Study of the Influence of the Thermal Insulation System on the State of Stress, Deformation and Vibration of a Rehabilitated Building with a Structure of Reinforced Concrete Frames

Mihai Țălu[1](✉), Bogdan Păpădie[1], Ştefan Țălu[2], Daniela Vintilă[1], Diana Călbureanu[1], Raluca Malciu[1], and Mădălina Călbureanu[1]

[1] Faculty of Mechanics, University of Craiova, Craiova, Romania
mihai.talu@edu.ucv.ro

[2] The Directorate of Research, Development and Innovation Management (DMCDI), University of Cluj-Napoca, Cluj-Napoca, Romania

Abstract. The paper presents the influence of the thermal insulation system applied following a thermal rehabilitation process on a block of flats with a GF + 6F height regime, regarding: the resulting linear deformation state, the stress state and the building's own vibration modes. The study model used in the analysis is based on the design dimensions of the full- scale architectural model developec in Archicad 24. The interior complexity is presented by the elevation sectioning of the building at different levels. The execution materials of the elements and their composition layers of the finishes are maintanied. The composition of the thermal insulation is taken into account. The percentage deviations of the different technical parameters that characterize the building with and without thermal insulation system are preented.

Keywords: Thermal rehabilitation · thermal insulation system · vibration mode · stress states · thermal loads · MEF analysis · parametric model

1 Important Premises Underlying the Rehabilitation of Buildings

Rehabilitation of buildings is a procedure applied in situations where it is desired to correct some alterations of functionality and of some technical performances of a construction in relation to the technical requirements for which it was designed [1–3].

These degradations, which must be corrected by rehabilitation, are determined by a series of causes, recalling that the most important ones are due to: seismic actions, design and design errors, landslides, destructive wind actions, or degradation of the grounding or subsidence soil, destructive fires or explosions determined voluntarily or not, effects of floods, errors of execution or assembly, actions of some chemical agents, or effects of some technological work processes carried out inside the building, losses of the resistance capacity generated by the aging of the materials, or structural degradations that evolve in time, etc. [4–6].

I. Dumitru et al. (Eds.): ICOME 2022, AHE 15, pp. 514–528, 2023.
https://doi.org/10.2991/978-94-6463-152-4_56

It is also worth mentioning that these actions do not manifest themselves singularly but these are generally actions combined with cumulative effects over time.

In accordance with the removal of the effects that alter the technical performance of the building, the rehabilitation directions are oriented towards the rehabilitation carried out on: thermal insulation, of the resistance of the resistance structure, of the rehabilitation of the foundation ground etc., and in the case of each type of rehabilitation the purpose has different interests [7–9].

For example, the improvement of the technical performances of the buildings aims at an increase of the thermal insulation of the construction elements, such as the elements of the resistance structures such as: beams, pillars, connecting nodes, the roof, the floor above the ground floor, the intermediate or roof floors, the thermal insulation of the carpentry which includes: the windows and access doors, the thermal insulation of the facade walls or of the interior walls, etc.

Instead, in the case of structural rehabilitation, action is taken on resistance structures, which aim at the local structural restoration, the partial replacement of the structure or the change of the construction destination.

The determination of the type and method of rehabilitation as well as its methods of implementation is conditioned by: the technical condition of the construction, the possibility of applying the method of rehabilitation, the technical staff and the equipment available, as well as the funds allocated to this action.

2 Studies Regarding the Behavior of Buildings During the Post-thermal Rehabilitation Time

The thermal rehabilitation of a structure involves an action on buildings with construction materials and specific procedures that lead to the improvement of the technical performance of buildings after rehabilitation.

This is highlighted by analyzing the energy performance parameters of buildings that are calculated for comparison before and after rehabilitation.

The present paper carries out a study on the modifications of the technical performances of a thermally rehabilitated building with a structure of resistance in reinforced concrete frames and masonry walls made of solid brick.

The states of stress or deformation of the resistance structures as a result of the thermal rehabilitation process are studied by applying a thermal system on the outer envelope of the building.

The modeling considers the application of different thermal loads inside the building spaces depending on the utility of the targeted space such as: hall, bathroom, kitchen, living room, closet, etc. At the same time, it went further with the study applying differentiated thermal loads, including on the infrastructure / respectively the foundation system / in accordance with the extreme thermal values of the location of the construction.

The study is based on a parameterized model of buildings on which load combinations are applied and spatial states of deformation and stress are performed using the SCIA 21 analysis software.

3 Presentation of the Architectural Model and the Structural Strength Model for Thermally Rehabilitated Building

The study of the technical parameters before and after rehabilitation is based on an existing construction of a block of flats with a height of GF + 6F that is thermally rehabilitated. The building is located in Buzau.

The height between the floors is He = 2.8 m, and the architectural plan shows that the distance between the beams in the longitudinal direction is L = 5/6/5/5/5/5 m and transversely by T = 6/6/6/6 m.

The resistance structure of the building is made of concrete frames. The investigation of the performance parameters in the paper is done analytically based on the finite element

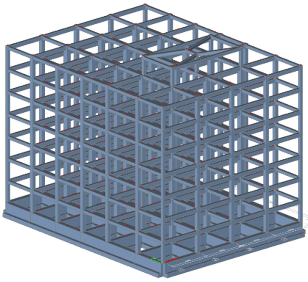

Fig. 1. Reinforced concrete frames of resistence structure of building with fundations

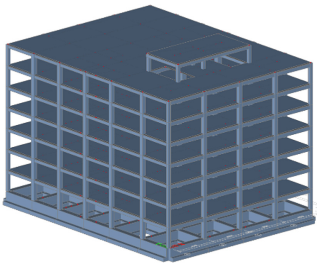

Fig. 2. Reinforced concrete of resistence structure with floors of building with fundations

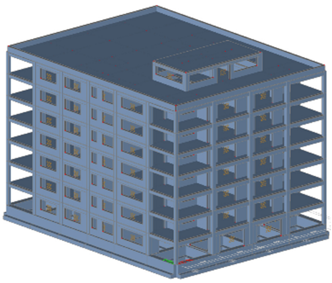

Fig. 3. The resistence structure of building with walls

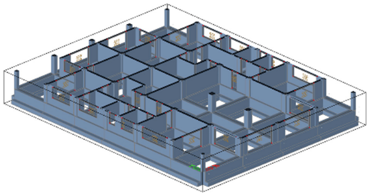

Fig. 4. Ground floor section

method. The accuracy of structural modeling ensures the correctness of the results and the composition of the parameterized model of the building starts from the architectural solution [10–19].

The modeling dimensions used are those on the natural scale of the construction.

The comparison of the results is made on the basis of the results provided by the initially unrehabilitated model and by the thermally insulated model.

The dimensions specified by the technical documentation, the construction materials of the building, the location and the degree of housing, the nature of the rehabilitation materials, etc. are observed.

Synthetically, the superstructure is made up as follows: the structure in reinforced concrete frames made of corner pillars with square section with a side of L = 40 cm, edge pillars with L = 50 cm and central pillars with L = 65 cm. The transverse or longitudinal grays have a rectangular section [with the dimensions of the sides of: S = 30cm x60 cm.

The structure in frames that support the system of foundation beams is given in Fig. 1. To this were attached the floors with a constant thickness of hp = 15 cm resulting in the shape of Fig. 2 and finally the masonry walls were placed in solid brick with a thickness of 30 cm provided for the facades of buildings and partition walls, Fig. 3.

It should be noted that in making the model, all the gaps in the floor are made / such as those through which the staircase passes from one floor to another or the passage of the elevator shaft and the gaps in the temple corresponding to the windows or access doors that have been drilled in the walls, respecting the positioning and dimensions given by the architectural model [20, 21].

In addition, the interior compartmentalization is faithfully made according to the architectural model, it being detailed in Fig. 3, Fig. 6.

These horizontal sections refer to a section made through the ground floor, Fig. 4, a section through the floor1, Fig. 5 and a section at the level of the technical space of the staircase on the roof terrace, Fig. 6.

This entire model is based on the architectural solution for which the upper right front view is given in Fig. 7 and the upper right rear view in Fig. 8.

The architectural modeling was done with the help of the Arhicad 24 program, and Fig. 9 … Fig. 12 shows views of the faces.

Main view, Fig. 9 and secondary view, Fig. 10.

View from the right, Fig. 11 and the view from the left Fig. 12.

Analyzing the spatial complexity of the structural model, we can say that it falls into the middle class.

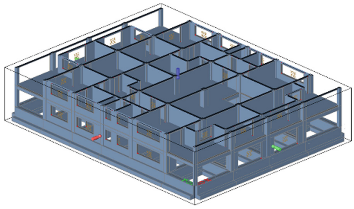

Fig. 5. Section of the first floor level

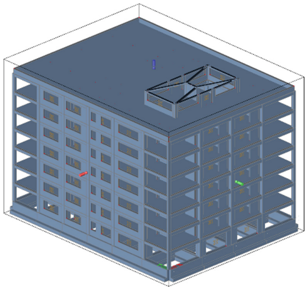

Fig. 6. Roof level house section

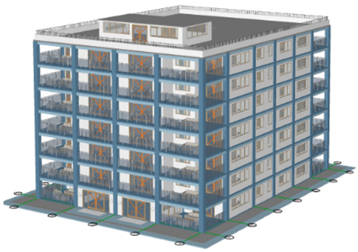

Fig. 7. Front right view of the building

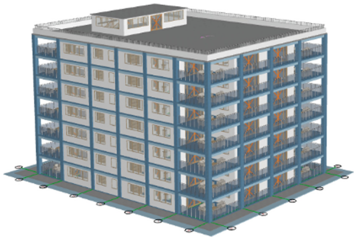

Fig. 8. Left rear view top right of the building

The model has stiffened monolithic slabs with a frame structure and the poured concrete in the structure is brand C30 / 37. Reinforcement housings are made of B500B steel for longitudinal reinforcement and B400B for transverse reinforcement.

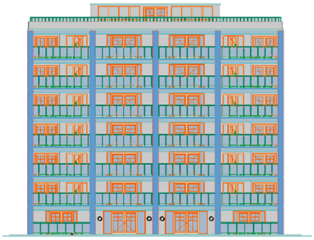

Fig. 9. Main view of the building

Fig. 10. Secondary view of the building

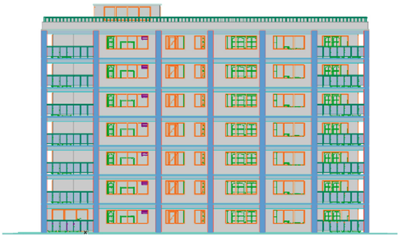

Fig. 11. The right view of the building

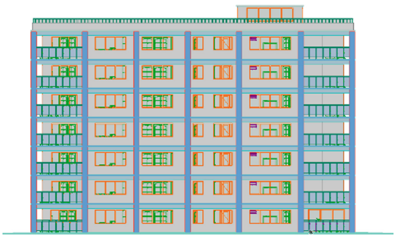

Fig. 12. The left view of the building

The thermal envelope of the building is made with Knauf Rock KR basalt wool boards, provided by Knauf, with a thickness of h = 10 cm, with wall clamps with dowels and adhesive.

4 Actions Applied on the Structure

For the analysis, the following actions used to compose the combinations that applied resistance structures were considered as:

- permanent weight of structures.
- loading with agglomeration of snow on the roof;
- useful loading of interior and exterior surfaces;
- seismic action;
- thermal loading of the structure.

Regarding the thermal loading of structures, the following specifications are made: (Fig. 14).

The behavioral behavior for the winter period took into account an outdoor ambient temperature of Te = -20 °C (Fig. 15).

Inside, for inhabited spaces, the temperatures are differentiated according to the destination of the spaces, so for spaces with warm floors such as: living rooms or bedrooms, the calculation temperature is T = + 22 °C, and for spaces with cold floors such as: hall, kitchen, etc., T = + 16 °C (Fig. 16).

In the infrastructure, a temperature of T = 0 °C was applied on the foundation elements (Fig. 17).

5 Analysis of Building Behaviors with Previous Thermal System and Post - Rehabilitation Analysis Using the FEM

The presence of the mass of the thermal insulation system and the differentiated thermal load determined by it affect without exception all types of loads (Fig. 18).

This is confirmed by the simulation results obtained, which are presented in Table 1, for different types of loads targeting the resulting linear displacement and the resulting effort σ (Fig. 19).

The mode of variation of the resulting linear displacements u for the structure with/without thermal systems and for the resulting effort σ, including the deviation calculated as a percentage, is presented in Fig. 13, Fig. 20.

It is specified that the percentage deviations are calculated based on the building without thermal system and for the analyzed technical parameters they are plotted in the graph from Fig. 20.

It is specified that the percentage deviations are calculated based on the building without thermal system and for the analyzed technical parameters they are plotted in the graph from Fig. 21. The study of the influence of the presence of the thermal insulation system was then extended to the fundamental vibration mode of the building, obtaining the results from Table 2.

Drawing the variation graphs on fundamental modes of vibration with and without thermal system on the structure is the following.

In Fig. 22 is given the variation of the maximum resulting linear deformation and in Fig. 23 that of the resulting stress.

Table 1. The influence of the thermal insulation system on the types of loads

	Without themal system		With thermal system		Deviations	
	u[mm]	[MPa]	u[mm]	[MPa]	u[%]	[%]
Load	0.6	2.2	0.55	2.24	-8.33	1.82
Snow load	0.52	1.5	0.56	1.52	7.69	1.33
OX Seism load	36.5	42	37.4	43.9	2.47	4.52
OY Seism load	41.4	29.7	42.6	30.6	2.90	3.03
SLU, for GF	11.1	41	10.7	41.8	-3.60	1.95
SLU, with S	45.8	57.3	54.1	60.2	18.12	5.06
SLS, quasy	7.6	28.5	7.45	29.1	-1.97	2.11
SLS characteristic	8.1	30.1	9.2	32.2	13.58	6.98
All SLU	54.9	57.3	60	58.2	9.29	1.57
All SLS /	8.1	29.4	9.15	30.1	12.96	2.38
All SLU + SLS/	56.2	58.4	61.7	59.7	9.79	2.23

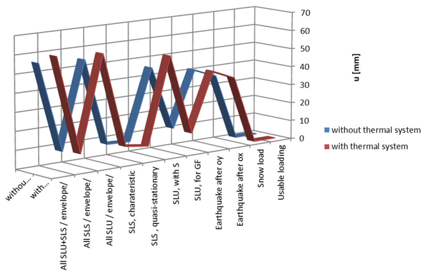

Fig. 13. Lnear displacements

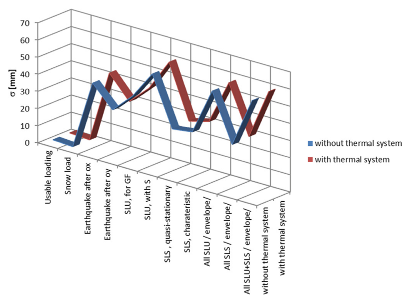

Fig. 14. Resulting effort

Also Fig. 24 shows how to vary the vibration frequency.

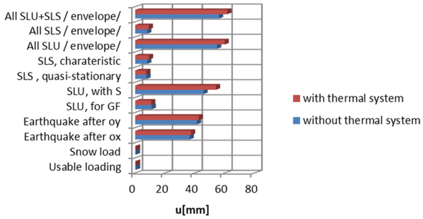

Fig. 15. Linear displacements of technical parameters

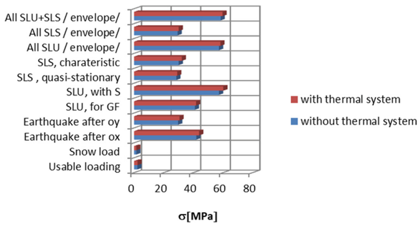

Fig. 16. Resulting efforts of technical parameters

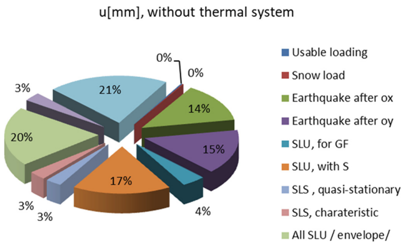

Fig. 17. Linear displacements of technical parameters without thermal system

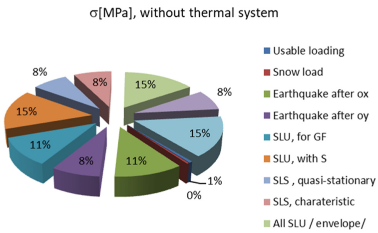

Fig. 18. Resulting efforts of technical parameters without thermal system

In Fig. 22 is given the calculated percentage deviation having as reference base the building without thermo-system, the variation of the resulting linear deformation in Fig. 25, and of the resulting effort in Fig. 26, as well as the frequency changes in Fig. 27.

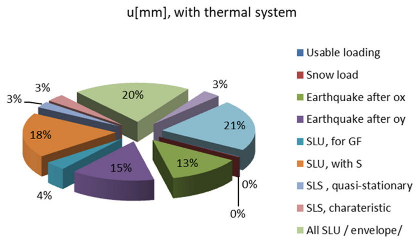

Fig. 19. Linear displacements of technical parameters with thermal system

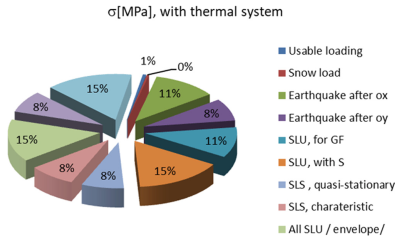

Fig. 20. Resulting efforts of technical parameters with thermal system

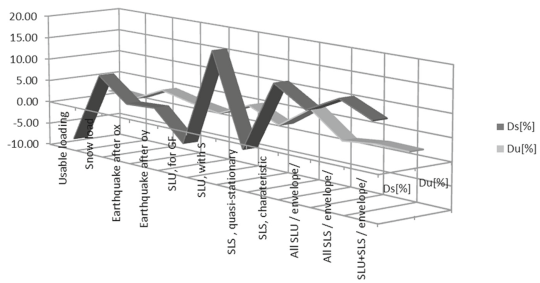

Fig. 21. Percentage deviations of technical parameters

Table 2. The influence of the thermal insulation system on its own fundamental vibration modes

Vibration modes	Without thermal system			With thermal system			Deviations		
	u[mm]	s[MPa]	f[Hz]	u [mm]	s[MPa]	f[Hz]	Du[%]	Ds[%]	Df[%]
M1	0.65	0.5	1.19	0.75	0.51	1.17	15.38	2.00	-1.68
M2	0.73	0.6	1.28	0.82	0.58	1.26	12.33	-3.33	-1.56
M3	0.86	1	1.34	0.81	0.98	1.32	-5.81	-2.00	-1.49
M4	0.71	1.5	3.74	0.71	1.46	3.69	-0.70	-2.67	-1.34
M5	0.76	2.1	4.02	0.73	2	3.96	-3.95	-4.76	-1.49

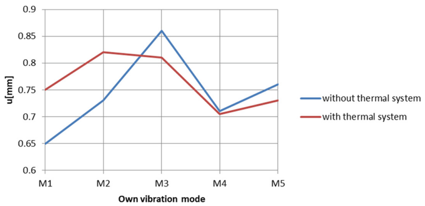

Fig. 22. Liniar deformation

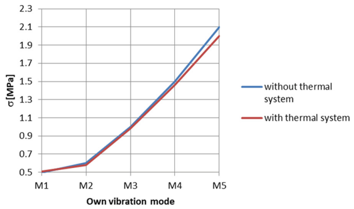

Fig. 23. Resulting stress

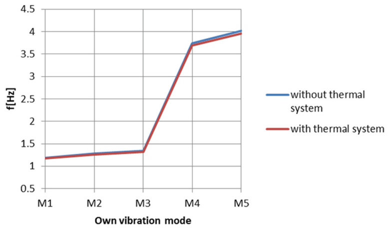

Fig. 24. Vibration of frequency

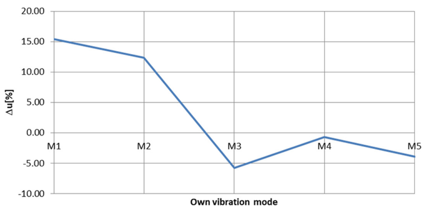

Fig. 25. Deviation of liniar deformation

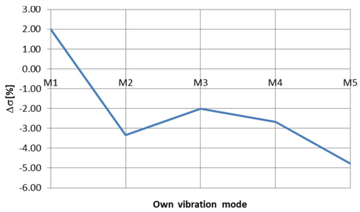

Fig. 26. Deviation of resulting stress

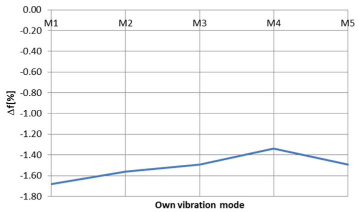

Fig. 27. Deviation of vibration frequency

6 Conclusions Regarding the Influence of Thermal Rehabilitation on the Post-rehabilitation Behavior of Buildings

- Performance parameters of thermal post-rehabilitation buildings depends on the type and manner of performing thermal rehabilitation;

- these evaluation parameters are defined and regulated by the norms and standards specific to the field of constructions that are in force;
- the investigation of the performance parameters achieved in a theoretical way is done either when designing and choosing an optimal solution, or after carrying out the rehabilitation following an experimental confirmation;
- thermal insulation is applied both to the facades and to the interior compartments, both to the superstructure level and to the infrastructure;
- the finite element analysis method involves the elaboration of a structural model of resistance coated with the adopted thermal insulation system;
- the thermal loading load is applied differently on the thermally insulated surfaces, both inside the building and outside;
- the calculation model is efficient for complex surfaces allowing combined loads specified by the CR0 / 2012 standard;
- multi-layer construction elements can be introduced in the calculation, with different mechanical and thermal insulation properties, in different construction variants offered by the supplier;
- the theoretical calculation was performed with variations of the loads over time, imposed for prescribed variation limits that were determined according to the location of the building;
- the results show a continuous decrease of the performance indices of the thermal system based on the increase of the working period of the operation;

- the modeling is performed for study with total or partial thermal system on construction elements depending on the constructive solution specified by the architect;
- the introduction of interior compartments increases the accuracy of the results through different temperatures of the spaces delimited by compartmentation, but increases the calculation effort;
- the study is carried out in parallel on two different models, one initially as a comparison of buildings made without thermal systems and another for thermal insulated buildings;
- the simulations are performed separately with the registration of the parameters of interest;
- the results are determined by applying the combinations of actions of the main accepted loads for buildings with structures in frames that have solid masonry walls;
- the analysis of the numerical results obtained from the simulation study shows that: the mass of buildings increases with the application of thermal insulation influencing the resulting state of deformation, stress and vibration;
- the load of uniform loading of the roof floor increases, as well as that of vertical action applied to the facade walls and interior partitioning;
- the payload has a negative deviation with $\Delta u = 8.33\%$ in case of deformation but the resulting stress state increases with $\Delta\sigma = 1.82\%$;
- the action of increasing snow loads in both states is also influenced, rising to values of $\Delta u = 7.69\%$ and $\Delta\sigma = 1.32\%$;
- the influence of the results following the seismic actions increases at forces applied on both axes: ox and oy, increasing the displacements by $\Delta u = 2.9\%$ and the resulting effort by $\Delta\sigma = 4.52\%$;
- the analysis of the combination at the fundamental grouping for SLU shows a decrease of the deformation with $\Delta u = 3.6\%$ and an increase of the effort with $\Delta\sigma = 1.95\%$;
- the same thing, but with the application of the earthquake, the deformation increases a lot, reaching $\Delta u = 18.2\%$ and the effort increases by $\Delta\sigma = 5.06\%$;
- the analyzed service limit states, for the quasi-stationary case show that the deformations are reduced by $\Delta u = -1.97\%$ and efforts increased by $\Delta\sigma = 2.11\%$, while at SLS characteristically the deformations and efforts increase approximately as at SLU, but are lower with values of: $\Delta u = 15.8\%$ with $\Delta\sigma = 6.98\%$;
- the analysis of the last limit states as winding shows generally high values, reaching in all SLU states limits of: $\Delta u = 9.29\%$ and $\Delta\sigma = 1.57\%$, and 'in all SLS": $\Delta u = 12.96\%$ and $\Delta\sigma = 2.38\%$, / so the increases are higher in SLS / and combined for ""all SLU + SLS": $\Delta u = 9.79\%$ and $\Delta\sigma = 2.23\%$;
- as a conclusion so far of the results presented, thermal insulation increases the state of stress and deformation of buildings, a compromise accepted in exchange for increasing thermal comfort;
- the specified variations are presented in the graphs from Fig. 12, Fig. 20;
- the investigation of the vibratory behaviors of the enveloped buildings shows in this case a significant influence of the existence of the thermal insulation system, modifying all the own vibration modes, thus according to table 2, only M1 and M2 shows a positive deviation in the deformation mode reaching the maximum value of $\Delta u = 15.38\%$, while the other nodes have negative deviations with an extreme $\Delta u = -5.81$ reached at M3;
- the stress state, on the other hand, is with a positive deviation of $\Delta u = 2\%$ only at M1] and in the rest without exception with negative deviations with the external minimum of $\Delta\sigma = -4.76\%$ in the case of the vibration mode own M5;

- all vibration frequencies have negative deviations with a maximum of $\Delta f = -1.68\%$ which occurs in the case of the fundamental vibration mode M1;
- The conclusion that emerges from the analysis of the simulation results is that the presence of the thermosystem directly influences the state of deformation and resulting stresses as well as the vibration mode of the building, for combinations that correspond to the ultimate or service limit states. / SLU or SLS /.

References

1. Leonte C. s.a. – Îndrumator pentru proiectarea planseelor din beton armat, I.P. Iasi.
2. Veres Al., Vasilache M. – Constructii civile. Elemente de constructii, Editura Cermi, Iasi, 2004.
3. Veres Al., Vasilache M. – Constructii civile. Forme structurale pentru constructii civile, Editura Cermi, Iasi, 2003.
4. Precupanu D. Fundamente de rezistenta a constructiilor, Editura Corson, Iasi, 2005.
5. Caracostea A., Manual pentru calculul constructiilor, vol. 1, Editura Tehnica, Bucuresti, 2007.
6. Gaina N., Popeescu A., Îndrumator pentru proiectarea si calculul constructiilor din beton, beton armat si beton precomprimat, Editura Tehnica, Bucuresti, 1978.
7. Cadar I. – Beton armat, Editura Orizonturi Universitare, Timisoara, 2004.
8. Dumitrescu D. – Îndrumator pentru proiectare si calculul constructiilor din beton, beton armat si beton precomprimat, Editura Tehnica, Bucuresti, 1978.
9. Tertea I. s.a, – Proiectarea bentonului armat, Editura Didactica si Pedagogica, Bucuresti, 1984.
10. P 100/2006 - Calculul de proiectare antiseismica.
11. CR0–2012 - Gruparea actiunilor în constructii.
12. *SR EN 1993–1.1–2006. Proiectarea structurilor de otel. Reguli generale si reguli pentru cladiri.
13. *SR EN 1990/2004. Bazele proiectarii structurilor.
14. *SR EN 1991–1–3/2004. Actiuni generale. Incarcari date de zapada.
15. *SR EN 1991–1–7/2007. Actiuni generale. Actiuni accidentale.
16. *SR EN 1992–1–1/2004. Reguli generale si reguli pentru cladiri.
17. *SR EN 1993–1–5/2007. Elemente structurale plane solicitate in planul lor.
18. *SR EN 1993–1–7/2007. Placi plane solicitate la incovoiere.
19. *SR EN 1998–1/2004. Partea 1. Actiuni seismice si reguli pentru cladiri.
20. * Archicad 24 – Graphisoft.
21. * SCIA Engineer 21 - Nemetschek Group.