ANALYSIS OF THE BEHAVIOR OF CIVIL CONSTRUCTIONS UNDER SEISMIC ACTION

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ABSTRACT

This paper presents several seismic simulations for different types of structures located in different seismic zones in Romania. These simulations are very important because the designers can see in real time, which is the behavior of a designed construction, what are the movements (displacement and deformations) and the extent to which these movements may occur. The behavior of constructions under the action of horizontal seismic forces is analyzed in an automatic computing program for structures program that models the designed structure introduced into a spatial framework x, y, and z. The obtained results are given in displacement diagrams, thus presenting a global situation of the analyzed structure.

Keywords: constructions, seismic action, displacement, loading

1. INTRODUCTION

Buildings are real estate products used only where they were finished and are directly linked to the land. Civilian buildings and especially housing have become over the past decades, for the most part, large series of industrial products, prefabricated or monolithic. Under these conditions, it is useful to address the construction issue in the same way as for other industrial products, always starting by specifying the issue to be solved, namely by indicating performance. The concept of performance helps designers to conceive constructions as closely as possible to the seismic requirements; any resolution or solution being valid only if it meets the set of requirements. Buildings are designed to create optimal conditions for sheltering and unfolding human activity and life, taking into account the conditions imposed by nature or the environment in which they will exist (land, climate, etc.). That is why the main factors that determine the conception, composition and execution methods of constructions generally are people, human activity and nature.

In constructions, different classifications are used, depending on the objectives: design, technical prescriptions, economic evidence or statistics, planning and organization of works, documentation, etc. In a functional classification or by destination, similar constructions are grouped in terms of functional requirements and geographic location. From this point of view, the constructions are divided into buildings and engineering works (Fig. 1).
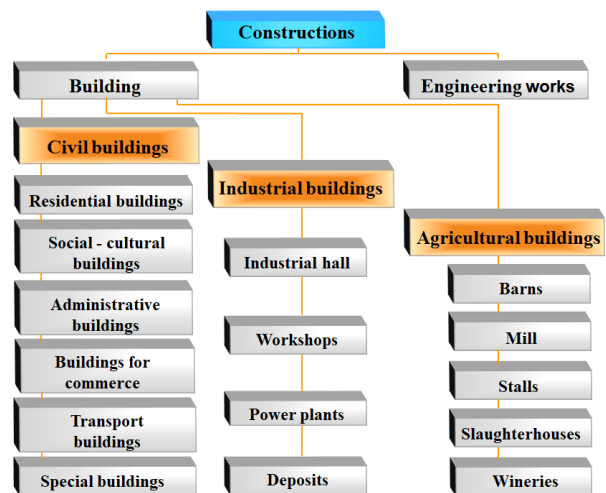

Fig. 1. General classification of constructions

Buildings or civil, industrial and agricultural constructions, shelter people or other living creatures, human activity and labor products against atmospheric weather (blizzard, frost, wind, rain, sunshine, etc.), making possible to adapt to the geographic environment, with so varied and so different climate conditions.

Each building is made up of a series of building elements, fulfilling well-defined roles or functions in the construction assembly. The main building components of a building are the load bearing elements (vertical or horizontal), bumper elements, partitioning, finishing etc.

2. ACTIONS IN CONSTRUCTION

Actions may take the form of forces, displacements or deformations and their limits (under the action of temperature, pressing supports, shrinkage, slow flow, humidity, pre-compression, etc.) in simple, combined or in more complex cases, as a result of the interaction phenomena and processes between the construction and the mechanical-climatic environment actions that, in general, may have different origins, due to: the weight of building elements, functional destination, natural factors as climatic or seismic ones, etc., or in some cases, exception cases (as explosions, radical change of the terrain configuration, etc.) and may have different distributions in space, with static or dynamic character. In calculations, it is necessary to take into account the specificity of these actions, from all these points of view [1].

The load is the result of an action used in construction calculations. Load schemes include graphical representations of forces, displacements or deformation systems, etc., parameters being specified: application points or areas, orientations, static action intensities, frequencies, amplitudes, etc. for dynamic actions. The normed values of the parameters characterizing the actions are benchmarks and are set in the specialized standards, taking into account the specificity of the statistical vulnerability for each type of action [6]. The calculation of the values for the parameters characterizing the actions is usually determined by multiplying the normalized values with load coefficients, taking into account the possible deviations towards the unfavorable sense of the values of these parameters, due to the statistical variability of the actions. They usually have the role of increasing the intensity and are set in the technical prescriptions for each action and for checking at certain limit states. The computed values are called, in an abbreviated way, limit values in verification at the ultimate limit state and exploitation values in checking at the limit states of normal exploitation [2].

Loads can act simultaneously on constructions clustered in different combinations and construction calculations should be done with consideration of the unfavorable combinations possible in practice due to different actions.

In designing civil constructions, it is necessary to identify the actions, to pre-dimension the structural elements that integrate the construction.

Permanent actions are the main actions that affect all constructions. They are continuously applied with a practically constant intensity in relation to time. This intensity can be sensitively reduced (or canceled) only in exceptional cases (for example, through the temporary absence of parts of the structure). Within the permanent actions, the weight of the permanent elements of constructions, the weight and pressure of the earth and the fillings and the effect of pre-compression are considered [12].

Variable actions vary sensitively in relation to time or they may be totally absent in certain time intervals. There are mentioned as temporary actions for civil engineering: current payloads of the plates of residential buildings and social-cultural due to the weight of people, mobile and lightweight machinery, or derived from partition walls, climatic loads due to snow, wind and temperature variations, the pushing ground due to the loading of land with deposited material.

Accidental actions occur very rarely, possibly never in the life of construction, at significant intensities. These are considered to be the actions of explosions or impact actions [2].

The seismic action gives rise to the oscillatory motion of the earth, which causes, in all points of a building located in a seismic area, inertia forces, directed in any direction, representing seismic charges.

The vertical components of these seismic charges are generally small and can be easily taken over by common constructions. However, the horizontal components of seismic charges cause, however, high stresses to the bearing elements, with a totally different distribution of the current/common loads (permanent, useful, etc.) [5].

Earthquakes are the terms used for earth movements, which consist of vibrations generated in the internal volumes of the planet, propagated in the form of waves through the rocks. These vibrations result from the movements of the tectonic plates.

Consideration of the seismic motion of the land as an action on civil constructions raises concerns about two basic aspects, namely, the specificity of physical phenomena occurring in the field and in construction during an earthquake and the succession in time, at a given location, of the generated seismic motion of different earthquakes.

From the point of view of the specific nature of physical phenomena, for the engineering activity, it is necessary to analyze the different modes of action of the seismic movement, in elevated buildings, on which it returns in continuation in the context of presenting general descriptive elements. The studies in this paper are the basis for establishing the fundamental relations used in the engineering calculations for different categories of constructions, equipment, etc. [13].

From the point of view of the time division, on the site of a building, of the various seismic movements, it is necessary to analyze the way in which seismic movements of different intensities, spectral characteristics etc. occur on the respective site. Studies in this direction stay at the base to determine the way of rational insurance and the calibration of the calculation parameters that occur in the relationships established as a result of the studies conducted in the first major direction (thus, allowing for solving the quantitative aspect on the basis of the qualitative solving obtained as a result of studies in the first direction) [4].

The two relevant aspects are, thus, complemented and the understanding of all the problems allows for achieving designed buildings and rationally ensuring them.

The energy released during an earthquake and transmitted through seismic waves is manifested in the area of the earth's surface as a seismic motion of the land. This movement, in turn, is an action on the constructions.

In the current cases, the forms of seismic action are: mainly the oscillatory motion of the abutment points of the buildings in elevation and in some cases, less frequent, the deformations imposed on the constructions [7].

The seismic action is manifested, in the case of elevated buildings, by engaging in the seismic movement of the area land-building contact. This movement spreads across the entire construction, generating a phenomenon of oscillatory, chaotic, spatial stress, particularly intense in the case of strong seismic movements.

3. THE REPRESENTATION OF SEISMIC ACTION FOR DESIGN

The main features of an earthquake outbreak point are the coordinates of the epicenter, φ and λ, the depth of the outbreak h, time at origin H and the magnitude M. The five parameters φ, λ, h, H and M are the simplest physical characterization of an earthquake. In space S_5, each earthquake defines a point with its coordinates (φ, λ, h, H, M)$_i$, and the set of the point i of the space S_5 underlies the notion of seismicity. The problem of the seismicity study is to find the particularities of the distribution of these points in space S_5 and to establish the laws to which this assignment is subject.

The magnitude (or energy) classification allows for studying the law of frequency and, thus, the obtaining of fundamental parameters of the seismicity of a region.

The frequency-magnitude relation of a series of earthquakes is expressed by the equation (1):

$$\log n(M) = a_1 - b_1 M \qquad (1)$$

where n is the number of earthquakes with the magnitude within the range $M \pm \delta M$.

The distribution of cumulative frequency for $M \geq M^*$ is expressed by the equation:

$$\log N (M) = a_2 - b_2 M \qquad (2)$$

obtained by integrating the previous relationship.

The coefficients a_1 and a_2 vary from region to region and depend on the observation period; they can be considered as a measure of seismic activity for a particular region.

The coefficient b should not depend on the observation period and it has long been considered that it would have a universal value. Further research has shown that this parameter significantly varies from region to region.

The coefficient value b in the equation corresponds to the slope of the straight, which best represents the set of observation points (log n, M); this can be determined by the least squares method, regardless of cumulative or non-cumulative frequency.

For designing new constructions in order to resist seismic action, Romanian territory is divided into seismic hazard zones. The seismic hazard level in each area is considered to be constant, in a simplified manner.

Seismic motion at a point on the ground is represented by the elastic response propagation for absolute accelerations. Horizontal seismic action for building design is described by two orthogonal components of the seismic motion, considered independent of each other; in design, the elastic response spectrum of absolute accelerations is considered the same for 2 components [3].

In the dynamic calculation of the structures, the seismic movement is described by the time variation of the acceleration. When a spatial computation model is required, the seismic motion is represented by three accelerograms, corresponding to the three orthogonal directions (two horizontal and one vertical), acting simultaneously. On the two horizontal directions, different accelerograms are used, simultaneously [8].

The fitting of new civil constructions into the natural environment and the built environment is achieved by avoiding the risks involved in the potentially direct or indirect effects of future strong earthquakes.

Three different seismic zones were selected in the present paper, and in each site, there are presented seismic simulations for two different types of civil structures: structures in reinforced concrete frames and dual structures (frames with a central core of reinforced concrete structural walls) having a different height regime: P+10E and P+4E (Figs. 2 and 3).

The chosen locations have accelerations of the different terrain, namely, the city of Sulina, in the Tulcea county, with ag=0.2g, city Vaslui in the county Vaslui, with ag=0.3g and city Focşani in the county Vrancea, with ag=0.4g.

Seismic hazard for design is described by the peak value of the horizontal seismic acceleration of the field, determined for an average reference recursion interval (IMR), hereinafter referred to as the terrain acceleration for the design [9]. The size ag, thus defined, is the characteristic value of the horizontal seismic acceleration of the ground for determining the characteristic value of the seismic action, A_{Ek}.

Conventionally, the design value of seismic action A_{Ed} is equal to the characteristic value of the seismic action A_{Ek}, multiplied by the factor of importance and exposure, $\gamma_{I,e}$:

$$A_{Ed} = \gamma_{I,e} \cdot A_{Ek}$$
$$A_{Ed} = F_b \qquad (4)$$

F_b represents the basic cutting force corresponding to its fundamental mode for each principal horizontal direction, taken into account in the building. The basic cutting force is calculated according to the ground acceleration, the values for the design ag being indicated in Table 1 and in Fig. 4.

4. METHODS, MODELS, AND MATERIALS

In order to establish the structure configurations and to perform the calculations, the SCIA Engineer software was used. SCIA is an automatic computing program for structures driven by static and/or dynamic loads, in accordance with the national and international regulations in force. The modeling of the elements is based on the finite element method, without directly working with the finite elements, but with self-contained entities that can be automatically discretized before calculating. The program can be used for calculating and dimensioning linear elements (linear finite elements) or flat finite elements (floors, walls, 2-bend surfaces).
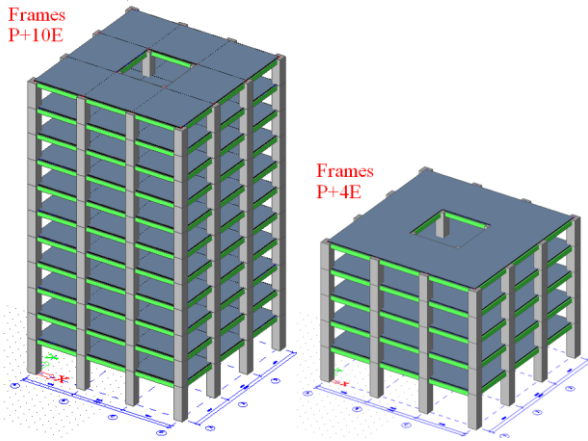
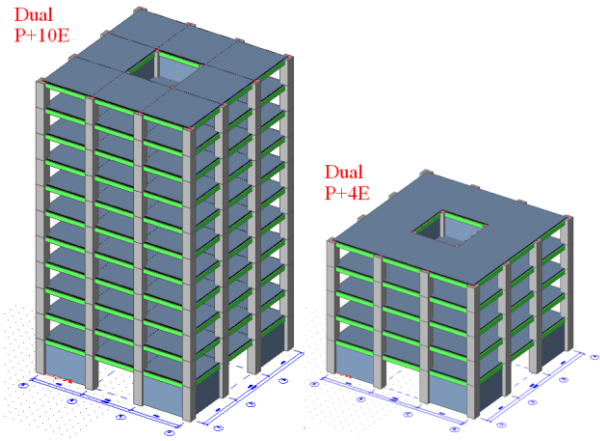Fig. 2. Structures in reinforced concrete frames with height regime P+10E and P+4E

Fig. 3. Dual structures in reinforced concrete with height regime P+10E and P+4E

Table 1. The values of the acceleration of the land for designing, for the chosen urban localities in Romania

Nr.	Locality	District	a_g for IMR=225 years
1	Sulina	TULCEA	0.2g
2	Vaslui	VASLUI	0.3g
3	Focsani	VRANCEA	0.4g
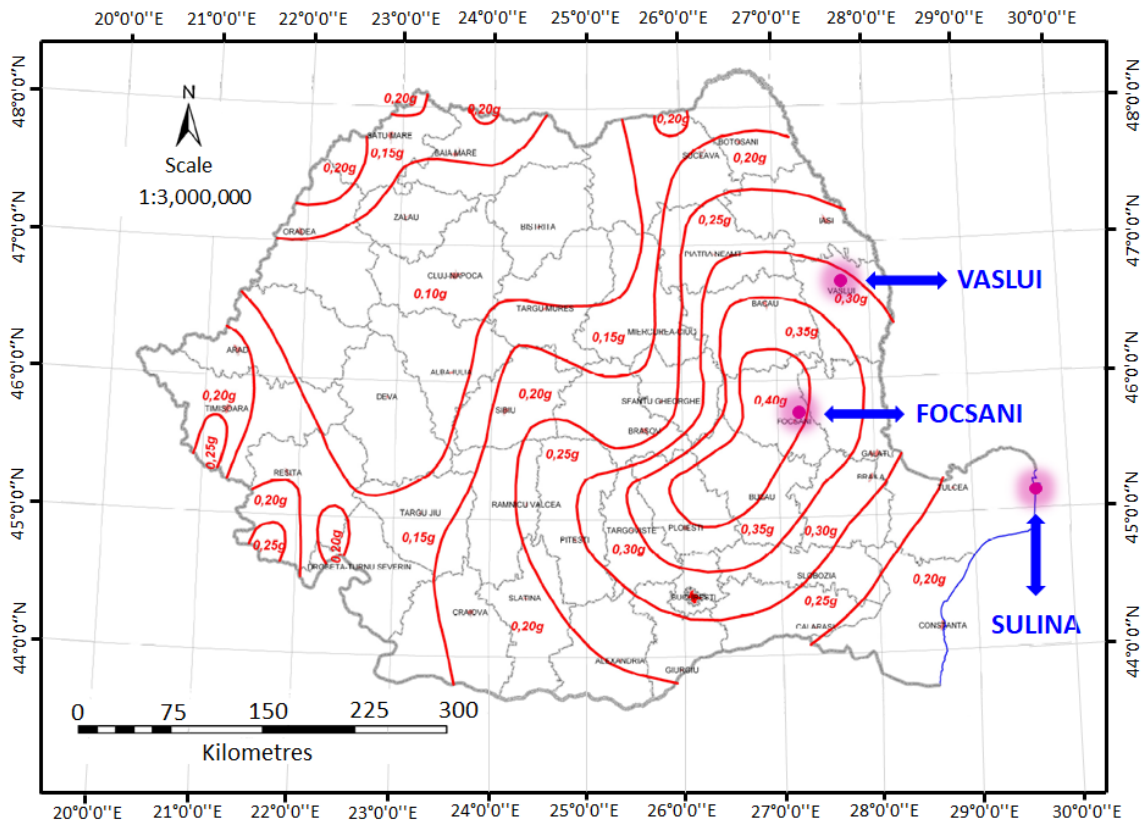
Fig. 4. Zoning of peak acceleration values for IMR design = 225 years and 20% probability of overtaking in 50 years

The program allows for introducing many types of loads, but they are not defined by themselves, but must be included in load cases that allow for their efficient use in defining load combinations.

Load groups are especially important for automatically generating combinations of load cases. The load group can be assigned to a specific load case. The group is considered when generating combinations of load cases, defined based on established relationships, avoiding the introduction of inappropriate load cases [10].

The program performs seismic scenarios for different types of structures, generates bending moment diagrams, cutting force, axial strains, displacements on the two main directions of construction.

The method used in the present context is shown in Fig. 5. By applying the modal analysis, spatial deformations of the construction were taken into account. The structures are represented in a tri-orthogonal system of axes X, Y, Z, in the plane, the Z axis being normal on the structure plane. The structure is constructed as a model of space frames embedded at the base of the pillars on the ground floor (Figs. 6 and 7). Reinforced concrete panels are rigid and resilient to take over the forces produced by the lateral forces, while being non-conformable in the plan.

Columns and beams are shaped as bar elements. When calculating the two types of structures as inputs, the columns have the following dimensions: 90 cm x 90 cm – the marginal columns and those of corner, 100 cm x100 cm – the central columns. The beams, both transversal and those longitudinal, have the size of 30 cm

x 50 cm. Thickness of the plates and structural walls is 15 cm and the height of the level being 3 meters. Cases of loads are appropriate loads from its own weight, load from unstructured wall partitioning, payload, loading from finishes, load from perimeter closures, wind load, snow load and earthquake load [14].

The results of seismic simulations are different for each site. Figures 8 and 9 (see next page) present seismic diagrams for frame structures and for dual structures with two different representations, namely when the seismic force acts in the first phase in the x-direction and when the seismic force acts in the y-direction.

Figure 10 presents the 3D shifts for the structures in reinforced concrete frames, the simulation being performed for the three chosen test areas: Sulina (Tulcea County) with ag = 0.2g, Vaslui (Vaslui County) with ag = 0.3g and Focșani (Vrancea County) with ag = 0.4g.

5. RESULTS AND DISCUSSIONS

The values of frame displacements differ from one test area to another. In the case of the P+10E structure, the maximum lateral displacements in Sulina (0.2g) reach the upper part of the structure of approximately 70 mm, in Vaslui (0.3g) the displacements reach up to 120 mm and in Focsani (0.4g) the deformations are even higher, 230 mm. For P+4E structures, Sulina displacements (0.2g) at the upper part of the structure reach up to 26 mm, in Vaslui (0.3g) the displacements reach up to 39 mm and in Focsani (0.4g) the displacements reach up to about 52 mm.
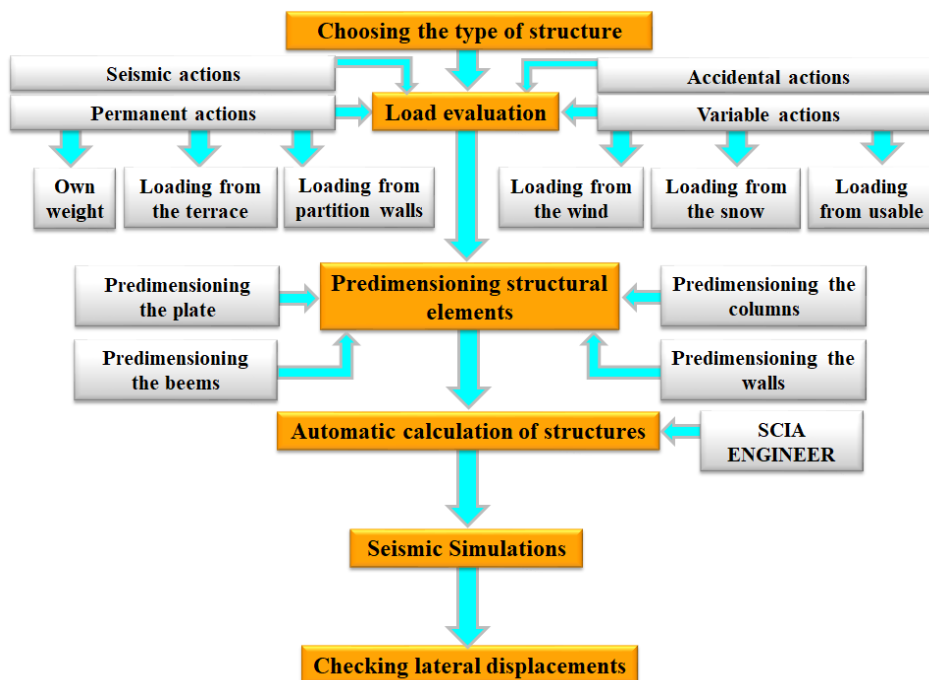

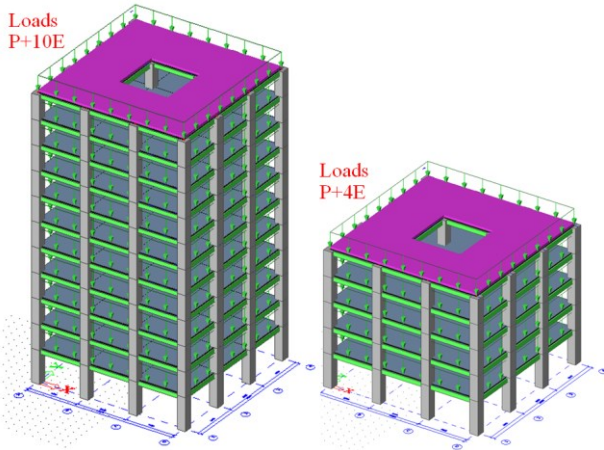**Fig. 5**. The applied method for generating seismic simulations

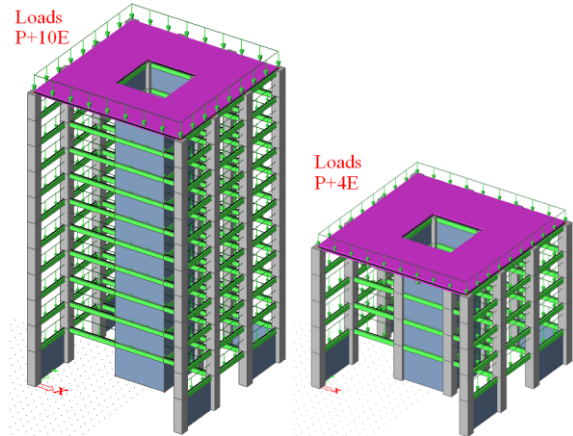**Fig. 6.** Introducing load cases for structures in frames

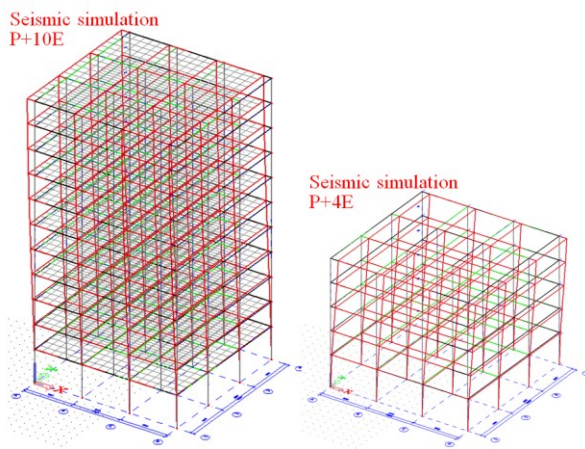**Fig. 7.** Introducing load cases for dual structures

Fig. 8. Seismic simulations for structures in frames when seismic forces act in the x direction
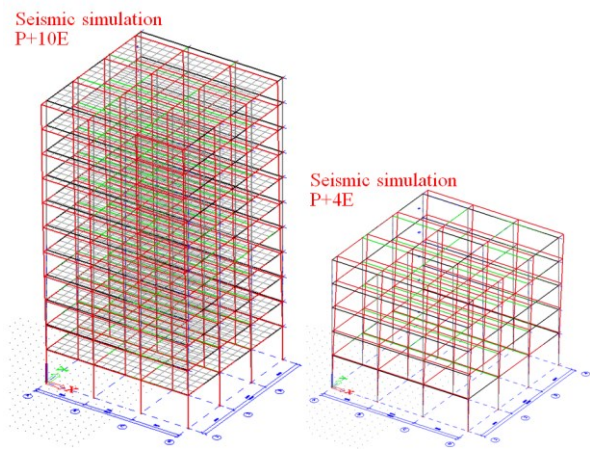

Fig. 9. Seismic simulations for structures in frames when seismic forces act in the y direction
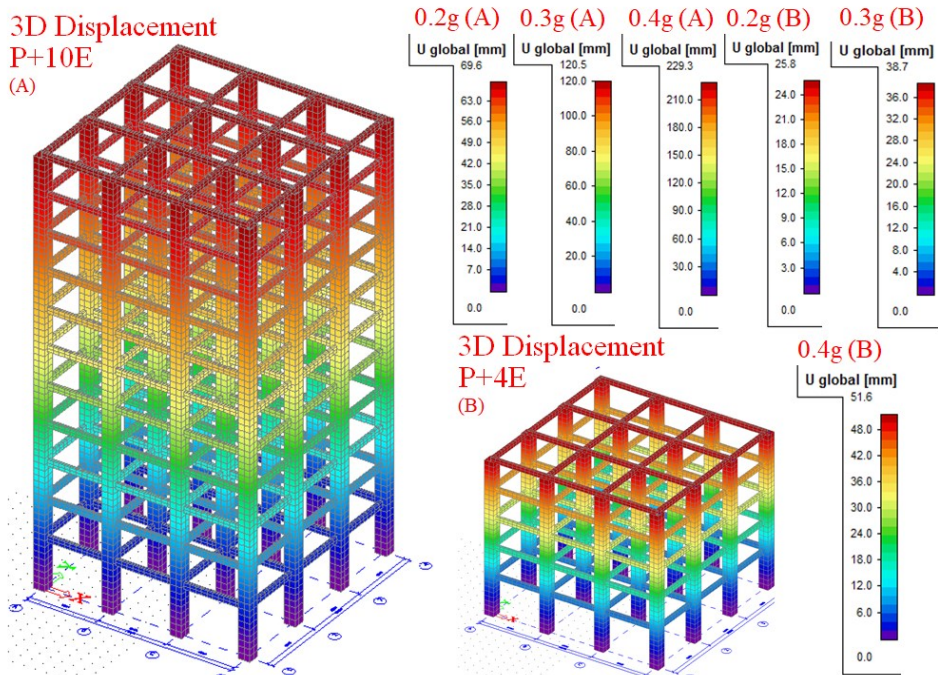

Fig. 10. 3D displacement diagrams for structures in frames, for the three chosen test areas: Sulina (Tulcea County) with ag = 0.2g, Vaslui (Vaslui County) with ag = 0.3g and Focşani (Vrancea County) with ag = 0.4g

Figures 11 and 12 present the diagrams of 3D displacements for the dual structures, the simulation being the same for the three chosen test areas: Sulina (Tulcea County) with ag=0.2g, Vaslui (Vaslui County) with ag=0.3g and Focsani (Vrancea County) with ag=0.4g. The results of the dual structures are presented in Figure 13, the presence of the central core and structural reinforced concrete walls at the ground floor of the structure makes the structure more rigid when subjected to the seismic action, thus, generating values of lateral displacements smaller than the frame structures shown above.

The conditions for controlling lateral displacements at the ultimate limit state involve assessing the displacement requirements, based on the displacement values provided by the elastic structural calculation under the design loads [11].

In this case, the dual structures are very rigid as compared to the structures in the frames, the values of the displacements related to the dual structures are much smaller than those in the frames, in the case of the P+10E structure, the maximum lateral displacements in Sulina (0.2g) are approximately 46 mm, in Vaslui (0.3g) the displacements reach 68 mm and in Focşani (0.4g) the displacements do not exceed 91 mm. The displacements in the P+4E dual structures at Sulina (0.2g) reach up to the maximum threshold of 5 mm, in Vaslui (0.3g) the displacements increase as compared to Sulina with 3 mm, reaching the value of about 8 mm and in Focşani (0.4 g) lateral displacements do not exceed 10 mm. Figure 14 presents the graph of the lateral displacements for the two types of structures.

In general, the earthquake behavior of high-rise structures in reinforced concrete frames and those dual differ both in terms of height (number of levels) and conformation or composition, as well as location, noticing the behavioral differences following the performed simulations.
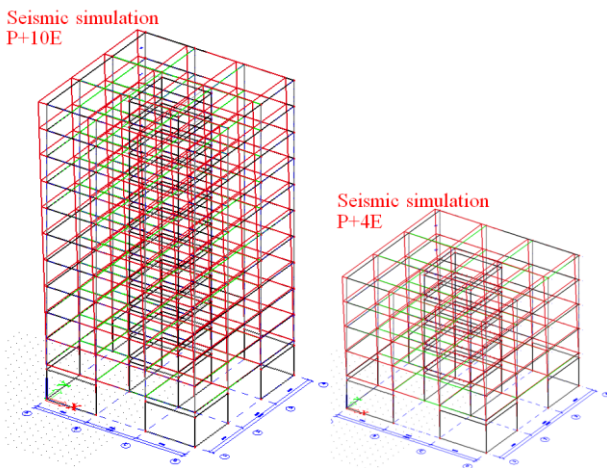

Fig. 11. Seismic simulations for dual structures when seismic forces act in the x direction
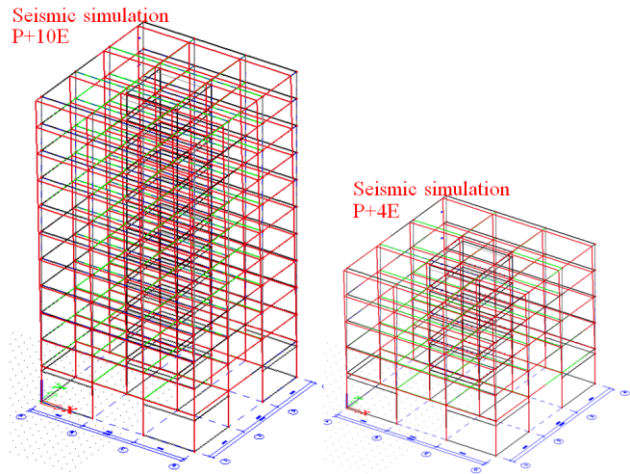

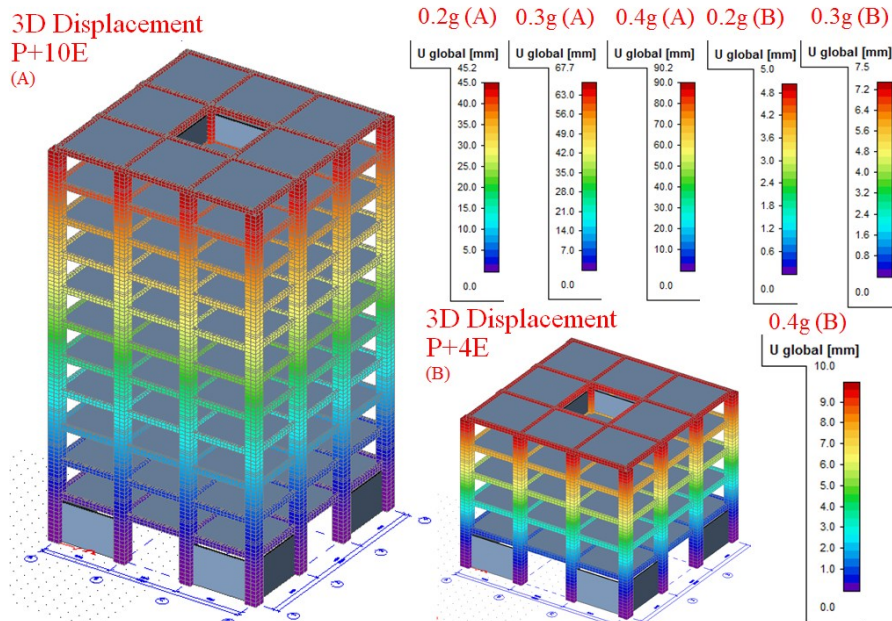**Fig. 12.** Seismic simulations for dual structures when seismic forces act in the y direction

Fig. 13. 3D displacement diagrams for dual structures, for the three chosen test areas: Sulina (Tulcea County) with ag=0.2g, Vaslui (Vaslui County) with ag = 0.3g and Focşani (Vrancea County) with ag = 0.4g
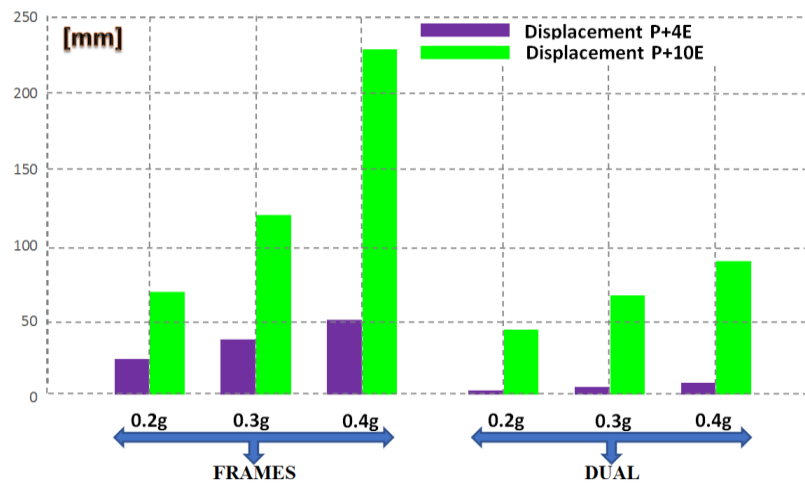
Fig. 14. The graphic of lateral displacements for frame structures and dual structures

The behavior of constructions subjected to complex dynamic movements, such as seismic ones, characterizes the dynamic (seismic) response of the construction itself, which depends on a multitude of factors linked to the specificity of the physical phenomena produced during the earthquake: the intensity of the seismic action, the spectral composition of the movement (geological, hydrological and other conditions), as well as the intrinsic characteristics of the construction (inertia, stiffness, damping capacity, ductility, etc.), the local conditions of land and location (geological, hydrological and other conditions), the phenomena of dynamic interaction between terrain and construction and other factors.

6. CONCLUSIONS

Seismic simulations have shown that the effects of the seismic action are more pronounced in the frame structures. On the other hand, the results show that the presence of structural walls as a central nucleus in dual structures makes the structure to better react to the seismic action, the center of stiffness being concentrated in the middle of the structure.

The results of structural modeling have also shown that structures behave differently on selected emplacement, with the seismic action being particularly important in designing new civil engineering constructions.

As far as one may notice, the construction seismic behavior is the result of an ample and complex process, involving many variable factors, taking into account that, besides the mentioned main factors, many other secondary factors may also interfere.

In analyzing the behavior of a building under the actions resulting from an earthquake, it must be assumed that the earthquake is a natural phenomenon itself, the manifestation of which is hardly predictable in time, the behavior of the construction will be determined by the capacity which the construction has, when it is triggered by that earthquake, to withstand the actual actions of the earthquake.

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