

ASPECTS ON SOIL STRUCTURES INTERACTION FOR BUILDINGS WITH DIFFERENT FUNCTIONS

PHD THESSIS

ABSTRACT

PHD ATTENDER: ZAINULABDEEN K ABDULFATTAH
ABDULFATTAH

SUPERVISOR: PROFESSOR EMERITUS RAMIRO SOFRONIE

BUCHAREST JULY 2021

CONTENT:

CONTENT	1
CHAPTER 1 - INTRODUCTION	5
1. PRESENTATION OF THE CURRENT STUDIES OF THE PROBLEM ANALYZED IN ROMANIA AND IN THE WORLD	5
1.1 Theoretical principles of the traditional design of reinforced concrete buildings	8
1.2 Theoretical aspects of design with the help of base insulation	9
1.2.1 <i>The concept of base insulation</i>	9
1.2.2 <i>Types of isolators</i>	12
2. ISOLATED BUILDINGS AND CONSTRUCTIONS AT THE BASE IN THE WORLD	22
2.1. The tomb of Cyrus the Great, Pasargadae	22
2.2. Pasadena Elementary School, California	23
2.3. San Francisco City Hall, California	24
2.4. Basarab Passage, Bucharest	26
2.5. Bucharest city Hall	27
2.6. Arcul de triumf Bucuresti	33
2.7. Victor Slavescu Building	35
2.7.1. Consolidation solution by base insulation method	36
2.7.2. Carrier frame calculation and base insulation technology	38
CHAPTER 2 THE MAIN OBJECTIVES OF THE PHD THESIS	40
CHAPTER 3 SEISMIC INSULATION OF THE BASE FOR BUILDINGS WITH MASONRY STRUCTURES	41
1. INTRODUCTION	41
1.1. Purpose	41
1.2. Concept	41
2. STUDY CASES	42
2.1. Structural solution	42
2.2. Loads taken into account:	43
2.3. Axis diagram	45
3. PRESENTATION OF TECHNICAL SOLUTIONS	46
3.1. According to the current design P100-1/2013	46
3.2. According to the current design P100-1/2013 in isolated solution at the base	55
3.3. Alternative base insulation solutions	64
3.4. Alternative solutions for base isolation, response spectrum method	66
4. COMPARATIVE RESULTS	69
4.1. Proper periods of vibrations	69
4.2. Lateral level displacements	70
4.3. Seismic force	70
4.4. Effects on uprights, steel consumption	71
4.5. Effects on foundations, steel consumption	72
5. REMARKS	73
5.1 Profitability	73
5.2. Aspects related to the interface with other specialties	75
5.2.1. <i>Architecture</i>	75
5.2.2. <i>Installations</i>	76
5.3.Final remarks	76

CHAPTER 4: SEISMIC INSULATION OF THE BASE FOR BUILDINGS WITH A STRUCTURE WITH REINFORCED CONCRETE FRAMES	77
1. TRADITIONAL DESIGN OF REINFORCED CONCRETE BUILDINGS IN FRAMES	77
1.1 Choice of structures for analysis	77
1.2 Detailed theme data	77
1.2.1 <i>Functions of buildings</i>	77
1.2.2 <i>General composition data of the buildings</i>	77
1.2.3 <i>Characterization of the site and construction according to P100-1 / 2013</i>	77
1.2.4 <i>Calculation of the foundation land</i>	78
1.2.5 <i>Design values of material strengths</i>	78
1.2.6 <i>Building dimensions</i>	78
1.3 Evaluation of loads and pre-sizing of structural elements	79
1.3.1 <i>Evaluation of gravitational loads</i>	79
1.3.2 <i>Pre-dimensioning of structural elements</i>	80
1.4 Calculation of structures for horizontal and vertical actions	82
1.5. Calculation and reinforcement of beams	85
1.6. Calculation and reinforcement of columns	90
1.7. Modeling the soil-structure interaction	94
2. COMPARATIVE STUDY OF REINFORCED CONCRETE BUILDINGS USING BASE INSULATION	97
2.1 Propose the types of isolators used in the case study	97
2.2 Sizing of isolators	99
2.2.1 <i>Mathematical modeling of HDRB isolators</i>	99
2.2.2 <i>Mathematical modeling of LRB isolators</i>	101
2.3 Results obtained from the case study of reinforced concrete buildings in frames, using the base insulation method	110
2.3.1 <i>Isolated buildings periods</i>	110
2.3.2 <i>Displacements obtained at the structures isolated at the base</i>	117
2.4 The efforts resulting in traditional design vs. design by base insulation method	128
2.4.1 <i>Maximum stresses in the columns</i>	128
2.4.2 <i>Maximum stresses in beams</i>	130
2.4.3 <i>Maximum stresses in isolators</i>	132
3. CONCLUSIONS	133
CHAPTER 5: SEISMIC INSULATION OF THE BASE FOR BUILDINGS WITH REINFORCED CONCRETE DUAL STRUCTURES	135
1. STUDY CASES	135
1.1 Choice of structures for analysis	135
1.2 Traditional design of structures	138
1.2.1 <i>Evaluation of loads</i>	138
1.2.2 <i>Evaluation of the basic shear force</i>	138
1.2.3 <i>Pre-dimensioning of structural elements</i>	139
1.2.4 <i>Lateral force design of the structure</i>	141
1.2.5 <i>Calculation of structural elements</i>	142
1.3. Design of seismically insulated buildings	152
1.3.1. <i>Pre-dimensioning and choosing the type of insulator</i>	152
1.3.2 <i>Modeling of isolators</i>	153
2. PRESENTATION OF THE CONTENT OF THE ANALYSIS PERFORMED AND THE RESULTS OBTAINED	154
2.1 Results obtained in non-insulated buildings	154

2.2 Results obtained for isolated buildings	166
3 CONCLUSIONS	202
CHAPTER 6 CONCLUSION	204
6.1 Personal contributions:	204
6.2 Main directions of study for the future	211
REFERENCES	212

CHAPTER 1 - INTRODUCTION

1. PRESENTATION OF THE CURRENT STUDIES OF THE PROBLEM ANALYZED IN ROMANIA AND IN THE WORLD

Over time, various methods of design and execution of buildings located in seismic areas have been tried. All methods have as development principle the observance of the equation $CAPACITY > DEMAND$ and have as purpose: avoiding collapse, avoiding as much as possible the degradations in the structural elements and last but not least avoiding the loss of human lives. [2]

The $CAPACITY > DEMAND$ equation led to two different approaches [5]:

1. The traditional approach: starting from the premise that it is not possible to intervene regarding the requirement. This approach strictly addresses the issue of capacity.
2. The “alternative” approach: a reduction of the demand is desired by introducing some mechanical devices:
 - Seismic isolation of the base;
 - Introduction of energy dissipation devices, in order to reduce the seismic response and therefore mitigation of damage.

1.1 Theoretical principles of the traditional design of reinforced concrete buildings

Traditional design is mainly based on increasing capacity in proportion to demand and increasing ductility. The structures are designed according to the principle "Strong pillars weak beams" so as to develop an optimal plasticization mechanism. An acceptable level of performance of the building, during a seismic movement, consists in the intrinsic ability of the resistance structure to absorb and dissipate energy in a stable way and for as many cycles as possible. The dissipation of energy takes place, for example, in the specially made areas of the beams where plastic joints appear and at the bases of the pillars, elements with an important role, however, also in the system for taking over the gravitational loads. Plastic joints are areas of concentration of degradation that usually cannot be repaired.

In essence, the classic anti-seismic design of structures is based on the concept of increasing its rigidity and resilience against earthquakes by using: structural walls, braces, linings, but these traditional methods lead to accelerations and large vertical displacements of buildings. Because of this, the components adjacent to the structure can suffer major damage even if it is not too much affected as a whole, this is not allowed if the adjacent components are more expensive than the structure itself. Constructions that house high-precision and fine equipment, such as hospitals, police and fire departments, communication centers, power plants (hydro, thermal and nuclear) must remain operational even after an earthquake.

1.2 Theoretical aspects of design with the help of base isolation

1.2.1 The concept of base isolation

Over time, a number of technologies and methods of designing structures have been developed to mitigate the effects of earthquakes on buildings. Worldwide, more and more buildings are designed to withstand seismic movement, with the help of the concept of base isolation, which involves decoupling the ground structure, by installing a special system mounted under the structure, called "base isolation system".

1.2.2 Types of isolators

Seismic isolation devices are classified into two broad categories:

- Isolators (possesses lateral flexibility to achieve isolation at lateral movements and high rigidity in the vertical direction for the transfer of gravitational loads):
 - Natural rubber isolators (NRB)
 - Natural rubber lead core isolators (LRB)
 - Synthetic rubber isolators with damping properties (HDBR)
 - Devices that allow slipping (SB)
- Shock absorbers/dampers (energy dissipators in order to reduce the relative displacement of the isolation layer and to stop the movement)
 - Hydraulic shock absorbers - viscous shock absorbers
 - Lead shock absorbers - hysteretic shock absorbers
 - Steel shock absorbers - hysteretic shock absorbers

A. NATURAL RUBBER BEARRING - elastomeric isolators made of natural rubber

Mechanical properties:

- These isolators consist of several layers of natural rubber with thicknesses between 3 and 9 mm, interspersed with steel plates with thicknesses between 2.5 and 4.5 mm.
- The diameter of an isolator is between 500-1550 mm.
- The main parameter that controls the vertical rigidity is the shape coefficient $S1 = D/4tR$, where D is the diameter of the isolator and tr the thickness of the rubber layer; the usual values of S1 are between 30 - 40.
- The ratio between the diameter of an isolator and the number of isolation layers, representing the shape coefficient $S2 = D/ntR$ is approximately equal to 5.
- The transverse modulus of elasticity can be chosen between 0.4, 0.7 or 1.1 N / mm².
- The long-term unit compression force varies between 10 and 15 N / mm², and the short-term compression effort varies between 20 and 30 N / mm².
- The design shear deformation is about 250-300% (450 -550 mm for 800 mm diam.), And the ultimate shear deformation, corresponding to the loss of overall stability, is usually equal to 400% (550-800 mm).
- Vertical and lateral stiffness ratio 2500-3000
- Consolidation of lateral stiffness after deformations > 300% (6-8 times)

A disadvantage of these types of isolators would be the lack of damping properties, and in order to obtain additional damping it is necessary to couple them with other damping devices.

B. HIGH DAMPING RUBBER BEARINGS - synthetic rubber elastomeric isolators with high damping properties

Mechanical properties:

- This type of isolator is similar in composition to natural rubber devices. The difference lies in the type of rubber used which has superior damping properties.
 - Damping properties of up to 20% of critical damping.
 - The values of the coefficients of form $S1 = D/4tR$ are generally lower than the NRB (between 25 - 35) to obtain a higher proportion of synthetic rubber so as to achieve the required damping.
 - the coefficients $S2 = D/nt$ have values between 3 ~ 10.

- The maximum recommended unit compression force is 10 N / mm^2 for long loads and the one for short loads varies between 15 and 20 N / mm^2 , lower compared to the corresponding NRBs.
- Lateral stiffness depends mainly on the maximum transverse deformation, temperature and compressive stress.
- The equivalent depreciation is around 20% for transverse deformation values of up to 100%.
- High efficiency in reducing seismic momentum and degradation.
- High lateral deformation capacity in conditions of high vertical loads.
- High viscous damping.
- Ability to return to the starting position.
- Low lateral rigidity allowing to greatly increase the fundamental period.

Disadvantages:

- Stability problems when the horizontal displacement becomes very large.
- Problems due to aging elastomeric material.
- Low lateral stiffness transposed in practice by travel and for small loads.

C. LEAD RUBBER BEARINGS - rubber core isolation devices

Mechanical properties:

- The device is an NRB type rubber isolator in which a lead core is inserted which has the role of hysterically dissipating the induced energy.
- LRB ensures lateral flexibility (due to the elastic properties of the rubber) as well as hysteretic cushioning (due to the plastic deformations of the lead).
- The limits for the maximum unit compression force as well as the values of vertical stiffness are similar to those corresponding to NRB.
- The commonly used analytical calculation model is a modified bilinear model with the dependency coefficients provided by the manufacturers in the product catalog.
- The maximum and final design deformations are 400 - 500 mm and 600 - 700 mm respectively.
- The lateral force corresponding to the flow is 100 KN (100 mm lead core diameter)

Benefits:

- initial high lateral stiffness (10 - 16 times higher than the post-flow lateral stiffness) associated with relatively low horizontal forces, generally produced by the wind.
- rigid-plastic behavior of the lead core at low loads
- very stable hysteretic behavior
- high damping capacity ($\xi = 30\%$)
- Lead has high resistance to cyclic fatigue

Disadvantages:

- stability problems when the horizontal displacement becomes very large
- problems due to aging elastomeric material
- due to the post-elastic deformations suffered by the lead core, the rubber loses the ability to return to the starting position

The lateral deformation capacity under low loads is limited, this isolator model being highly recommended to limit wind deformations to tall and light buildings, where a minimum lateral resistance must be opposed with zero deformations while ensuring a very high deformation and dissipation capacity. in the case of an important seismic event.

D. FRICTION PENDULUM BEARINGS - inverted pendulum friction isolators

Frictional seismic isolators are probably among the first devices proposed for decoupling the infrastructure superstructure. FPB systems consist of blocks of PTFE (polytetrafluoroethylene) that slide on stainless steel plates. The main feature of FPB is the high initial lateral stiffness, which decreases significantly after the slip is initiated.

The friction pendulum system is based on the friction between two sliding surfaces to dissipate seismic energy. The sliding action it is also combined with a return force generated by geometry. This system consists of a sliding joint over which is placed a concave stainless-steel surface. The face of the sliding joint that is in contact with the spherical surface is lined with a composite material with a low coefficient of friction. The supports are closed and sealed with a sliding surface placed face down to avoid contamination. The bearing acts as a fuse, activated only when the shear force on the sliding surface is greater than the static friction force. In motion the joint slides on the spherical surface, resulting in a lifting of the mass, similar to a pendulum (Figures 23 to 24).

Mechanical properties:

- Very high initial rigidity
- Negligible stiffness after initiation of movement (used in conjunction with NRB, HDRB, LRB)
- Mainly adopted to reduce the stiffness at high displacements of isolated buildings.
- The coefficient of friction generally depends on the vertical pressure and the speed of movement.

Benefits:

- stable hysteretic curve
- high ability to return to the starting position
- high rigidity at low loads (wind)
- reduction of displacements in the last stage due to friction

Disadvantages:

- high cost of production
- problems in defining the coefficient of friction due to corrosion sensitivity
- high sensitivity to high vertical loads (oval surface may deform)
- degradation of sliding surfaces after several loading cycles

2. ISOLATED BUILDINGS AND CONSTRUCTIONS AT THE BASE IN THE WORLD

2.1. The tomb of Cyrus the Great, Pasargadae

Considered to be the first isolated building at the base in the world, the Tomb of Cyrus the Great, located in the archaeological site Pasargadae (included in the list of UNESCO monuments) has at the foundation the isolation system consisting of two rows of well-polished stones, sliding a seismic event. Cyrus the Great (590 I.E.N - 530 I.E.N) was a Persian emperor (or Shahenshah) who founded the Persian Empire during the Achaemenid dynasty.

2.2. Pasadena Elementary School, California

Pasadena City Hall was strengthened using 240 friction pendulum isolators, in addition to conventional reinforced concrete walls to stiffen the east wing of the building. The solution came from engineers from Forell / Elsesser Engineers Inc. which proposed in addition to isolating the base and new structural walls and connecting the two bodies of the building to obtain a closed-contoured building, much less susceptible to adverse effects during a seismic event.

2.3. San Francisco City Hall, California

San Francisco, California City Hall was consolidated in 1999 after suffering major damage following the 1989 Loma Prieta earthquake (the main dome had rotated 102 mm at the base). The team of engineers who developed the project was also Forell / Elsesser Engineers Inc. When it was reopened to the public in 1999, it was the largest isolated structure in the world.

2.4. Basarab Passage, Bucharest

Basarab Passage, the longest hob bridge in Romania, measuring 360 m, the widest hob bridge in Europe (43.3 m) and the longest road passage in Bucharest (1.9 km) has in its base isolation systems produced by the company ALGA, rubber isolators with lead core.

2.5. Bucharest city Hall

The building where the General City Hall of Bucharest operates was built between 1906 and 1911 on the land in front of the Cismigiu Garden, being designed by the architect Petre Antonescu. The project of the resistance structure was drawn up by Eng. Elie Radu and Eng. Gogu Constantinescu.

The consolidation solution through the "base isolation method" has a number of important advantages over the classic consolidation option, including:

- the institution does not interrupt its activity with the public, because the works are carried out from the elevation of the land down, in the basement of the building;
- preserving the initial architectural configuration, regarding the plasticity of the facades and its volumetry (without changing the dimensions of the structural elements, implicitly of the construction as a whole), the building being declared a historical and architectural monument;
- the execution duration of the consolidation works is much reduced, because the constructor can carry out his activity in the basement of the building without having difficulties from the beneficiary with the release of the work front.

The behavior of the brick masonry in the seismically required structures presents a high degree of complexity, compared to the case of ordinary, static actions. Repeated actions, medium and high intensity, applied at high speeds, specific to seismic movements, due to the short time in which the loading effect is exerted, do not allow the degradation of the internal structure to reach the same parameters as static loads of equivalent intensities.

2.7. Victor Slavescu Building

The studied building is made of brick masonry with a roof type roof and sheet metal roofing. The floor above the basement is made in a solution of brick vaults on metal profiles, a system often found at the end of the 19th century and the beginning of the 20th century for the spaces with utilitarian destination in the basements or semi-basements.

The exteriors are finished with simple plasters, to which are added plaster and plaster decorations.

2.7.1. Consolidation solution by base isolation method

The consolidation solution was determined by two factors:

- The building is a historical and architectural monument;
- It is desired to ensure the functionality of the building during the consolidation works.

2.7.2. Carrier frame calculation and base isolation technology

For existing constructions, the separation of the superstructure of the land connection construction must meet several conditions:

- the practical non-deformability of the construction superstructure, or more precisely the preservation of the deformability within acceptable limits;
- maintaining the horizontal section at the base of the construction, in all work phases, in a horizontal plane.

CHAPTER 2 THE MAIN OBJECTIVES OF THE PHD THESIS

Considering the entire documentation reviewed on the subject of this PhD thesis, described in the previous chapter, it appears that the base seismic isolation devices have been and are used in Romania and worldwide for buildings with various height levels, especially for the rehabilitation of existing buildings, from heritage or historical monuments, to which the classical retrofitting methods would bring a complete change both of the structural system itself and of the architectural-functional conformation. Also, these devices can be used for new buildings, in order to reduce the consumption of materials in the structures.

For all the case studies conceived and carried out, it started from the simple premise that any company has at least one calculation program for design (and this was considered in most cases to be ETABS or similar) and that, due to acquisition costs, no one allows the purchase of specialized programs only on the seismic isolation of the base. For this reason, the use of ETABS was chosen, because it is also the first finite element computing program used in the world, but also the only one that, for this reason, has been continuously improved to meet all user requirements. Also, the use of basic isolators produced in other regions like Japan and specialized Japanese programs were not considered feasible, Japan being a "pioneer" country in many aspects but the distance Romania-Japan being very large but also from the simple fact that European products in the European Community has priority and are cheaper.

Precisely for this reason, one of the chapters refers specifically to the seismic insulation of the base of buildings with masonry structures, as a starting point for further studies that construction engineers, experts and verifiers in the field may consider for the optimal safety solution and seismic risk reduction. More than 100 studies were carried out to obtain some clear responses.

The field is very vast and a multitude of case studies can be carried out to provide structural answers regarding the use of this modern design method, but for this thesis the following main objectives are established:

- The behavior of low-rise buildings with structure made of confined masonry, with and without the use of seismic insulation devices of the base (in the idea that this method can be applied to any of the existing types of masonry structures);
- The behavior of small, medium and high-rise buildings with reinforced concrete (RC) frames structure, with and without the use of seismic insulation devices of the base;
- The behavior of small, medium and high-rise buildings with reinforced concrete structural frames and walls (dual structures), with and without the use of seismic insulation devices of the base.

These objectives will be presented in the following chapters (3, 4 and 5), and in the sixth chapter will be presented the conclusions emerged from the over 50 case studies elaborated and analyzed in the thesis.

It is desired to highlight the contribution of the use of these devices in offering the safety and overall stability of the buildings with the resistance structure made of masonry and / or reinforced concrete.

The last chapter (6) will also present proposals for further future studies on seismic isolation of the base.

CHAPTER 3 SEISMIC ISOLATION OF THE BASE FOR BUILDINGS WITH MASONRY STRUCTURES

1. INTRODUCTION

1.1. Purpose

The purpose of this application is to see whether or not it is cost-effective to isolate the base of ordinary houses, made of load-bearing masonry. Certainly, the isolation of the base is suitable for structures of high importance, as well as historical monuments, but the common man does not live in a structure of high importance. Is the solution cost-effective for the average person?

To test this hypothesis, we proposed a low structure (GF+1L) of confined masonry, located in a seismic area (Bucharest, $a_g = 0.30g$, $T_c = 1.6$ sec) urban. The example is a multifamily duplex home.

1.2. Concept

The proposed structure being low, its own vibration period is small enough to be located in the area of maximum dynamic amplification in the response spectrum. For the simplified analysis we analyzed starting from the hypothesis of a seismic force represented by the equivalent lateral force, according to the provisions of P100-1/2013. The basic concept of base isolation, respectively the decoupling of the structure from the foundation ground, also implies the increase of the own period sufficiently so that the structure is no longer in the area of maximum dynamic amplification of the response spectrum.

The seismic force will be considered in the post-elastic stage for the normally designed structure, with a behavior factor $q = 3.125$ (according to P100-1 / 2013 Table 8.4.), And respectively in the elastic domain with a behavior factor $q = 1.5$ (according to P100 -1/2013 11.10 (5)) and with the value of the coefficient η diminished depending on the type of isolators.

The structure will be dimensioned and verified so as to fully comply with the norm P100-1 / 2013.

2. STUDY CASES

2.1. Structural solution

The structure is a duplex multifamily house, GF + 1 height regime (2 levels) in masonry type solution confined with reinforced concrete columns and belts. The material used in the masonry structural walls is of the Porotherm 30 Sth type, 30 cm thick (manufacturer's and material's website: <http://www.wienerberger.ro/porotherm-30-sth.html>) with M10 type mortar and type plaster. Ceresit CT 63 3 mm thick on both sides. The concrete used is type C20 / 25 and the reinforcements taken into account are type S355 with periodically hot profiled profile (PC52).

The level height is 3 meters both on the ground floor and upstairs.

2.2. Loads taken into account:

According to SR-EN 1991-1-1/2004, the construction is classified in category A, Residential Building, Rooms in houses, villas or blocks of flats, bedrooms and hospital rooms, rooms and corridors, kitchens and toilets. The payload is thus $q = 2 \text{ kN/m}^2$.

2.3. Axis diagram

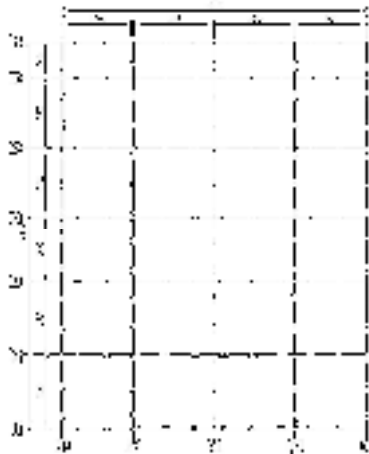


Figure 1- Scheme axis in plan

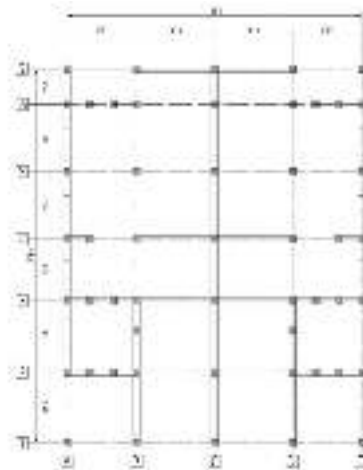


Figure 2 - Location of reinforced concrete columns and masonry piers

The positioning of the structural walls made of confined masonry as well as the position of the reinforced concrete columns (placed according to CR 6/2013) are highlighted in the drawing below:

3. PRESENTATION OF TECHNICAL SOLUTIONS

3.1. According to the current design P100-1/2013

The structure was modeled using the ETABS program.

The considered columns have a section of 30x30 cm, being reinforced minimally constructively according to the norms in force at the percentage of 1% considering 8 bars Φ 12 mm diameter. RC belts and beams are rectangular sections 30x40 cm.

If the amount is strongly demanded at the shear force, we also proposed a possible reinforcement in the masonry joints, necessary if the $1.25 V_{ed}/V_{rd}$ ratio is super unitary.

The pre-sizing of the foundations was based on an approximate calculation, proposing a system of continuous foundations consisting of a two-stage reinforced concrete block. The foundation depth was considered to be about -1.20 m, thus avoiding the frost depth. The plate on the ground floor is considered to be 0.00.

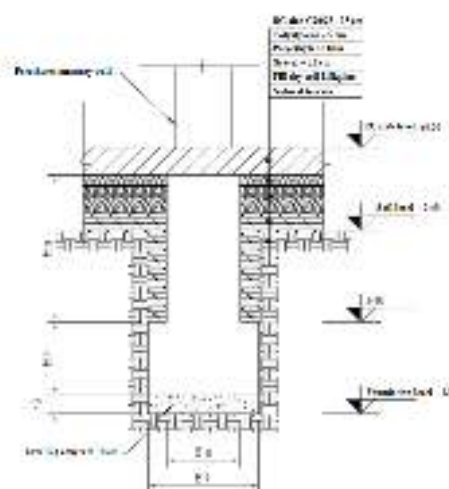


Figure 4 - Interior wall foundation

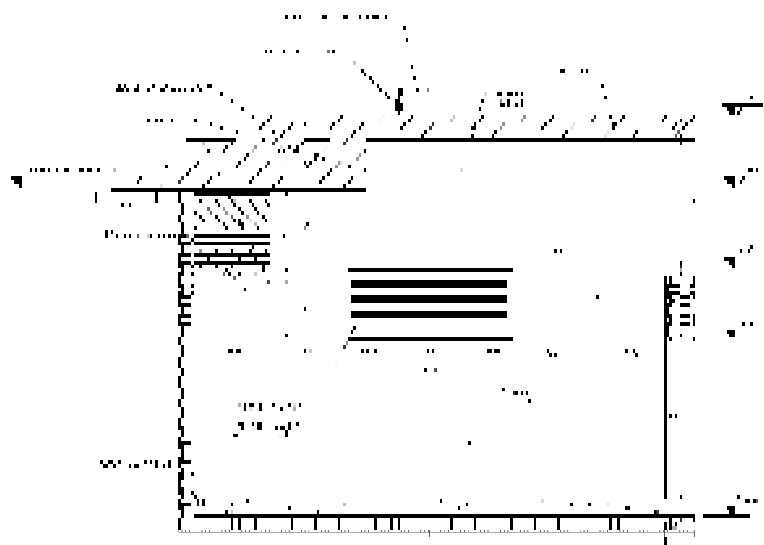


Figure 9 – Seismic isolator foundation detail

Thus, we were able to model the structure together with the beams and the foundation soles, attaching to each node in the system an elastic spring, modeling according to the bed coefficient and the afferent area according to the table attached above. The continuous foundations under the walls were reinforced according to the effective efforts in them, considering an elastic behavior of the whole. To model the elastic behavior the seismic coefficient was amplified by 2.5.

The isolators were placed below the level of the foundation beams, modified so that they are in the form of rectangular beams of 40x80 cm. The isolators are of the HDS 1000x220 type. Under the isolators itself the foundation was made so that under each isolator is an isolated foundation. Due to the manufacturer's recommendation not to make completely isolated foundations, they were stiffened by a system of reinforced concrete beams arranged as in the figure below (figure 9).

3.2. According to the current design P100-1/2013 in isolated solution at the base

The structure was modeled using the ETABS Nonlinear program v9.7.1. considering the seismic force in the elastic field, but keeping in mind the damping due to the damping elements. The isolators used are of the HDRB (High Damping Rubber Bearing) type with the properties of those from the technical data sheet from the ALGA manufacturer (www.alga.it). The location of the isolators was designed to be on the main directions.

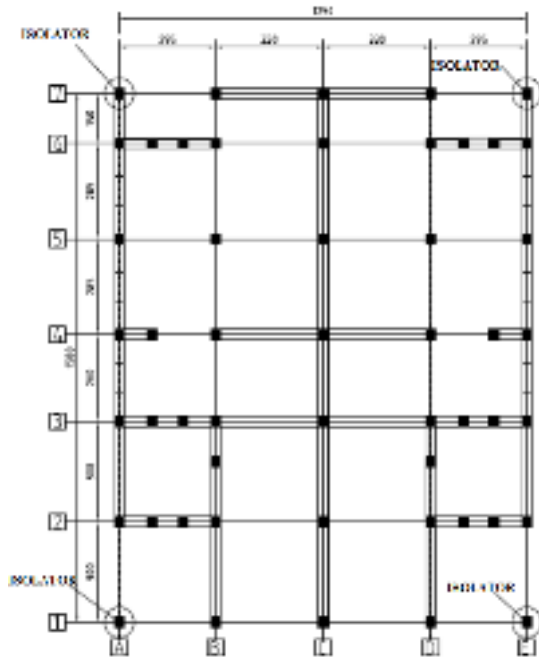


Figure 8 - Positioning the isolators under the structure

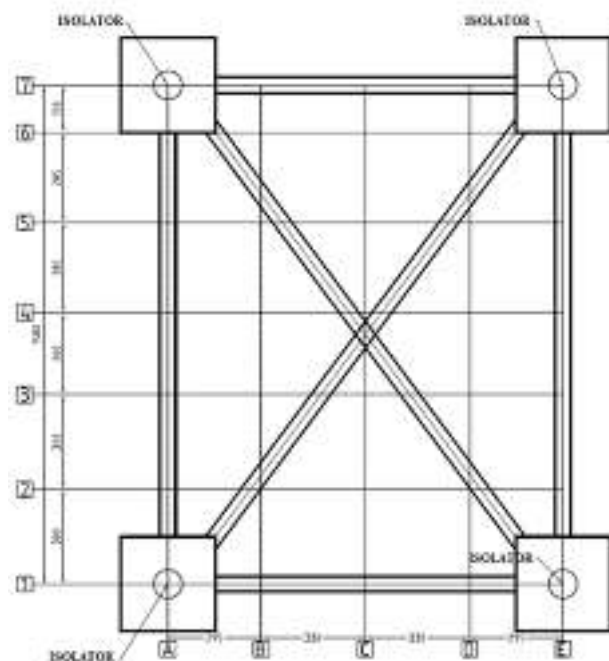


Figure 9 - The foundation system of seismic isolators

The isolators were placed below the level of the foundation beams, modified so that they are in the form of rectangular beams of 40x80 cm. The isolators are of the HDS 1000x220 type.

The columns were reinforced more strongly to increase the load-bearing capacity of the uprights as can be seen in the table. The increased efforts of the marginal uprights in particular show the rigid solid behavior of the house.

The reinforcements for the foundations under the isolators were calculated as isolated foundations, required at the maximum axial forces in the isolators, and their stiffeners, the beam system was

calculated in the completely unfavorable hypothesis in which two of the isolators stand in place while the others are loaded. with the maximum shear force at the base of the structure.

It is also observed that the mass participation factor on x and y has increased significantly, being approximately 100% of translation in both directions. Thus, it is observed how the torsional tendency of the structure due to the different rigidities on the two directions is canceled by the isolation at the base, which forces the structure to behave like a rigid solid that can only take over translation. The fundamental mode 1 of vibration in isolated solution is observed to have a much longer period and amplitude of displacements than the uninsulated version of the house. The strictly translational behavior of the displacements is also observed.

3.3. Alternative base isolation solutions

For a more general study we tried different other models of seismic isolators. Thus, we tried to replace the HDRB type shock absorbers with lead core isolators, as well as friction pendulum type isolators.

It is found that the lowest seismic coefficient is obtained in lead core isolators, due to the lower dynamic amplification factor than in the case of other types of isolators. This is also observed by the fact that the fundamental period of the system is longer in this case, going lower on the spectral acceleration curve.

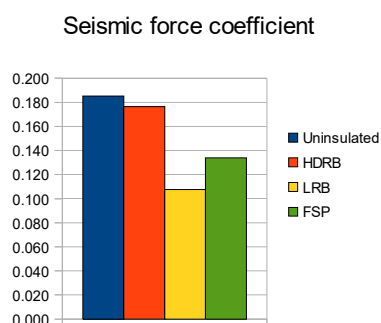


Figure 12 – Seismic force coefficient

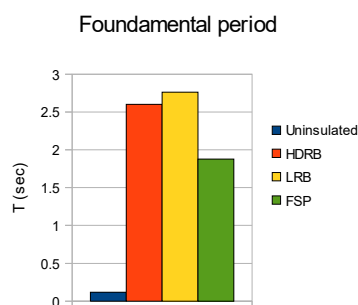


Figure 13 – Fundamental period

In order to obtain an effect on the structure, we only extracted the efforts from the YC column, the one that separates the living spaces.

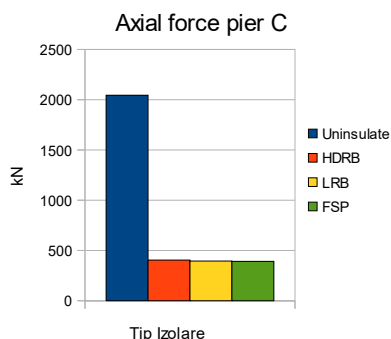


Figure 14 – Axial force for pier C

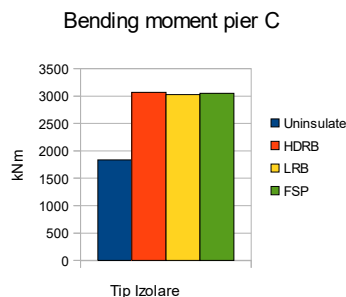


Figure 15 – Bending moment for pier C

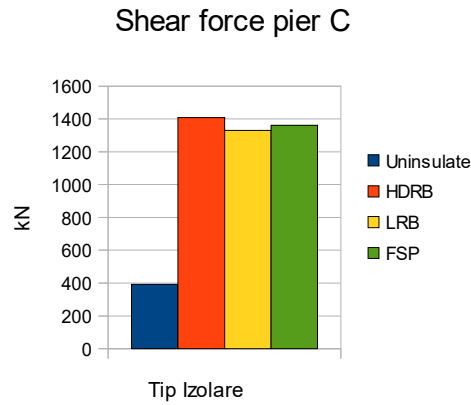


Figure 16 – Shear force for pier C

3.4. Alternative solutions for base isolation, response spectrum method

Since the lateral force method can only be applied under some aspects of regularity in plane and elevation, as well as with restrictions on the importance class, we made tests using the response spectrum method.

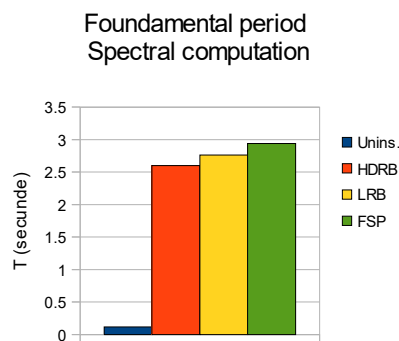


Figure 18 – Fundamental period spectral computation

We can thus compare the modeling efforts with the lateral force equivalent to those obtained from the response spectrum method and we obtain the following variation graphs:

Figure 19 - Axial forces

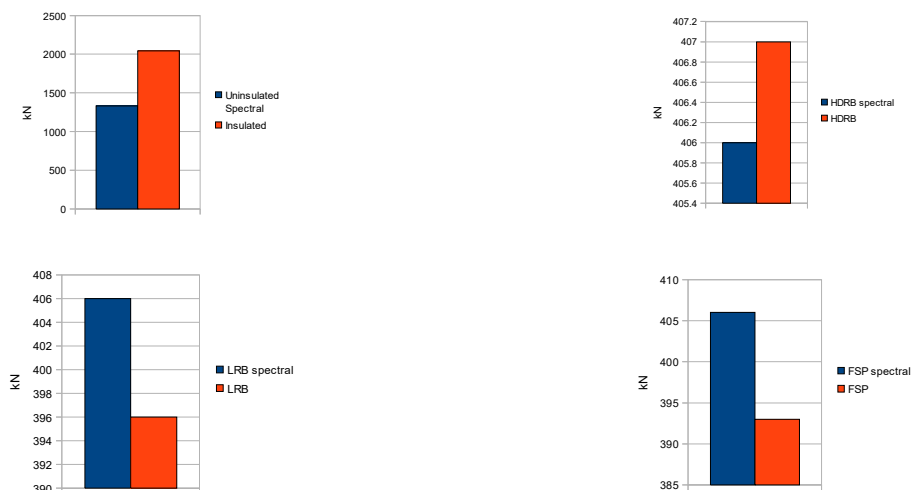


Figure 20 - Bending moments

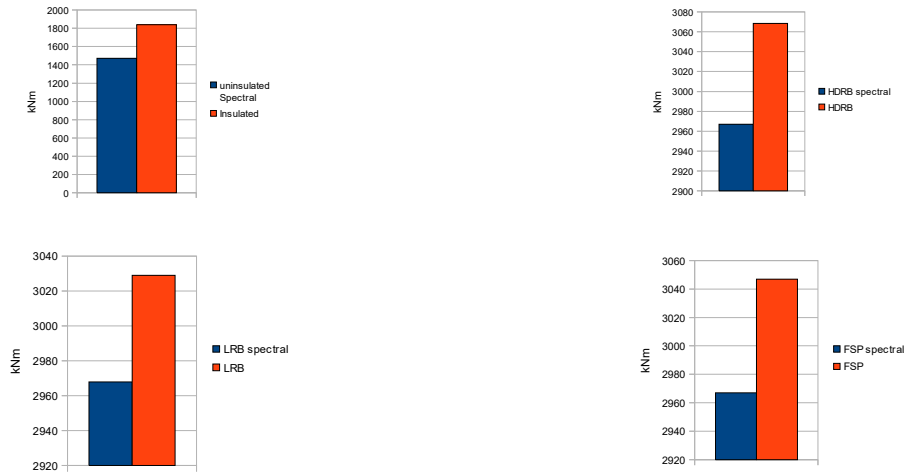
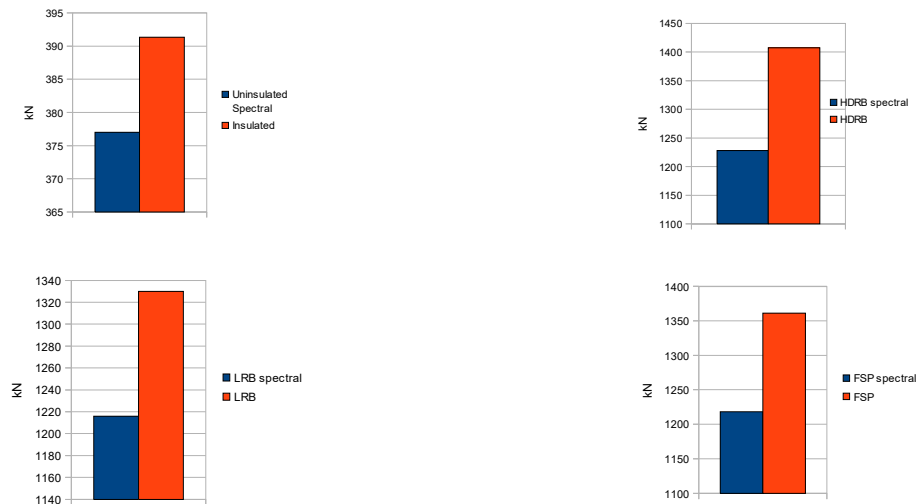


Figure 21 - Shear forces



It can be seen that the axial effort differs very little (practically a few decimals), while the bending moment and the shear force decrease significantly in the method of spectral calculation compared to the method of statically equivalent lateral force.

4. COMPARATIVE RESULTS

4.1. Proper periods of vibrations

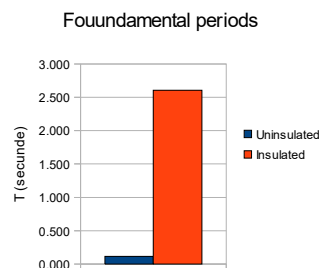


Figure 22 – Fundamental periods

The fundamental proper period from the isolated variant is recommended to be as long as possible in order not to be in the area of dynamic amplification of the response spectrum. Although the

period is quite far from the control period (corner, $T_c = 1.6$ seconds) it is not far enough to greatly reduce the seismic effects.

4.2. Lateral level displacements

The values of the relative lateral side displacements increase significantly, but they do not approach the limits imposed by P100-1 / 2013, respectively 0.5% relative displacement in the Service Limit State, and 2.5% in the Ultimate Limit State.

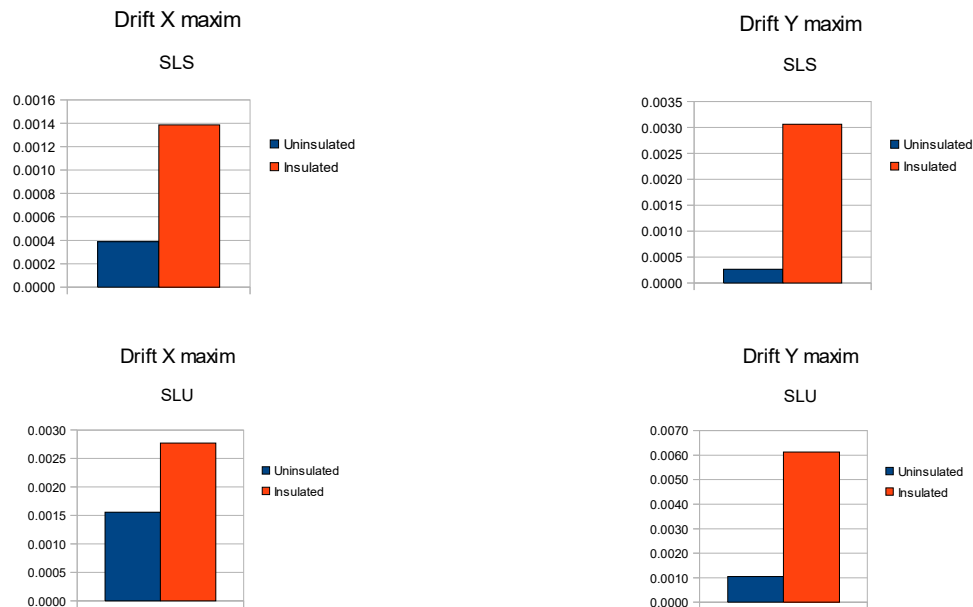


Figure 23 – Maxim drifts

4.3. Seismic force

The seismic force in the equivalent lateral force method will depend on the period of the structure, as well as on the dynamic damping factor. Below is attached both tabularly and graphically the difference between the two hypotheses, adding in addition the lateral force equivalent to an elastic seismic calculation without isolators or additional damping.

4.4. Effects on uplifts, steel consumption

There is a significant increase in stress (bending moments and shear forces), as well as a strong increase in axial stress in the peripheral amounts (in the area of seismic isolators) while in other areas the axial stress decreases significantly, in some cases becoming almost negligible.

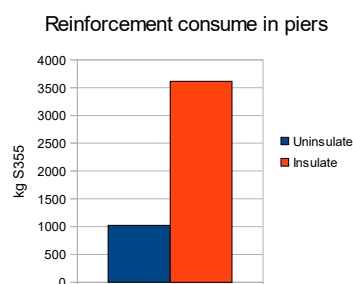


Figure 24 – Reinforcement consumes in piers

4.5. Effects on foundations, steel consumption

The foundations are practically "doubled" by the isolation system of the base, because both at and above the isolators, a structure with rigid diaphragm behavior must be created. Considering the openings large enough for the beams over the isolators and the fact that they are practically simply supported on the entire opening, the supports being only the isolators at the end, their efforts are very large, requiring suitable reinforcements.

5. REMARKS

5.1 Profitability

The idea of the application started from the simple question "is it profitable to isolate the base of masonry houses?".

For example, considering some purely statistical calculations, we chose a structure large enough to make the need for this additional investment feasible.

Cost-effectiveness consists of cost, so below are summarized the additional consumption of necessary materials (except labor, transportation, formwork, and any other additional cost.

We considered for simplicity that the same amount of formwork needed to build the superstructure can be used to build infrastructure).

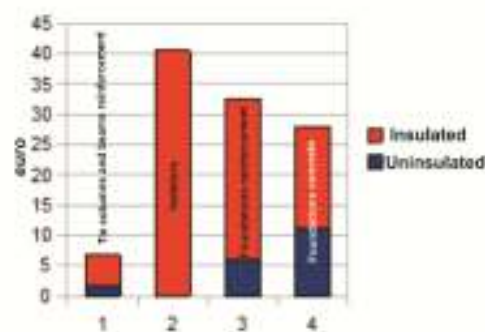


Figure 26 – Resource consumption

The investment of the house was approximately at about 250,000 euros, so that the total cost of isolation of about 28,000 euros represents only 11.20% of the total value.

A developer can build such housing units with values between 400 and over 1000 euro / sqm, so that the percentage of isolators in this cost begins to be considerably easier to bear.

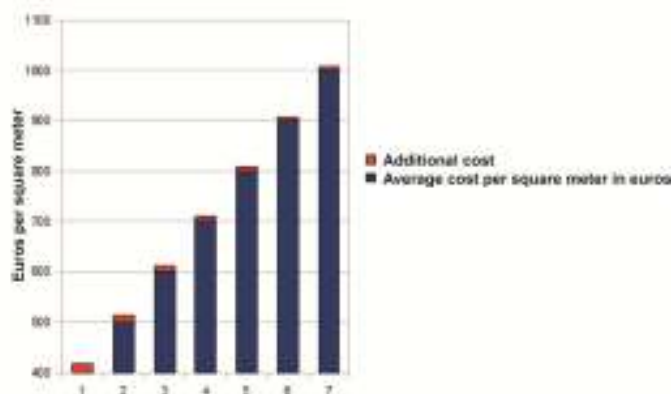


Figure 27 - Additional cost for isolation compared to the average cost

5.2. Aspects related to the interface with other specialties

5.2. Final remarks

The base isolation system is a very efficient system for reducing the seismic impact from all points of view.

Benefits:

- reduces or even eliminates structural damage or their size
- diminishes or even eliminates the damages of the non-structural elements
- diminishes or even eliminates material damage
- reduces the social impact of the earthquake (even if an earthquake exceeds the level of the one designed according to the code valid at that time, the structure will have a behavior clearly superior to a structure dimensioned in the post-elastic field of behavior)
- increases the life of the structure (limiting structural damage eliminates the need for consolidation and thus increases the life without the need for intervention)
- allows uninterrupted operation (if the structure is a registered office of a legal entity for example)

Disadvantages:

- the initial cost of the investment increases
- the execution duration increases due to the additional foundation system
- the average recurrence interval of earthquakes in Romania is relatively long, making potential investors skeptical about the need for such a system
- the life duration of the isolators is limited and in time these must be replaced with all the disadvantages may occur.

CHAPTER 4: SEISMIC ISOLATION OF THE BASE FOR BUILDINGS WITH A STRUCTURE WITH REINFORCED CONCRETE FRAMES

1. Traditional design of reinforced concrete buildings in frames

1.1 Choice of structures for analysis

For the present study we wanted to analyze nine models of RC frame structures, the difference between them being the shape and height rises. The modeling of the structures was performed using the ETABS program as follows:

- 9 analysis models were made for superstructures:
 - square shape building (with 3 height rises: Ug+Gf+14L; Ug+Gf+9L; Ug+Gf+4L);
 - rectangular building (with 3 height rises: Ug+Gf+14L; Ug+Gf+9L; Ug+Gf+4L);
 - round shape building (with 3 height rises: Ug+Gf+14L; Ug+Gf+9L; Ug+Gf+4L);
- 9 analysis models were made with the same types of buildings, taking into account the modeling of the soil-structure interaction
- 18 analysis models were made with the same types of buildings, taking into account the seismic base isolation, with LRB and HDRB type isolators.

1.2 Detailed theme data

1.2.1 Functions of buildings:

- Office function;
- Terrace: non-circulating.

1.2.6 Building dimensions:

each bay has a size of 5 m, each opening has a size of 5 m, the level height for the floor is 3 m, the height of the basement is 3 m, as can be seen in Figures 1, 2 and 3.

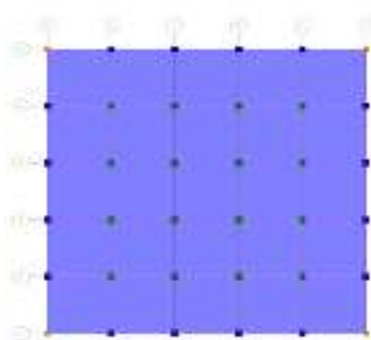


Figure - 1 Square shape

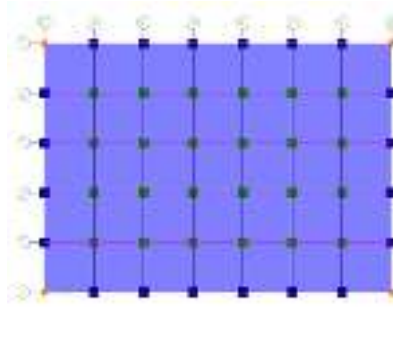


Figure - 2 Rectangular shape

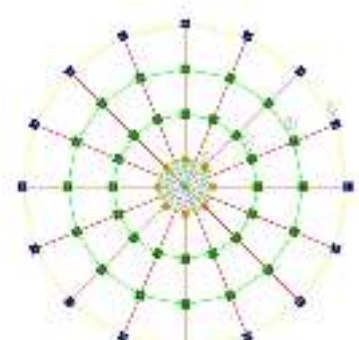


Figure - 3 Circular shape

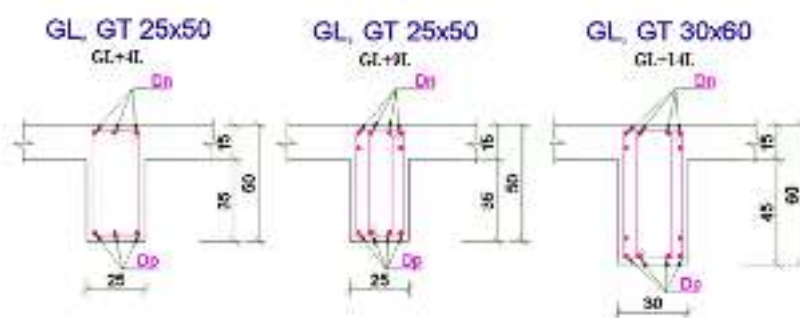


Figure - 4 Arrangement of the transverse and longitudinal reinforcement in the beam sections in the GF + 4L, GF + 9L and GF + 14L structures

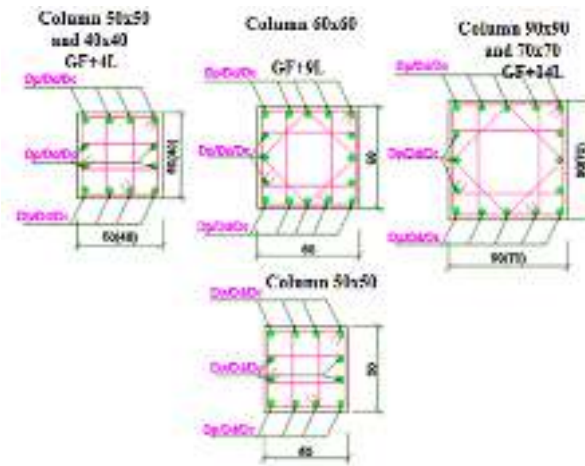


Figure - 5 Arrangement of transverse and longitudinal reinforcement in columns

2. Comparative study of reinforced concrete buildings using base isolation

2.1 Propose the types of isolators used in the case study

Starting from the equation of Professor Kelly TE, 2001, $CAPACITY > REQUIREMENT$, unlike the traditional approach to designing structures in seismic areas, which starts from the hypothesis that the requirement cannot intervene and deals only with the problem of capacity, the principle of base isolation, as an “alternative” approach proposes a reduction of the requirement by introducing mechanical devices (energy dissipation systems).

2.2 Sizing of isolators

2.2.1 Mathematical modeling of HDRB isolators

To perform the linear calculation equivalent to the response spectrum on the isolated structures, the following steps were considered:

1. The response spectrum of the area in question was determined - Bucharest, corresponding to each type of shock absorber using the spectrum from P100-1 / 2013 (the difference between isolated and non-isolated buildings being the behavior factor q , which is 1.5 according to the literature, compared to 6.75 for non-isolated buildings in frames, but also the equivalent viscous damping ξ).
2. A target value of the vibration period was chosen for the isolated structure (normally it is considered to be 3 times higher than the vibration period of the non-isolated structure).
3. The total seismic mass of the structure was determined.
4. Given the parameters T_{iz} , The vibration period of the isolated system and M the mass of the structure, the required overall stiffness, K_r , for the isolation system was determined by the following equation:

$$K_r = 4 \cdot \pi^2 \cdot M / T_{iz}^2$$

5. The isolators from the ALGA catalog were chosen, taking into account the following parameters:
 - total stiffness (the sum of the stiffnesses of each isolator must, as far as possible, be equal to K_r);
 - vertical load for each isolator;
 - horizontal displacement, which was calculated using the following formula:

$$S_{max} = a_g \cdot (T/2 \pi)^2$$

6. The modeling of the isolators was done with the help of the ETABS program, introducing LINKS of ISOLATOR1 and ISOLATOR2 type. The locations were chosen to install the isolators in the structure. 4 isolators were used for the Ug + Gf + 4L buildings square shape, 8 isolators for the Ug + Gf + 4L buildings - rectangular and cylindrical shape, 16 isolators for the Ug + Gf + 9L buildings and 28 isolators for the Ug + Gf + 14L buildings, so that the center of rigidity is as close as possible to the center of mass. In this way, during the earthquake only the vibration translation modes were activated, while the torsion on the first two vibration modes was negligible. Translational vibration modes have the obvious advantage of making all isolators work in the same way.
7. After the isolators have been chosen, the modified response spectrum has been introduced, by entering the damping value corresponding to the isolators, depending on the following factor:

$$\eta = \sqrt{10 / (5 + \xi * 100)}$$

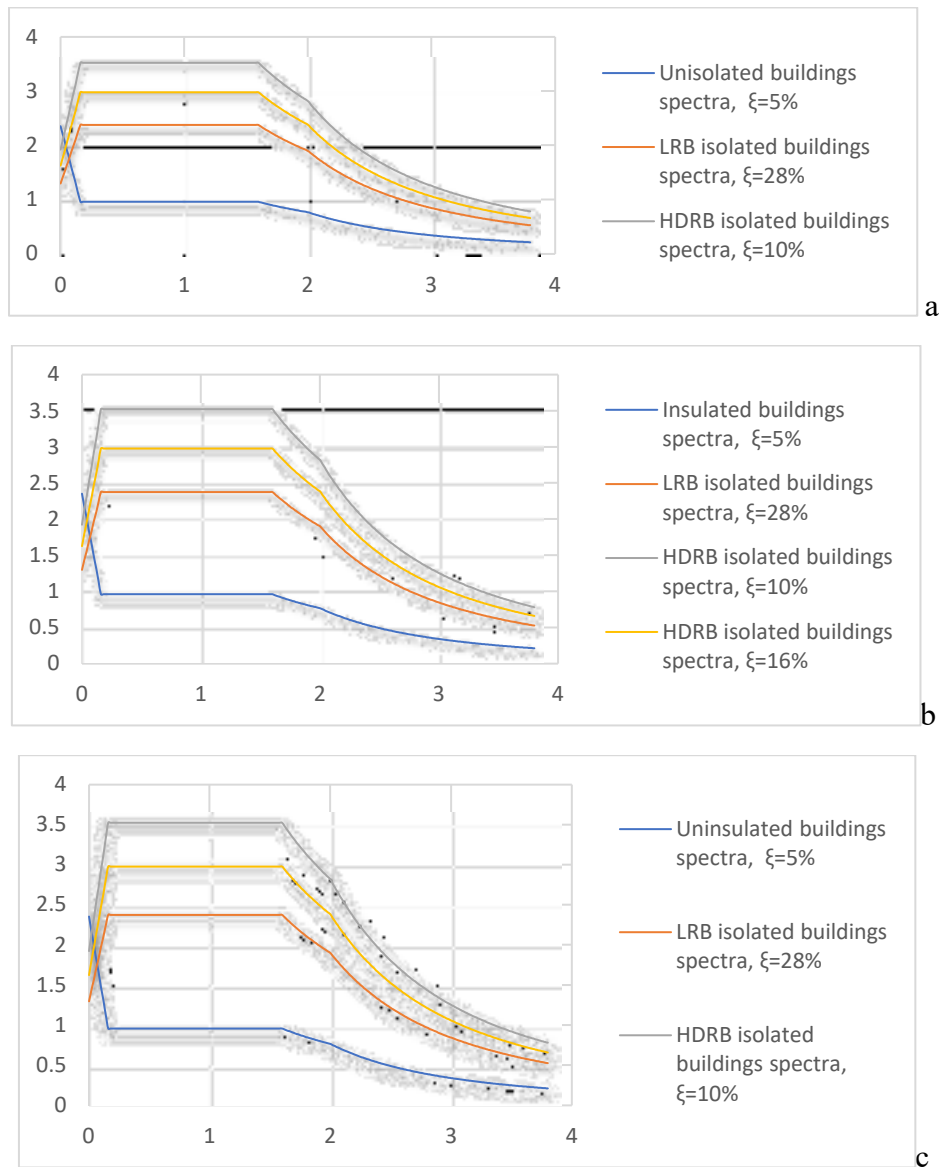


Figure - 11 Graphical representation of the spectral response spectra functions (a-GF+4L; b-GF+9L; c-GF+14L)

2.2.2 Mathematical modeling of LRB isolators

Their behavior can be defined by the following parameters:

- F_y the flow point of the lead core
- K_{lead} horizontal stiffness
- K_r horizontal stiffness

The values for these parameters are presented in the tables with properties of the isolators provided by ALGA. The equivalent linear calculation is performed with the same procedure described above for HDRB type isolators, with the following differences:

- Instead of K_r , consider K_{eff} , the effective horizontal rigidity
- Instead of $\xi - \beta r$ is taken into account, the actual damping.

2.3 Results obtained from the case study of reinforced concrete buildings in frames, using the base isolation method

2.3.1 Isolated buildings periods

Table 20 shows the own vibration periods obtained on the first vibration mode, for GF + 4L buildings. In the first 3 columns are presented the proper periods corresponding to the square buildings, in the next 3 columns, those corresponding to the rectangular buildings, and in the last 3, the proper periods corresponding to the circular buildings.

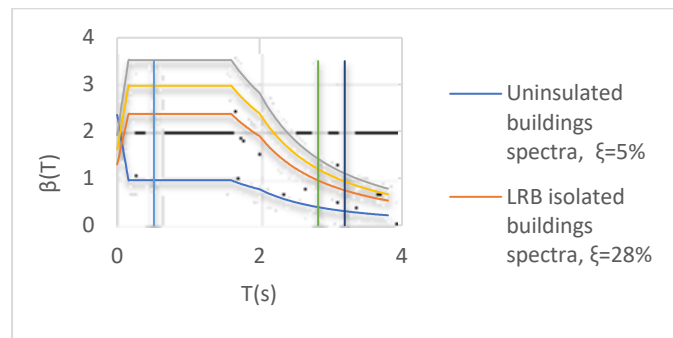


Figure - 13 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 4L buildings, square shape on the response spectrum

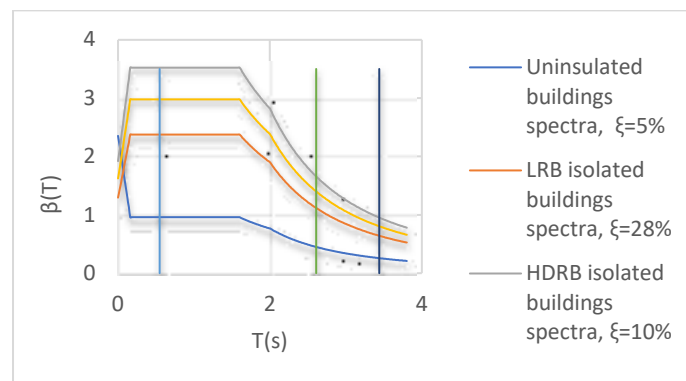


Figure - 15 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 4L buildings, rectangular shape on the response spectrum

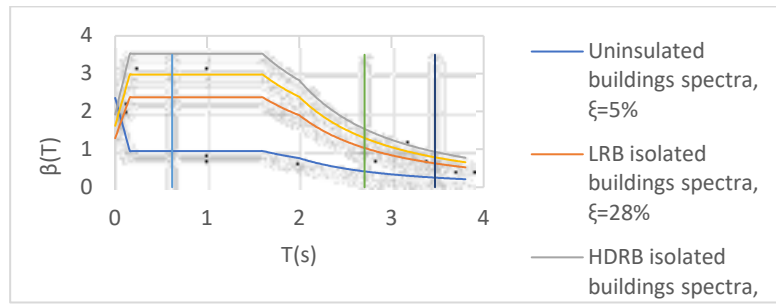


Figure - 17 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 4L buildings, circular shape on the response spectrum

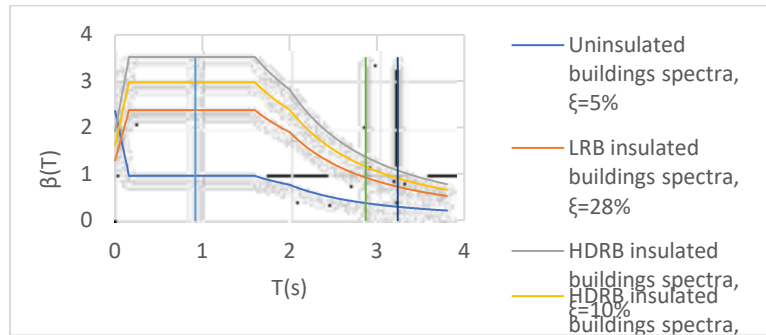


Figure - 19 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 9L buildings, square shape on the response spectrum

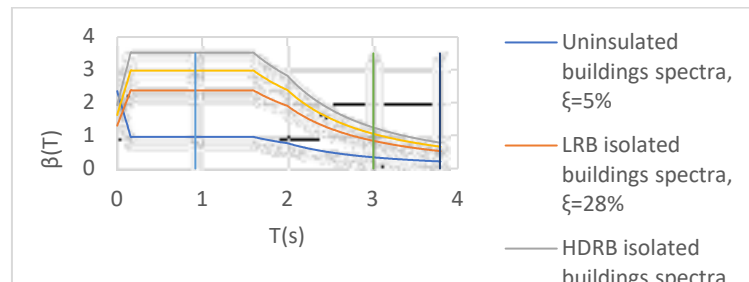


Figure - 21 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 9L buildings, rectangular shape on the response spectrum

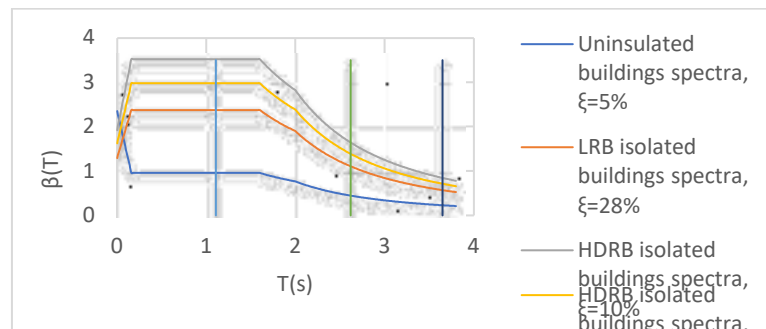


Figure - 23 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 9L buildings, circular shape on the response spectrum

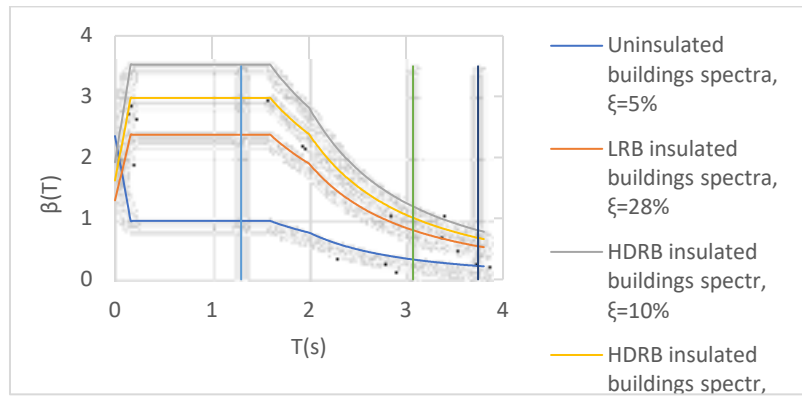


Figure - 25 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 14L buildings, square shape on the response spectrum

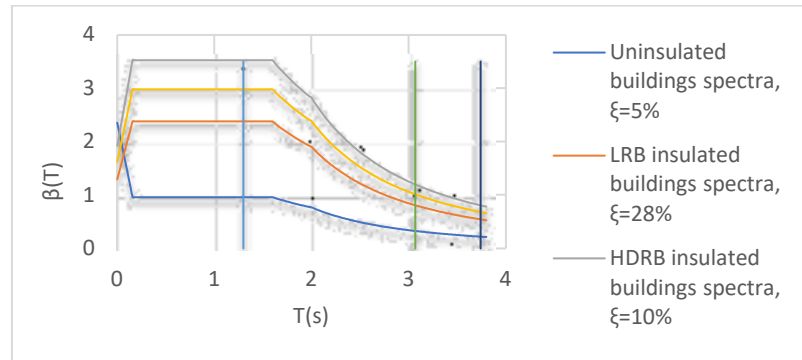


Figure - 27 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 14L buildings, rectangular shape on the response spectrum

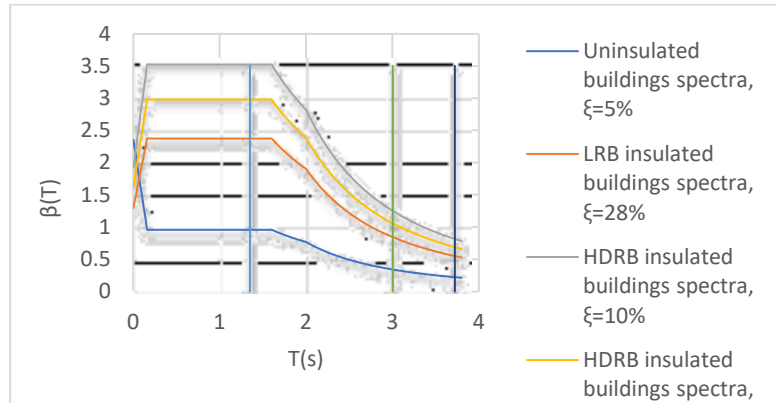


Figure - 29 Representation of the periods obtained for the non-isolated and isolated buildings at the base, for the Ug + Gf + 14L buildings, circular shape on the response spectrum

2.3.2 Displacements obtained at the structures isolated at the base

Next, the results obtained for the same systems with isolated base, but from the perspective of earthquake-induced displacements, will be presented.

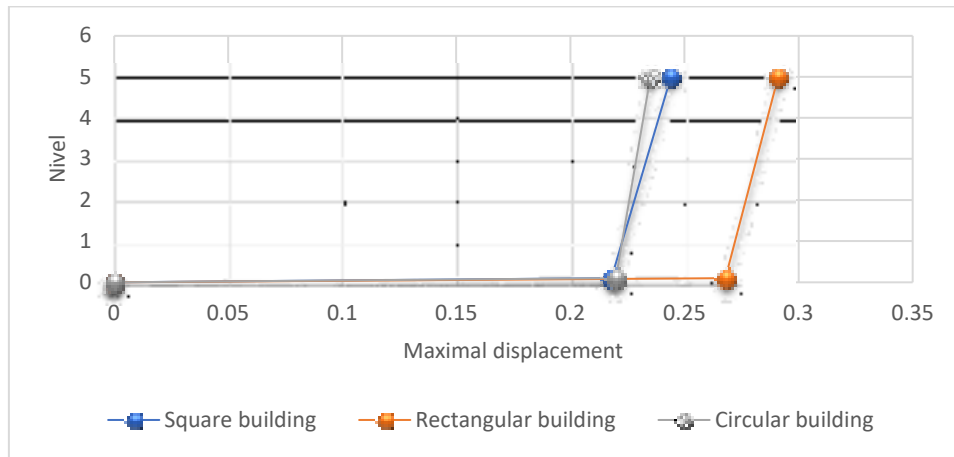


Figure - 30 Maximal displacement at the base and top of the structure for $U_g + G_f + 4F$ with isolated base, using HDRB type isolators [m]

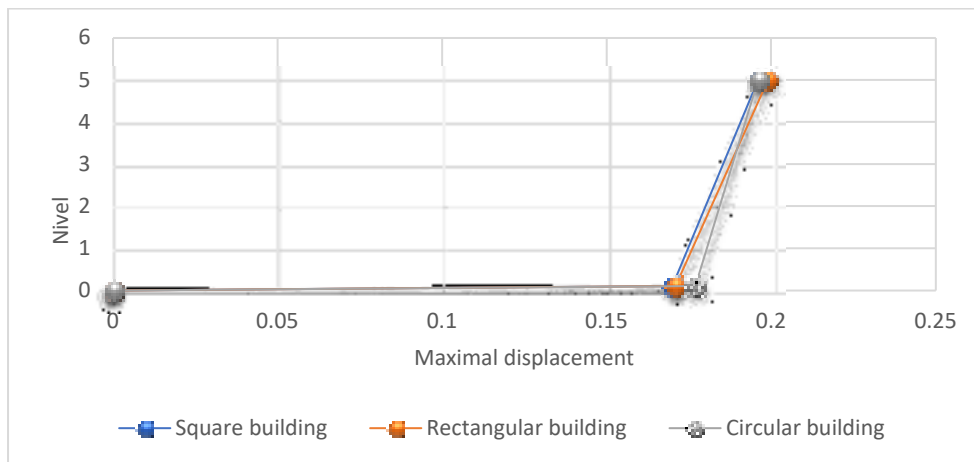


Figure - 31 Maximal displacement at the base and top of the structure for $U_g + G_f + 4F$ with isolated base, using LRB type isolators [m]

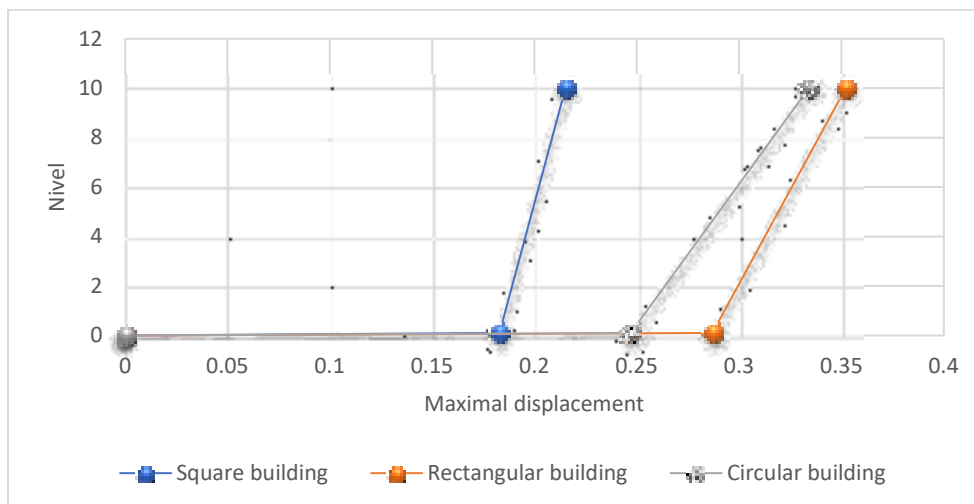


Figure - 32 Maximal displacement at the base and top of the structure for $U_g + G_f + 9F$ with isolated base, using HDRB type isolators [m]

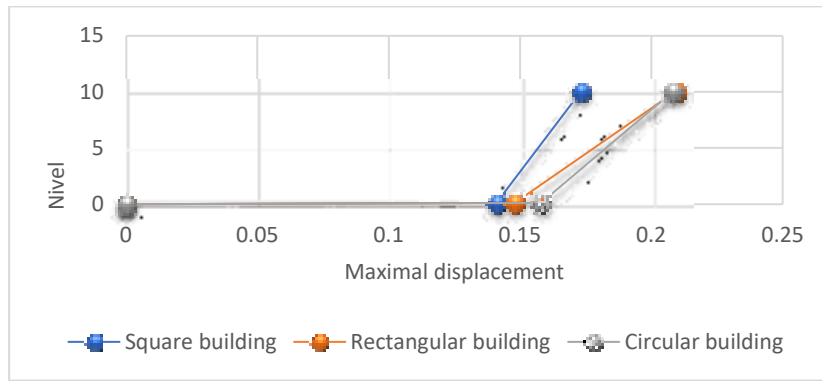


Figure - 33 Maximal displacement at the base and top of the structure for $U_g + G_f + 9F$ with isolated base, using LRB type isolators [m]

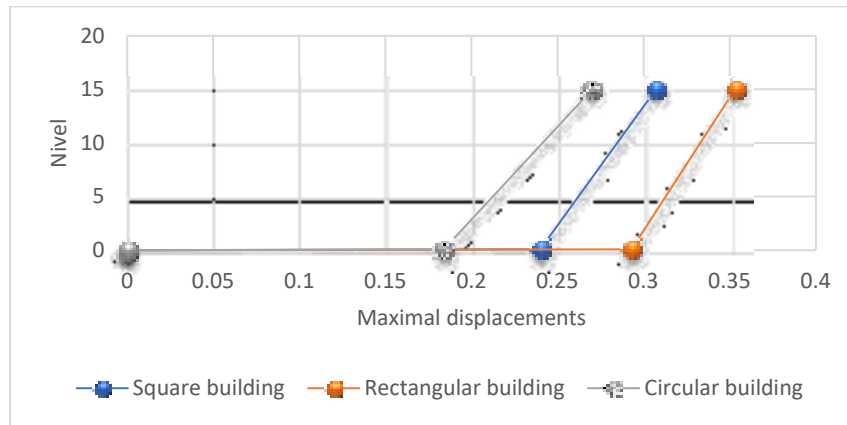


Figure - 34 Maximal displacement at the base and top of the structure for $U_g + G_f + 14F$ with isolated base, using HDRB type isolators [m]

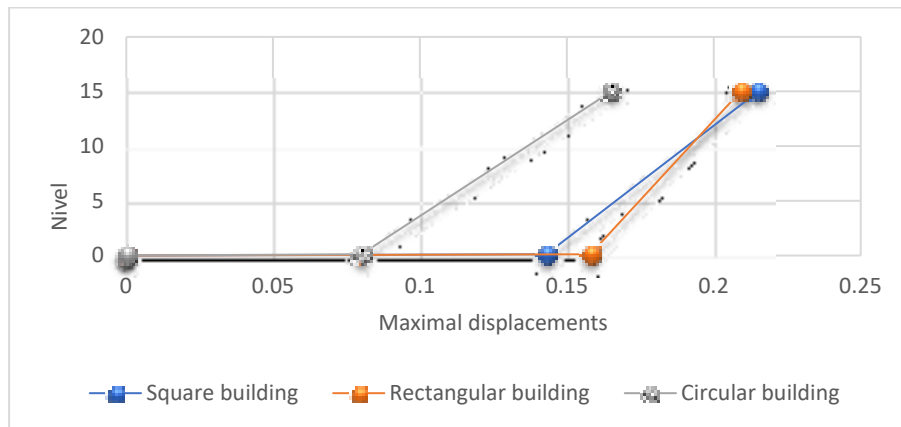


Figure - 35 Maximal displacement at the base and top of the structure for $U_g + G_f + 14F$ with isolated base, using LRB type isolators [m]

A conclusion resulting from the analysis of the above figures is the following: the more flexible the superstructure, the more obvious the contribution of the superior modes in the global response (there is an amplification of the heights). It is also observed that increasing the damping level in the isolation layer has a beneficial effect, by reducing the displacement requirements in the superstructure (in the present study a damping of 10% and 16% was considered for HDRB type isolators and a damping of 28% for LRB type isolators). These conclusions confirm the study

carried out by Opreșoreanu V. V. in his doctoral thesis "Contributions to the application of base isolation in seismic design in Romania" (2012).

The relative level shifts for isolated and non-isolated structures will be analyzed below:

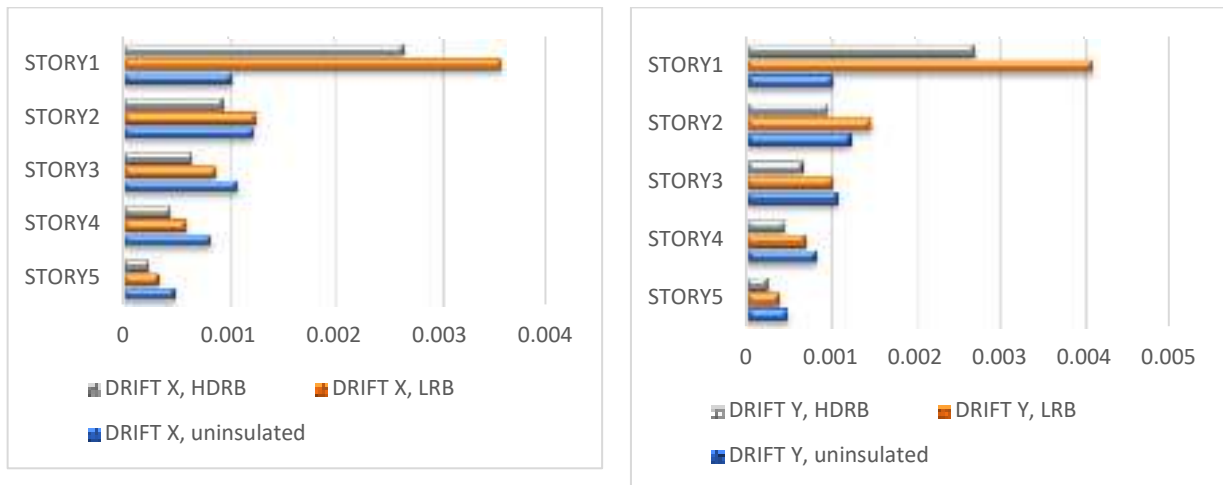


Figure - 36 Relative displacements for circular buildings with UG+GF+4L on x and y directions



Figure - 37 Relative displacements for square buildings with UG+GF+4L on x and y directions



Figure - 38 Relative displacements for rectangular buildings with UG+GF+4L on x and y directions

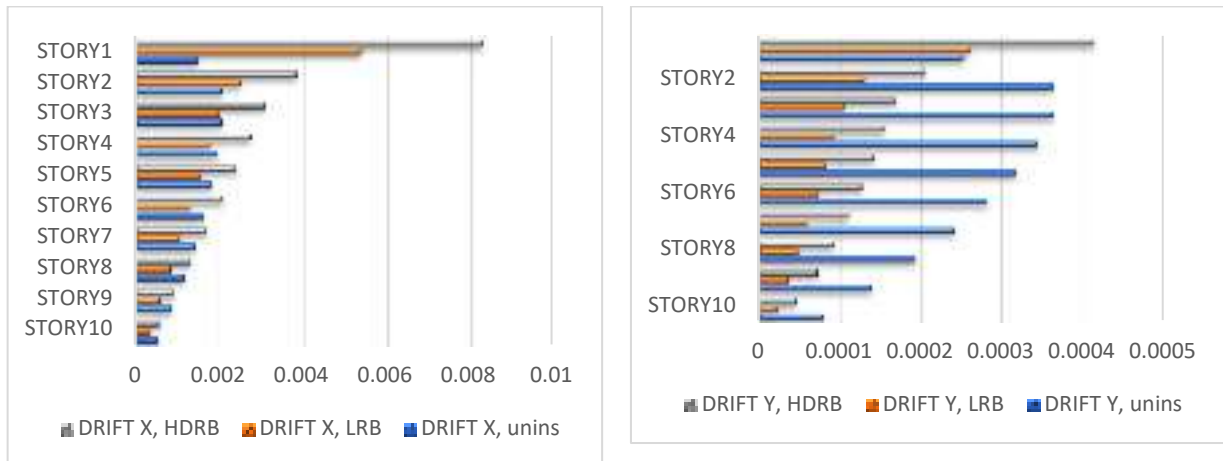


Figure - 39 Relative displacements for circular buildings with UG+GF+9L on x and y directions

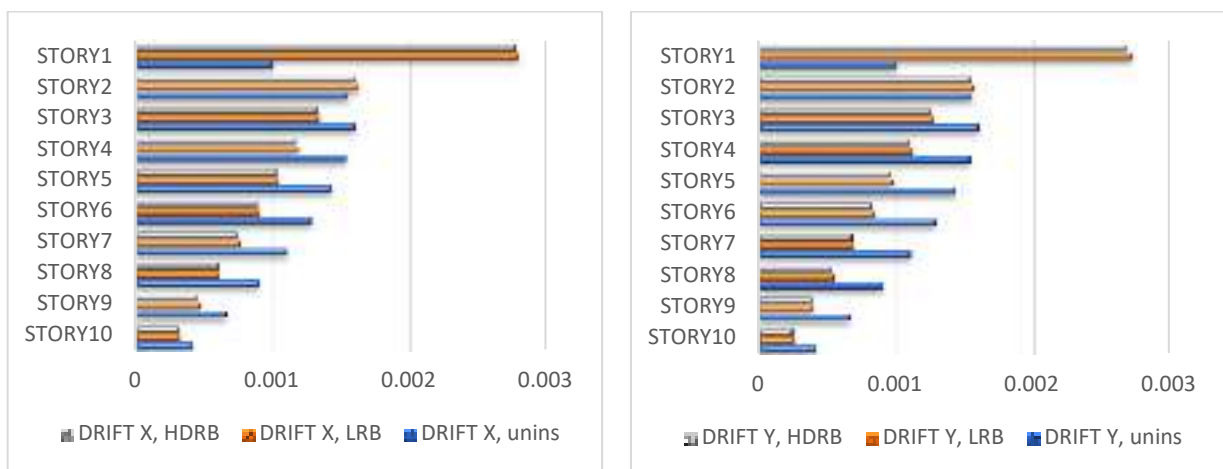


Figure - 40 Relative displacements for square buildings with UG+GF+9L on x and y directions

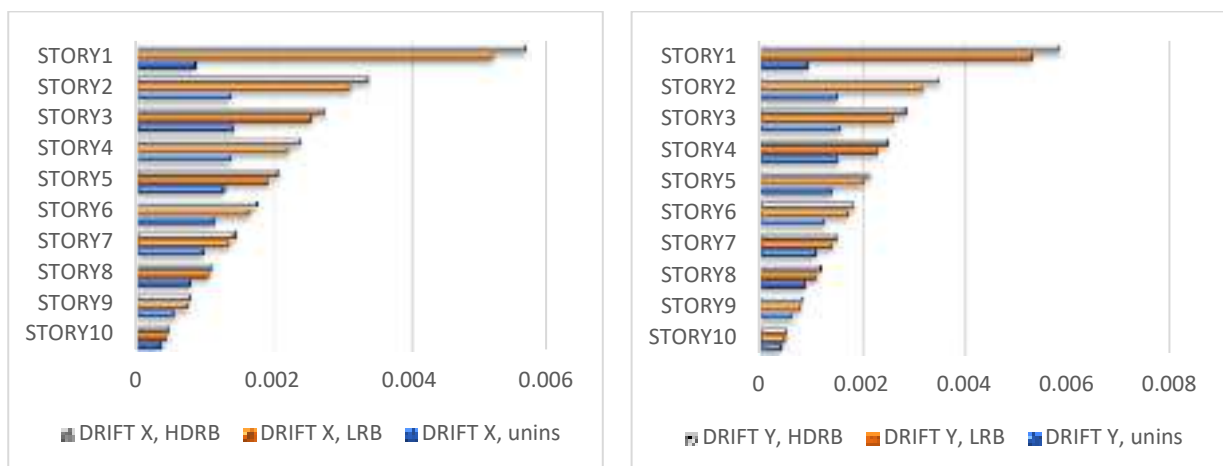


Figure - 41 Relative displacements for rectangular buildings with UG+GF+9L on x and y directions

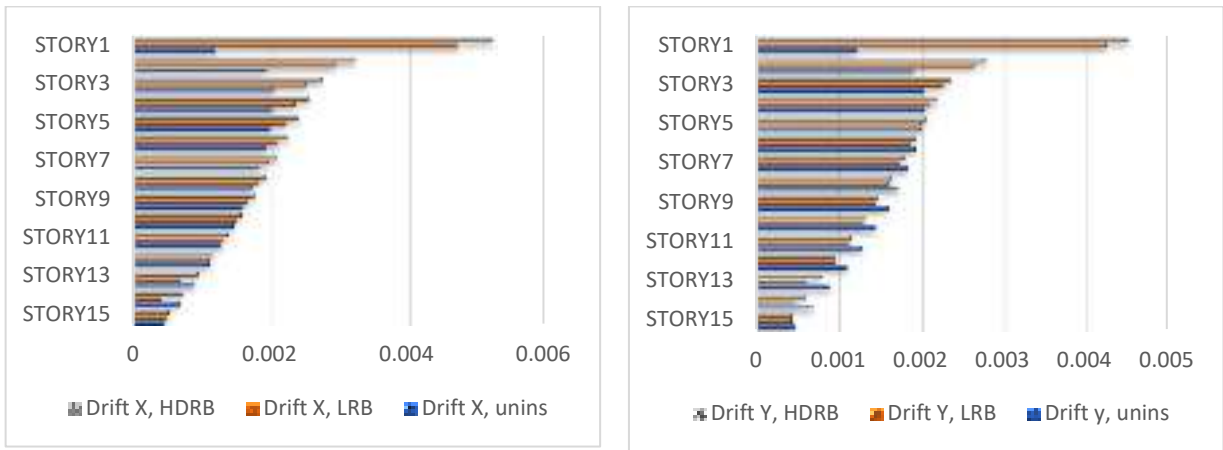


Figure - 42 Relative displacements for circular buildings with UG+GF+14L on x and y directions

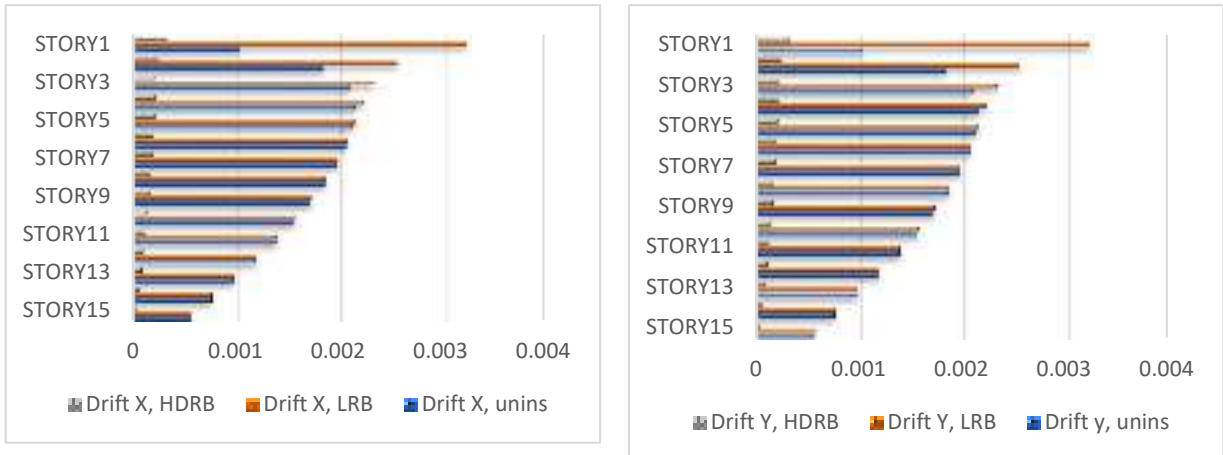


Figure - 43 Relative displacements for square buildings with UG+GF+14L on x and y directions

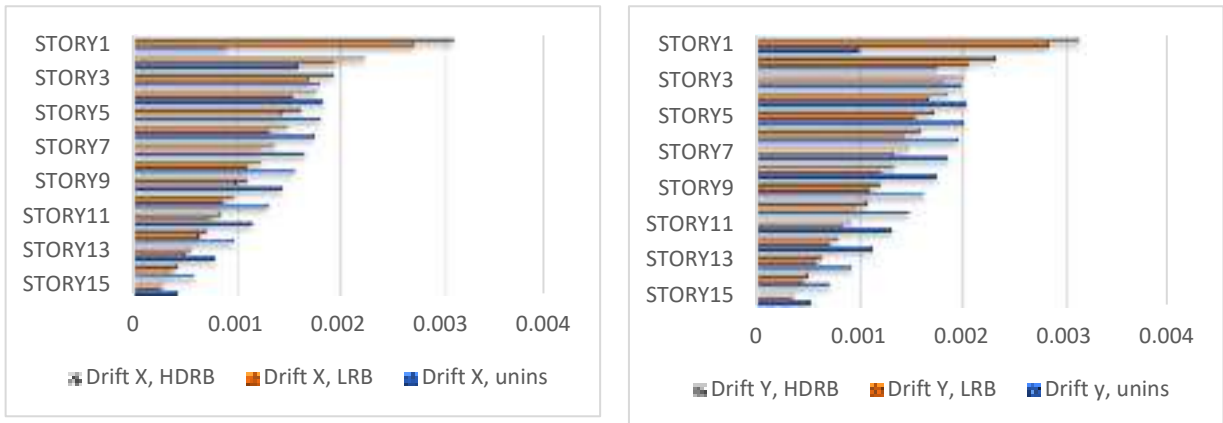


Figure - 44 Relative displacements for rectangular buildings with UG+GF+14L on x and y directions

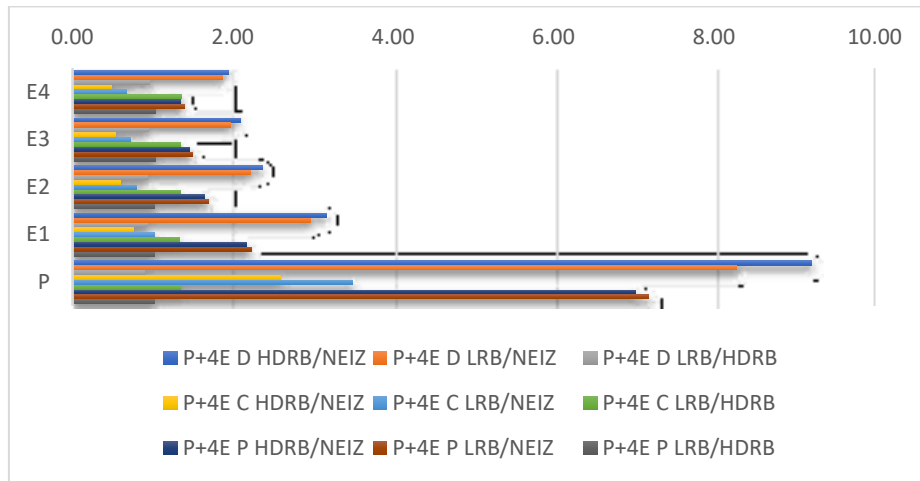


Figure - 45 Relative level displacement ratio for structures for $U_g + G_f + 4L$ structures

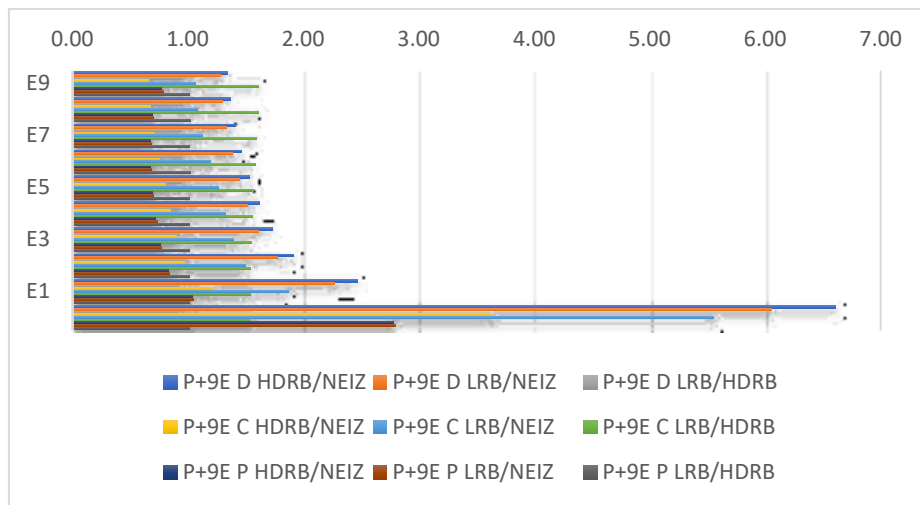


Figure - 46 Relative level displacement ratio for structures for $U_g + G_f + 9L$ structures

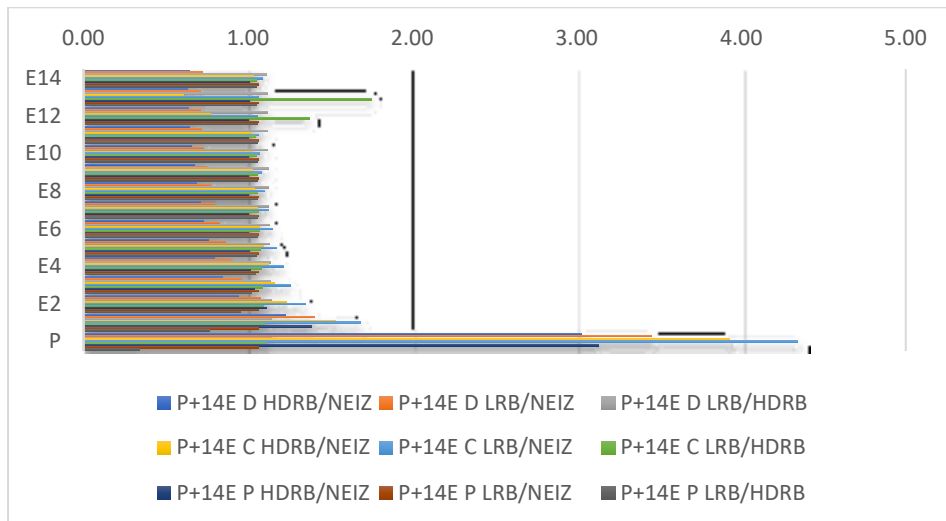


Figure - 47 Relative level displacement ratio for structures for $U_g + G_f + 14L$ structures

2.4 The efforts resulting in traditional design vs. design by base isolation method

2.4.1. Maximum stresses in the columns

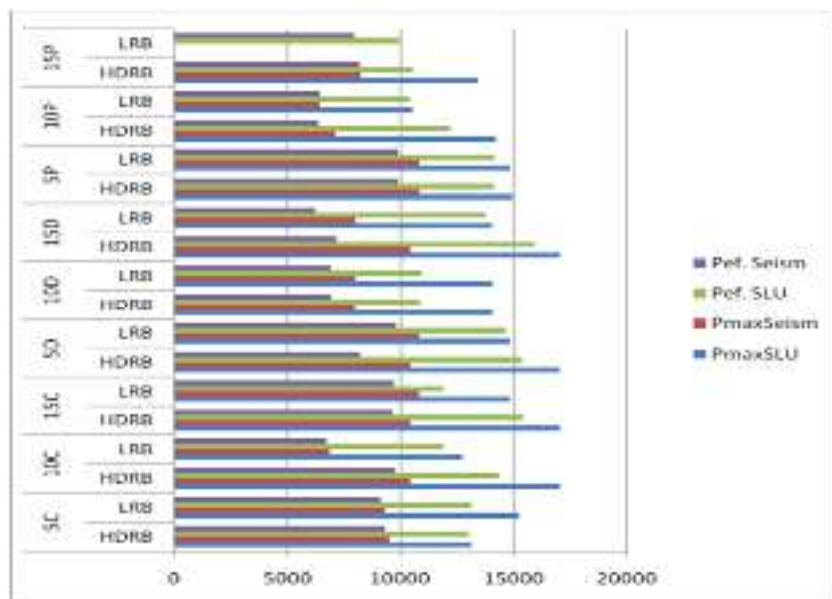


Figure - 48 Maximum effective efforts and capable efforts of the isolators used in the case study

3. CONCLUSION

Following the case study, regarding the behavior of buildings in reinforced concrete frames, located in Bucharest, designed using the base isolation method, the following were found:

1. From the point of view of the fundamental periods of vibration:

- For buildings with 5 levels, the fundamental vibration periods increase by about 6 times in case of using HDRB type isolators, respectively 5 times in case of using LRB type isolators;
- For buildings with 10 levels, the fundamental vibration periods increase by about 3.6 times in the case of using HDRB type isolators, respectively by about 3 times in the case of using LRB type isolators;
- For buildings with 15 levels, the fundamental vibration periods increase by about 3 times in the case of using HDRB type isolators, respectively 2.3 times in the case of using LRB type isolators;
- Conclusion - the more rigid the buildings, the shorter the length of the fundamental vibration periods by using seismic isolators.
- In general, the fundamental vibration periods when using LRB type isolators are about 80% of the fundamental vibration periods for using HDRB type seismic isolators (so HDRB makes the structure 20% more flexible than LRB).

2. From the point of view of displacements (including the isolators displacements):

- For buildings with 5 levels, the drifts increase in case of using HDRB type seismic isolators by about 149% and by 153% in case of using LRB type seismic isolators;
- For buildings with 10 levels, the drifts increase in case of using HDRB type seismic isolators by about 41% respectively by 57% in case of using LRB type seismic isolators;

- For buildings with 15 levels, the drifts decrease in case of using HDRB type seismic isolators by about 11% and respectively increase by 16% in case of using LRB type seismic isolators;
- In the case of using seismic isolators, the more levels the buildings have (the more flexible they are) the drift decreases respectively the more rigid the buildings (fewer levels) the drift increases. It is found that HDRB type seismic isolators are more efficient in terms of drift.
- At the base it is found that on average the displacements increase more for the buildings that use seismic isolators of LRB type compared to HDRB.
- For buildings with 5 levels the displacements are on average about 23 cm, for buildings with 10 levels they are 25 cm and for buildings with a structure in reinforced concrete frames with 15 levels they reach about 27 cm.

3. From the point of view of the sectional efforts in the elements of the structure:

• Table 36: For RC columns:

Level	Bending moments			Shear forces			Axial forces		
	M_{HDRB}/M_{unins}	M_{LRB}/M_{unins}	M_{LRB}/M_{HDRB}	V_{HDRB}/V_{unins}	V_{LRB}/V_{unins}	V_{LRB}/V_{HDRB}	N_{HDRB}/N_{unins}	N_{LRB}/N_{unins}	N_{LRB}/N_{HDRB}
5	0.55	0.60	0.88	0.84	1.00	1.25	1.00	0.92	0.93
10	0.76	0.74	0.97	0.78	0.75	0.97	1.01	1.01	1.00
15	0.95	0.81	0.84	0.78	0.70	0.89	1.00	0.99	0.99

- The sectional efforts of bending moments and shear forces, at the RC columns, in case of using seismic isolators, are reduced to about 68-98% of the efforts corresponding to the non-isolated structure;
- The sectional efforts of axial force type practically remain with the same values;
- Sectional stresses decrease more when using HDRB type seismic isolators compared to LRB.

• Table 37: For RC beams:

Level	Bending moments			Shear forces			Axial forces		
	M_{HDRB}/M_{unins}	M_{LRB}/M_{unins}	M_{LRB}/M_{HDRB}	V_{HDRB}/V_{unins}	V_{LRB}/V_{unins}	V_{LRB}/V_{HDRB}	N_{HDRB}/N_{unins}	N_{LRB}/N_{unins}	N_{LRB}/N_{HDRB}
5	0.99	0.99	1.00	1.00	1.00	0.99	1.00	0.99	0.99
10	0.84	0.97	1.17	0.91	0.99	1.10	0.85	0.96	1.13
15	0.81	0.96	1.19	0.88	0.97	1.11	0.80	0.96	1.12

- By using seismic isolators, the sectional efforts on the beams (positive and negative bending moments as well as the shear forces) decrease only for buildings with more than 5 levels. The more levels the building has, the more and more there is a decrease (81-96% at 15 levels).
- It is also found that (in the sense of those presented above) the efforts decrease more in the case of using HDRB type seismic isolators than LRB type ones.

Final conclusion

Considering all the above, for the buildings that are designed with RC frame structures, with low and medium height regime (up to 15 levels) it is found that HDRB type seismic isolators are more efficient than LRB type seismic isolators.

CHAPTER 5: SEISMIC ISOLATION OF THE BASE FOR BUILDINGS WITH REINFORCED CONCRETE DUAL STRUCTURES

1. STUDY CASES

1.1 Choice of structures for analysis

For the present study we wanted to analyze 9 models of dual structures, the difference between them being the shape and height regime. The modeling of the structures was performed using the ETABS program as follows:

- 9 analysis models were made for superstructures:
 - square shape building (with 3 height rises: Ug+Gf+14L; Ug+Gf+9L; Ug+Gf+4L);
 - rectangular building (with 3 height rises: Ug+Gf+14L; Ug+Gf+9L; Ug+Gf+4L);
 - round shape building (with 3 height rises: Ug+Gf+14L; Ug+Gf+9L; Ug+Gf+4L);
- 9 analysis models were made with the same types of buildings, taking into account the modeling of the soil-structure interaction
- 9 analysis models were made with the same types of buildings, taking into account the seismic base isolation, with LRB and HDRB type isolators.

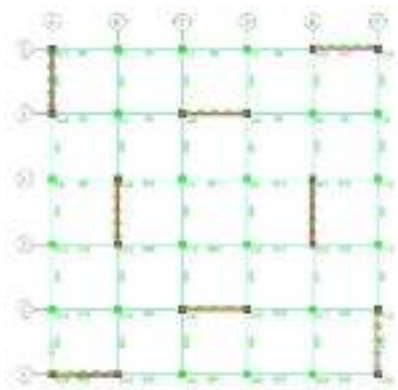


Figure1 square shape

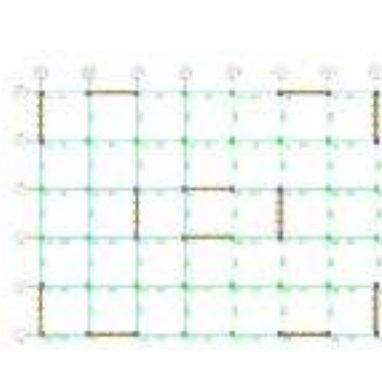


Figure 2 rectangular shape

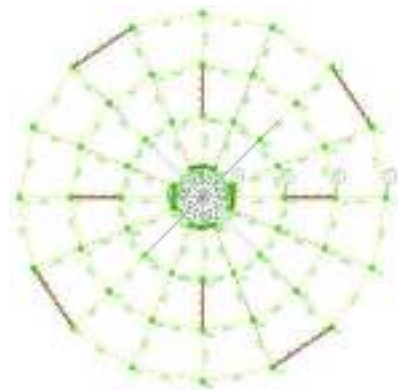


Figure.3 circular shape

The buildings have the function of offices and are located in Bucharest. The structural system is made of general screed, walls, columns and beams of reinforced concrete, with terrace roof. The exterior and interior walls are made of BCA masonry. The carpentry is made of PVC with double glazing, the floors will be finished with tiles in wet areas and parquet and ceramic tiles in the rest. Vertical traffic is provided by a two-ramp staircase and an elevator.

1.3.2 Modeling of isolators

For the modeling of the base isolation system, in both variants, the structure placed on a concrete foundation. The isolation system is made of a number of isolators installed for each building. Two types of isolators were used, namely High Damping Rubber Bearing (HDRB) and LRB (Lead Rubber Bearings) replaced for modeling with "link" type elements, for the calculation considering a damping coefficient $\nu = 16\%$ respectively $\nu = 28\%$ of the critical depreciation.

2. PRESENTATION OF THE CONTENT OF THE ANALYSIS PERFORMED AND THE RESULTS OBTAINED

2.1 Results obtained in non-isolated buildings

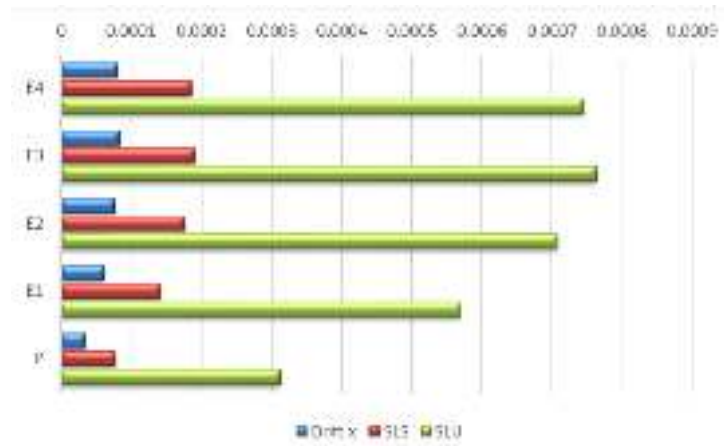


Figure 8 "Drift direction X building UG+GF+4Lcircular"

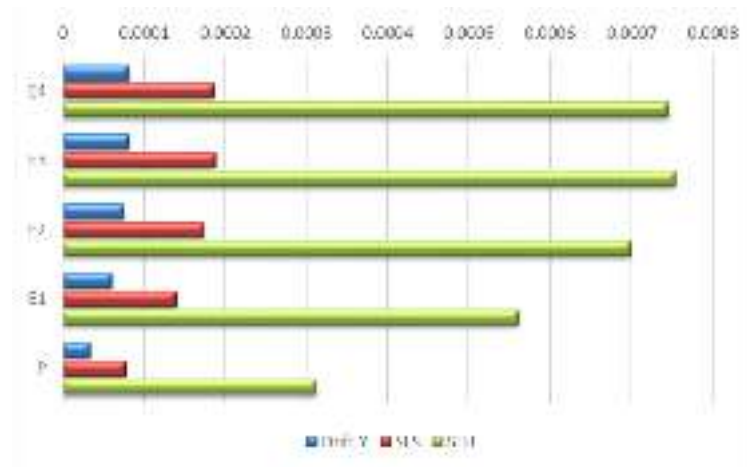


Figure 9 "Drift Y direction UG+GF+4Lcircular building"

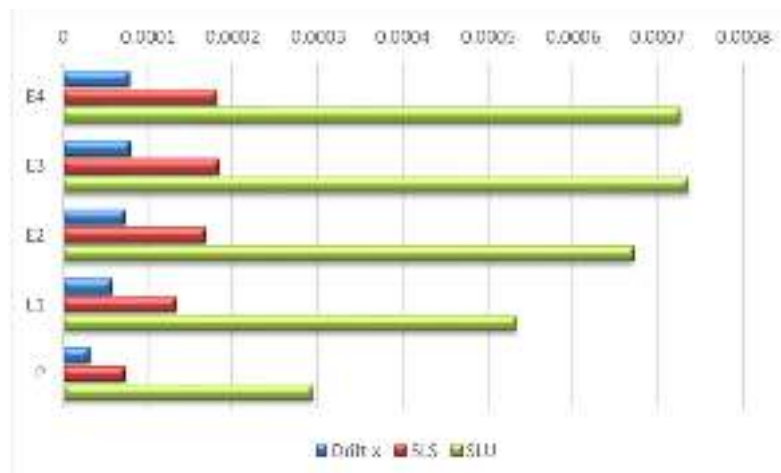


Figure 10 "Drift direction X building UG+GF+4Lrectangular"



Figure 11 "Drift Y direction building UG+GF+4Lrectangular"

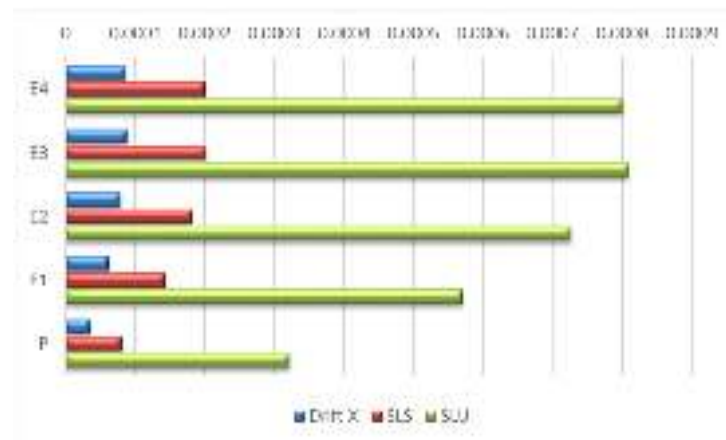


Figure 12 "Drift X direction building UG+GF+4L square"

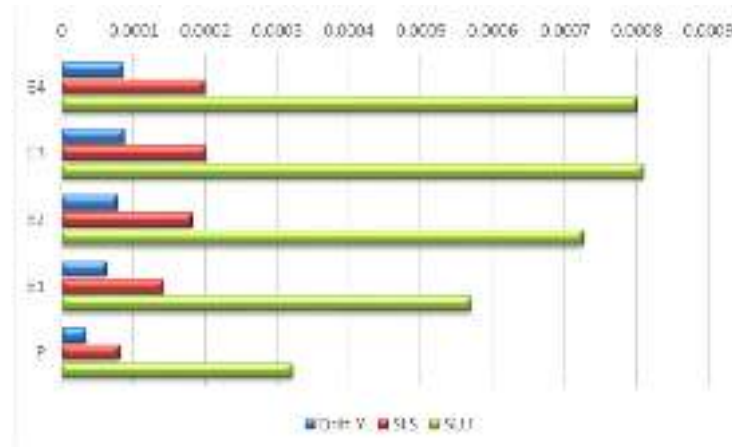


Figure 13 "Drift Y direction building UG+GF+4Lsquare"

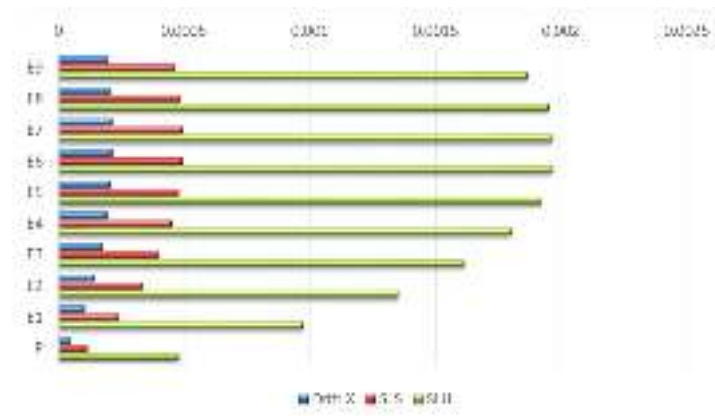


Figure 14 "Drift direction X building UG+GF+9Lcircular"

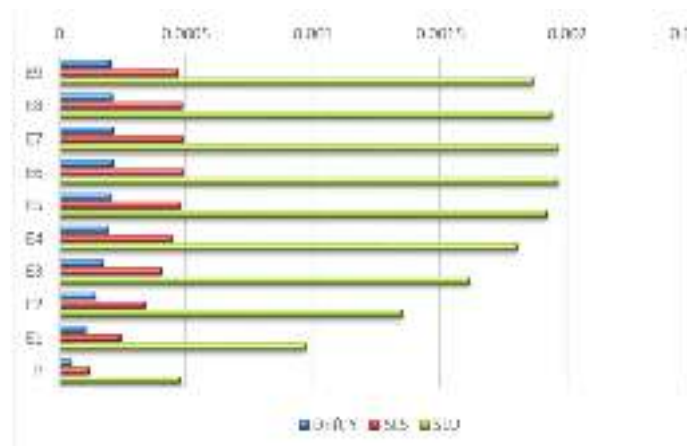


Figure 15 "Drift Y direction UG+GF+9Lcircular building"

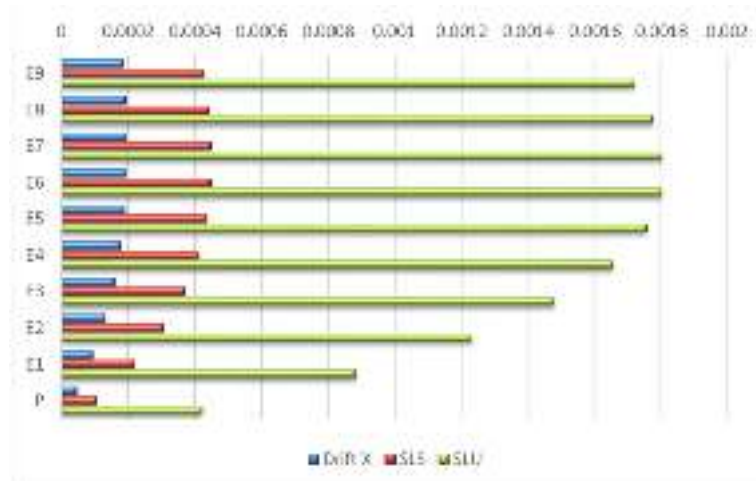


Figure 16 "Drift direction X building UG+GF+9Lrectangular"

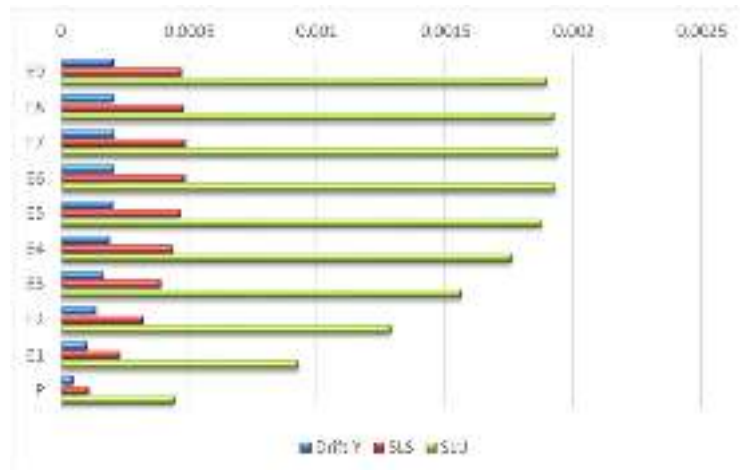


Figure 17 "Drift Y direction building UG+GF+9Lrectangular"

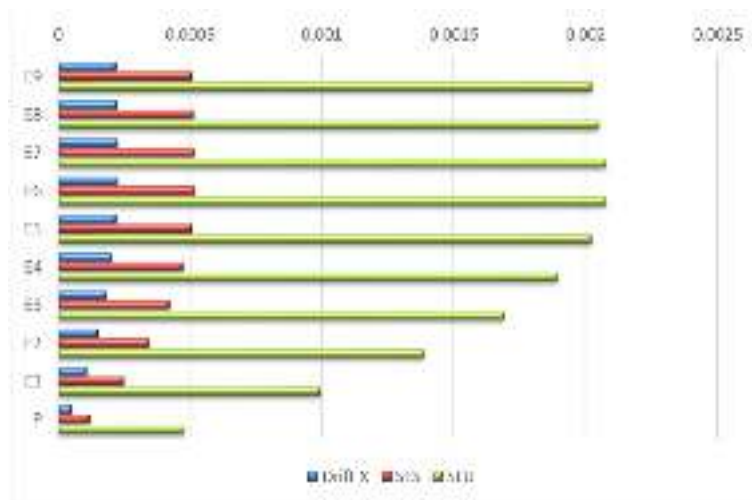


Figure 18 "Drift direction X building UG+GF+9L square"

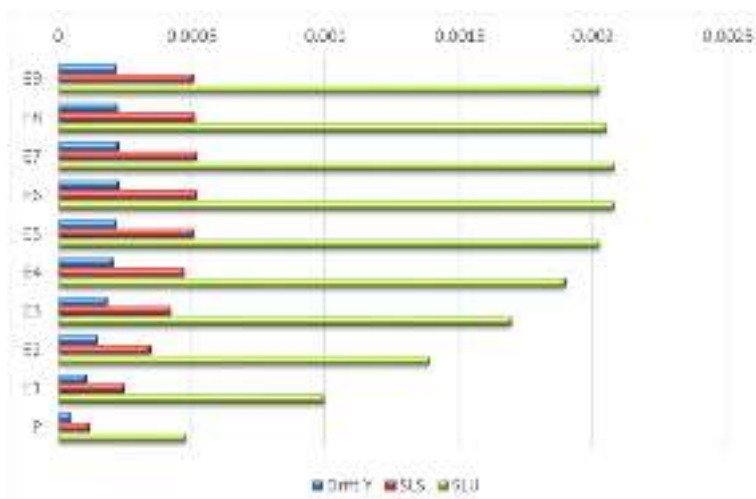


Figure 19 "Drift Y direction building UG+GF+9Lsquare"

The following periods were obtained:

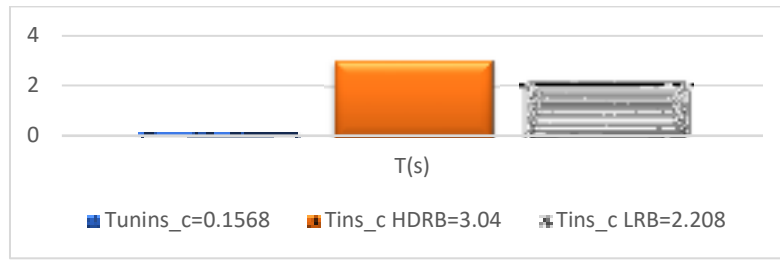


Figure 26 "Circular UG+GF+4L building periods"

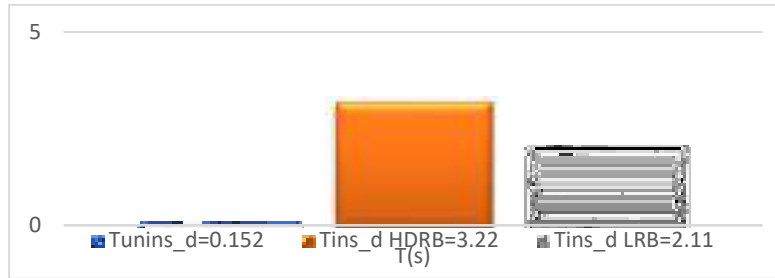


Figure 28 "Rectangular UG+GF+4L building periods"

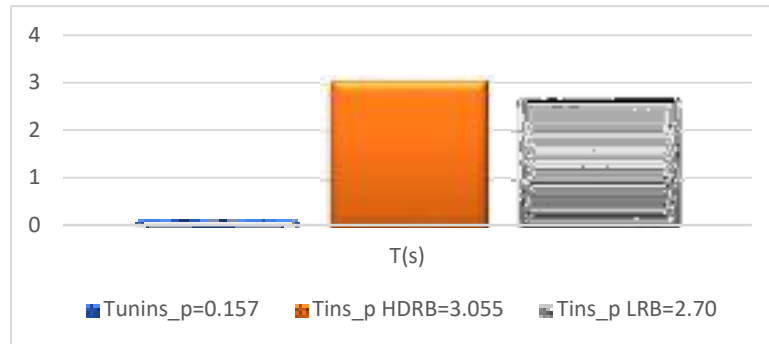


Figure 30 "Square Ug + Gf + 4L building periods"

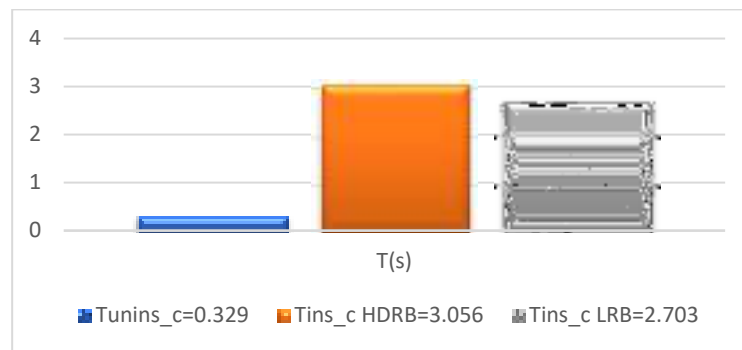


Figure 32 "Circular Ug + Gf + 9L building periods"

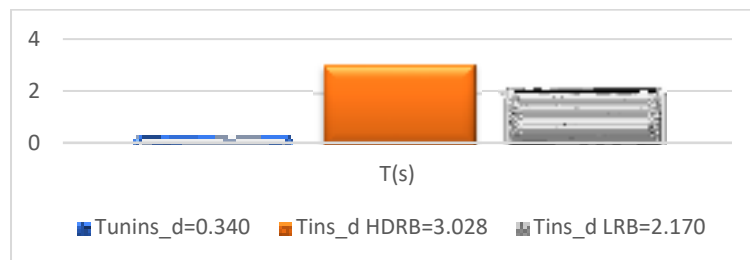


Figure 34 "Rectangular Ug + Gf + 9L building periods"

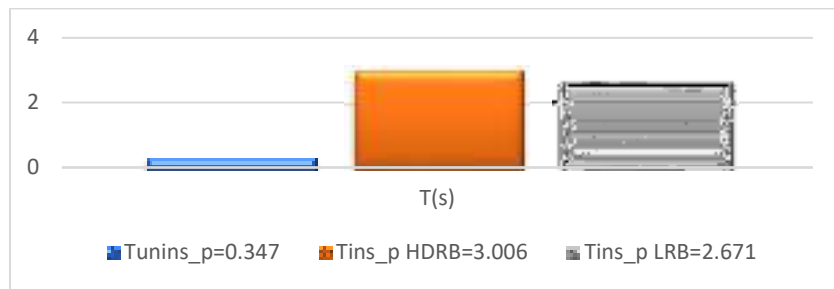


Figure 36 "Square UG+GF+9L building periods"

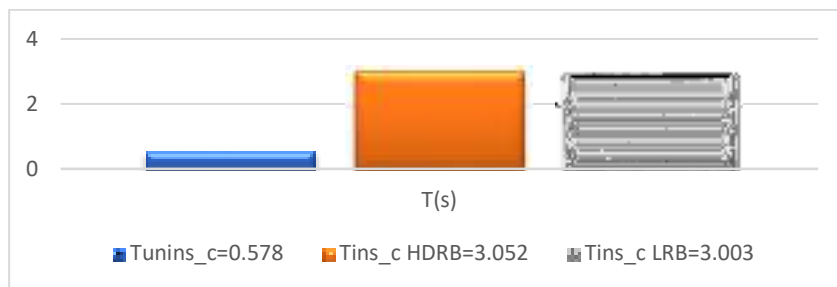


Figure 38 "Circular UG+GF+14L building periods"

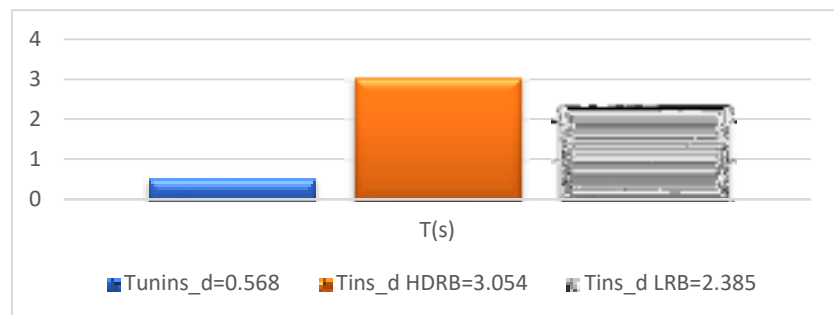


Figure 40 "Rectangular UG+GF+14L building periods"

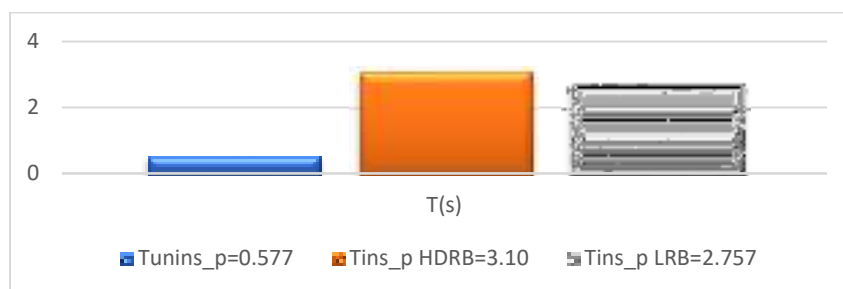


Figure 42 "Square GF + GF + 14L building periods"

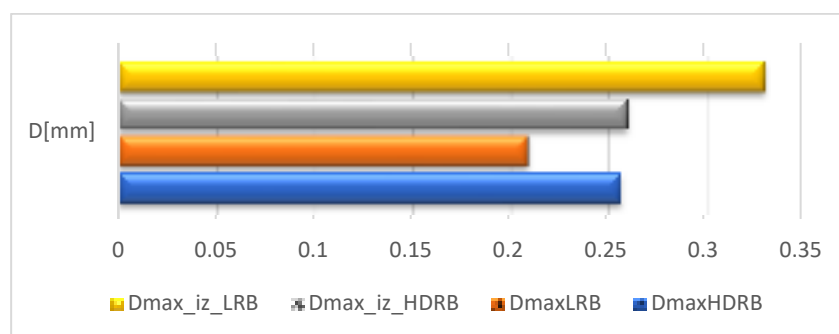


Figure 45 "Lateral displacement at the base of the circular UG+GF+4L"

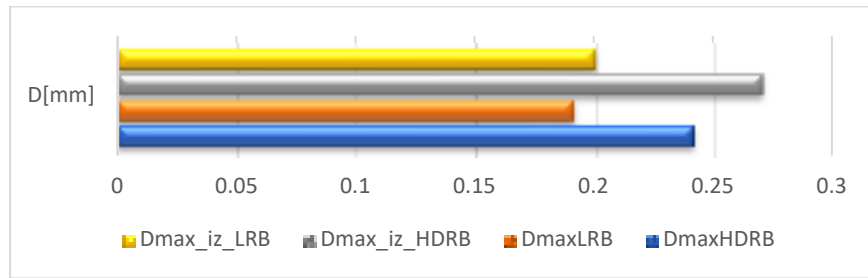


Figure 46 "Lateral displacement at the base of the rectangular UG+GF+4L"

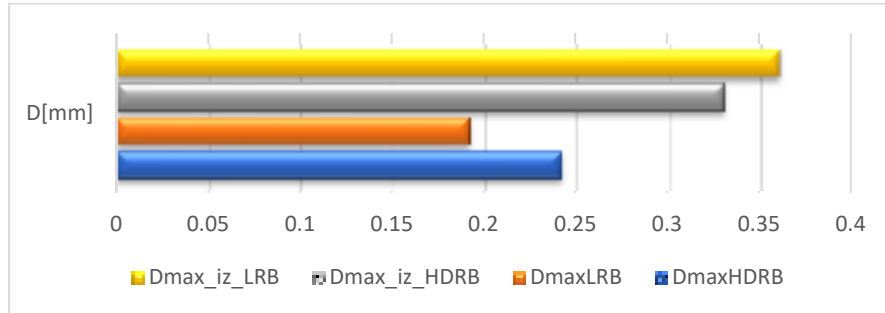


Figure 47 "Lateral displacement at the base UG+GF+4L square"

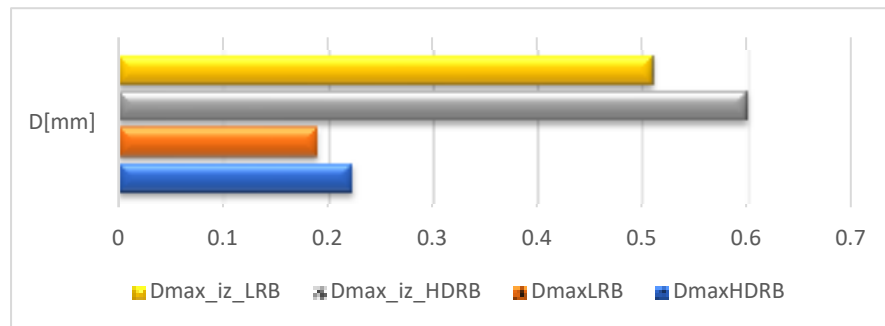


Figure 48 "Lateral displacement at the base of the circular UG+GF+9L"

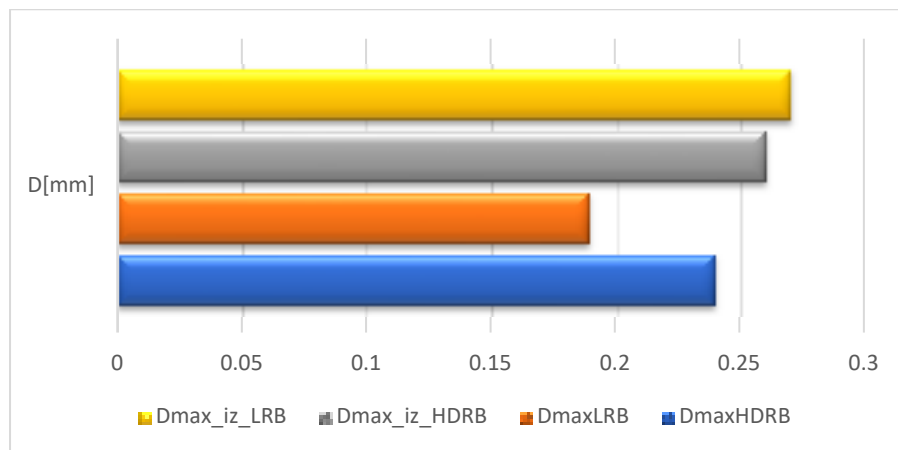


Figure 49 "Lateral displacement at the base of the rectangular UG+GF+9L"

The following relative level shifts were obtained:

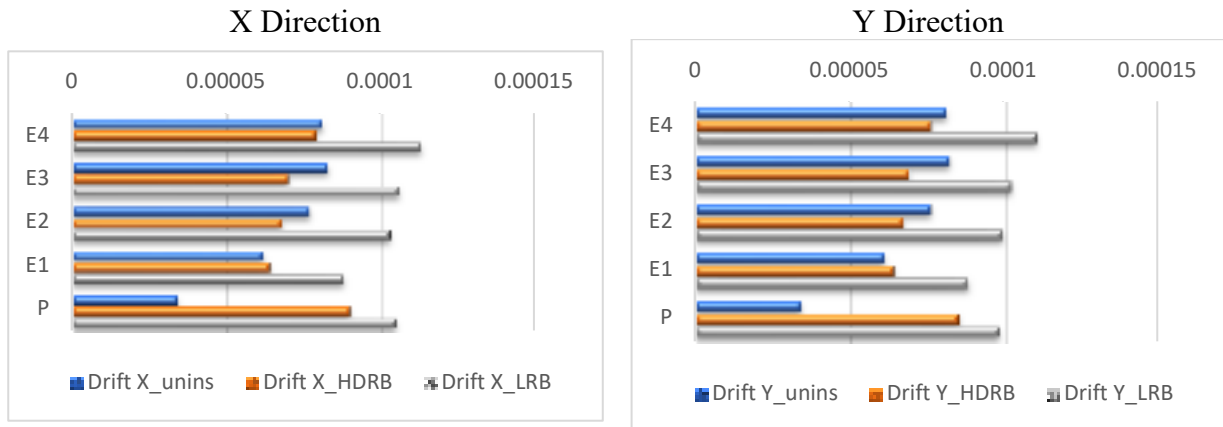


Figure 56 "Relative displacements of circular UG+GF+4Llevel"

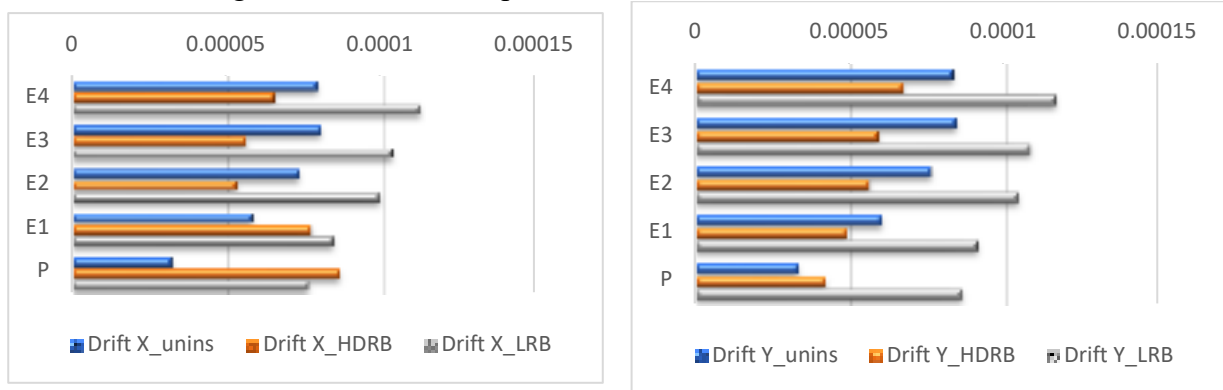


Figure 57 "Relative displacements of level UG + GF + 4F rectangular"

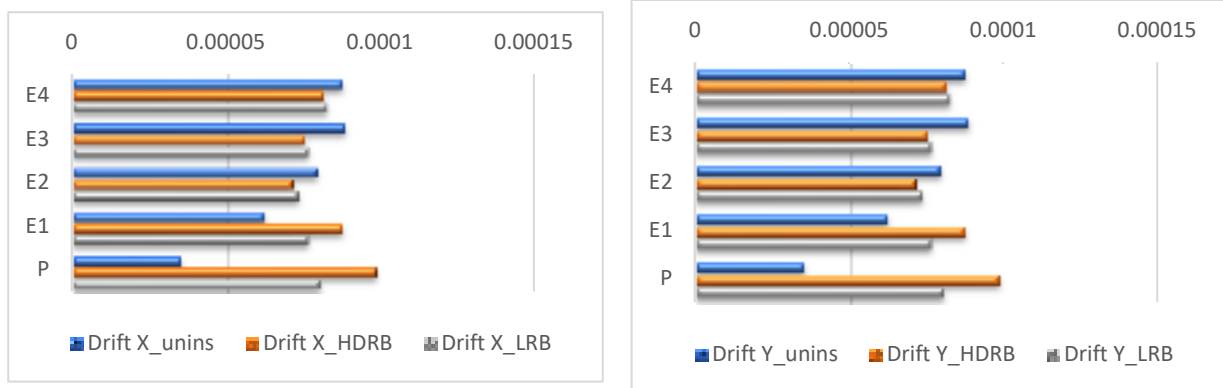


Figure 58 "Relative displacements of level UG+GF+4L square"

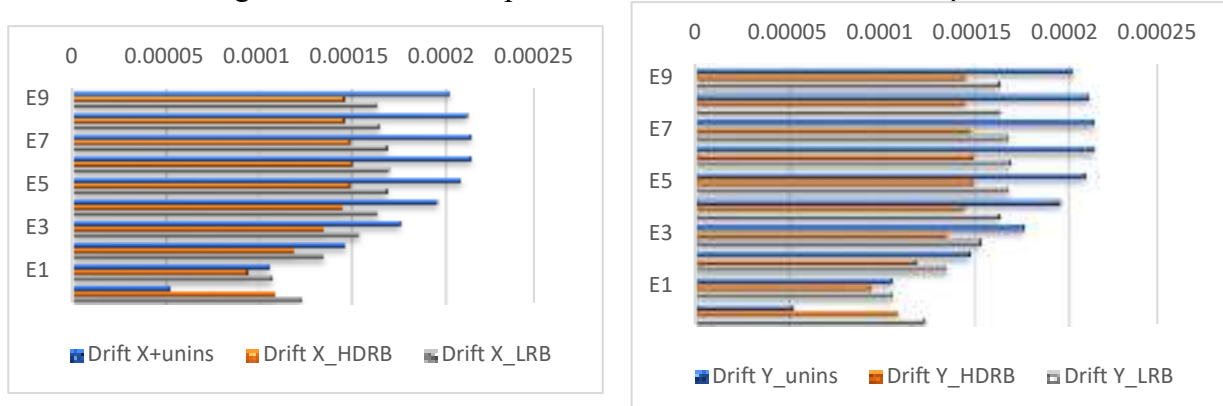


Figure 59 "Relative displacements of circular UG+GF+9Llevel"

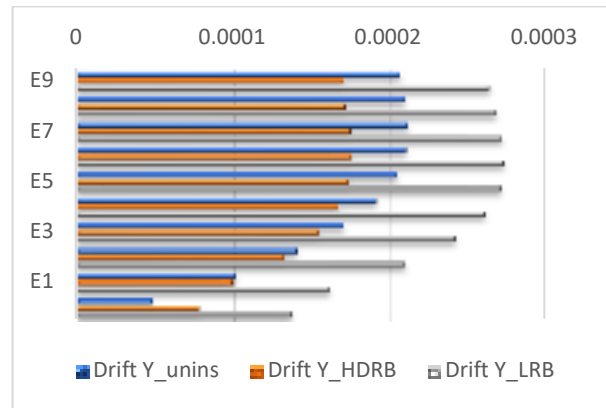
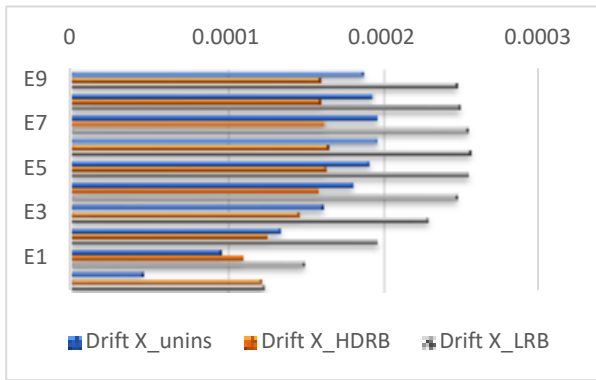


Figure 60 "Relative displacements of level UG+GF+9Llevel rectangular"

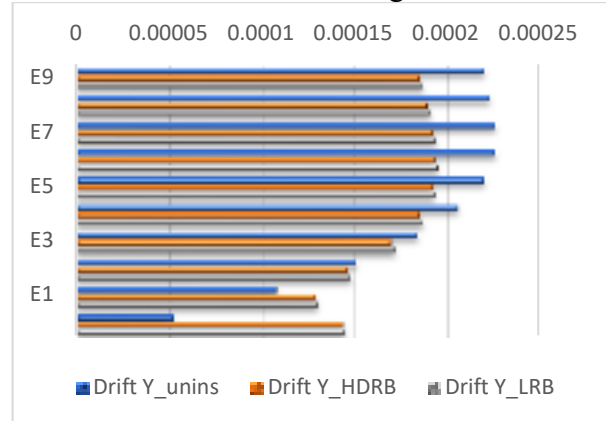
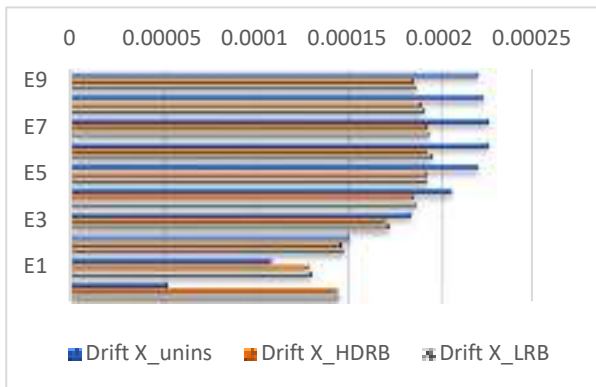


Figure 61 "Relative displacements of level UG+GF+9L square"

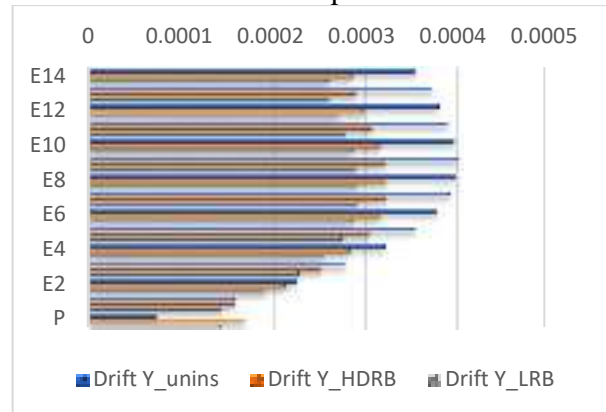
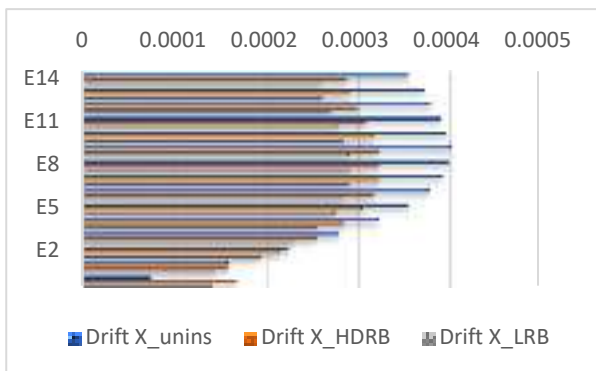


Figure 62 "Relative displacements of circular UG+GF+14Llevel"

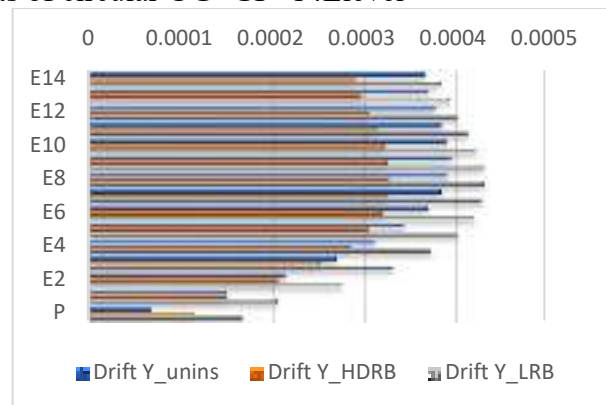
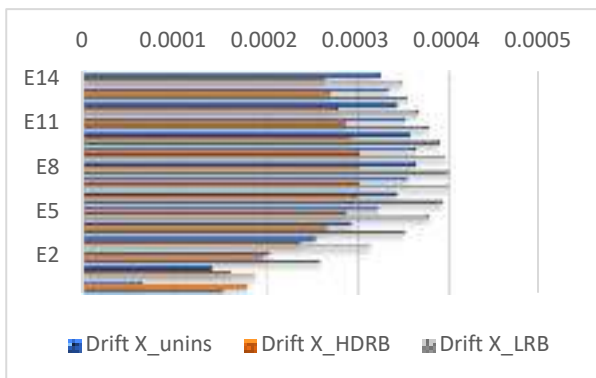


Figure 63 "Relative displacements of level UG+GF+14Llevel rectangular"

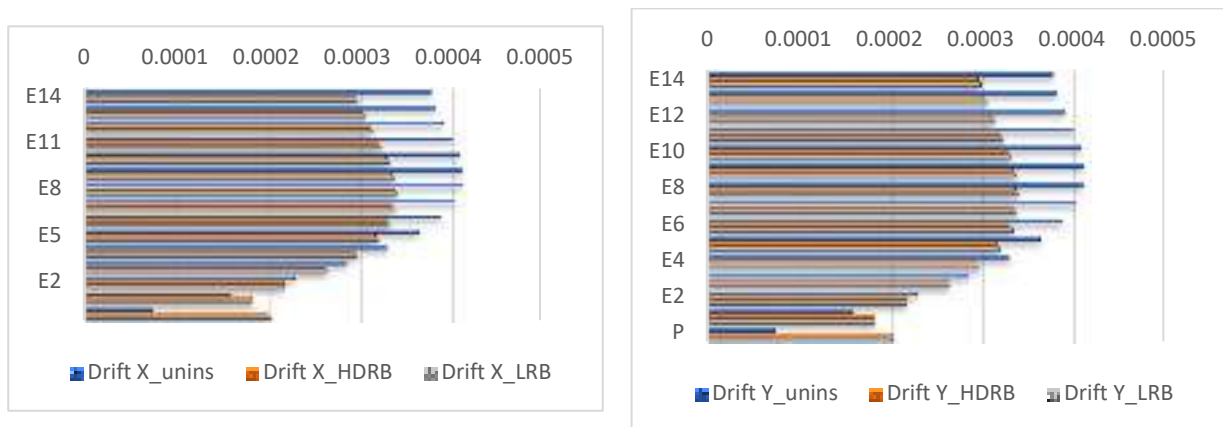


Figure 64 "Relative displacements of level UG+GF+14L square"

The following efforts were made in the structural elements:

Structural walls:

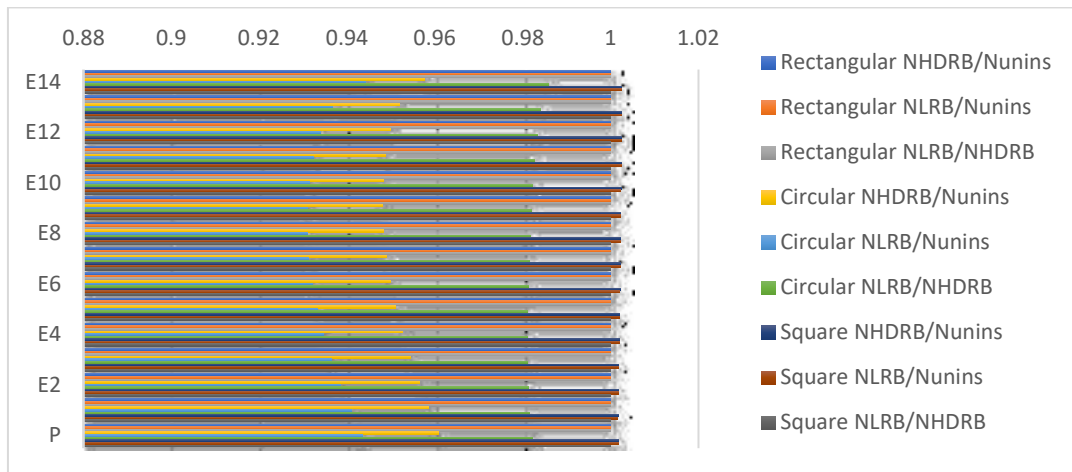


Figure 76 "Maximum axial force ratio in walls for Ug + Gf + 14L buildings"

Column efforts:

Figure 84 "Ratio of maximum shear forces in columns for Ug + Gf + 14L buildings"

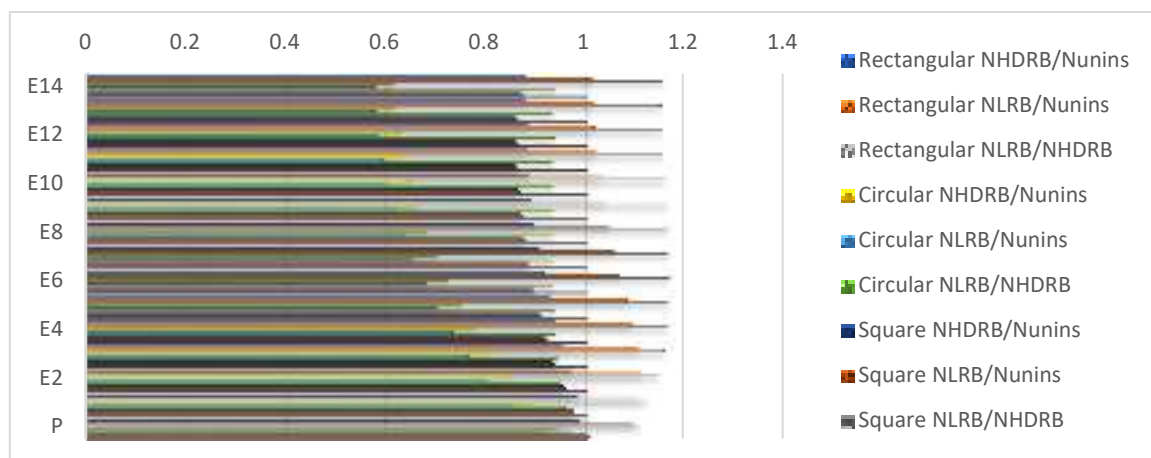


Figure 85 "Ratio of maximum axial forces in columns for Ug + Gf + 14L buildings"

Beam efforts:

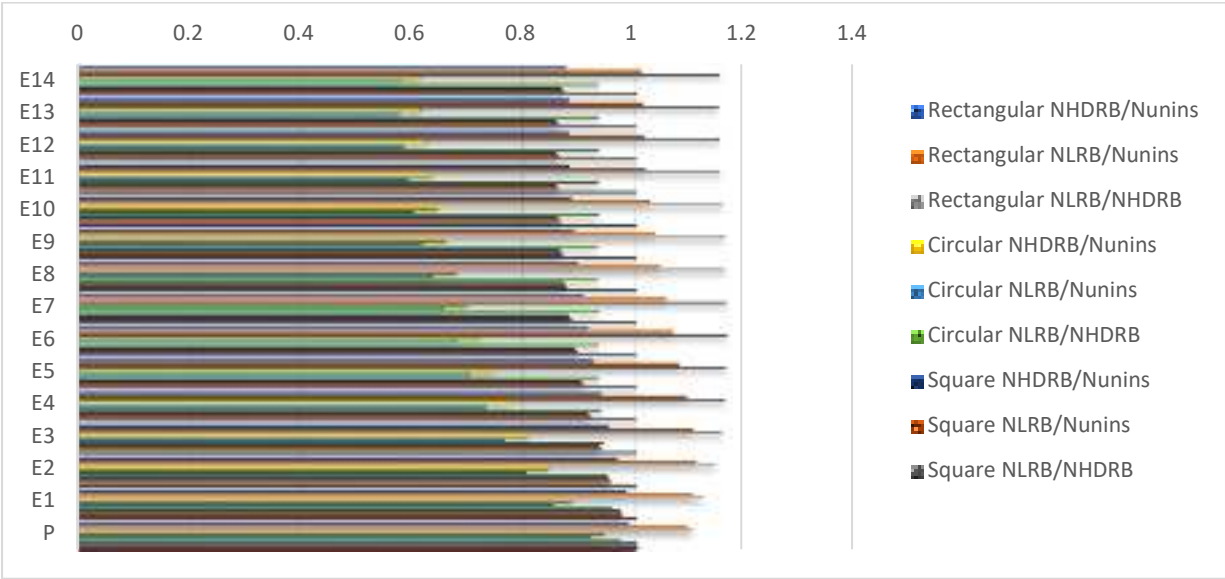


Figure 94 "Maximum beam cutting force ratio in beams for Ug + Gf + 14L buildings"

From the following figure you can see the capable and effective axial forces of the isolators.

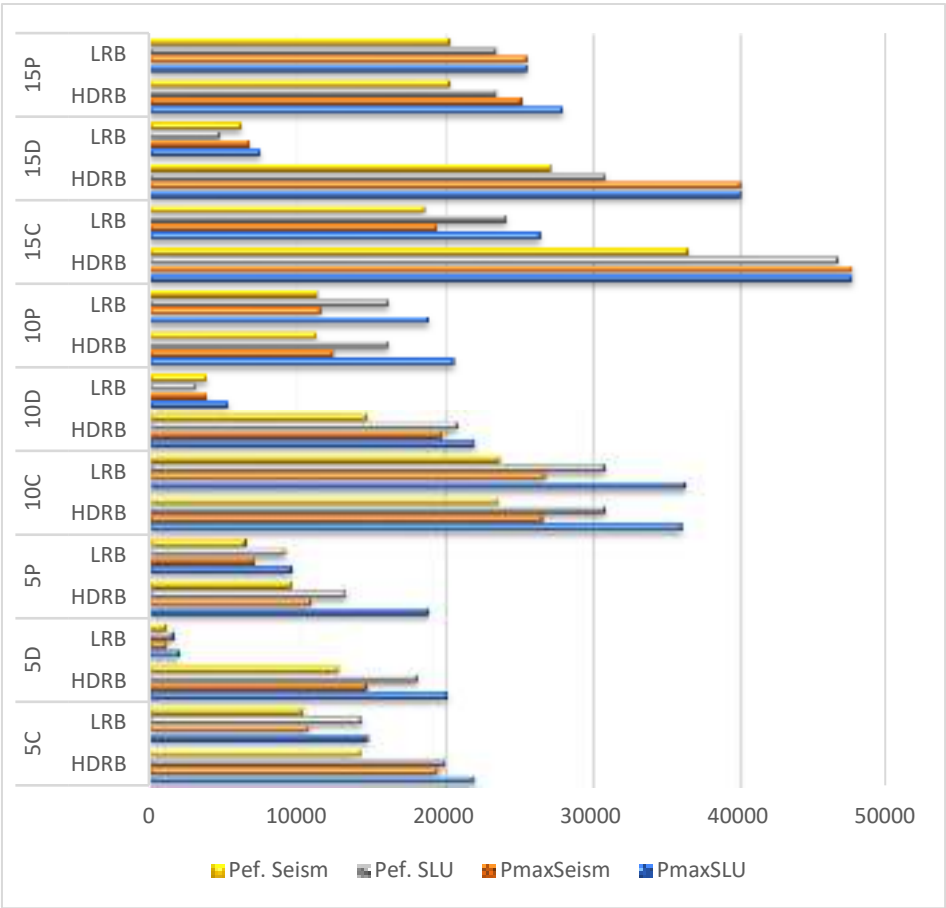


Figure 95 "Axial stresses in isolators depending on the shape and height regime of buildings"

3 CONCLUSIONS

From the point of view of the fundamental periods of vibration:

- For buildings with 5 levels, the fundamental vibration periods increase by about 20 times in case of using HDRB type isolators, respectively 15 times in case of using LRB type isolators;
- For buildings with 10 levels, the fundamental vibration periods increase by about 9 times in the case of using HDRB type isolators, respectively 7.4 times in the case of using LRB type isolators;
- For buildings with 15 levels, the fundamental vibration periods increase by about 5.4 times in the case of using HDRB type isolators, respectively by 4.7 times in the case of using LRB type isolators;

Conclusion - the more rigid the buildings, the shorter the length of the fundamental vibration periods by using seismic isolators.

This conclude that it looks like HDRB type isolation systems, regardless of the type of structure chosen (masonry, reinforced concrete frames or reinforced concrete dual RC systems), the fundamental vibration periods when using LRB type isolators are about 80% of the fundamental vibration periods for using HDRB type seismic isolators (so HDRB makes the structure 20% more flexible than LRB).

In terms of displacements (including the isolated base displacements):

- For 5-level buildings, the drifts increase in case of using HDRB type seismic isolators by about 30% and by 50% in case of using LRB type seismic isolators;
- For buildings with 10 levels, the drifts increase in case of using HDRB type seismic isolators by about 2% and by 20% in case of using LRB type seismic isolators;
- For buildings with 15 levels, the drifts decrease in case of using HDRB type seismic isolators by about 2% and respectively increase by 2% in case of using LRB type seismic isolators;
- In the case of using seismic isolators, the more levels the buildings have (the more flexible they are) the drift decreases respectively the more rigid the buildings (fewer levels) the drift increases. It is found that HDRB type seismic isolators are more efficient in terms of drift.
- At the base it is found that on average the displacements increase more for the buildings that use seismic isolators of LRB type compared to HDRB.
- For buildings with 5 levels the displacements are on average about 30 cm, for buildings with 10 levels are 35 cm and for buildings with dual structure with 15 levels reach about 40 cm.

From the point of view of the sectional efforts in the elements of the structure:

• For RC walls:

Table 44 "Reports of maximum efforts in the walls"

Levels	BENDING MOMENTS			SHEAR FORCES			AXIAL FORCES		
	HDRB/ /Uns	LRB/ /Uns	LRB/ HDRB	HDRB/ Uns	LRB/ Uns	LRB/ HDRB	HDRB/ Uns	LRB/ Uns	LRB/ HDRB
5	0.67	0.93	1.38	0.73	1.22	1.77	1.01	1.00	0.99
10	0.48	0.59	1.22	0.60	0.74	1.22	1.01	1.01	1.00
15	0.81	0.86	1.07	0.53	0.58	1.08	0.98	0.98	0.99

- Sectional efforts such as bending moments and shear forces, at the RC walls in the case of using seismic isolators, they are reduced to about 48-93% of the efforts corresponding to the non-isolated structure;
- The sectional efforts of axial force type practically remain with the same values;
- Sectional stresses decrease more when using HDRB type seismic isolators compared to LRB.

• For RC columns:

Table 45 "Maximum stress reports in columns"

Levels	BENDING MOMENTS			SHEAR FORCES			AXIAL FORCES		
	HDRB/ Uns	LRB /Uns	LRB/ HDRB	HDRB/ Uns	HDRB/ Uns	LRB/ HDRB	HDRB/ Uns	LRB/ Uns	LRB/ HDRB
5	0.83	0.92	1.12	0.82	0.93	1.13	1.00	1.00	1.00
10	0.68	0.98	1.03	0.83	0.98	1.19	0.99	0.94	0.94
15	0.76	0.84	1.10	0.76	0.74	0.98	1.11	1.07	0.97

- The sectional efforts of the type bending moments and shear forces, at the RC columns, in case of using seismic isolators, are reduced to about 68-98% of the efforts corresponding to the non-isolated structure;
- The sectional efforts of axial force type practically remain with the same values;
- Sectional stresses decrease more when using HDRB type seismic isolators compared to LRB.

• For RC beams from:

Table 46 "Maximum Beam Strength Reports"

Levels	BENDING MOMENTS			SHEAR FORCES			AXIAL FORCES		
	HDRB /Uns	LRB / Uns	LRB/ HDRB	HDRB/ Uns	HDRB/ Uns	LRB/ HDRB	HDRB/ Uns	LRB/ Uns	LRB/ HDRB
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.86	0.95	1.11	0.88	0.97	1.10	0.91	0.92	1.02
15	0.79	0.84	1.06	0.85	0.89	1.05	0.79	0.83	1.03

- By using seismic isolators, the sectional efforts on the beams (positive and negative bending moments as well as the shear forces) decrease only for buildings with more than 5 levels. The more levels the building has, the more and more there is a decrease (86-95% at 10 levels).
- It is also found that (in the sense of those presented above) the efforts decrease more in the case of using HDRB type seismic isolators than LRB type ones.

Considering all the above, for the buildings that are designed with the RC dual structure, with low and medium height regime (up to 15 levels) it is found that HDRB type seismic isolators are more efficient than LRB type seismic isolators.

CHAPTER 6 CONCLUSION

6.1 Personal contributions

This is just a doctoral thesis and after more than almost 100 case studies, I considered, listed and presented some of the answers and conclusions collected for all the data obtained and included in the previous chapters.

My first conclusion is that everyone is good at seismic isolation of the base, as well as at football, but very few specialists in the field have ever tried to make personal calculations. To have a representative and well serious conclusion a lot of study cases must be solved, and the conclusion occur from here.

According to the main objectives presented in the second chapters and after the conclusions highlighted on each chapter, here finally I presented some general conclusion.

Several buildings and constructions were presented for which the principle of base insulation was applied, both internationally and from Romania.

I, as a personal idea, considered, for this thesis, three distinct types of structures for usual buildings:

- Masonry structures - to be able to have information regarding possible consolidation works, especially for historical buildings with historical or later masonry;
- Reinforced concrete structures:
 - Only with reinforced concrete frames;
 - With two structural subsystems (reinforced concrete frames and reinforced concrete walls).

Different height regimes were considered, starting from the low ones with 1-2 levels (for masonry) and going further to 5, 10 and 15 levels (for reinforced concrete structures). Of course, anyone can easily make (from now on) calculations for different height regimes, for different shapes in the plan and different types of seismic isolators.

It is for sure, from the real specialist in the field, that for the low-rise buildings - which are pretty much stiff than the others, that the drifts increase more than for the others.

Also, to observe the coupling phenomena between the fundamental translation periods of vibration and torsion, 3 types of shapes in the plane were chosen (square, rectangular and circular).

In each of the modeled, in-depth and analyzed case studies, comparisons were made both between the “initial” model, without seismic isolation of the base, but also for the use of two types of basic seismic isolators, LRB and HDRB type (established from the beginning).

Of course, other basic seismic isolators can be used and countless calculations can be performed, but all these will start from principles similar to those outlined in this thesis.

The fact that in the analyzed case studies the height regime is comprised from a few levels and going up to 15 (low rise to high rise buildings), confers to the conclusions obtained and presented at the end of each chapter, the character of generality. That is why in this chapter are listed only the personal contributions assumed and the main directions of future studies.

Following all the cases analyzed and presented, general conclusions were established, as follows:

- The adoption of structural systems in the idea of seismic isolation of the base involves:

- Choice of a manufacturer (because all subsequent calculations will be based on data provided by each manufacturer, for the basic seismic isolators they produced) - so, unlike current calculations, with the method of ranking hierarchies, in the case of using basic seismic isolators, the acceptance of a manufacturer is paramount;
- Adoption of technologies to achieve all the necessary structural elements, starting from the base to the superstructure (accepting a maximum displacement at the base capable of isolators) but also devices to prevent upper movements, sidewalks and access stairs that allow these movements in plan horizontal, flexible connections to water, gas, electricity and other networks;
- Future concepts regarding technologies for time replacement of previously chosen seismic isolation devices, because of the overtime aging.
- Comparisons were made at the level of fundamental periods of vibration, deformations but also sectional efforts (for columns, structural walls and beams – as well for axial forces, shear forces and bending moments) between structural systems without seismic isolation of the base but also for the use of base seismic isolators type LRB and HDRB. It was clearly and obviously that from the two initial chosen isolation systems (LRB and HDRB), the HDRB type meets all the aspects necessary for the initially chosen concept of seismic isolation of the base.
- Regardless of sources, inspired or not from all over the world (European, Japanese or American manufacturers), the problem of achieving these structural systems but also maintenance over time is difficult to assess and for this reason, the main conclusion of this thesis, including aspects of existing case studies but also of those performed, briefly, is the following:
 - As an alternative structural system, the seismic base isolation is unanimously recognized but very little chosen for almost all the designers;
 - Due to the unanimous lack of knowledge about the occurrence or recurrence of earthquakes in the world and regardless of location;
 - Due to the initial adjacent costs;
 - Due to the service life of the isolation systems and the need to replace them over time.

For this reason, additional studies can be done for structural systems:

- With seismic insulation (not only for the base) but also at several other levels (because the interface between the soil and the structure it is not the only one solution of seismic isolation position);
- With seismic isolation of the base but also with additional vertical attenuation measures as well the dampers solution or the TMD (tune mass dampers);
- Mixed structural systems.

The conclusion is that the seismic insulation of the base can be an alternative to the design of new strength structures or to the retrofitting of existing buildings or constructions, only that all these alternatives must be judged in relation to all the costs that will exist.

Following all the research, the idea is simple, despite the cracks in the field: seismic insulation of the base can be an alternative for buildings with small, medium and height rise depending on the type of the buildings analyzed and / or if it is buildings existing or new. In short, everything comes down to costs. For historic heritage buildings, sometimes the best system is this one (but in accordance with all the UNESCO, Iscarah and all the monuments and heritage codes and pacts.

6.2 Main directions of study for the future:

- Carrying out comparative case studies, for existing buildings with the RC frame and dual structure, designed in accordance with the type codes P13-63; P13-70; P100-78; P100-82 and P100-92, in case of choosing the seismic isolation solution of the base;
- Carrying out comparative studies are regarding the seismic insulation of the base of some adjacent sections of the existing buildings with dual structure.
- Avoiding collisions between sections by using special devices to attenuate them or by coupling the sections.
- Using of different isolators for the base/substructure but also dampers for the superstructure.

REFERENCES

1. P100-1/2013 - Cod de Proiectare Seismica - Partea I - Prevederi de proiectare pentru clădiri, Bucuresti, 2013
2. Anil K. Chopra - Dynamics of Structures - Theory and Applications to Earthquake Engineering, New Jersey, 1995
3. Cristian Ghindea, Nicolai Țopa - Studiu de Caz Asupra unor Structuri cu Bază Izolată, 2007
4. Ahmed Elgamal, Michael Fraser - Seismic Isolation & Energy Dissipation Systems, 2004
5. Trevor H. Kelly - Base Isolation of Structures, Design Guidelines, 2001
6. Satish Nagarajaiah, Andrei M. Reinhorn, Michalakis C. Constantinou -Nonlinear Dynamic Analysis of 3D Base-Isolated Systems, 1991
7. Opreșoreanu V. V. – “Contribuții la aplicarea izolării bazei în proiectarea seismică din România”, 2012
8. A.B.M. Saiful Islam, Mohammed Jameel, Mohd Zamin Jumaat - Seismic Isolation in Buildings to be a Practical Reality: Behavior of Structure and Installation Technique, 2011
9. Michael D. Symans - Seismic Protective Systems, Seismic Isolation
10. M. Ala Saadeghvaziri, Maria Q. Feng - Experimental and Analytical Study of Base-Isolation for Electric Power Equipment
11. Wang Yen-Po - Fundamentals of Seismic Base Isolation, Taiwan
12. Sajal Kanti Deb - Seismic Base Isolation - An overview, India, 2004
13. Farzad Naeim, James M. Kelly - Design of Seismic Isolated Structures, From Theory to Practice, 1999
14. M. Garevsky, J. M. Kelly - Analysis of 3-d vibrations of the base isolated school building "Pestalozzi" by analytical and experimental approach
15. Iordăchescu A & E., Consolidarea clădirii “Victor Slăvescu” prin metoda izolării bazei. Revista AICPS Nr.2-3 , 2010
16. Algasism (2012) FRICTION PENDULUM ISOLATORS, Alga Brochure
17. Eurocode 2 - Design of concrete structures - Part 1-1: General rules and rules for Buildings
18. Eurocode 8 - Design of structures for earthquake resistance
19. <https://www.ibtimes.co.uk/2011-earthquake-tsunami-60-powerful-photos-disaster-that-hit-japan-five-years-ago-1548255#slideshow/1496941>
20. <https://www.revistaconstructiilor.eu/index.php/2007/11/09/consolidarea-cladirii-primariei-municipiului-bucuresti-prin-metoda-izolarii-bazei/>
21. <https://da.zf.ro/companii/constructii/strazile-pe-care-inca-se-afla-istoria-capitalei-harta-strazilor-din-bucuresti-cu-cele-mai-multe-cladiri-monument-istoric-galerie-foto-11046267/galerie-foto/?p=11>
22. <https://www.revistaconstructiilor.eu/index.php/2008/10/30/consolidarea-cladirilor-prin-metoda-izolarii-bazei/>
23. Andersen, L., Hausgaard Lyngs, J. (2009). Shortcomings of the Winkler Model in the Assessment of Sectioned Tunnels under Seismic Loading, DCE Technical Memorandum No. 10, Aalborg University.
24. Anderson, D.G., Richart, F.E. Jr. (1976). Effects of Straining on Shear Modulus of Clays, Journal of Geotechnical Engineering, Division ASCE, pp.1-27.
25. ASCE Standard 4-86 (1986). Seismic Analysis of Safety Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety Related Nuclear Structures, Published by the American Society of Civil Engineers.
26. Bazavan Domnita – Efectele interactiunii seismice teren-structura la constructii partial ingropate si ingropate – Teza de doctorat – UTCB 2010

27. Bilotta, E., Lanzano, G., Gianpiero, R. et.al. (2007). Pseudostatic and Dynamic Analyses of Tunnels in Transversal and Longitudinal Directions, 4th International Conference on Earthquake Geotechnical Engineering, Thessaloniki, Greece.
28. Biswal, K., Bhattacharyya S. K., Sinha, K. (2003). Dynamic Characteristics of Liquid Filled Rectangular Tank with Baffles, IE (I) Journal, Vol 84, August.
29. Boncheva, H. (1977). Soil Amplification Factor of Surface Waves, Proceedings of the 6th World Conference on Earthquake Engineering, January, New Delhi.
30. Bozorgnia, Y., Bertero, V.V. (editors, 2004). Earthquake Engineering from Engineering Seismology to Performance-Based Engineering, CRC Press. C239–92 (1993). Îndrumător tehnic provizoriu pentru calculul terenului de fundare, al presiunii pământului pe lucrări de susținere și al stabilității taluzurilor și versanților la acțiuni seismice, Buletinul Construcțiilor, vol. 3/1993.
31. Chang, C.Y., Power, M.S., Mok, C.M., Tang, Y.K., Tang, H.T. (1990). Analysis of Dynamic Lateral Earth Pressures Recorded on Lotung Reactor Containment Model Structure, Proceedings, 4th U.S. National Conference on Earthquake Engineering, pp. 643-652, EERI.
32. Chen, W-F., Scawthorn, C. (editors, 2003). Earthquake Engineering Handbook, Vol.1, CRC Press.
33. Chopra, A.K. (2007). Dynamics of Structures. Theory and Applications to Earthquake Engineering, Pearson, Prentice Hall, NJ.
34. Das, B.M. (2004). Principles of Foundation Engineering, 2nd Edition, PWS–KENT Publishing Company, Boston.
35. Day, R.W. (2002). Geotechnical Earthquake Engineering Handbook, McGraw-Hill Handbooks.
36. Duke, C.M. (1960). Foundations and Earth Structures in Earthquakes, Proceedings of the Second World Conference on Earthquake Engineering, Vol.1, Tokyo and Kyoto, Japan, pp.435-455.
37. Electric Power Research Institute (1989). Proceedings: EPRI/NRC/TPC Workshop on Seismic Soil–Structure Interaction Analysis Techniques Using Data from Lotung, Taiwan, Report No.EPRI/NP-6154, March, Palo Alto, California.
38. Electric Power Research Institute (1991). Post – Earthquake Analysis and Data Correlations for the ¼- Scale Containment Model of the Lotung Experiment, EPRI Publication No.EPRI/NP–7305SL, October, Palo Alto, California.
39. Erdey, C.K. (2007). Earthquake Engineering, Application to Design, John Wiley&Sons, Inc.
40. Ghiocel, D. (2004-2006). Comunicări personale.
41. Ghiocel, D.M. (1996). Seismic Motion Incoherency Effects on Dynamic Response, 7th ASCE EMD/STD Joint Specialty Conference on Probabilistic Mechanics and Structural Reliability, Worcester M.A.
42. Ghiocel, D.M. (1998). Uncertainties of Seismic Soil–Structure Interactions Analysis: Significance, Modeling and Examples, US-Japan Workshop on Soil–Structure Interaction, San Francisco.
43. Ghiocel, D.M. (1999). SUPER SASSI/PC: A Complete Dynamic Soil-Structure Interaction System on Personal Computers, Advanced Computational Software, INC. Pittsford, N.Y.
44. Hadjian, A. H., Tang, H.T. (1991). Soil Spring SSI Improvements Based on Test Correlation of the Lotung SSI Experiment – Horizontal Excitation, Proceedings of the 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, March 11-15.
45. Haiano, K., Matsumoto, M., Tatsuoka, F., Koseki, J. (2001). Evaluation of Time-Dependent Deformation Properties of Sedimentary Soft Rock and Their Constitutive

- Modeling, Soils and Foundations, Japanese Geotechnical Society, Vol.41, No.2, 21-38, April 2001.
46. Hani M. (1992). Soil-Structure Interaction under Random Excitation, Ph.D. Thesis, I.C.B.
 47. Hardin, B.O., Black, W.L. (1969). Closure to Vibration Modulus of Normally Consolidated Clays, Proceedings ASCE: Journal of the Soil Mechanics and Foundations Division, Vol.95 (SM6), pp.1531–1537.
 48. Hardin, B.O., Drnevich, V.P. (1972). Shear Modulus and Damping in Soils: Design Equations and Curves, Proceedings of ASCE: Journal of the Soil Mechanics and Foundations Division, Vol. 98 (SM7), pp.667–692.
 49. Hirota, M., Sugimoto, M., Onimaru, S. (1992). Study on Dynamic Earth Pressure through Observation. Proceedings of 10th WCEE, Madrid, Spain.
 50. Idriss, I.M., Boulanger, R.W. (2008). Soil Liquefaction during Earthquakes, EERI Monograph, MNO-12.
 51. Iwasaki, T., Tatsuoka, F. (1977). Effects of Grain Size Dynamic Shear Modulus of Sands, Soils and Foundations, Vol. 17, No.3., pp.19-35.
 52. Iwasaki, T., Tatsuoka, F., Takagi, Y. (1978). Shear Moduli of Sands under Cyclic Torsional Loading, Soils and Foundations, Vol. 18, No. 1, pp. 39-56.
 53. Kausel, E. et al. (1978). The Spring Method for Embedded Foundation, Nuclear Engineering and Design, No.48, North Holland Publishing Company.
 54. Kokusho, T., et.al. (1982). Dynamic Properties of Soft Clay for Wide Strain Range, Soil Foundations, Vol.22, No.4, pp.1-18.
 55. Koyama, K., Kusano, N., Ueno, H., Kondoh, T. (1992). Dynamic Earth Pressure Acting on LNG in-Ground Storage Tank During Earthquakes, Proceedings of 10th World Conference on Earthquake Engineering, July, Madrid, Spain.
 56. Koyama, K., Watanabe, O., Kusano, N. (1988). Seismic Behavior of In-Ground LNG Storage Tanks During Semi-Long Period Ground Motion, Proceedings of 9th World Conference on Earthquake Engineering, August 2–9, Tokyo-Kyoto, Japan.
 57. Kusano, N., Koyama, K., Ueno, H., Kondoh, T. (1992). Dynamic Earth Pressure Acting on LNG In-Ground Storage Tank During Earthquakes, Proceedings of 10th World Conference on Earthquake Engineering, July, Madrid, Spain.
 58. Kramer, S.L. (1996). Geotechnical Earthquake Engineering, Prentice-Hall, Englewood Cliffs, NJ.
 59. Lee, K.L., Chan, K. (1972). Number of Equivalent Significant Cycles in Strong Motion Earthquakes, Proceedings of the International Conference on Microzonation for Safer Construction Research and Application, Vol. 2, October 30-November 3, Seattle, Wahington, pp.609-627.
 60. Lee, W.H.K., Kanamori, H., Jennings, P.C., Kisslinger, C. (editors, Part A: 2002. Part B: 2003). International Handbook of Earthquake & Engineering Seismology, Academic Press.
 61. Loganathan, N., Poulos, H.G., Xu, K.J. (2001). Ground and Pile-Group Responses Due to Tunneling, Soils and Foundations, Japanese Geotechnical Society, Vol.41, No.1, 57-67, February.
 62. Luco, J.E. (1974). Impedance Functions for a Rigid Foundation on a Layered Medium. Nuclear Engineering and Design, No.31 (2), pp.204-217, North Holland Publishing Company.
 63. Lysmer, J., Tabatabaie–Raissi, M., Tajirian, F, et al. (1981). SASSI, A System for Analysis of Soil–Structure Interaction, Report No.GT (2), pp.1-54, University of California at Berkeley.
 64. Lysmer, J., Udaka, T., Tsai, C.F., Seed, H.B. (1975). FLUSH a Computer Program for Approximate 3D Analysis of Soil-Structure Interaction Problems, Earthquake Engineering

- Research Center, Report no. EERC 75-30 November 1975, College of Engineering, University of California at Berkeley, California, U.S.A.
65. Lysmer, J., Udaka, T., Tsia, C.F., Seed, H.B. (1975). FLUSH—A Computer Program for Approximate 3D Analysis of Soil–Structure Interaction Problems, Report EERC No.75-30, pp.1-83, Earthquake Engineering Research Center, University of California at Berkeley.
 66. Marcuson III, W.F., Wahls, H.E. (1972). Time Effects on Dynamic Shear Modulus of Clays, *Journal of the Soil Mechanics and Foundations Division*, Vol.98, No.12, pp.1359-1373.
 67. Matsumoto, H., et.al. (1991). Earthquake Observation of Deeply Embedded Building Structure, *Proceedings of 6th Canadian Conference on Earthquake Engineering*, June, Toronto, Canada.
 68. Miller, C.A., Constantino, C. (1994). Seismic Induced Earth Pressures in Buried Vaults, *Natural Hazard Phenomena and Mitigation*, ASME, Vol.271, pp.3-11.
 69. Mononobe N, Matsuo H. (1929). On the Determination of Earth Pressures during Earthquakes, *Proceedings of World Engineering Conference*, Vol.9, Paper 388.
 70. Nadim, F., Whitman, R.V. (1984). Coupled Sliding and Tilting of Gravity Retaining Walls During Earthquakes, *Proceedings of the 8th World Conference on Earthquake Engineering*, Vol.3, San Francisco, pp.477-484.
 71. NIST GCR 12-917-21 - Soil-Structure Interaction for Building Structures - 2012
 72. Normativ P100-1-2006 (2006). Cod de proiectare seismică – Partea I – Prevederi de proiectare pentru clădiri, MTCT, București.
 73. Nuclear Regulatory Commission (1991). Proposed Staff Positions on Lateral Earth Pressures on Retaining Walls and Embedded Walls of Nuclear Power Plant Structures, Civil Engineering and Geoscience Branch, Division of Engineering of Nuclear Reactor Regulations.
 74. Ohtsuka, Y., Fukuoka, A., Akino, A., Ishida, K. (1996). Experimental Studies on Embedment Effects on Dynamic Soil-Structure Interaction, *Proceedings of 11th World Conference on Earthquake Engineering*, Acapulco, Mexico, Paper 59.
 75. Ohtsuka, Y., Fukuoka, A., Yanagisawa, E., Fukudome, H. (1992). Embedment Effects on Dynamic Soil-Structure Interaction, *Proceedings of 10th World Conference on Earthquake Engineering*, Madrid, Vol.3, pp.107-1712.
 76. Okabe, S. (1926). General Theory of Earth Pressure, *Journal, Japanese Society of Civil Engineers*, Vol. 12, No. 1, Tokyo.
 77. Onimaru, S., Sugimoto, M., Ohmiya, Y., Sugawara, Y., Ogihara, M. (1995). Study of Dynamic Earth Pressure Acting on a Deeply Embedded Structure, *Transactions of the 13th International Conference on Structural Mechanics in Reactor Technology*, Eschola de Engenharia – Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil.
 78. Ostadan, F., White, W.H. (1997). Lateral seismic Soil Pressure an Updated Approach, Bechtel technical grant report, Bechtel Corporation, San Francisco, California.
 79. Ostadan, F., White, W.H. (1998). Lateral seismic Soil Pressure – An Updated Approach, US–Japan SSI Workshop, September 22-23, USGS, Menlo Park, California.
 80. Prange, B. (1977). Parameters Affecting Damping Ratio, *Proceedings of dynamic Methods in Soil and Rock Mechanics*, Vol. 1, September, pp.61-78.
 81. Ramberg, W., Osgood, W. T. (1943). Description of Stress-Strain Curves by Three Parameters, Technical Note 902, National Advisory Committee of Aeronautics, Washington DC.
 82. Richards, R., Elms, D.G. (1979). Seismic behavior of gravity retaining walls, *Journal of Geotechnical Engineering Division*, ASCE 105 GT4, pp. 449–464.
 83. Romo M.P., Chen, J.H., Lysmer J., Seed, H.B. (1980). PLUSH—A Computer Program for

84. Probabilities Finite Element Analysis of Seismic Soil–Structure Interaction, Report EERC No.7701, Earthquake Engineering Research Center, University of California at Berkeley.
85. Sandi, H. (1979). Measures of ground motion, Proceedings of 2nd US National Conference on Earthquake Engineering, Stanford University, CA.
86. Sandi, H. (1983). Elemente de dinamica structurilor, Editura Tehnică, București.
87. Sandi, H. (2006-2008). Comunicări personale.
88. Sandi, H., Borgia, I.S., Stancu, M., Stancu, O., Vlad, I., Vlad, N. (2004). Influence of source mechanism versus that of local conditions upon content of ground motion, Proceedings of 13th World Conference on Earthquake Engineering, Vancouver.
89. Scott, R.F. (1973). Earthquake induced pressures on retaining walls, Proceedings of 5th World Conference on Earthquake Engineering, Vol.2, pp.1611-1620, Rome, Italy.
90. Seed, H.B., Idriss, I.M. (1970). Soil Module and Damping Factors for Dynamic response Analysis, Report EERC 70-10, University of California at Berkeley.
91. Seed, H.B., Idriss, I.M. (1983). Ground Motions and Soil Liquefaction during Earthquakes, Earthquake Engineering Research Institute, Oakland, California.
92. Seed, H.B., Schnabel, P., (1976). Soil and Geologic Effects on Site Response during Earthquakes, Seminar on Seismic Microzoning, June 1976, Thessaloniki – Greece.
93. Seed, H.B., Whitman, R.V. (1970). Design of Earth Retaining Structures for Dynamic Loads, State-of-the-art paper presented at the 1970 ASCE Specialty Conference on Lateral Stresses in the Ground and Design of Earth-Retaining Structures, June 22-24, Cornell University, Ithaca, New York.
94. Stoica, D. - Modelarea interactiunii teren-structura pentru cladiri – note de curs – UTCB 2013
95. Tsai, N.C. (1980). The Role of Radiation Damping in the Impedance Function Approach to Soil – Structure Interaction Analysis, Lawrence Livermore Laboratory, Livermore, California, UCRL-15232.
96. Valera, J.E., Donovan, N.C. (1977). Soil Liquefaction Procedures—A Review, Journal of Geotechnical Engineering, Division ASCE, Vol. 103, pp.607–625.
97. Veletsos, A. Younan, A.H. (1994). Dynamic Soil Pressure on Rigid Vertical Walls, Journal of Earthquake Engineering and Soil Dynamics, Vol. 23, Issue 3, pp.275 – 301.
98. Veletsos, A., Younan, A.H. (1994). Dynamic Modeling and Response of Soil–Wall Systems, Journal of Geotechnical Engineering, Vol. 120, No.12, December, pp.2155-2179.
99. Waas, G. (1972). Linear Two Dimensional Analysis of Soil Dynamics Problems in Semi – Infinite Layered Media, PhD Thesis, University of California at Berkeley.
100. Watakabe, M., et.al. (1992). Earthquake Observation of Deeply Embedded Building Structures, Proceedings of 10th WCEE, July, Madrid, Spain.
101. Wood, J.H. (1973). Earthquake-induced pressures on retaining walls, Report EERL 73-05, Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena
102. P100-1/2006 - Cod de Proiectare Seismica - Partea I - Prevederi de proiectare pentru cladiri, Bucuresti, 2006
103. Anil K. Chopra - Dynamics of Structures - Theory and Applications to Earthquake Engineering, New Jersey, 1995
104. Cristian Ghindea, Nicolai Topa - Studiu de Caz Asupra unor Structuri cu Baza Izolata, 2007
105. Ahmed Elgamal, Michael Fraser - Seismic Isolation & Energy Dissipation Systems, 2004
106. Trevor H. Kelly - Base Isolation of Structures, Design Guidelines, 2001
107. Satish Nagarajaiah, Andrei M. Reinhorn, Michalakis C. Constantinou -Nonlinear Dynamic Analysis of 3D Base-Isolated Systems, 1991

108. A.B.M. Saiful Islam, Mohammed Jameel, Mohd Zamin Jumaat - Seismic Isolation in Buildings to be a Practical Reality: Behavior of Structure and Installation Tehnique, 2011
109. Michael D. Symans - Seismic Protective Systems, Seismic Isolation
110. M. Ala Saadeghvaziri, Maria Q. Feng - Experimental and Analytical Study of Base-Isolation for Electric Power Equipment
111. Wang Yen-Po - Fundamentals of Seismic Base Isolation, Taiwan
112. Sajal Kanti Deb - Seismic Base Isolation - An overview, India, 2004
113. Farzad Naeim, James M. Kelly - Design of Seismic Isolated Structures, From Theory to Practic, 1999
114. "Dinamic of structures" – R.W.Clough, J. Prezien (1993)
115. "Application of tuned mass damper for vibration control of frame structures under seismic excitation" – Rasmi Mishra (2011)
116. "The effect of tuned-mass dampers on the seismic response of base-isolated structures" – Hsiang-Chuan Tsai (1993)
117. "Optimal design theories and applications of tuned mass dampers" - Chien-Liang Leea, Yung-Tsang Chen (2006)
118. D. Cretu; E. Tulei; C. Ghindea; R. Cruciat - Eficienta dispozitivelor pasive de control la reabilitarea seismica a unei cladiri din bucuresti
119. Tulei E., Cretu D., Ghindea C. (2008), Seismic rehabilitation of a reinforced concrete framed structure by the use of tuned mass dampers and viscous dampers, Proceedings of the International Conference Constructions 2008, 9-10 may 2008, Cluj-Napoca, Romania, Vol.1, p.283-290
120. Tulei E., Cretu D., Lungu D. (2009), Study on seismic upgrade of 5 storey reinforced concrete building by Tuned Mass Damper, Proceedings of the International Conference on Protection of Historical Buildings, Prohitech 09, Rome, Italy, 21-24 june 2009, Vol.1, p.563-568