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SEISMIC STRENGTHENING OF THE HISTORIC BUILDING OF "SOKOLANA" IN KUMANOVO

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Abstract

The historic building of "Sokolski dom" in Kumanovo belongs to the plain masonry type of buildings. Built in the thirties of the last century for the needs of the "Sokolski Society", this building was once the main impetus for enrichment of cultural, entertainment and sports life, enabling the proper development of many generations. Due to its significance it was put under the protection as cultural-historic heritage in the country.

The subject of this paper is a detailed analysis of the stability of existing structure, which proved the need for its repair and seismic upgrading. With detailed analysis of the bearing and deformation capacity it was determined that the existing structure does not meet the requirements according to the national regulations. Therefore, the need for repair and strengthening was imposed, with the main goal of ensuring seismic stability of the building. Considering the possibilities and certain limitation for structural interventions from one hand, and the required bearing and deformation characteristics of the elements and the structure as whole from other hand, a traditional solution for strengthening was adopted, by reinforced concrete jackets and horizontal belt course. This technical solution provides increase of the structural bearing and deformation capacity of the system, as well as its ductility capacity, which is especially important for this type of buildings in case of seismic excitations. By increasing the deformation capacity, the input energy in the system would be consumed, which would greatly increase the seismic safety and security of the building.

Keywords: Repair, Strengthening, Masonry Structures, Capacity Analysis.

1. Introduction

Masonry structures, as a traditional type of construction, are especially present in the Balkan region. With cross-analysis of the statistical data from the last censuses from 1991 and 2002 and the available data from the State Statistical Office, it can be summarized that one third of the buildings in the Republic of North Macedonia belong to this type of constructions. Most of them were built in the second half of the XX century, before enactment of first seismic code in the country, and constructed on the basis of experiential knowledge. The most important and undeniable fact is that these buildings are still operating as buildings of vital importance for the society (schools, hospitals, cultural-historical monuments, etc.), Shendova et al. (2019).

The building of "Sokolana" in Kumanovo (Fig. 1), belongs to this type of buildings. Built in the thirties of the last century for the needs of the "Sokolski Society" from Kumanovo, this building was once the main impetus for enrichment of cultural, entertainment and sports life, enabling the proper psycho-physical development of many generations.

This paper presents a detailed analysis of the stability of the existing structural system of the "Sokolana" building, the need for repair and strengthening of the "Sokolana" building, the selection of the most adequate solution for repair and strengthening, as well as an analysis of the stability of the strengthened structural system of the building. For that purpose, the multidisciplinary approach was applied,

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developed in the Institute of Earthquake Engineering and Engineering Seismology in Skopje (UKIM-IZIIS) based on gathered experience in the field of earthquake protection. This approach includes detailed technical and experimental investigations of the facility, in order to determine the actual input parameters for the analysis, and then analysis for the load-bearing elements in order to determine the limit state of strength, deformability and ability of load-bearing elements and the system as a whole to dissipate seismic energy, Bozinovski et al. (2019).

Figure 1. Front view of the building “Sokolski dom” in Kumanovo

2. Analysis of the existing building

2.1 Description of the structural system of the existing building

For the purposes of the analysis visual inspection of the building was carried out, with outdoor visual inspection, control measurements of building dimensions and structural elements, indoor visual inspection for identification/verification of the structural system.

The building consists of a central part (sports hall), with a maximum height on the load-bearing walls up to level + 9.60m, and total floor area of 525m2. In one part, above the main entrance there is a gallery (level + 3.86m). The building also has three additional ground floor structures of lower height that were built through the years of exploitation, with a total area of approximately 440m2. (Fig. 2, 3).

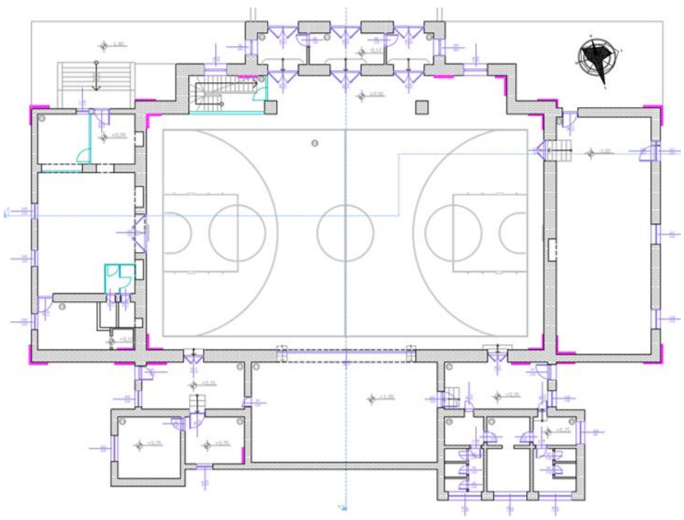

Figure 2. Ground floor of the building

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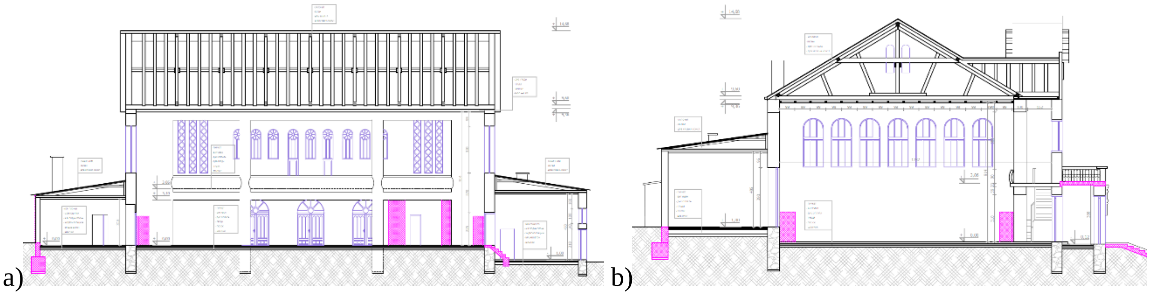

Figure 3. a) Longitudinal cross section of the building, c) Transverse cross section of the building

The principal structural system consists of bearing walls made of brick, in both orthogonal directions. The wall thickness varies from 75cm, for the main hall, and 35-60cm for the annex ground floor structures. The foundations are made of stone. For the gallery, there is a wooden floor structure. The main entrance is covered with a reinforced concrete slab. The roof for both the hall and the accompanying ground floor parts is made as a wooden structure, only on small part there is a ribbed reinforced slab. Many years ago an attempt for strengthening intervention was made, with reinforced concrete jackets. This process was stopped, so for the new solution as a starting point was reviewing and analysing the existing construction interventions.

During the inspection, significant damage was observed on the load-bearing wall elements, manifested with large cracks on the walls. Heavy damage was observed also in the roof - wooden structure and ribbed reinforced slab, in the annex ground floor structures. (Fig. 4) After the visual inspection it was concluded that, in order to bring the building in functional condition, it is necessary to make a repair and strengthening.

Figure 4. a), b), c), d) Severe cracks on the load-bearing wall elements

The input values for quality of the masonry of the load-bearing walls of the building, expressed through the modulus of elasticity, compressive and tensile strength, were assumed based on the experiences of examined elements of similar quality and construction time, and were confirmed by experimental

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testing. Therefore, the following input parameters are adopted: modulus of elasticity E = 680MPa, shear modulus G = 170MPa, compressive strength f_c = 12MPa, tensile strength f_t = 0,12MPa.

2.2 Analysis of bearing and deformation structural capacity

Based on the defined geometry of the structural systems of the building, the physical-mechanical characteristics of the embedded materials and the load of the elements, an analysis was performed to determine the load-bearing capacity and deformability of the building, with the main purpose of defining its behaviour under seismic action.

To determine the real strength and deformation characteristics depending on the quantity and quality of the embedded materials, the computer program developed in UKIM-IZIIS was used. The program determines the displacement and the lateral force at yielding point (Δy and Qy), the ultimate displacement and lateral force (Qu and Δu), for each individual element of the storey, i.e., the initial stiffness and the stiffness at yielding point. In this way, the force-displacement relationship is obtained for each element of each storey separately, whereby, the load-bearing and deformation capacity of each storey is defined. The deformation capacity also defines the displacement ductility capacity for each floor as μ = Δu / Δy. The load-bearing and deformation capacity are determined for both orthogonal directions. The strength capacity is shown in the form of the ultimate storey shear force, which compared to the equivalent seismic force gives the safety factor.

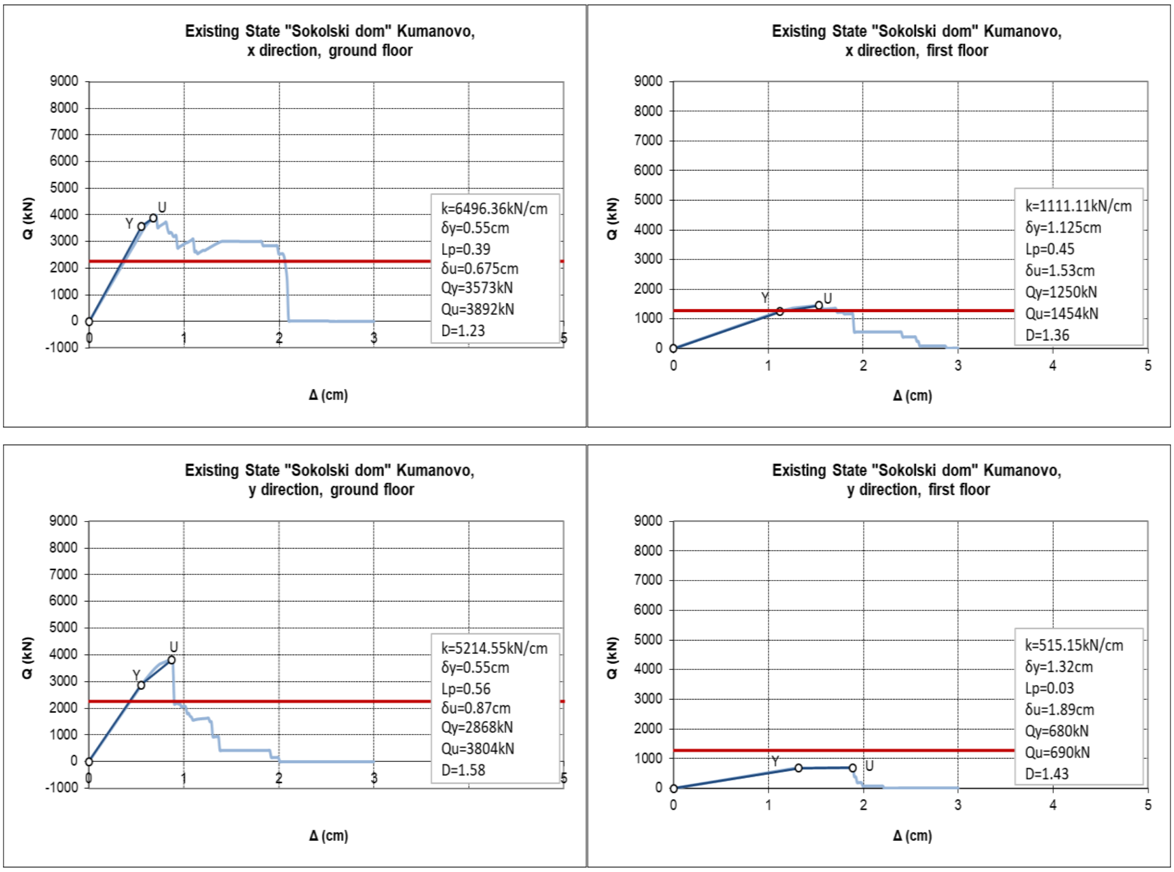

Figure 5. Storey Q-Δ relationship (existing state) for both orthogonal directions

The results of the analysis, in the form of summary storey Q - Δ diagrams for the two orthogonal directions respectively, are shown in Fig.5. The bilinear diagrams with the characteristic yield points "Y" and the ultimate point "U" are shown in blue, while the required load capacity of each floor is marked in red. Table 1 summarizes the obtained and required load-bearing capacities of the structure for each storey.

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Table 1 – Structural bearing capacity for the existing structure

Existing state, x-direction

Level	Qy [kN]	Qu [kN]	Qs [kN]	Qy/Qs	Qu/Qs
1st floor	1250	1454	1280	0.97	1.13
GF	3573	3892	2259	1.58	1.72

Existing state, y-direction

Level	Qy [kN]	Qu [kN]	Qs [kN]	Qy/Qs	Qu/Qs
1st floor	680	690	1293	0.52	0.53
GF	2868	3804	2259	1.26	1.68

Based on the performed analysis of the existing structure and the obtained results, it was concluded that the strength capacity of the building for the ground floor for x-direction and y-direction is higher than the required according to the regulations, but for the first storey in both directions, it does not meet the requirements according to the regulations, PIOVS (1981). The ductility capacity for both directions in height is relatively small. The structure does not have sufficient strength for the ground floor for both directions, also the bearing capacity and deformability is relatively small for both directions, Bozinovski, Shendova et al. (2021). Given that structural interventions are going to be made, it is necessary to provide adequate strength and sufficient deformability, providing structural elements with greater ductility and increasing the integrity of the structure in both directions. From the above, the need for repair and strengthening is justified and necessary to improve the strength and deformation requirements and to achieve the desired dynamic response during future earthquakes.

3. Repair, strengthening and analysis of the structural system

3.1 Description of the technical solution for strengthening of the existing structure

Based on the required strength and deformation characteristics of the elements and the whole structural system, several variant solutions for strengthening of the structure were considered. During the selection of the repair and strengthening solution a few aspects were considered including the possibilities for interventions in the building and the economic aspect. Also, for each variant solution a preliminary analysis was obtained (for the structure stability for the two orthogonal directions). Comparison was made of the strength and deformability characteristics obtained with the required by the regulations.

From several variant solutions, a traditional solution for strengthening has been selected, the most appropriate from the economic aspect and from the aspect of assuring the strength and deformation requirements, according to the current technical regulations.

The solution for strengthening of the structural system includes the following, Bozinovski, Shendova et al. (2021): (i) strengthening of load-bearing walls with reinforced concrete jacketing in longitudinal and transverse direction along with the new foundations (shown with red color in figures 6, 7, 8); (ii) connecting the RC jacketings with horizontal reinforced concrete belt courses (shown with blue color in figures 7, 8) or rectangular steel profiles (shown with green color in Figures 7, 8), in transverse and longitudinal direction; (iii) strengthening of wooden joists from the roof truss with steel profiles (shown in figures 7,8 with green color) in order to form ties for connecting the elements in the transverse direction; (iv) local repair of the cracks manifested in the bearing walls; (v) local remove and replacement of the damaged wooden roof structure; (vi) local remove and replacement of the damaged ribbed reinforced slab above the ground floor. Figures 6, 7 and 8 show the formwork plans and characteristic cross-sections of the proposed technical solution for strengthening the "Sokolana" Structure.

The new reinforced concrete elements are intended to be of quality MB30 concrete (E_c = 31500Mpa, f_c = 21.5MPa) and reinforcement of the type RA400 / 500-2 (E_a = 210000MPa, f_{ta} = 400Mpa). Reinforced concrete elements of the structure are proportioned according to the theory of limit loads, i.e., according to PBAB (1987).

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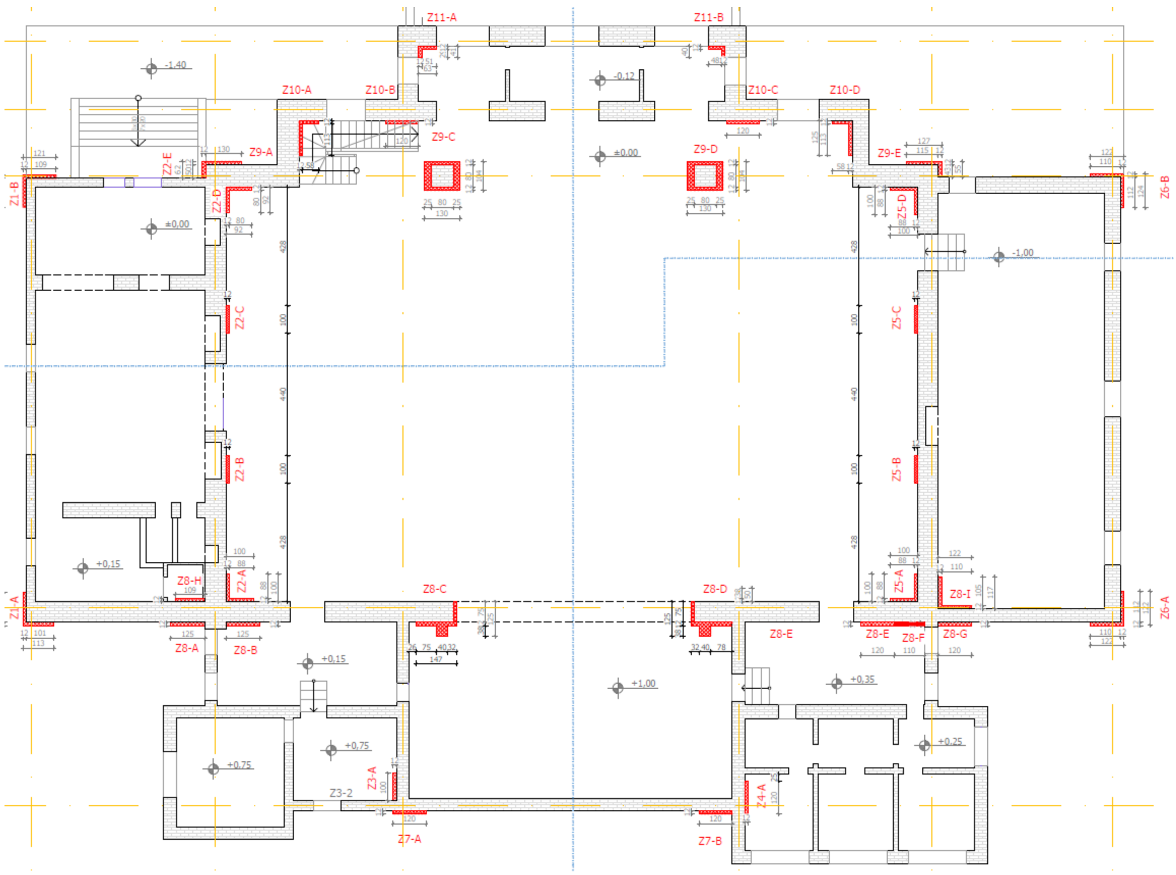

Figure 6. Formwork plan of the ground floor for the proposed strengthening solution

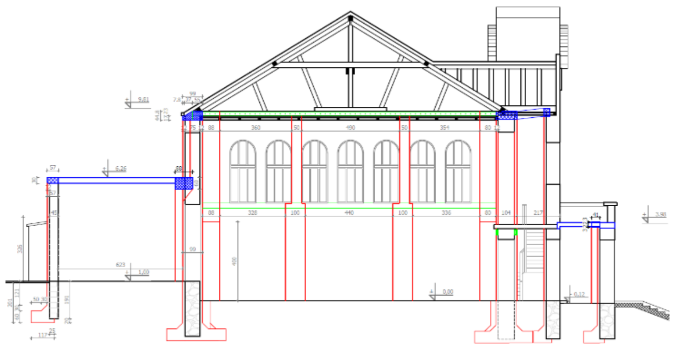

Figure 7. Characteristic cross sections for the proposed strengthening solution: transverse cross section

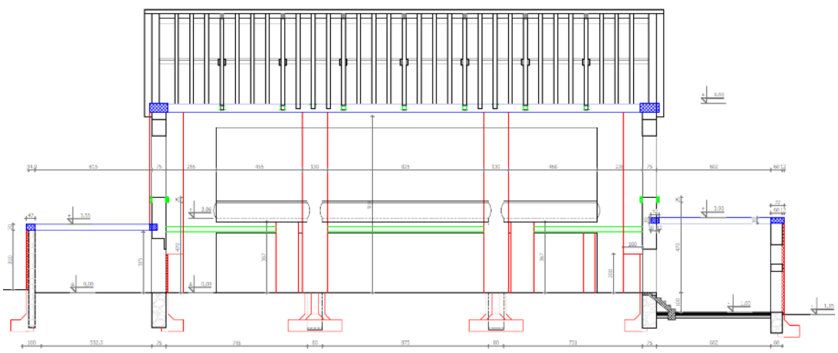

Figure 8. Characteristic cross section for the proposed strengthening solution: longitudinal cross section

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3.2. Analysis of bearing and deformation capacity for the strengthened structural system

For verification of the proposed technical solution for repair and strengthening of the building, the procedure shown in Chapter 2.2 was applied again, through which the load-bearing and deformation capacities are defined, but this time of the strengthened structure. The computer program recalculates the displacement and shear force at yielding point (Qy and Δy), as well as at the ultimate point (Qu and Δu) for each individual element of each storey, but for the integrated structural system of masonry and reinforced concrete elements, with the corresponding characteristics of the built-in material. The results are presented in the form of summary storey Q - Δ diagrams for the two orthogonal directions respectively.

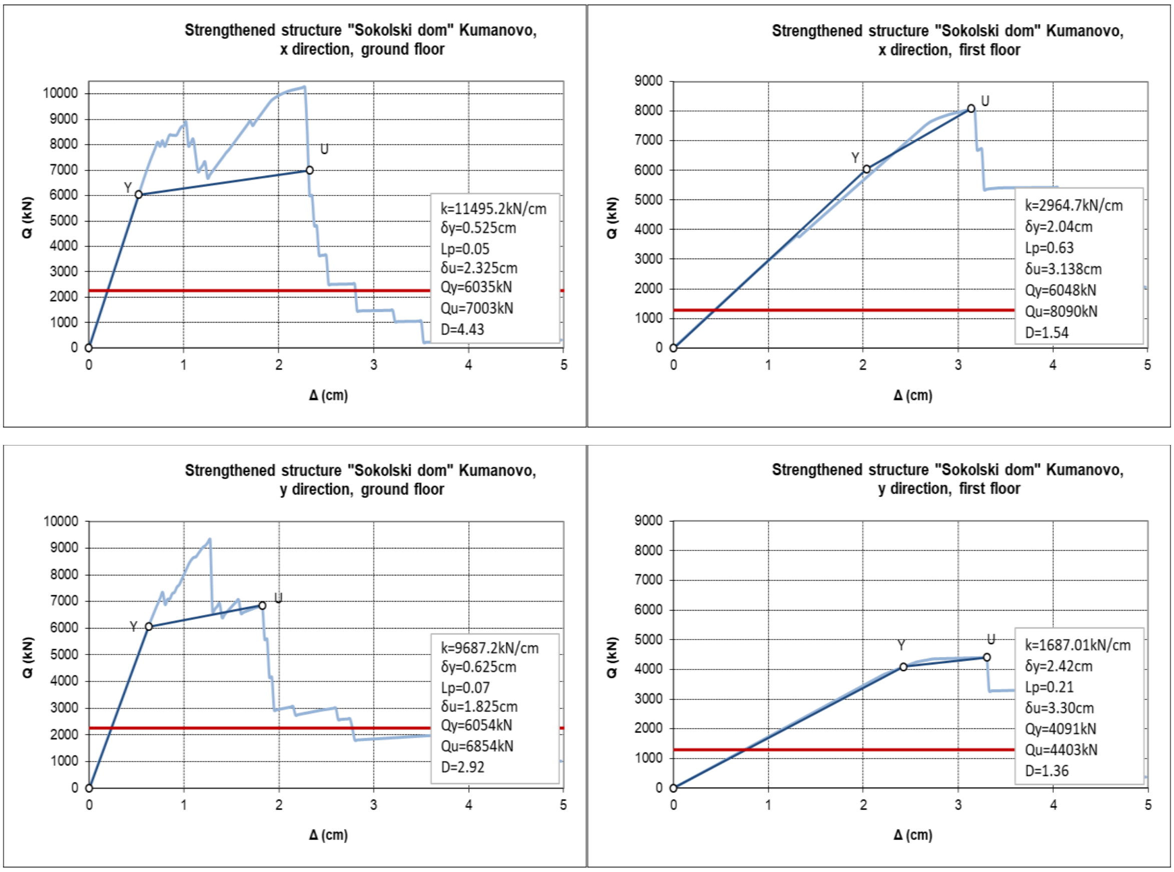

Fig. 9 - Storey Q-Δ relationship (strengthened structure) for both orthogonal directions

The bilinear diagrams with the characteristic yield points "Y" and the ultimate point "U" are shown in blue, while the required load capacity of each floor is marked in red (Fig. 9). Table 2 summarizes the obtained and required load-bearing capacities of the building by storey and directions, showing the new calculated safety factor.

Table 2 – Structural bearing capacity for the strengthened structural system

Strengthened structure, x-direction

Level	Qy [kN]	Qu [kN]	Qs [kN]	Qy/Qs	Qu/Qs
1 floor	6048	8090	1280	4,725	6,32
GF	6035	7003	2259	2,67	3,10

Strengthened structure, y-direction

Level	Qy [kN]	Qu [kN]	Qs [kN]	Qy/Qs	Qu/Qs
1 floor	4091	4403	1293	3,16	3,40
GF	6054	6854	2259	2,67	3,03

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From the results of the analysis of the repaired and strengthened structure, it is noted that the capacity of the strength in both orthogonal directions of the building is significantly greater than the required limit capacity according to the regulations, PIOVS (1981). The bilinear diagrams show an increase in the deformation capacity of each of the storeys in both directions respectively, with an increase in the ductility capacities. This leads to the conclusion that the strengthening will increase the ability of the system for greater dissipation of energy, Bozinovski, Shendova et al. (2021). This is especially important for this type of buildings in case of seismic excitations. By increasing the deformation capacity, the input energy in the system would be consumed, which would greatly increase the seismic safety and security of the building, Bozinovski et al (2021).

4. Conclusions

The building of “Sokolana” in Kumanovo is a historic building built in the thirties of the last century. During the visual inspection, significant damage was observed on the load-bearing walls, due to the negligence of the building, manifested with large cracks on the walls. Heavy damage was observed also in the roof-wooden structures, and ribbed reinforced slab in the annex ground floor structures.

Based on the results form performed analysis of the existing structure it was concluded that the strength capacity of the building for the ground floor is higher than the required one according to the regulations, but for the first storey it does not meet the requirements for both directions. The ductility capacity for both directions is relatively small. The structure does not have sufficient strength, also the deformation capacity are relatively small, for both directions. Given the results of the existing structure, the need for repair and strengthening is justified and necessary in order to improve the strength and deformation capacity and achieve the desired dynamic response during future earthquakes.

From several analysed variants, a traditional solution for strengthening has been selected, the most appropriate from the economic aspect, satisfying the strength and deformation requirements according to the current technical regulations. The analysis of the repaired and strengthened structure of the “Sokolana” building, clearly shows that the strengthened system has significantly increased strength (load-bearing capacity) in both orthogonal directions and satisfies the required limit load capacity in accordance with current regulations. At the same time the results of the strengthened structure show an increase in the deformation capacity of each of the storeys in both directions respectively, i.e. an increase in the ductility. This leads to the conclusion that the proposed strengthening will increase the ability of the system to greater dissipation of energy, which is especially important for this type of buildings in case of seismic excitations.

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