Proceedings of the 2nd Croatian Conference on Earthquake Engineering - 2CroCEE
Zagreb, Croatia - March 22 to 24, 2023
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DOI: https://doi.org/10.5592/CO/2CroCEE.2023.45

REPAIR AND STRENGTHENING OF OLD FIRST CATEGORY BUILDING IN SKOPJE, N. MACEDONIA IN ACCORDANCE WITH IZIIS METHODOLOGY

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Abstract

The potentially high vulnerability and poor performance of the existing buildings, after past seismic events, including exploitation period has raised awareness of the need to improve their seismic performance. Repair and strengthening gives new life to existing or ageing structures that might otherwise be demolished and replaced.

This paper will address the issues related to repair and strengthening techniques for the first category building in Skopje, N Macedonia dated from 1924. Structural and nonstructural damages were observed due to the inappropriate foundation and maintenance of the building, which have increased during exploitation period and seismic actions. In order to define the stability of the building, non-destructive tests were applied for definition the material characteristics, further used in numerical analysis. Based on the performance assessment, retrofit schemes were proposed to address the main structural deficiencies and to meet national code requirements in N. Macedonia.

The results of the overall investigations and analyzes for the capacity of the building are presented in this paper. Also summarized are the necessary structural interventions to ensure the necessary stability and reliability of the building for gravitational and seismic actions in accordance with the existing legislation in the Republic of North Macedonia. Since it is a first category, the dynamic response of the structure to real seismic actions, expected at site, is also considered according to the valid legislature which defines the assessment of seismic force considering local soil conditions.

The outcomes from this project indicate the efficiency of the retrofit options utilized in reducing both the economic losses and collapse vulnerability of the building.

Keywords: repair, strengthening, non-destructive tests, structural and non-structural damages, dynamic analysis

1. Introduction

This paper is part of a project that was realized for the needs of the army of the Republic of North Macedonia.[1] In this paper a detailed analysis of the stability of the existing structural system has been presented, the necessity for repair and strengthening of the building has been proven, and an analysis of the stability of the repaired and strengthened structural system of the building has been performed. In the following, the results of the overall investigations and analyzes for the capacity of the building are presented. Also summarized are the necessary structural interventions to ensure the necessary stability and reliability of the building for gravitational and seismic actions in accordance with the existing legislation in the Republic of North Macedonia. The building is analysed as first-category building according to the current technical regulation, including the dynamic response of the structure to real seismic actions expected at the site.

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2. Existing structural system

The building consists of ground floor, first floor and an attic with a relatively low height. The principal structural system represents brick masonry in lime mortar load-bearing perimeter walls, in combination with reinforced concrete frames in the interior of the building. Reinforced concrete slabs are constructed above the ground and first floor, which are supported on longitudinal and transverse beams. The foundation structure of the perimeter walls consists of strip foundations made of brick masonry in lime mortar without extensions, which represents an unusual foundation for this type of building. The columns located in the middle longitudinal line of the building are constructed on individual reinforced concrete footings. Façade of the building and building interior is shown in Fig. 1.

Figure 1. Façade of the building and building interior

Structural and non-structural damages were observed due to the inappropriate foundation and maintenance of the building, which have increased during the exploitation period and seismic actions (Fig. 2, Fig. 3).

Figure 2. Horizontal and diagonal cracks

Figure 3. Cracks in masonry walls

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In order to define the stability of the building, non-destructive tests (Fig. 4) were applied[1] for definition the material characteristics, further used in numerical analysis.

Figure 4. Non-destructive tests

3. Analysis of the existing structure

An analysis of the existing structure was performed, due to the gravitational and equivalent seismic forces in accordance with the existing legislation in the Republic of North Macedonia. Seismic forces are defined based on the characteristics of the building and its purpose, as well as the characteristics of the location where the building is placed.

The analysis up to strength and deformability limit states was performed, with aim of defining the actual capacity of the structure and comparing it with the requirements in accordance with the existing legislation. Since it is a first-category building, the dynamic response of the structure to real seismic actions, expected at site, is also considered.

3.1 Quality and characteristics of the embedded materials

For the purposes of the analysis, a visual inspection of the structure was performed. The inspection defined the type and condition of the embedded material for the masonry walls, the quality of the materials, its strength and deformation characteristics. The quality of the masonry, for the structural walls, expressed through the limit bearing capacity of pressure (σ_c) and tension (σ_t) is evaluated based on the experiences of tested elements of similar quality and construction time. From the experimental tests carried out by the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) on other buildings, the following characteristics of the existing masonry were determined: σ_t =100 – 300 kPa; σ_c =1000 – 3000 kPa.

For the existing condition, when we have clean masonry with vertical horizontal and diagonal cracks, as in the case, the analysis used σ_t = 100 kPa and σ_c = 1000 kPa, which according to the condition of the masonry and the degree of damage, are real.

With the strengthening, the masonry gets horizontal and vertical cerclages, reinforced concrete foundations and jackets, which significantly improves the strength and deformable characteristics of the structural elements, so in the analysis for the strengthened state, slightly higher characteristics were used, namely: σ_t = 150 kPa and σ_c = 1500 kPa.

The quality of the concrete and the embedded reinforcement is defined through non-destructive tests (Fig. 4). From the results, it was determined that the strength of the embedded concrete in the columns ranges from 22-25MPa, while in the beams from 19-22MPa. Reinforcement bars in the columns with a diameter of 16Φ, 18Φ, 20Φ, longitudinal, as well as 10Φ, 12Φ, 14Φ transverse, were found, and it was determined that smooth reinforcement GA240/360 was used.

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3.2 Analysis of the strength-deformation characteristics of the existing structural system

The existing structural system presents a combined system of load-bearing walls made of solid brick in lime mortar, combined with reinforced concrete frames inside the building. The results of the analysis are given in the form of floor diagrams Q-Δ, separately for the two orthogonal directions (Fig. 5).

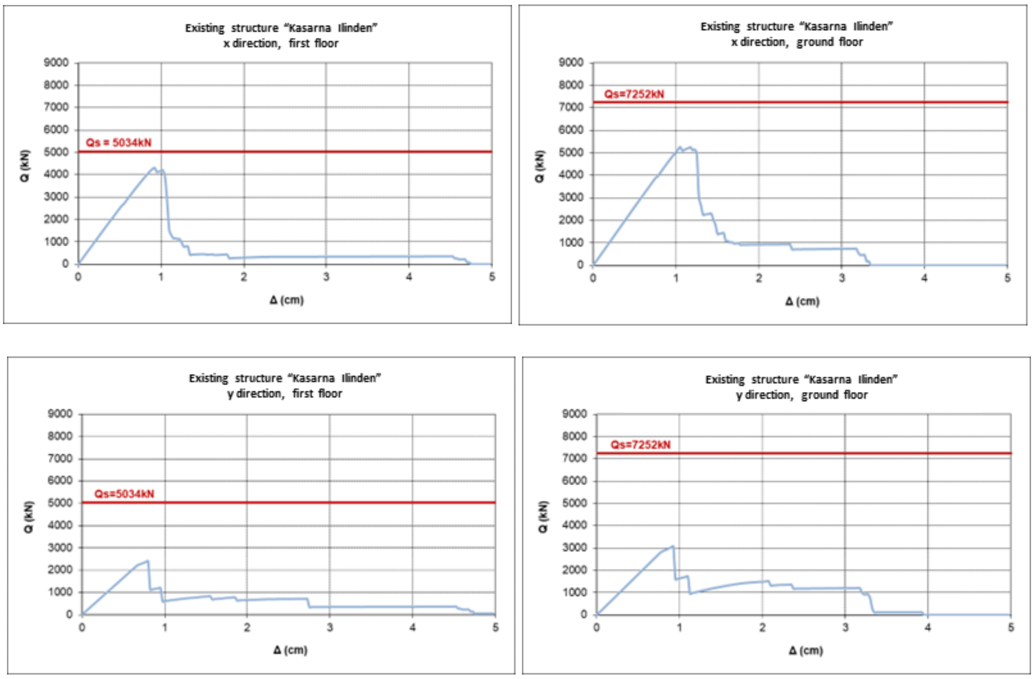

Figure 5. Floor Q-Δ diagrams for x and y direction

The summary strength and deformation characteristics are given in Table 1 and Table 2.

Table 1. Strength and deformation characteristics

Mass and seismic forces of the building by floors - existing structure

level	Hi	m	Sx	QSx	Sy	Qsy
	[m]	[kN]	[kN]	[kN]	[kN]	[kN]
1st F	3,72	12530	5034	5034	5034	5034
GF	3,72	11643	2218	7252	2218	7252

Existing structure (x-direction)

level	K	δY	L.P.	δU	D_cap	Qy	Qu
	[kN/cm]	[cm]		[cm]		[kN]	[kN]
1st F	4286	0,70	0,817	1,00	1,43	3000	4050
GF	5000	0,80	0,440	1,30	1,63	4000	5100

Existing structure (y-direction)

level	K	δY	L.P.	δU	D_cap	Qy	Qu
	[kN/cm]	[cm]		[cm]		[kN]	[kN]
1st F	3333	0,60	0,450	0,80	1,33	2000	2300
GF	3636	0,55	0,963	0,85	1,55	2000	3050

3.3 Analysis results and conclusions on the necessity for strengthening

Based on the performed analysis of the existing structure and the obtained results, it was concluded:

Table 2. Strength and deformation characteristics

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Existing structure (x-direction)					
level	Qy	Qu	Qs	Qy/Qs	Qu/Qs
	[kN]	[kN]	[kN]		
1stF	3000	4050	5034	0,525	0,551
GF	4000	5100	7252	0,804	0,703
Existing structure (y-direction)					
level	Qy	Qu	Qs	Qy/Qs	Qu/Qs
	[kN]	[kN]	[kN]		
1stF	2000	2300	5034	0,397	0,275
GF	2000	3050	7252	0,457	0,421

The structure's strength capacity for both directions is lower than required by the regulations, PIOVS 81, which is 16.5% for the X-X direction and 8.27% for the Y-Y direction of the total weight of the building. The required capacity according to regulations is 30%. Consequently, the structure does not have sufficient strength for the longitudinal direction and significantly insufficient strength for the transverse direction. The deformability capacity is relatively small for both directions. In addition to the requirements for seismic stability of the building, which have not been met, the building also has severe structural damage due to settlements of the foundation structure. The above mentioned demonstrates the necessity of improving the strength and deformation characteristics, in order to satisfy the basic requirements according to the existing technical regulation.

4. Selection of the Most Adequate Repair and Strengthening Solution for the Principal Structural System

Out of a number of variant solutions, the most appropriate solution has been selected from both low-cost aspect and the aspect of satisfying the strength and deformation requirements in compliance with the valid technical regulations. The solution for strengthening of the principal structural system mainly anticipates strengthening of the structural bearing elements, walls, columns and beams, creating lines of defence against external seismic effects in both orthogonal directions (Fig. 7, Fig. 8). Repair of cracks in bearing walls and reinforced concrete elements as well as partial repair of the floor structure is done additionally. More specifically, this involves the following:

- Strengthening of the foundation structure and recommendations for drainage of atmospheric waters from the structure;
- Strengthening of the bearing walls by reinforced concrete jackets in longitudinal and transverse direction;
- Strengthening of reinforced concrete columns mainly along strengthening lines of external walls;
- Strengthening of transverse beams along the strengthening line of walls and columns;
- Foundation of reinforced concrete jackets into own footings. The same also holds for the strengthened reinforced concrete columns;
- Inter-connection of jackets by horizontal reinforced concrete belt courses mainly along the perimeter of the structure and at the level of the floor structure over the ground floor and over the storey;
- Local repair of cracks manifested in bearing walls and reinforced concrete elements;
- Local repair of the deformed floor structure at the ground floor.

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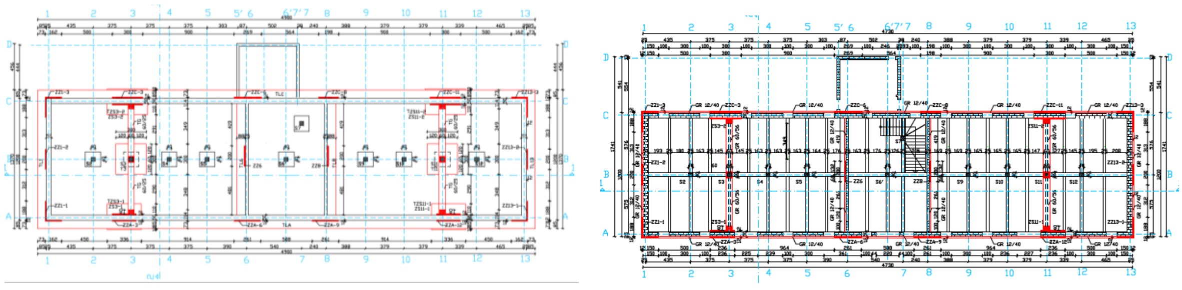


Figure 6. Strengthened and existing state at plan of foundations (left), ground floor and storey (right)

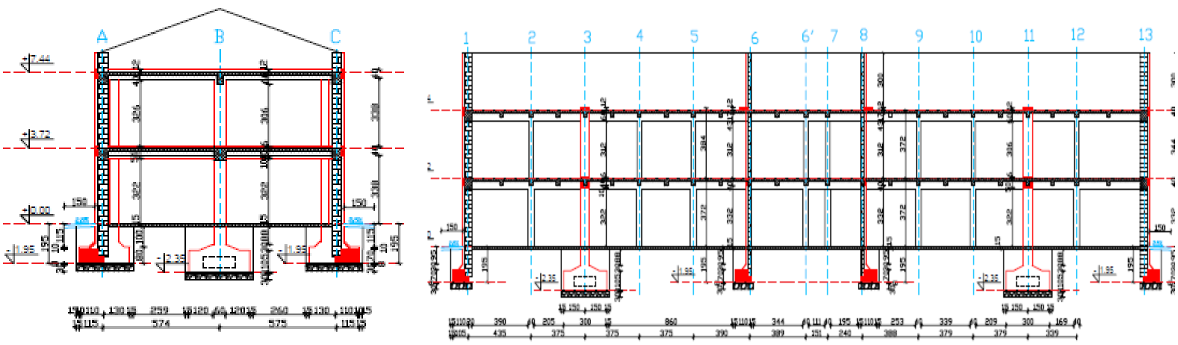


Figure 7. Cross-section of the strengthened and existing structure.

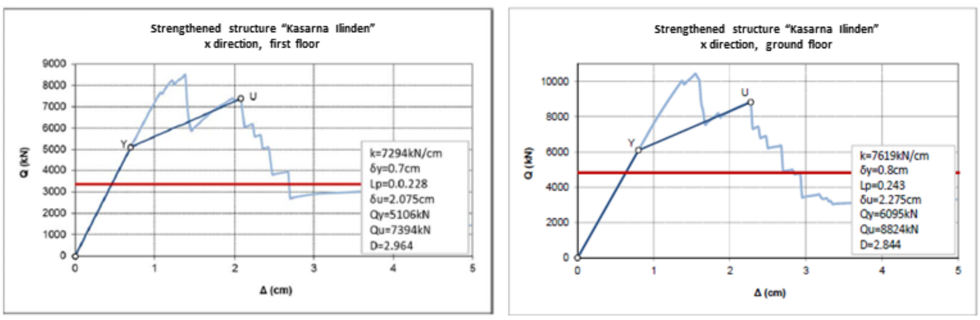
5. Analysis of the repaired and strengthened structural system

For the strengthened structural system, analysis of strength and deformability to strength and deformability limit states was performed, for the structural elements and the global structural system, for its dynamic response under real expected seismic actions.

On the basis of the performed analysis of the strengthened structural system the following condition was established.

5.1 Storey diagrams Q-Δ

On the basis of the defined diagrams base shear-displacement and moment-curvature for every element and their transformation in diagrams force-displacement, the following floor diagrams force-deformation were defined (Fig. 8).



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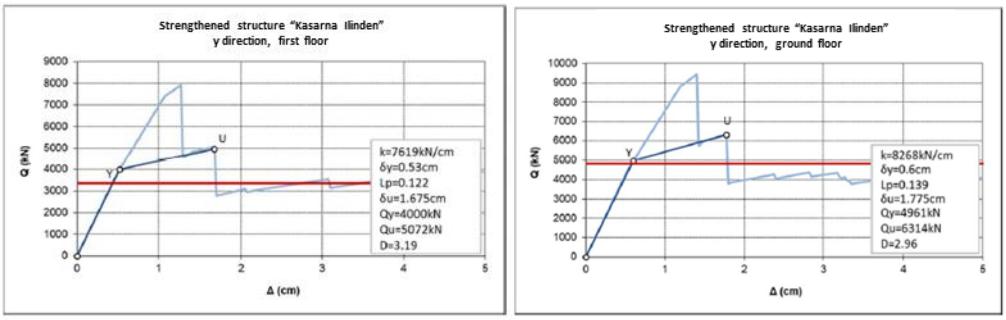

Figure 8. Floor diagrams force- deformation in X and Y direction (strengthened structure)

The total strength and deformability characteristics are given in the Table 3 and Table 4:

Table 3. Total strength and deformability characteristics

Strengthened structure Direction X-X								
	Qy [kN]	dy [cm]	Qu [kN]	du [cm]	K1 [kN/cm]	K2 [kN/cm]	L. P.	Ductility
1st F	5106	0.7	7394	2.075	7294	1664	0.228	2.964
GF	6095	0.8	8824	2.275	7619	1850	0.243	2.844
Strengthened structure Direction Y-Y								
	Qy [kN]	dy [cm]	Qu [kN]	du [cm]	K1 [kN/cm]	K2 [kN/cm]	L. P.	Ductility
1st F	4000	0.525	5072	1.675	7619	932	0.122	3.190
GF	4961	0.6	6314	1.775	8268	1151	0.139	2.958

Table 4. Total strength and deformability characteristics

Strengthened structure Direction X-X					
level	Qy [kN]	Qu [kN]	Qs [kN]	Qy/Qs	Qu/Qs
1st F	5106	7394	3362	1,52	2,20
GF	6095	8824	4825	1,26	1,82
Strengthened structure Direction Y-Y					
level	Qy [kN]	Qu [kN]	Qs [kN]	Qy/Qs	Qu/Qs
1st F	4000	5072	3362	1,18	1,51
GF	4961	6314	4825	1,03	1,31

The analysis of strength and deformability characteristics of the structure show that the capacity of strength at the base of the stracture totals 36.5% of the total weight of the structure for X-X direction and 26.12% of the total weight of the structure in Y-Y direction. The demand capacity from the codes is 19.5% because of the change in the coefficient of ductility and damping for strengthened masonry. These data are from manually schematized diagrams force-displacement. From the diagrams, it is clear that the capacity of strength and deformability are larger, as well as the capacity for dissipation of seismic energy. The capacity of the strength of the structure in both directions is larger than the demand according to technical regulations.

5.2 Dynamic response for real seismic actions

For the location of the structure, a maximal acceleration of 0.25g was defined, together with recommended accelerograms (time- history records):

- Ulcinj (Albatros) N-S;

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- El Centro;
- Ulcinj (Olimpik) N-S;
- Bar (municipality parliament) N-S;
- Robic- excitation with wide frequency range;

The results are shown as diagrams floor- displacement and floor- ductility (Fig. 9).

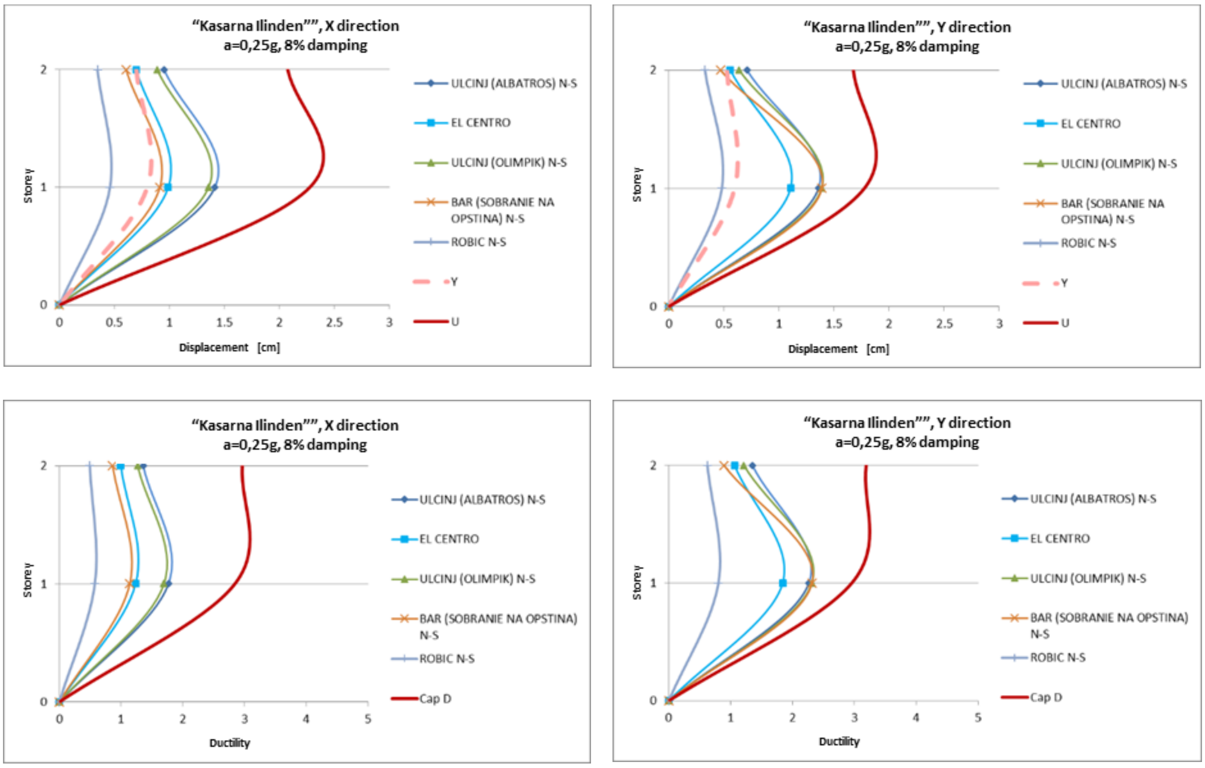

Figure 9. Diagrams floor- displacement and floor – ductility for X and Y direction

With the repair and strengthening of the structural system, a significant increase in ductility capacity and dissipation of seismic energy capability of the elements and the structural system as a whole can be noted. The dynamic response for real expected seismic actions for the location confirms that too.

5.3 Dynamic response for real seismic actions

Proportioning of new RC elements according to the theory of limit states i.e. current technical regulations in the country was performed. For part of the elements, reinforcement is placed gradually from 0.6% to reach the necessary strength and deformability.

6. Technology of Construction

The strengthening effect depends on the consistency of the performance of the construction works. The preparation works are not carried out simultaneously for the jackets, the foundation of the external walls and the foundation of the central column. The foundation of the external wall beyond the jacket is performed in parts of 2 – 3 m. Prepared and constructed simultaneously is a jacket on the left front wall, a jacket on the rear external wall, one column and 4 parts of the foundation of the external walls according to the construction plan approved by the Engineer following the excavation for the first jacket and assessment of the rockfall hazard and possibility for performance of simultaneous activities in a long run. One of the reasons for controlled construction is also a possible earthquake that may affect the weakened structural system. Parallel to the preparation works, injection of cracks in the solid brick walls is performed. The crack is cleaned and widened upon the surface of the cracked and damaged

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bricks and is injected with repaired concrete or strong cement mortar. Local strengthening is done irrespective of strengthening because global strengthening of the structure prevents further opening of cracks.

Preparation works consist of: chase cutting of mortar on the walls made of solid bricks in lime mortar at places of their strengthening with reinforced concrete jackets. Then, half bricks are taken from the wall at distance of 40 cm along horizontal and vertical line, in a chess shape, in order to provide a better connection between the masonry and the concrete part.

As an example, the figure below shows a detail of a jacket with minimal reinforcement and way of efficient connection with a solid brick wall. In addition to dowels, the wall is additionally connected to the jacket by a reinforcing wire and a metal plate on the opposite side. The next step is excavation for the foundation of the jacket. The excavation is done beside the wall, at depth down to the lower edge of the existing foundation plus 30 cm for the tooth, 8 cm for the lean concrete and 30 cm for the gravel layer. Details of the technology of performance of repair are shown on Fig. 10.

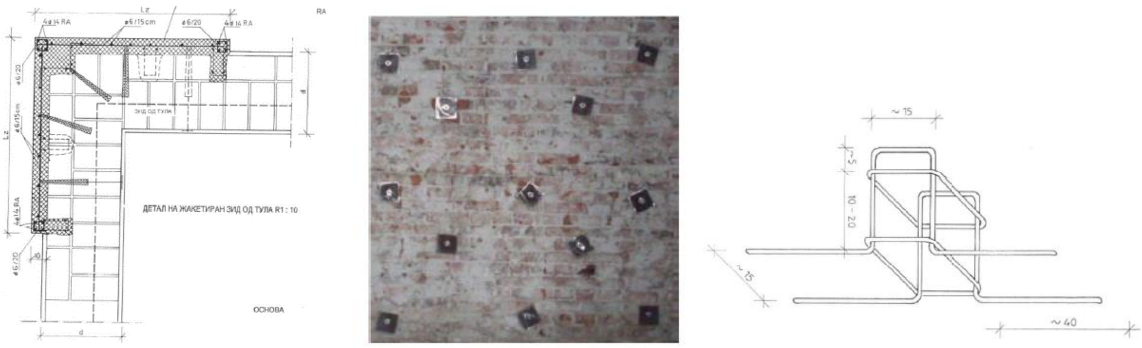

Figure 10. Details of the technology of performance of repair.

Following the excavation, compaction of the base is done by means of a light rammer (the so called frog rammer). Consolidation is done by light compaction. Upon the base, a layer of lean concrete is poured. With this, conditions are created for the construction of the jacket. The wall and the foundation are prepared for the placement of the anticipated reinforcement. Following placement, connection and checking of the reinforcement, shuttering of the jacket and the foundation into the planned shape is done. Concreting is done per phases, the first phase - upper edge of the foundation, i.e., down to the lower edge of the connecting foundation beam, second phase – connecting foundation beam, third phase – down to the lower edge of the transverse beam and longitudinal belt course. In the fourth phase, concreting of belt courses and transverse beams is done. The fifth phase involves the jackets over the storey and the last one includes the end belt courses over the storey. After concreting of the foundation, the earth is returned over the foundation and conditions are created for the construction of the footways. Simultaneously with these activities, preparations for the connection of the transverse beam and the external jackets are made, leaving sufficient space for embeddment of reinforcement and the jacket–transverse beam concrete connection. Details of repair of end column and central column are shown on Fig.11.

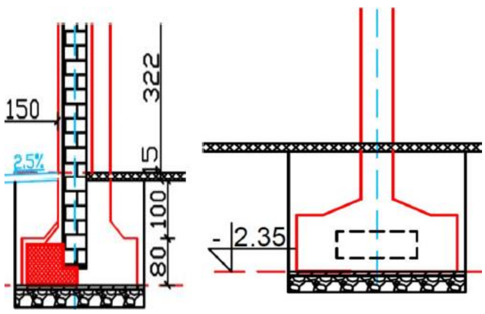

Figure 11. Details of repair of end column and central column

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A similar procedure is applied in strengthening of a central column. Chase cutting of the mortar from the column and roughening of the external surface are done in order to create a better connection between the old column and the jacket. Excavation for the foundation follows. The base is compacted, the gravel layer and the lean concrete are placed. Further on, reinforcement, shuttering and concreting are done in a number of phases. The transverse beam is constructed as entirely continuous. The same holds also for the external horizontal belt courses.

7. Conclusions

With its strength and deformability characteristics, the existing structural system does not satisfy the requirements pertaining to the Regulations and recent knowledge on behaviour of masonry structures exposed to gravity and seismic effects.

A number of variant solutions have been proposed and analyzed for repair and strengthening of the principal structural system.

Selected out of a number of variant solutions has been the most appropriate one from low-cost aspect and from the aspect of satisfying the strength and deformability requirements of the valid technical regulations.

The repair and strengthening of the bearing structural system have been done in such a way as to satisfy the requirements of valid technical regulations and enable a favourable dynamic response to the realistic seismic effects defined for the considered location.

Strengthening practically enables greater stiffness, strength and deformability by optimizing these three characteristics, obtaining thus optimal quantities and providing the required seismic safety.

A greater percentage of the strengthening activities refers to strengthening due to inappropriate foundation resulting in diagonal cracks in bearing walls made of solid bricks in lime mortar, whereas strengthening against seismic effects is done to a relatively lesser extent.

This report contains the minimal necessary elements for repair and strengthening of the principal structural system, by means of dimensions and reinforcement.

Out of own reasons, the Contractor may adopt, according to the possibilities for performance or available equipment and material, different dimensions of elements or different reinforcement provided that the dimensions and the reinforcement are not lesser than those defined in this report. Each change should be reported to us in order that we can check whether the change affects the level of seismic protection and stability of the structure.

The analysis of the strength and deformability capacity of the repaired and strengthened structure has proved that it satisfies the strength and deformability requirements of the valid regulations and the most recent knowledge on behaviour of masonry structures exposed to static-gravity and dynamic-seismic loads.

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