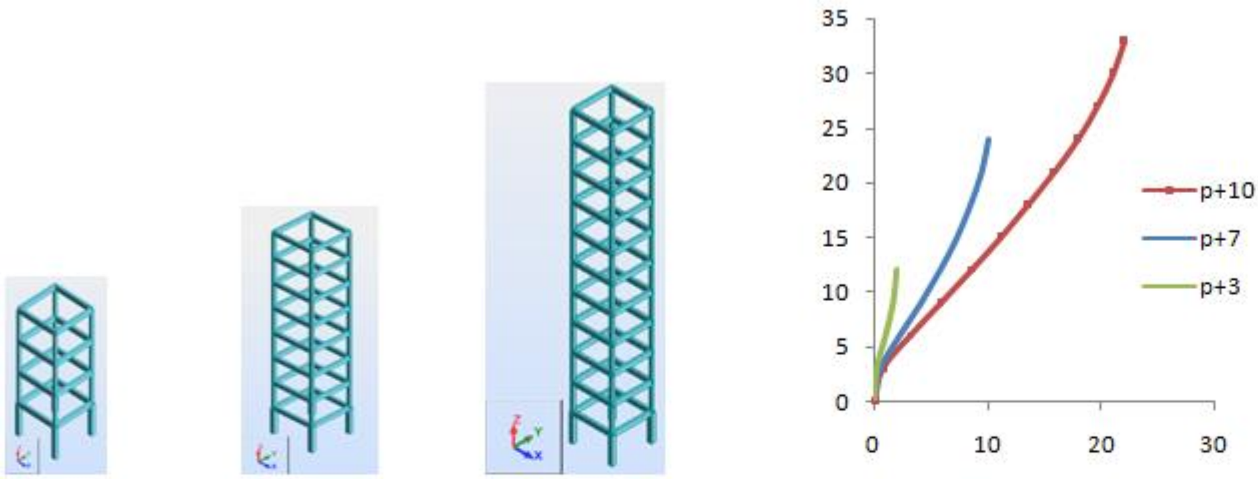

Figure 4. 3D representation of the structures and comparative chart of displacements on x direction

In Figure 5 you can see the 3D deformation shape of buildings after the seism induced on the X direction, and in the right part of the figure is a chart that contains periods of oscillation for each structure. These periods correspond to the first three fundamental modes of oscillation.

Following graphs in Figure 5 it can be seen that the periods of time obtained for the highest structure have the highest values, signifying that it has greater flexibility. In the three cases it can be seen that the first two periods of oscillation modes have equal values and higher than the third. Equal values of the first two periods can be explained through regular shapes that they have.

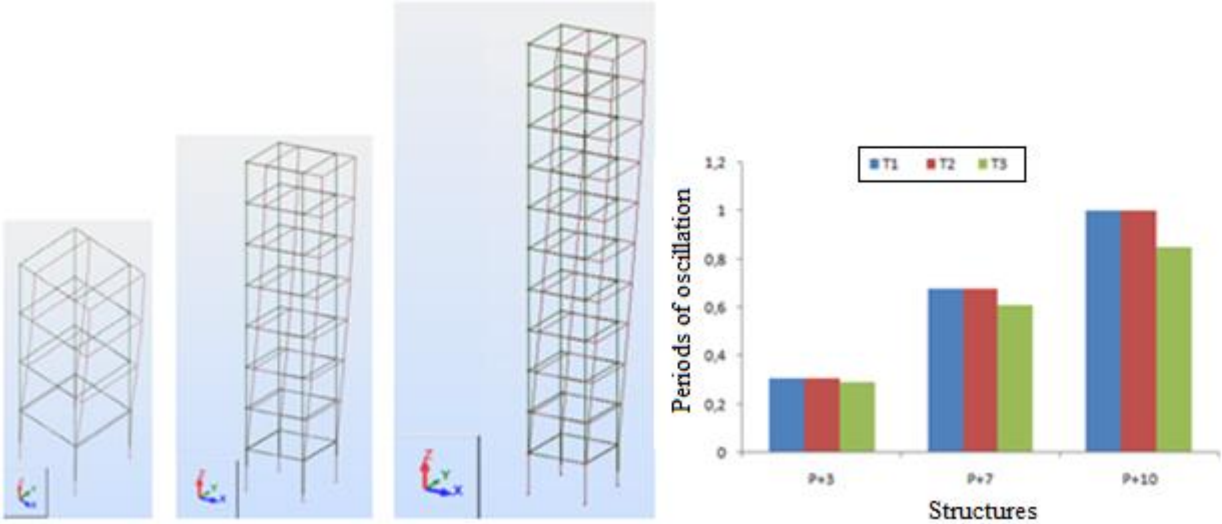

Figure 5. Representation of the four 3D deformation shapes and the structure displacements

In the second part of the study we considered the buildings with the same height and the same characteristics, with different shape in plan, to observe the differences in their displacements (Figure 6).

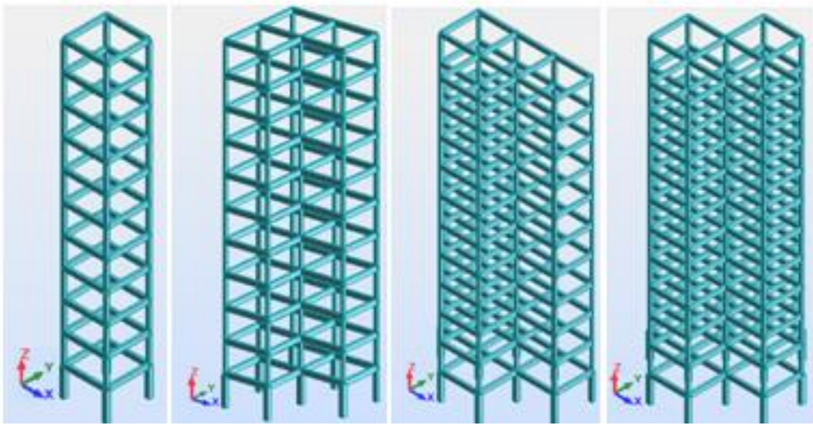

Figure 6. 3D representation of four structures with different shape in plan and with the same height regime

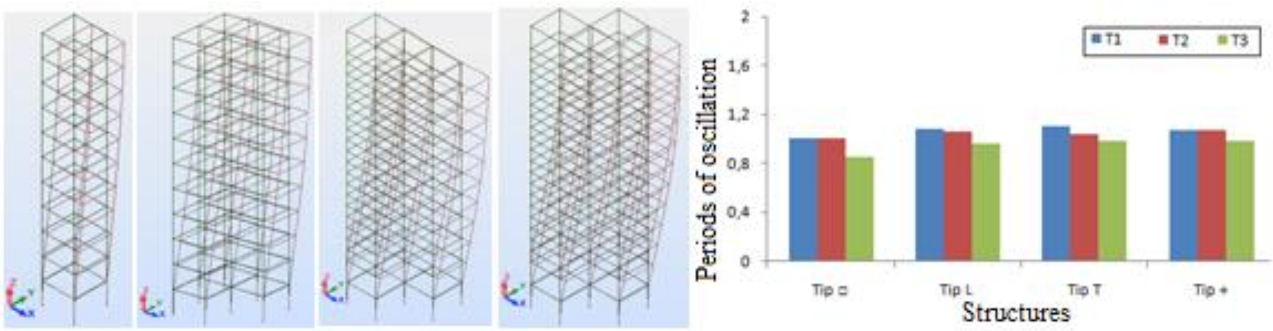

Figure 7. Representation of the four 3D deformation shapes and the structure displacements

In figure 7 where those four buildings have the same height, it can observe that only symmetric buildings have the first two periods equal (□ and **+)** while the irregular structures (L and T) have their first two periods of oscillation different on the strength of their eccentricity which can be seen in figure 9. We can also observe that the irregular structures have a longer period of oscillation than the symmetrical ones on the strength of the same reason: their eccentricity.

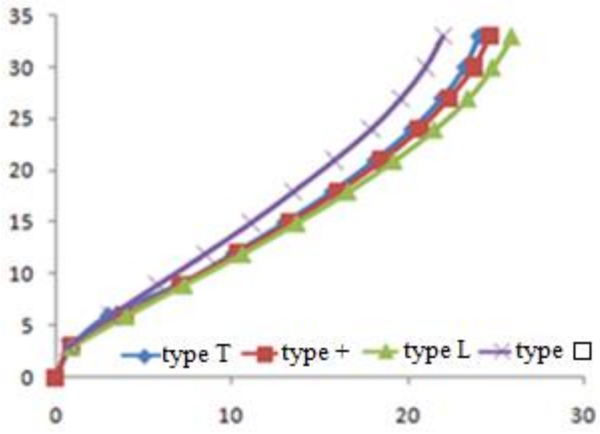

Figure 8. Representation on the vertical displacements of the structures

In figure 8, it is emphasised a chart that compares building displacements under seismic action, where it can observe that the regular square buildings are the safest, with the smallest displacement, and the „L" shaped structures are the most dangerous, having the biggest displacement.

In Autodesk Robot Structural Analysis Professional software it can also calculate the eccentricities, calculus was done, and found out that the symmetrical structures have no eccentricities, the „T" shaped structure has eccentricity on only one direction, and the „L" shaped building have eccentricities on both horizontal directions which make it the most unstable (Figure 9).

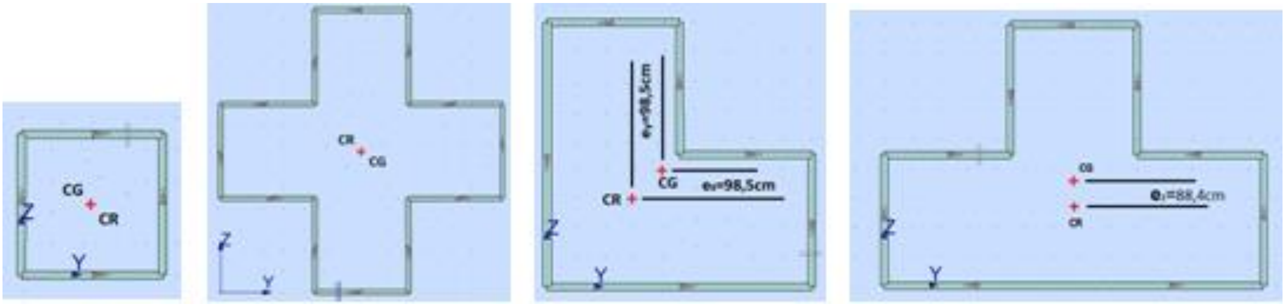

Figure 9. Eccentricities on the two directions in plan

CONCLUSIONS

Using Autodesk Robot Structural Analysis Professional was emphasised the answer of different types of buildings to side action with specification that, in calculus, were considered only the efforts given by its own weight. The analysis showed that largest displacements were obtained for structures with the largest height. It was also validated the clause on irregular plan shapes of structures, both defined in the Code P100-1: 2006 and in Eurocode 8.

Analysing the results we can say that at irregular buildings the weight - geometry relation has an important role, and irregularities are controlled using the principles of conceptual design code P100-1: 2006 or Eurocode 8.

There are no perfect buildings and from this point of view deviation from perfection means additional cost.

Building irregularities cannot be avoided. They appear from functional reasons in plan, and technological on height.

Theoretical problems of irregularities are treated with the study of relative relation between the center of rotation CR and center of gravity CG.

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