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ENHANCING THE STRUCTURAL BEHAVIOUR OF REINFORCED CONCRETE BUILDINGS UNDER SEISMIC ACTIONS

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Abstract

Romanian earthquakes since 1940 and 1977 have produced severe damages to a significant number of RC framed buildings whose plans were characterized predominantly by irregularities like flexible diaphragms, structural discontinuities or L or H shapes, among others. These conceptual characteristics contributed in a decisive way to the damage or collapse of buildings designed and built according to old seismic codes.On the other hand, European and internationalexperience of the past strong earthquakes during last decades shows that, in many urban areas besides many old building, there is a number of modern RC buildings that do not meet the requirements of additionally improved Codes for seismic resistant design. The paper presentssome types of structural interventions on buildings and solutions for determine the dynamic building response. On basis of dynamic response recorded for buildings, a methodology for analyzing the structural behavior of this typology of buildings by adequatesoftware for 3D seismic analyzing is presented. For this purpose non-destructive and geodynamic methods were used. The non-destructive methods are based on auscultation, ultrasound and percussion with Schmidt hammer, and the geodynamic methods are based on the GEODAS equipment with Microwave software.The results proved that the mass and stiffness is not always beneficial and also emphasizes the role of geometry on dynamic response of building.

Key words:*earthquake, structure, seismic response, building instrumentation.*

INTRODUCTION

The paper presents a detailed study of buildings with irregular forms in plan and elevation.
To improve the seismic response it were considered different tipes of structural interventions. Certainly the paper presents a comparative study between the buildings with different forms in plan and elevation and GF+8Storeys heigh.
To make the optimum choice of consolidation were used the methods presented in the seismic design code P100-3:2008.The evaluation of existent buildings,the annex with refference at reinforced concrete and brickwork buildings (Dragomir, 2013).

MATERIALS AND METHODS

As methods of structural calculation the Autodesk Robot Structural Analysis Professional software based on the method of equivalent static seismic forces andthe method of modal analysis with response spectra were used (Gruia et al., 2013).
The method of equivalent static seismic forcescan 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 translationhas 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, isdetermined as followed:

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

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 2 floors and $\lambda = 1{,}0$ in the other cases.
The primary fundamental period T_1 is determined using a dynamic structural calculation.For the structures considered in the calculation the following expression regarding the main shear force:

$$F_b = \gamma_I S(T_1) m\lambda = 1{,}20x0{,}24x\frac{2{,}75}{4{,}725}x0{,}85xm \Rightarrow F_b = 0{,}14m$$

In the method of modal analysis, seismic action is 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 action is 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 principal directions. For buildings with structural elements located in two perpendicular directions can be considered as relevant. Usually, the main directions corresponding with the bases hear 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.
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.

RESULTS AND DISCUSSIONS

In the first part of the study it was choosed as example five different shapes of structures in plan and elevation (Dragomir, 2011):
- The first one and the second have rectangular form and the dimensions in plan are different from each other (the second structure is 25% longer than the first);
- The third one has the shape of "L" with one of sides longer than the other with 25%;
- The fourth structure has the shape of "L" with equal sides in plan.
- The fifth structure has the shape of "L" with equal sides in plan but unequal in elvation (the side coresponding the x axe is in steps form starting from the superior part of the building).

It was considered a span of 5 meters and a constant storey heigh of 3 meters.

Concrete used is C16/20, sections of columns are 45x45 cm; the beams sectionsare 30x50 cm and the reinforcement has been made according to the current regulation. It should be mentioned that in each case the structure were embeded at the base.

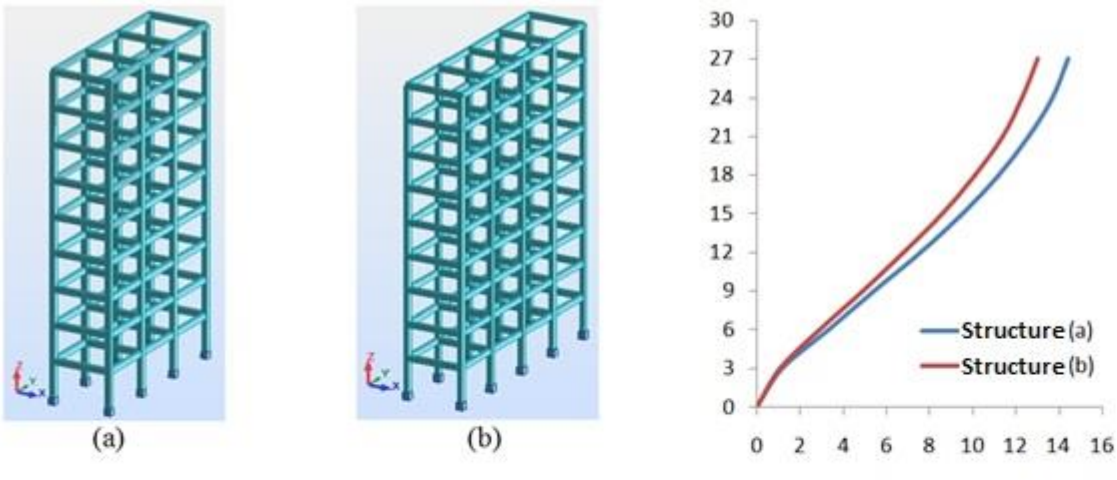


Figure 1. 3D representation of the structures and comparative chart of displacements on x direction

We observe that between the first types of structures, (Figure1.a and 1.b) the displacement values are relatively small (about 8%).

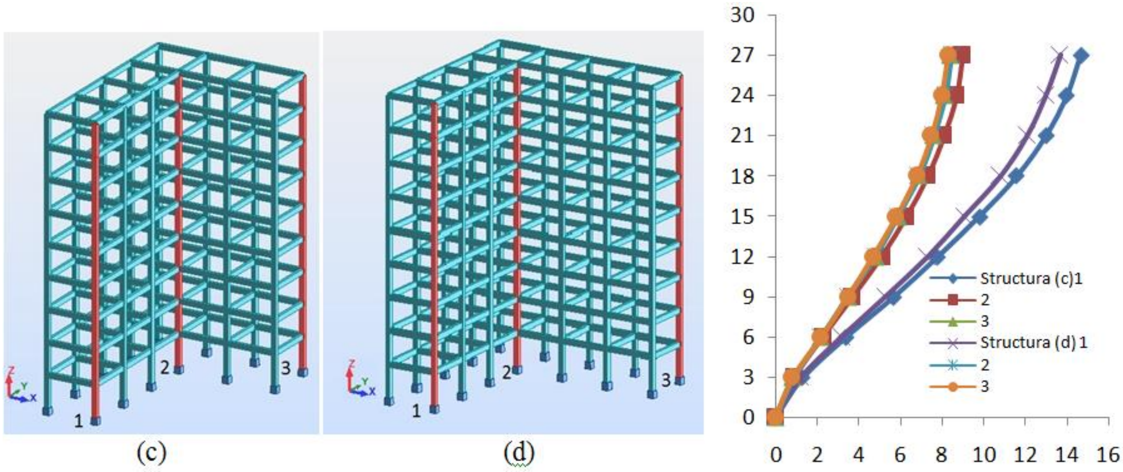


Figure 2. 3D representation of the structures and comparative chart of displacements on x direction

Incase of irregular shape dbuildings the displacements will be consider on the three edgesof the buildingas it can be observed emphasized in red colour in the Figure 2 and 3.It clearly observed that the displacements from the edge 1 are considerably higher than the values of edge 2 and 3.

The displacement values on first edge of the building are more 50% higher than the other.The overall difference between those buildings is very small, similar with the first case.

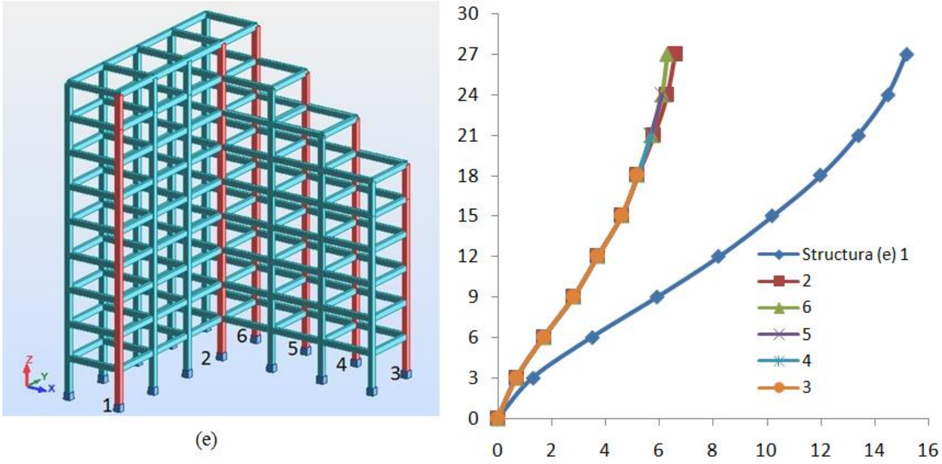


Figure 3. 3D representation of the structures and comparative chart of displacements on x direction

For the building with irregular shape in plan and elevation, as you can see in Figure 3, the displacement of edge 1 is more than 50% comparating with the other edges.In conclusion the elevation irregularity produces this difference in seismic behavior.

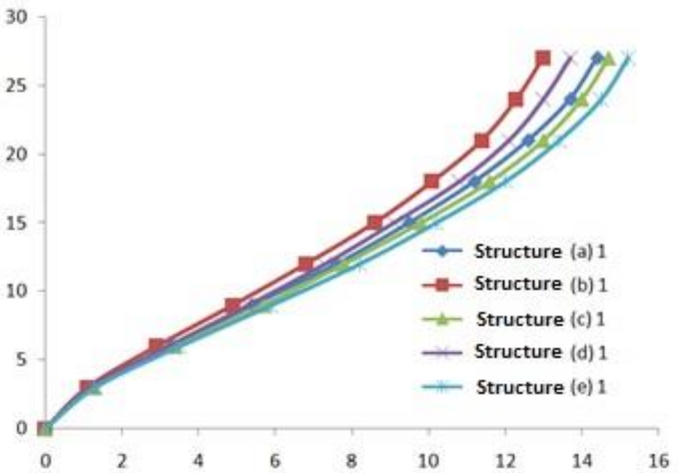


Figure 4.The comparative representation of displacements for all five structures on x direction

In Figure 4 are represented vertical edge displacements versus the height regime of buildings. It can be observed that the difference between the extremes is not very high.

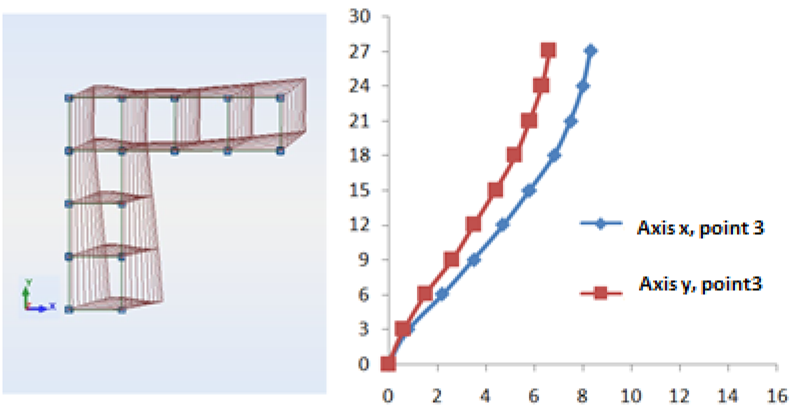
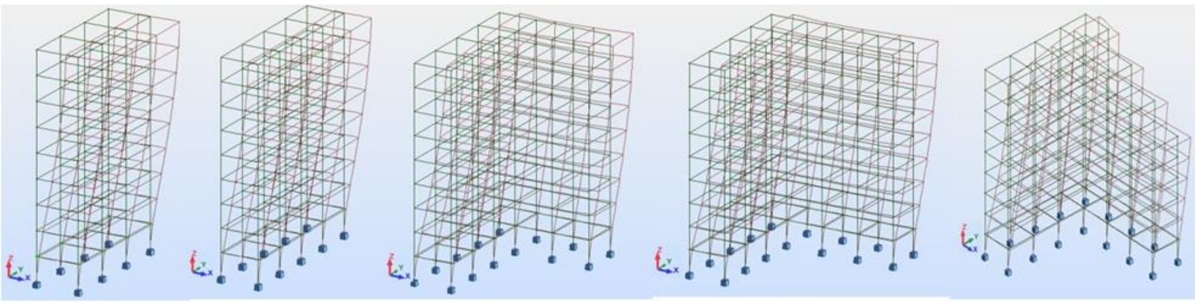


Figure 5.The deformed at the superior side and the comparative displacement on x and y direction

It is worth mentioning that al though the earthquakeis induced exclusively on the x axis, on buildings with L-shapes, appear large displacements on y directionas shown in the Figure 5.

In Figure 6 it can be seen specific movements of the buildings on the x-axis under seismic action induced in the x direction,and in the Figure 7 is presented the graph that contains periods of oscillation for each structure depending on the shape. These periods correspond to the first three fundamental modes of oscillation.



(a) (b) (c) (d) (e)

Figure 6.Representation of the five 3D deformation shapes and the structure displacements

In Figure 7 it can be observed that for buildings with irregular shape the oscillation period varies in each of the three modes.

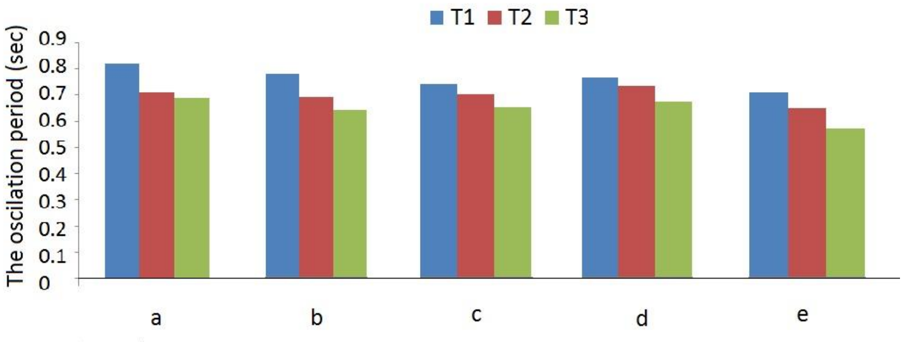


Figure 7.The values of the oscilation periods for the structures

Strengthening the structures applying the base isolation method

In the second part of the studyit was chosen a rectangular structure in plan with GF+8 Storeys, which was under a strengthening work. This intervention was determined radically changes on the behavior of the building during an earthquake. In literature, the method is known as *the base isolation method***.**

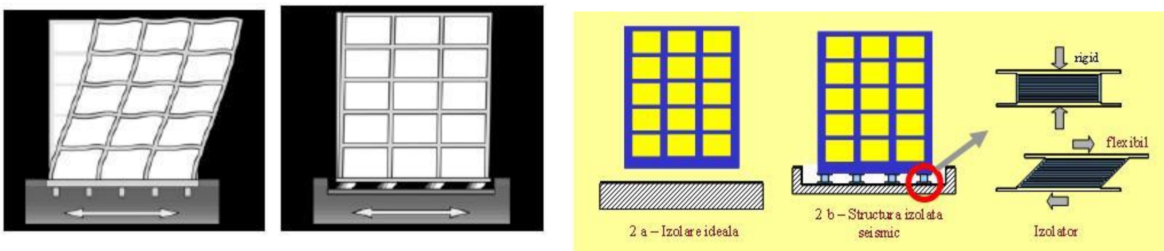


Figure 8.The concept of base isolation

It is probably the best decision when choosing a precautionary measure to avoid a disaster produced by earthquakes. The method basically involves separating the superstructure of the building infrastructure, or better said, the method replaces "rigid fitting", which offers no degree of freedom, with an "elastic fitting" which allows the building, at a certain extent, to move in absolute any direction.This movement that occurs, in this case at base of the building is controlled by hydraulic systems for the amortization of translational motion.The structures with the isolated base are generally equipped with additional devices to increase the amortization in order to reduce large displacements at interface level of isolation.These devices can operate in passive mode, in which case the amortization provided is constant throughout the operation, or under semi-active or active, in which case the variable amortization is adjustable upon request.

In the seismic isolation, the main purpose is to reduce the substantial energy and seismic forces transmitted to the structure. This is achieved by settlement of the structure on an insulating layer with very low lateral rigidity so that during an earthquake, when the ground strongly vibrates, in structure is induced only moderate movements. Due to the low lateral stiffness of the insulation layer,the structure has a fundamental period greater than the fundamental period of the same structure but with fixed base.

Depending on the type of device used, the level of damping can vary significantly (from a few percent of critical damping at levels of 40% or more).It is obvious that a low level of amortization does not benefit the structural response, but at the same time an excessively high level of amortization can also be a deficiencies generator by focusing the substantial local forces and by changing the overall dynamic response to negative.Also, in the case of a semi-active amortization the power in these devices is limited and reduced to the force generated in a passive device.The level of a force in the semi-active mode similar to that in the passive mode, the two devices have similar behavior, and for a very low power in the semi-active mode against the passive mode, the effectiveness of amortization device itself is no longer interesting.

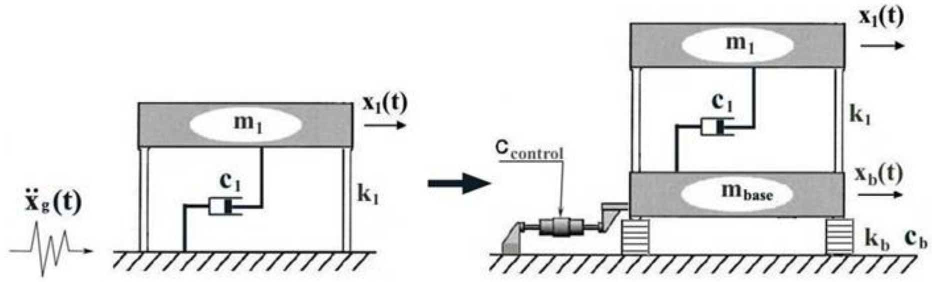


Figure 9.The model which parametric study is conducted to identify optimal amortization characteristics.

The model above is derived from a model with fixed base (left). The mass and rigidity are chosen so that it leads to their own vibration period of 0.93 seconds. Natural amortization level of the system is 5%. This model is equipped with an interface of base isolation composed of base isolators without additional amortization with dynamic features chosen so that the period of the isolated system to be 3.39 seconds (right). The rigidity parameter thus remains constant during the analysis.

Energy balance system with 1 DDF

It will analyze, from the energy point of view, balance equations for a conventional system with one DDF, the usual mass and rigidity characteristics, respectively for one isolated and provided with additional passive amortization, modeled as a 2-DDF system and will present proportion which the different forms of energy dissipation have against the total energy.

For a dynamic system starting from relative response values, the energy balance can be made according to the relation 2.

$$E_{cr}+E_d+E_{abs}=E_i \quad (2)$$

where:E_{kr}- kinetic energy is "relative", E_d - the energy dissipated by viscous amortization, E_{abs} - energy absorbed by the system and E_{ir} - "relative" induced energy.

The absorbed energy system consists of energy consumed for elastic deformation (recoverable)

- E_s and the energy dissipated by plastic deformation or dissipated due to nonlinear elastic behavior of the material - E_{hyst}

$$E_{abs}=E_s+E_{hyst} \quad (3)$$

In systems with linear elastic behavior practically all the induced energy is dissipated by viscous amortization because E_{hyst}=0.
For isolated base systems or equipped with additional energy disipators is preferred that the induced energy is dissipated by the special dissipation devices and not any particular set of plastic deformation. In the second case, the control mode of how induced energy is consumed by plastic deformation is hard to do.The first example relates to the 1-DDF system with linearly elastic behavior. The system is so dimensioned as to have a period of 0.5 seconds, and an amortization level of 5% of critical amortization. The distribution of the energy absorbed by the system and thepostelastic deformation E_{hyst}, as a proportion of total energy induced E_{ir} leads to the graphs which are shown in Figure 10.

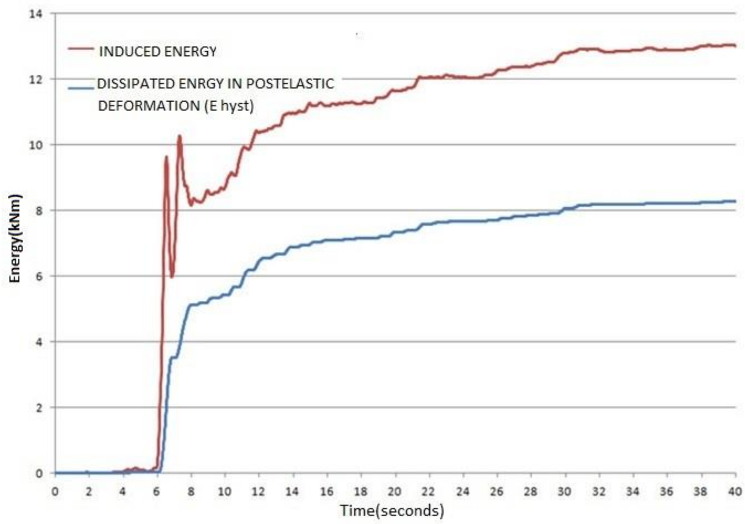


Figure 10. Distribution of energy absorbed by the system and reflected by postelastic deformation (Pavel, 2012)

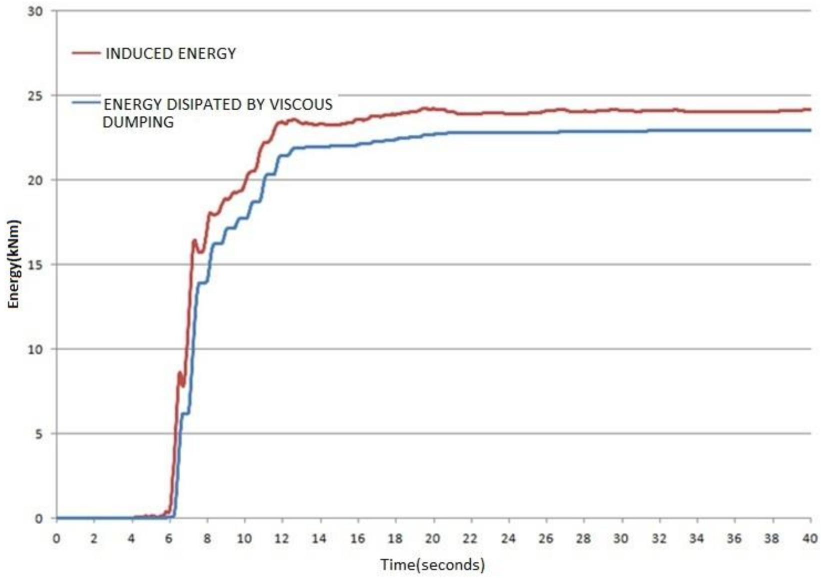


Figure 11.Distribution ofenergy dissipatedbyamortization(Pavel, 2012)

In comparison, the same system with one DDF will equip an isolation interface with rigidity and mass chosen so that the isolated system will provide a period of 3.0 seconds and an amortization coefficient equivalent to a fraction of critical amortization of 25%. Taking into account the mass and rigidity of the isolation system and the new level of amortization,the changes of the energy distribution by the system is shown in Figure 11.

By benchmarking graphs above it is noted that in the case of the isolated system and additional amortized, most of the induced energy is dissipated at the level isolation interface. In these conditions, the system will have an elastic behavior, whereas the proportion of energy dissipated by viscous equivalent amortization for the isolated system is significantly higher than that dissipated by hysteretic deformations in the case of the conventional system.

Issues related to design spectra

In Figure 12 is shown the elastic spectra of accelerations (AS) and displacements (DS). It can be clearly observed the dynamic effect obtained by seismic base isolation.

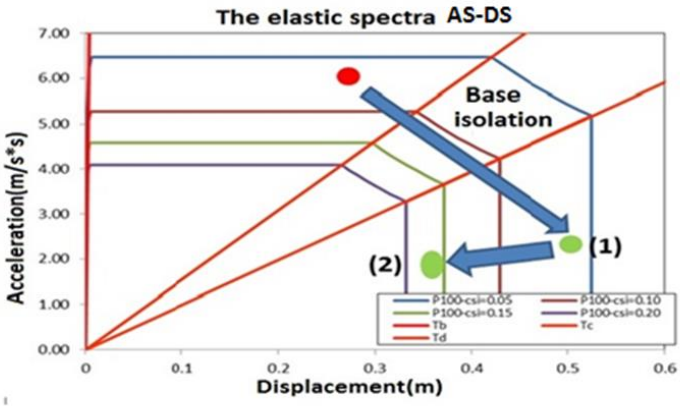


Figure 12.The AS-DS spectra (Oprisoreanu, 2012)

By decoupling the infrastructure of the superstructure and introduction the isolation devices it is obtain an "extention" of the fundamental period of vibration. This extension results at the acceleration requirement in the superstructure but increasing movement requirement (step 1). By introducing a degree of damping in the isolation system it`s reduces the requirement of the superstructure displacements (step 2). Note that as mentioned above this displacement requirement is concentrated almost entirely in the isolation system.

Acceleration spectrum analysis reveals the following:

a) Ground seismic generate maximum spectral accelerations in their periods of 1.20 .. 1.50 sec. This interval is associated with fundamental periods of vibration of buildings with medium to high altitude regime (8-15 floors). In conclusion, the maximum dynamic amplifications of acceleration are registered at these buildings and not at those with low heights.

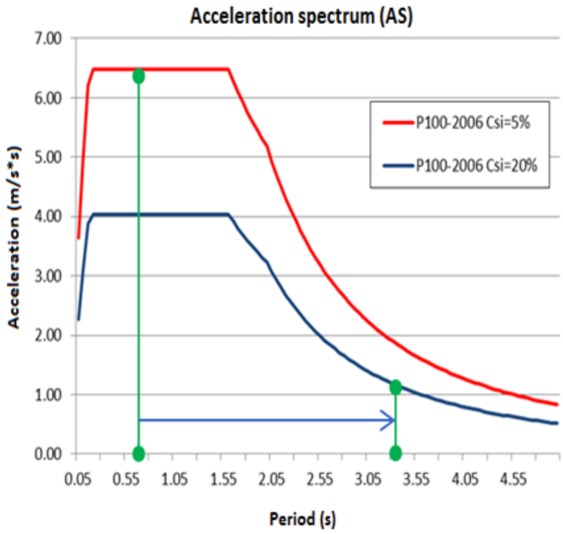


Figure 13. The acceleration spectrum (Oprisoreanu, 2012)

b) The philosophy of structural response control methods through the type base isolation technology involves decoupling the structure of the ground so that she has an answer like a rigid solid (no lateral deformations) with a period close to that of isolators. A typical value for the period isolated system recommended in the literature in this field is about 2.5 sec. The particular conditions of seismicity of our country, this value is unsatisfactory and should be increased to 3.5 to 4.0 seconds to remove the effects of relative motion of the structure, given that, from numerical studies, the value of 2, 5 seconds still recorded dynamic amplifications relative movement of isolated structure;

c) By reducing the acceleration spectra it can be obtained an elastic response for a force design level comparable to that used for conventional structures in which are used behavioral factors significantly above unit. This reduction is not effective in periods below 3.5…4 seconds

Displacement spectrum analysis reveals the following:

a) The elastic displacement spectra family for different amortization levels emphassis the high requirement of specific movements of Vrancea earthquakes and significant importance to high amortization level. An amortization level of the order of 20-40% results in a reduction of the requirements for up to 2-3 times the requirements of the elastic displacement;

b) travel requirements particularly high lead, among other things, to the need to ensure a point of the order of at least 40..50 cm between the isolated structure and the environment. They can also generate problems relating to the return of the building to its original position after the termination of seismic action, as well as the design of izolators.

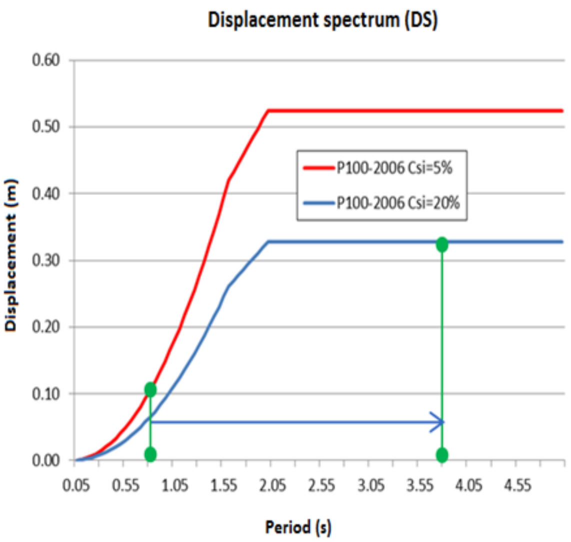


Figure 14. The displacement spectrum (Oprisoreanu, 2012)

CONCLUSIONS

Analyzing the results it can be say the construction irregularities cannot be avoided and they appear from functional reasons in plan, and technological for height. Theoretical problems of irregularities are treated with the study of relative relation between the center of rotation CR and center of gravity CG.At constructions of irregular weight-geometry relation, has an important role and are controlled using the principles of conceptual design code P100-1/2013 or Eurocode 8, Part 1. In the case of base isolation, displacement occurs only at the bottom of the building. Inother words, the building no longer behaves as an elastic body but as rigid because a large part of the energy transmitted to the top of the building is taken amortization systems that provide functionality integrated along with elastic elements acting as bearing for the building. As a result, the effectiveness of seismic isolation devices is lower in the particular case of our country. Also, the use of base isolation devices must necessarily be accompanied by the use of passive amortization devices, semi-active or active to reduce the large movements supported by insulators.

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