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# CASE STUDY - COMPARATIVE ANALYSIS OF AN RC STRUCTURE, PART OF A COMPLEX OF ADJACENT BUILDINGS

BY

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**Abstract.** The paper presents the results of a comparative study on the behavior of structures to seismic action in the case of a group of three buildings with mixed structure of spatial frames and reinforced concrete walls calculated separately and together in the hypothesis of a common foundation. They are located on a site in Focşani, Vrancea, a seismic area characterized by land acceleration of 0.40 g. On the site studied the 3 buildings have different height regimes. Two of them with a height of up to 30 m have the shape of the letter L in the plan. They are separated by vertical joints but with a common general foundation. The results show the importance of structural evaluation in different modelling scenarios on separate structures and on a complete model highlighting the differences between these approaches.

**Keywords:** RC structure; seismic behavior; common foundation.

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## 1. Introduction

In recent years, the calculation technique and the design rules of the resistance structures for constructions have required obtaining a high level of structural performance. Obviously, everything is reported in economic costs. Thus, the tendency of investors is to maximize the space obtained for the built surface and the chosen built system (Bisch *et al.*, 2012; Murty *et al.*, 2012; Lobacheva *et al.*, 2020).

Fig. 1 – Hotel architectural overview.

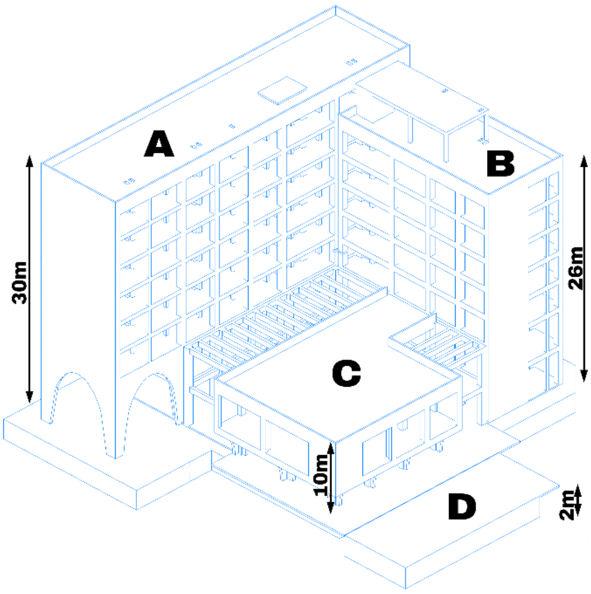


Fig. 2 – Structural system overview.

Most often the technology and materials existing on the local market are the dominant criteria in choosing the structural system. Thus, in geographical areas where the availability of advanced construction technologies or skilled labor does not exist, the most accessible structural solutions are accepted even if sometimes they can be more expensive (Olteanu *et al*., 2015; Paulos *et al*., 2016; Stratulat *et al*., 2017; Mohamed *et al*., 2020; Sococol *et al*., 2020).


Fig. 3 – Plan view of the complex buildings.

The case study presented consists of a hotel complex with 3 buildings presented in Fig. 1. These buildings are to be made in the seismic area of Vrancea, Romania characterized by the peak ground acceleration of 0.40 g and the corner period Tc = 1.0 s. Each of the 3 buildings have different destinations but communicate with each other. These are being separated by vertical joints from base level to the top.

From the conditions imposed by the architectural functions, it was desired that at the first level the openings and heights be as large as possible.

The height of the first level is 4.50 m and the largest openings of 9.00 m between axes A-C and 1-3 (Figs. 3, 4, 5). Also, the main entrance to the building located between axes 1-3 and A-C has a height of 9.00 m.

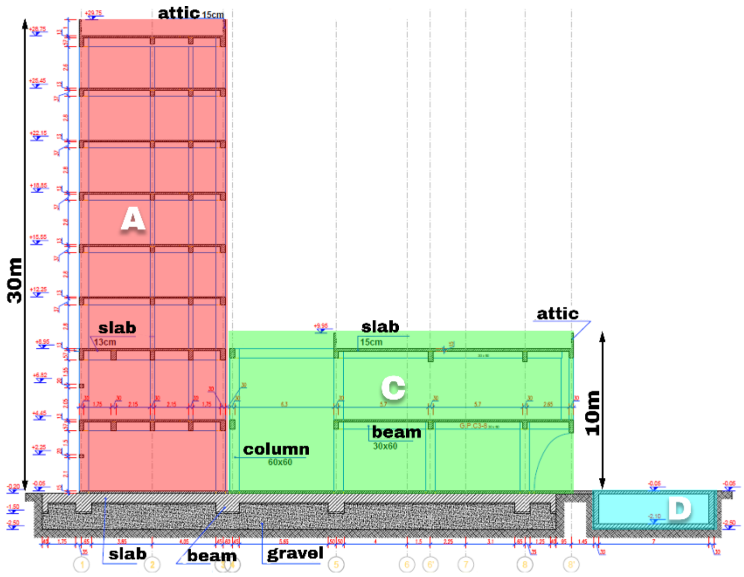


Fig. 4 – Section 1.

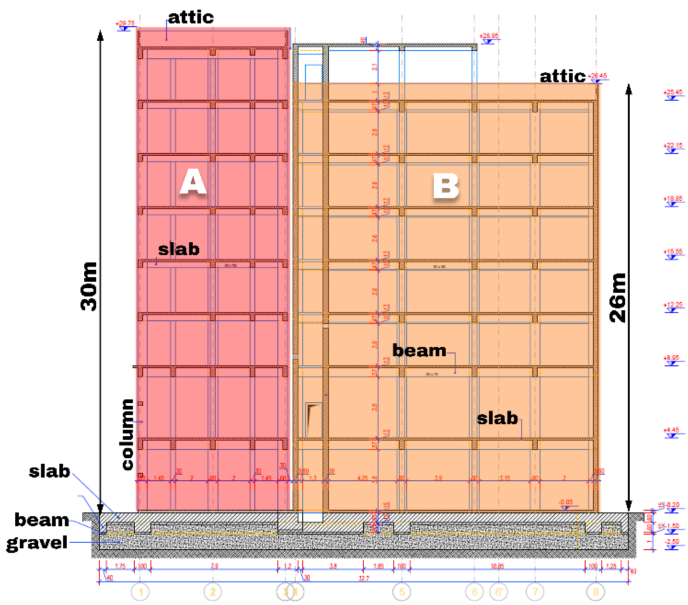


Fig. 5 – Section 2.

"C" building has at second level a conference room with the dimensions of 11.50 mx 15.00 m. In building "A" between the axes F-H and 2-3 is the elevator shaft, and in building B between the axes H-I near the axis 4. Over the elevation +9.00 m, the accommodation rooms are distributed in the two buildings "A" and "B". From fire safety conditions, it is proposed to build a water tank with the dimensions of 8.00m x 17.00m x 2.00m.

The site of the construction is in Focsani city, Vrancea seismic zone which is located in the central-eastern part of Romania Figs. 6, 7. According to the Seismic Design Norm (P100-1, 2013), the maximum level of peak ground acceleration on the studied location is 0.40g.

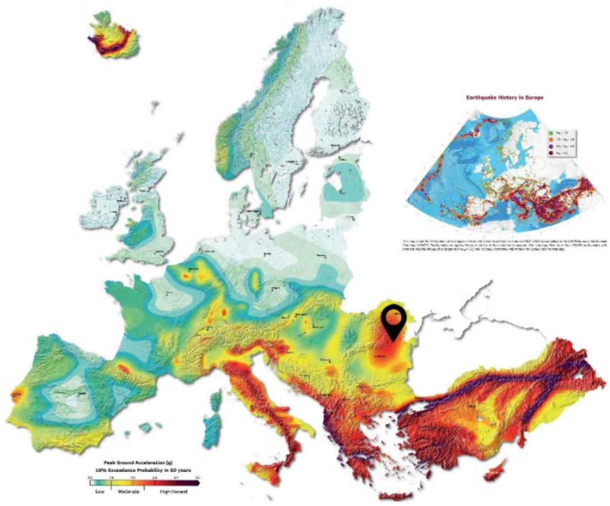

Fig. 6 – European seismic map (https://i.imgur.com/FrDPcQl.jpg).

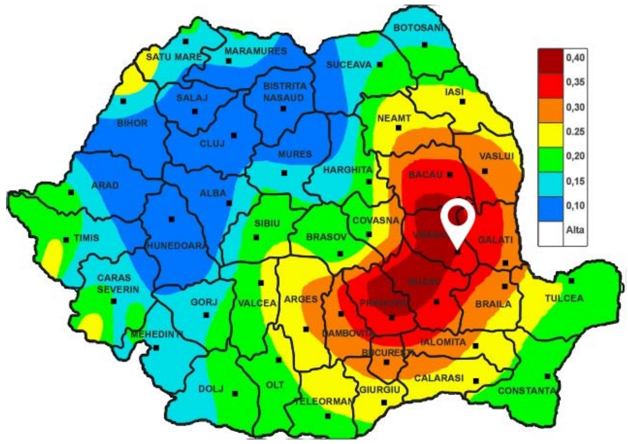


Fig. 7 – The location of the studied building on Romania map level of peak ground acceleration (https://graitecromania.files.wordpress.com/2014/01/screenshot1382.jpg).

## 2. Materials and Structural Concept

The chosen structural system is a combination of reinforced concrete spatial frames with walls and slabs. The materials used for modeling the structure are presented in Table 1.

**Table 1**
*Structural Materials*

| Element | Material | E (MPa) | Re (MPa) | Displacement evaluation E factor | Strength evaluation E factor |
|---|---|---|---|---|---|
| *Foundation slab* | *C30/37* | *17000* | *30* | *0.5* | *0.5* |
| *Foundation beam* | *C30/37* | *17000* | *30* | *0.5* | *0.5* |
| *Ground level walls* | *C30/37* | *17000* | *30* | *0.5* | *0.5* |
| *Columns* | *C35/45* | *27200* | *35* | *0.5* | *0.8* |
| *Walls* | *C35/45* | *27200* | *35* | *0.5* | *0.8* |
| *Beams* | *C35/45* | *20400* | *35* | *0.5* | *0.6* |
| *Slabs* | *C35/45* | *20400* | *35* | *0.5* | *0.6* |

The loads on the structure are considered under the current rules. In addition to their own weight, loads were added from the weight of the closing and partition walls, made of autoclaved aerated concrete masonry, the weight of the layers at the level of each floor, respectively the equipment attached to the structure. Category A payloads with intensities between 1.5 and 2.5 kN/m$^2$ depending on the position on the plane. The main characteristics of the loads are presented in Table 2.

**Table 2**
*Loads and Combinations*

| Type | Standard | Value (kN/m$^2$) | Combination | Factor |
|---|---|---|---|---|
| *Self weight* | *SR EN 1991-1-1:2004* | *automated* | *ULS/ SLS/ ACC* | *1.35/1.00/1.00* |
| *Walls weight* | *SR EN 1991-1-1:2004* | | *ULS/ SLS/ ACC* | *1.35/1.00/1.00* |
| *Permanent from floors* | *SR EN 1991-1-1:2004* | *3.5* | *ULS/ SLS/ ACC* | *1.35/1.00/1.00* |
| *Imposed loads category A and C* | *SR EN 1991-1-1:2004* | *1.5 to 2.5* | *ULS/ SLS/ ACC* | *1.5/1.05/0.3* |
| *Wind* | *CR-1-1-3/2012* | *0.6* | *ULS/ SLS* | *1.5/0.6* |
| *Snow* | *CR-1-1-4/2012* | *2.0* | *ULS/ SLS/ ACC* | *1.5/1.00/0.2* |

**Table 3**
*Seismic Characteristics*

| Type | Standard | *Importance category* | *Category of importance* | Behavior factor (q) | Acceleration ($a_g$) | $T_c$ |
|---|---|---|---|---|---|---|
| *Earthquake* | *P100-1/2013* | *III* | *C* | *4.5* | *0.40 g* | *1.0 s* |

Terrain characteristics are presented bellow according to geotechnical study:
-0.00 – 0.40 m Concrete layer
-0.40 – 1.00 m Fillers and topsoil
-1.00 – 2.60 m Yellow dusty sand, light plastic consistently
-2.60 – 6.50 m Dusty clay and yellow clay strongly plastic with calcareous concretions
-6.50 – 7.00 m Consistent plastic clay powder
-7.00 – 8.00 m Strongly yellow plastic clay

The groundwater level was not intercepted in the boreholes. The foundation soil is characterized by the layer of dusty clay and hard plastic yellow clay with calcareous concretions. The depth of frost is 90 cm from the level of the natural terrain. Conventional capacity of the soil is 180 kPa. Bed coefficient $k_s$ according to NP 112/2014 is considered 4 kN/m$^3$.

## 3. Results and Discussion

After several stages of verification of the dynamic behavior at the seismic action, the sections of the structural elements and the position of the walls were established. The structural analysis was performed using FEM and Autodesk Robot Structural software (Robot software, 2020). Thus in Figs. 8, 9 are presented the fundamental modes of vibration for building “A” as a separate structure. In Figs. 10 to 13 are presented the vibration modes of the structures considered on the same foundation on Winkler medium.

Table 4 shows the values of the natural vibration frequencies of building A obtained on the separated and together structural models.

**Table 4**
*Modal Analysis Results*

| Building | *Structural model analysis type* | | | |
|---|---|---|---|---|
| | *Separated* | | Together | |
| | *Translation X Frequency (Hz)* | *Translation Y Frequency (Hz)* | *Translation X Frequency (Hz)* | *Translation Y Frequency (Hz)* |
| *A* | *1.27* | *1.75* | *1.23…1.35* | *1.29* |

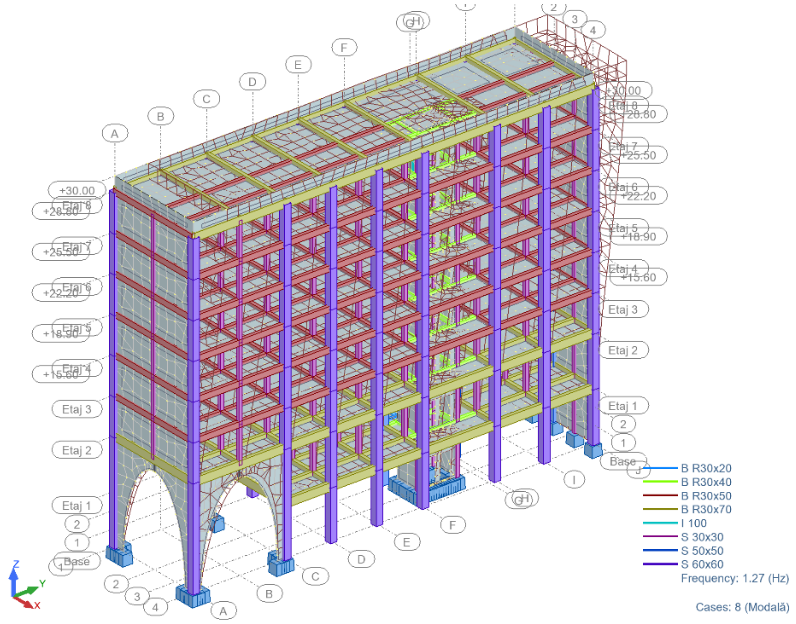


Fig. 8 – Vibration mode 1 of building “A” separated
F=1.27 Hz (mass participation 75.52% Y).

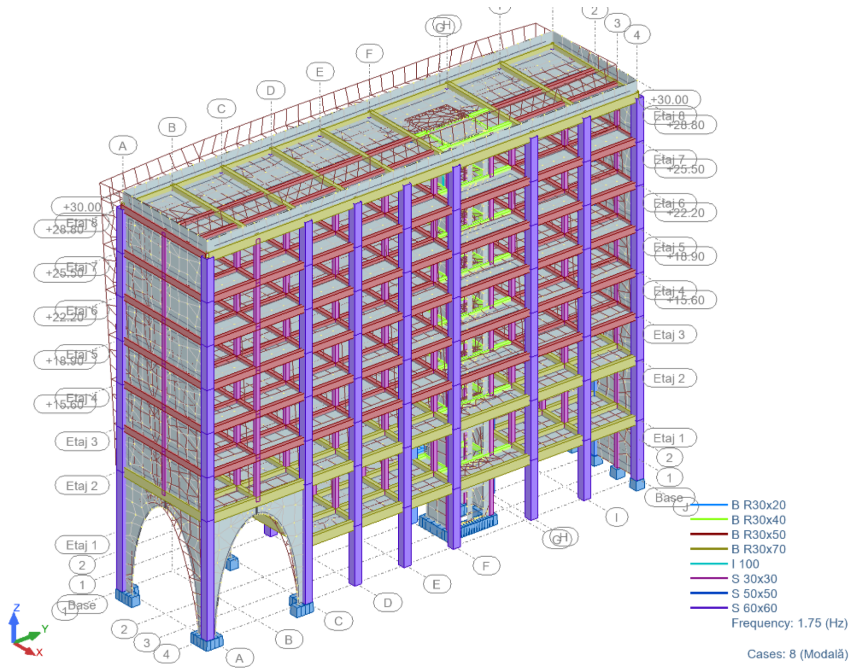


Fig. 9 – Vibration mode 2 of building “A” separated,
F=1.75 Hz (mass participation 75.77% X).

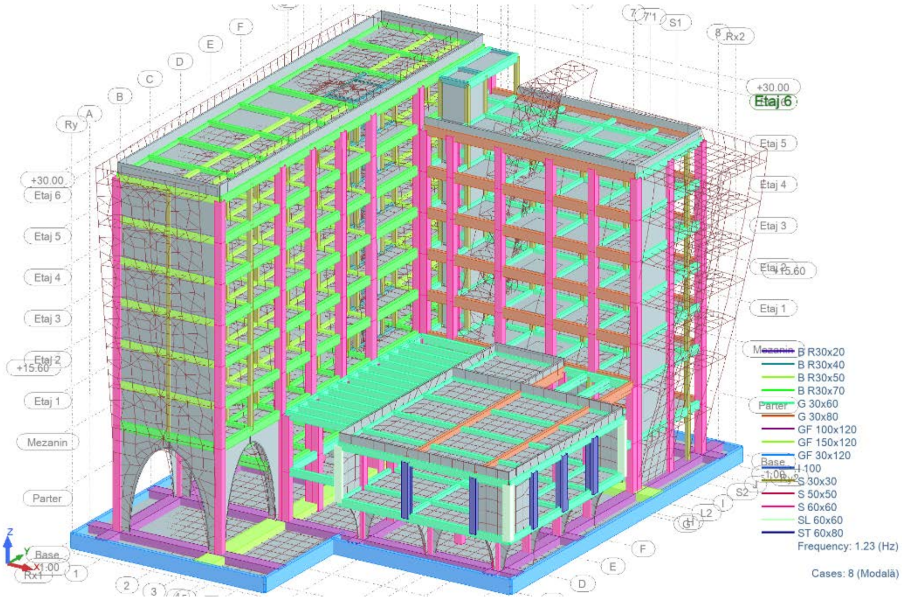


Fig. 10 – Vibration mode 1, F=1.23 Hz
(mass participation 5.74% X; 1.79% Y).

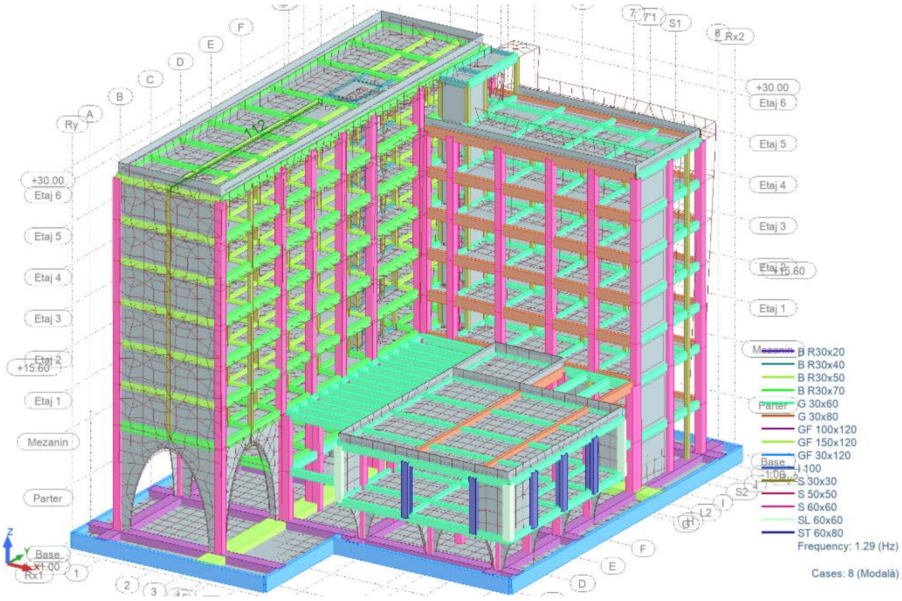


Fig. 11 – Vibration mode 2, F=1.29 Hz
(mass participation 5.02% X; 0.24% Y).


Fig. 12 – Vibration mode 3, F=1.29 Hz
(mass participation 3.30% X; 44.63% Y).


Fig. 13 – Vibration mode 4, F=1.35 Hz
(mass participation 35.93% X; 3.02% Y).

Table 5 shows the distribution of reduced seismic forces in the horizontal plane directions (X - transversal, Y-longitudinal).

**Table 5**

*Reduced Seismic Forces of Complete Structural Model*

| Case/ story | Fx (kN) | FY (kN) | Mz (kNm) | Fx to columns (kN) | Fx to walls (kN) | Fy to columns (kN) | Fy to walls (kN) |
|---|---|---|---|---|---|---|---|
| 9/1 | 14547.06 | -2205.72 | -37239.67 | 6197.02 | 8350.04 | -1189.24 | -1016.48 |
| 9/2 | 13926.15 | -2124.09 | -38408.46 | 3406.84 | 10519.32 | -621.14 | -1502.95 |
| 9/3 | 12634.34 | -1968.76 | 15679.62 | 4518.04 | 8116.3 | -827.94 | -1140.82 |
| 9/4 | 11332.18 | -1731.97 | 17495.66 | 3723.1 | 7609.08 | -756.89 | -975.08 |
| 9/5 | 9721.92 | -1441.67 | 16607.34 | 3352.62 | 6369.3 | -695.29 | -746.38 |
| 9/6 | 7759.11 | -1085.04 | 15601.89 | 2950.35 | 4808.76 | -612.16 | -472.88 |
| 9/7 | 5370.37 | -663.79 | 13032.18 | 2514.42 | 2855.95 | -580.47 | -83.32 |
| 9/8 | 2594.06 | -233.55 | 4281.9 | 1082.17 | 1511.89 | -269.79 | 36.24 |
| 10/1 | 2205.72 | 15376.14 | -82372.68 | 971.21 | 1234.51 | 6911.02 | 8465.13 |
| 10/2 | 2136.15 | 14745.72 | -83563.99 | 708.94 | 1427.21 | 4510.36 | 10235.36 |
| 10/3 | 1975.01 | 13486.7 | -28522.93 | 908.84 | 1066.17 | 7401.36 | 6085.33 |
| 10/4 | 1780.23 | 12112.61 | -17805.5 | 811.45 | 968.77 | 6543.63 | 5568.98 |
| 10/5 | 1526.98 | 10341.79 | -16950.39 | 710.71 | 816.27 | 5997.99 | 4343.8 |
| 10/6 | 1214.77 | 8171.39 | -15850.74 | 601.61 | 613.16 | 5313.99 | 2857.39 |
| 10/7 | 843.43 | 5569.59 | -13023.58 | 502.34 | 341.09 | 4657.53 | 912.06 |
| 10/8 | 430.97 | 2611.89 | -1915.03 | 218.46 | 212.51 | 3598.57 | -986.68 |

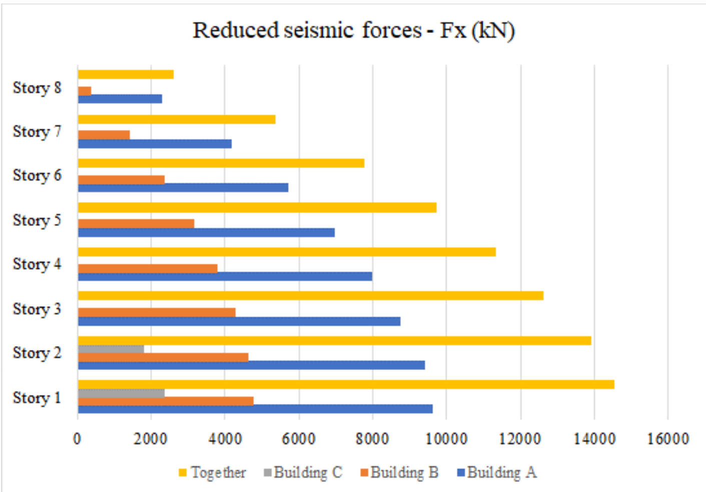


Fig. 14 – Comparative values of the reduced seismic forces on X direction.

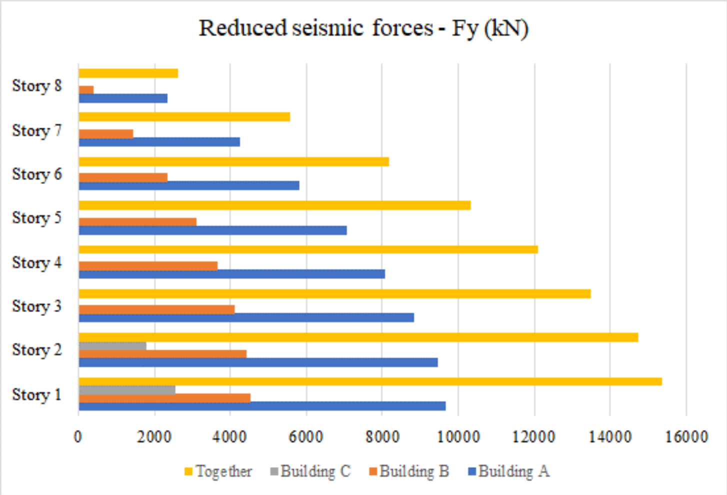


Fig. 15 – Comparative values of the reduced seismic forces on Y direction.

The two comparative graphs in Fig. 14 and 15, show the distribution of reduced seismic forces on each level in calculation models separately and together. In the calculation model with the common foundation on the X direction, the result of the reduced seismic forces at levels 1, 2, 7 and 8 is less than the sum of the forces calculated on the separate calculation models (Fig. 16).

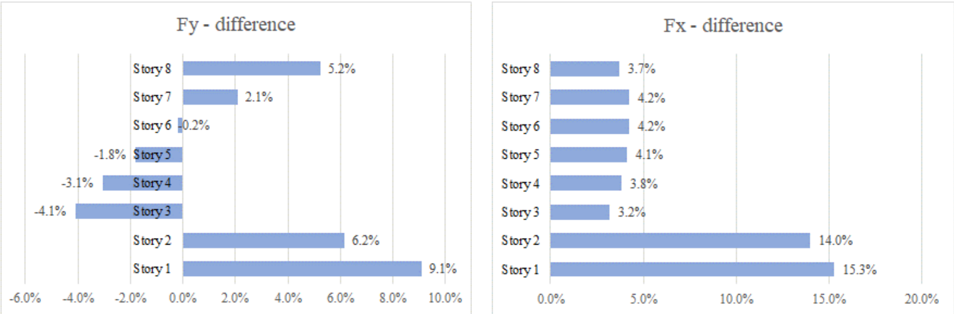


Fig. 16 – Differences between sum of reduced forces on separated model and complete model.

At levels 3,4,5,6 on the complete calculation model the result of the seismic forces on each level is higher than the sum of the forces obtained on the separate models. On the Y direction it is observed that the value of the seismic forces on each level calculated on the whole model is less than the sum of the forces calculated on each separate model.

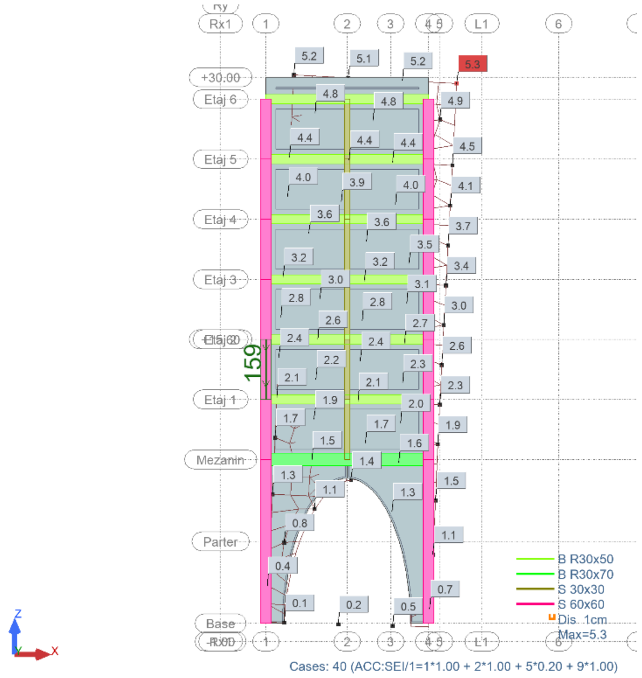


Fig. 17 – Deformed shape and horizontal X displacement on building A – complete model.

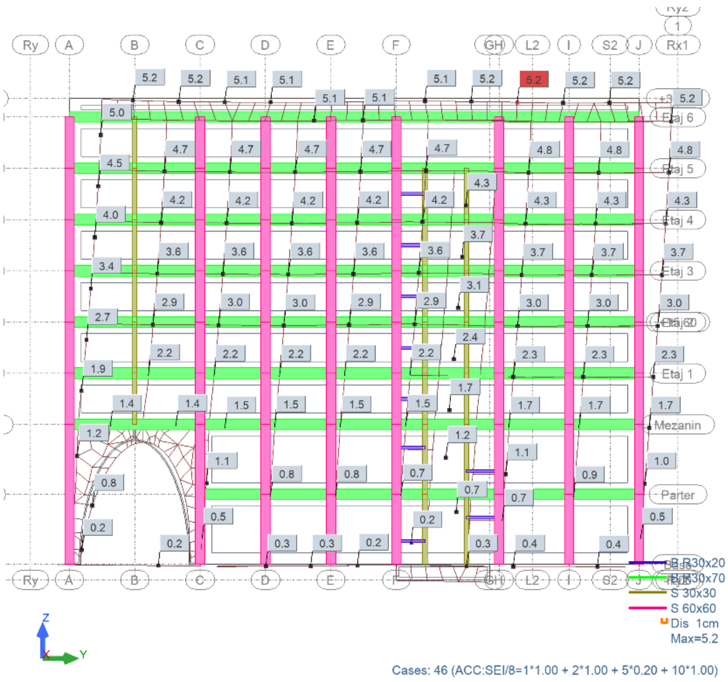


Fig. 18 – Deformed shape and horizontal Y displacement on building A – complete model.

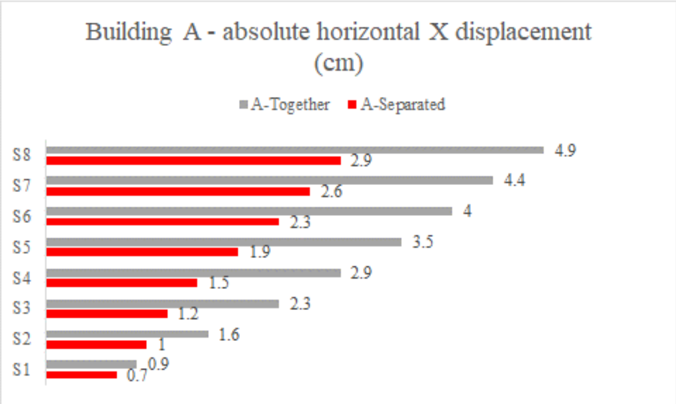


Fig. 19 – Comparative results on absolute X displacement.

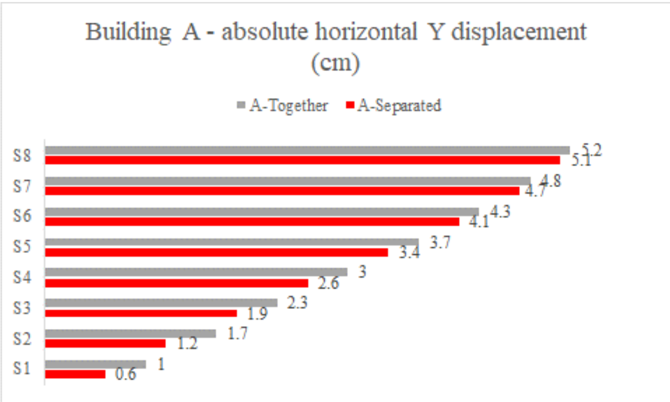


Fig. 20 – Comparative results on absolute Y displacement.

Regarding the evaluation of the general stiffness by evaluating the absolute and relative displacements on the both calculation models, a 70% increase of the maximum displacement on the transversal direction X at the upper level of building A is observed on the complete model on Winkler medium. On the Y direction there is a reduction of the general stiffness but in a smaller proportion, the biggest differences between the values of displacements being at the base of the structure by almost 40%. These aspects are shown in the comparative graphs in Figs. 19, 20.

## 4. Conclusions

In this article were presented the results of a case study of a complex of buildings with different heights arranged next to each other. The studied location is characterized by the maximum seismic level that can be anticipated in Romania, in Vrancea county. The structural solution was chosen for technological and economic reasons and consists in a structural system of reinforced concrete spatial frames combined with structural walls positioned so that the dynamic behavior produces the most balanced and well-distributed demands.

The complex buildings with a maximum height of 30 m has two of the buildings arranged in shape of the letter L while a third body with a height of 10 m is located near of them. The evaluated problems consisted in identifying a common foundation solution and highlighting the differences regarding the seismic behavior of the building complex in the separate analysis and complete model analysis with slab foundation on a Winkler medium.

The obtained results showed that in terms of the seismic loads the complete model on elastic medium is lower by up to 15% at base levels while the maximum values of absolute displacements are bigger by up to 70% which means a more flexible structure.

The separate and combined evaluation of the structural models offers an appropriate image regarding the seismic behavior and interaction between buildings which is very useful for obtaining a geometric conformation as adequate as possible to the seismic behavior and structural performance.

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*** *Robot Structural Analysis Softwarre*, https://www.autodesk.com/products/robot-structural-analysis/overview

https://i.imgur.com/FrDPcQl.jpg

https://graitecromania.files.wordpress.com/2014/01/screenshot1382.jpg

## STUDIU DE CAZ - ANALIZA COMPARATIVĂ A UNEI STRUCTURI DIN BETON ARMAT, PARTE A UNUI COMPLEX DE CLĂDIRI ALĂTURATE

(Rezumat)

Lucrarea prezintă rezultatele unui studiu comparativ privind comportamentul structurilor la acțiunea seismică în cazul unui grup de trei clădiri cu structură mixtă de cadre spațiale și pereți de beton armat calculate separat și împreună în ipoteza unei fundații comune. Acestea sunt situate în Focșani, Vrancea, o zonă seismică caracterizată prin acceleraţia maximă a terenului de 0,40 g. Pe locul studiat, cele 3 clădiri au regimuri de înălțime diferite. Două dintre ele cu o înălțime de până la 30 m şi formează litera L în plan. Sunt separate prin rosturi verticale, dar cu o fundaţie generală comună. Rezultatele arată importanţa evaluării structurale în diferite scenarii de modelare pe structuri separate și pe un model complet, care evidențiază diferențele dintre aceste abordări.