ASEISMIC DESIGN AND CONSTRUCTION OF MASONRY BUILDING ROOFTOP EXTENSION

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ABSTRACT

The masonry building rooftop extension issue is not entirely covered by technical norms. It is essential to comprehend and analyze existing structural system and building condition before reaching the structure extension decision, and to apply engineering principles in design and construction procedures.

Design and construction of masonry building extension in seismic active regions, based on fundamental principles is considered in this paper. Basic principles of modeling, design and construction of elements, as well as the fundamental methods of strengthening of foundations, vertical and horizontal elements are stated.

Key words*: building extensions, design, strengthening foundations, walls, story structure.*

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1. INTRODUCTION

Building rooftop extension or changing the purpose of an existing one, as well as the construction of a new one, among other things, must be preceded by an architectural-urban analysis, that is, the development of appropriate projects. Sometimes, due to specific conditions, the problem of designing an rooftop extension is much more complex than designing a new facility. As the rooftop extesion increases the overall dimensions of the object, changes its previous appearance, its relation to the neighboring objects and the environment, the designer is obliged to bring the existing and upgraded part of the object into a harmonious whole, both with each other and with the environment. In addition, when designing the function and layout of rooms, and often interiors, there are a number of limitations and conditions, primarily the position of stairs, elevators, facades, toilets etc. In such jobs, the knowledge, ability and imagination of the designer come to the fore.

It is not uncommon to change parts or even entire objects during the exploitation time of an object. In addition, for a variety of reasons, one or more floors may sometimes be added to an existing building.

In principle, the problem of changing the purpose or rooftop extension of an object is not much different from any other, usual construction. It is necessary to prepare documentation for the project and provide all approvals, conditions and permits, as well as when constructing a new facility.

In the analysis of the economic justification of the rooftop extesion, it must start from the fact that the structural aspects are the most important. The rooftop extension must in no way compromise the stability, bearing capacity, safety and durability of the existing facility and its upgraded part. Only when these conditions are satisfied can one speak of functionality, aesthetics or economic justification, which are of course indispensable factors.

In the process of analyzing the possibilities and conditions for rooftop extension, from a structural aspect, it is necessary, first of all, to define the structural system of an existing building. This applies to the vertical and horizontal structural elements, the roof structure, and in particular to the method of foundation and type of foundation (foundation strips, single foundations, piles, etc.). The structural system can most easily be viewed from the project documentation, if it exists, that is, if it is preserved and available.

A particular problem when considering the structural aspect of building rooftop extensions is the seismic resistance of the building after the rooftop extension. Namely, since our first regulations for construction in seismic areas were made only after the earthquake in Skopje in 1963, this may, at first glance, mean that the huge number of structures that were built before that do not automatically meet the provisions of the regulations. Of course, it is true that there are previously constructed buildings, mostly of lower floors, which, according to the applied structural system and building materials, fully satisfy the provisions of these new regulations. However, the question arises as to what happens to the seismic resistance in the event of an rooftop extension and an increase in the mass of the object. Due to such dilemmas, in the period when the rooftop extension of facilities in our country became very widespread, an amendment in the form of Article 115a was introduced in the current “Rulebook on Technical Standards for the Construction of Buildings in Seismic Areas”. This article prescribes that the seismic resistance of existing structures after the adaptation and reconstruction (rooftop extension?) must be as it was before the works were carried out or must be in accordance with the provisions of the Regulations. In doing so, the notion of "substantial change" was introduced, which in many constructors still leaves doubts and different interpretations. In any case, the most correct route is a detailed computational analysis of the behavior of the object for the action of seismic forces in the state before and after the rooftop extension. Of course, the provisions of our Regulations should be respected, but it is advisable to analyze other regulations, in particular Eurocode 8 (Design of Seismically Resistant Structures).

The main design for the rooftop extension requires a detailed analysis of the impact on the object in the state before and after the anticipated extension, analysis of the mechanical characteristics of the soil and the calculation of additional subsidence of the foundation (of course, additional stress to the ground below the foundation is a basic parameter for analysis) and carry out an analysis of bearing capacity of existing structural elements. On this basis, a decision is made on the need to strengthen the foundations, walls, floor structures or other parts of the structure. The choice of a solution for strengthening an existing masonry structure when upgrading, as already pointed out, depends on several factors (floors, structural system, number of walls, etc.). The basic starting point for a structural strengthening project should be a clear concept of a structural system for accepting horizontal forces from seismic effects. In this connection, the following structural systems of masonry structure with rooftop extension with or without strengthening may be defined:

- system of walls without vertical and horizontal tiles (ordinary masonry structures),

- system of walls framed by vertical and horizontal RC elements,

- system with reinforced masonry walls,

- system with masonry and reinforced concrete elements for strengthening.

For all of these systems, the basic requirement is that there be ceiling floors rigid in their plane to ensure the joint work of the vertical structural members to accept horizontal forces from seismic action and to conduct them from the ground up.

In any case, the structural solution of the rooftop extension depends largely on the structural engineer, his experience, knowledge of construction technology, knowledge of building codes and materials, and often his wit. Any more serious upgrade poses a challenge for the constructor and generally, in collaboration with the architect, investor and contractor, an acceptable solution can be found.

2. DESIGN OF ROOFTOP EXTENSION OF MASONRY STRUCTURES

In most cases, when upgrading existing masonry structures, a "significant change" occurs, as defined in the Rulebook on Technical Standards for the Construction of Buildings in Seismic Areas. It is then necessary to check the load-bearing capacity and stability of the existing structure for the newly designed condition with the rooftop extension and then, mainly, to design appropriate strengthening of the existing structure. Analysis of load-bearing capacity and stability refer to increased vertical and horizontal loads due to rooftop extension. Increasing the horizontal load, mainly due to seismic effect, is the most common reason for strengthening masonry structures when upgrading.

When adopting the concept of a structural solution by introducing new structural elements, the following aspects should certainly be considered:

- Arrangement of newly designed reinforced concrete elements for structural strengthening.

When adopting the layout of newly designed structural elements, it is necessary to follow the general guidelines on the proper layout of the walls with respect to the center of mass, as well as the necessity of placing the elements in both directions. It is often the case in existing masonry structures that masonry walls in a direction perpendicular to the bearing direction of the floor structure have significantly greater rigidity than walls from the other direction, which do not receive vertical load from the ceilings. If only the weaker direction was strengthened, a structure would be formed with elements for accepting horizontal forces from the seismic effect very different in displacement and ductility in two orthogonal directions, which is not desirable.

- Displacement compatibility of newly designed (reinforced concrete) and existing (masonry) elements.

For all forms of structural strengthening, and especially strengthening by the addition of reinforced concrete elements (walls), certain existing walls, which are not taken into account when forming a system for accepting horizontal forces, accept a vertical load and must be checked for maximum horizontal displacements of the structure. The displacement compatibility is a limiting factor for the ductility of the entire structure, resulting in the higher required rigidity and load-bearing capacity of the newly designed elements.

- Connection of newly designed and existing elements.

This connection is important on two grounds. The first is the connection of an existing ceiling and newly designed elements in order to transfer the induced inertial forces from the ceiling to the new walls, in order to integrate them into a structural system that accepts the effects of seismic action. On the other hand, it is necessary to connect new and existing walls when they are touched. It is a very common case that newly designed walls are formed by concreting along existing walls. In this case, the connection of the old and the new element, in addition to providing joint displacements, leads to the "activation" of the gravitational load from the higher floors in the newly designed walls at large horizontal displacements, which is advantageous in terms of the bearing capacity of these elements.

- Achieving the required ductility of the structure.

It is known that masonry structures are characterized by poor ductility and that this is a factor, as noted, ductility constraints of newly designed reinforced structure. Subsequent strengthening of existing walls in horizontal joints, torking of wall surfaces with appropriate mesh reinforcement or treatment of wall surfaces with modern mortars reinforced with plastic nets are some ways to increase ductility and horizontal displacement of walls.

- Funding for newly designed elements.

With significant structural strengthening, the introduction of new elements for accepting horizontal forces from seismic action, their foundation is a particular problem, in terms of the load-bearing capacity and stability of the strengthened structural base.

Calculation modeling of masonry structures in order to determine the forces and displacements under the action of vertical and horizontal loads, primarily the effect of seismic forces, depends on the chosen structural system for the strengthening of the buildings with rooftop extension.

In the case of ordinary masonry buildings, without additional reinforcement and RC elements, each vertical element, in accordance with the Regulations, should be checked against the main tensile stresses, by comparison with the maximum allowable or limit values.

In the case of walls framed by vertical and horizontal RC elements, the masonry fill can be modeled as a diagonal pressure-transmitting element within a frame structure formed by vertical and horizontal RC elements. Eurocode 8, as well as our Regulations, among other things, prescribe conditions in the form of minimum dimensions and quantities of reinforcement.

3. PROCEDURES AND METHODS OF WALL STRENGTHENING IN CASE OF ROOF EXTENSION

If after calculation of the rooftop extended structure it is stated that it is necessary to strengthen the walls to receive additional vertical and horizontal loads, it is of great importance to choose a method of strengthening that will be simple and economical to perform. In addition, the strengthened structure must provide the required security and stability for all vertical and horizontal impacts.

In case strengthening of an existing masonry is required, the use of reinforced mortar or concrete cover is a logical way to improve the seismic resistance of the structure. As the method it is easy to apply and very effective, it is widely used all over the world. The decision on the method of strengthening (mortar and concrete cover, on one or two sides of the wall) should be based on an appropriate calculation. In doing so, efforts should be made minimize the disturbance of the normal life and functioning of the users of the building during the execution of structural strengthening works.

When structure is strengthened with RC cover, elements of the existing structural assembly should be systematically strengthened. Strengthened elements should be uniformly distributed at the base and cross-section of the building. These elements improve the seismic resistance and ductility of the system. If there are cracks larger than 3 mm in the wall, they must be injected with cement-based mixture The wall is well cleaned, moistened with water, after which the first layer of cement mortar (grade M 10) 10-15 mm thick is applied. Apply a reinforcing mesh over the mortar (welded mesh or mesh formed of horizontal and vertical bars - 5-6 mm in diameter at a distance of 100-150 mm). The reinforcement nets within the mortar should be connected to the existing walls, and this is ensured by performing horizontal anchors with a diameter of Ø6 (4-6 pieces per m^2 of wall surface), by placing them in previously drilled holes in the wall.

The process of coating the walls with a reinforced mortar layer initially involves removing the mortar from the entire wall surface, with the deepening of the joints between the bricks to a depth of 15-20 mm.

Strengthening with a reinforced concrete cover implies a similar procedure to the application of a mortar cover. Depending on the thickness of the cladding, MB 30 concrete is torked in one or two layers (30-80 mm) or conventionally poured in the formwork (80-100 mm). For strengthening of walls, reinforcement with nets or nets formed by horizontal and vertical reinforcing bars (diameter 8-10 mm at a distance of 150-250 mm) is also used. Particular attention should be paid to the continuity of the reinforcement. The reinforcement nets are connected to the walls by anchors Ø8 (4-6 pieces per m^2 of wall surface). The concrete cover should be properly groomed so as not to crack (Figure 1).

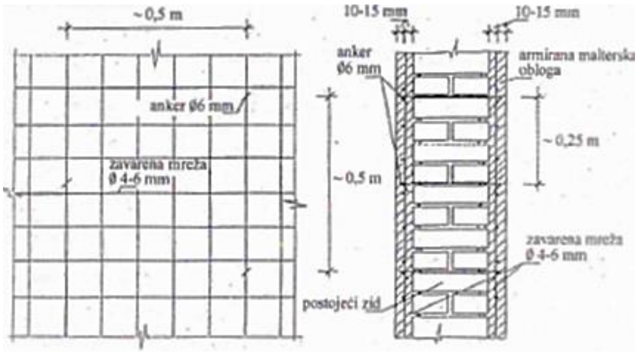

Fig. 1. Application of reinforced cover on brick wall

When strengthening is applied within a building, which implies reinforcement grids arranged in height from the upper surface of the floor structures to the ceiling surfaces, it is necessary to achieve continuity of reinforcement from floor to floor. This is achieved by vertical anchors that anchor into the sloping holes in the lower and upper horizontal RC members. Anchoring of all anchors is accomplished by the use of an adequate prefabricated cement-based anchoring mass. As the reinforcement mesh connects to the anchors, a second layer of cover is applied so that the total thickness does not exceed 30 mm.

In addition to the above methods and principles for strengthening of masonry walls, other methods and new materials are being increasingly applied today, such as the FRP (Fiber Reinforced Polymer) composites within which fibers (usually glass or carbon fiber) with pronounced mechanical characteristics are present. These composite materials are available as finished factory products, usually in the form of strips, cloth and bars. The application of FRP composites is to adhere them with suitable adhesives (usually epoxy based) for the exterior surfaces of the strengthening structural members. The adhesive used must be compatible with a particular product (strips, cloth or bar), and this is almost regularly defined and conditioned by the manufacturer. The application of this method of strengthening of masonry structure involves appropriate licenses, equipment, experience in that type of work, as well as trained workforce.

Strengthening with vertical RC elements placed at all corners of the object, at the points of contact of structural walls, in the middle of walls of larger lengths, as well as along the vertical edges of large openings, allows an otherwise brittle wall to have a certain degree of ductile behavior during earthquake. Vertical RC element do not significantly increase the load-bearing capacity of the wall they frame (increase 5-15%), but significantly improve its deformation properties. However, the strengthening of a building by vertical RC elements is reasonable only in the case of masonry structures with horizontal RC elements and rigid floor structures.

Performing vertical RC elements is carried out from the lowest floor to the upgraded part of the building. At the site of the future vertical RC element, the bricks are first removed from the wall, one by one, so that the contact zone between the wall and the new concrete is serrated (Figure 2). Concrete of horizontal RC element is removed by stamping to allow the reinforcement of the two elements to bond well, by welding or otherwise. Vertical RC elements are reinforced with a minimum of 4Ø14 and stirrups Ø6/20 cm. It must be ensured that vertical RC elements are properly anchored into the foundation structure. After the formwork is done, the concrete is tiled. Concreting the joint between the vertical and horizontal RC elements is the final step of strengthening on that floor.

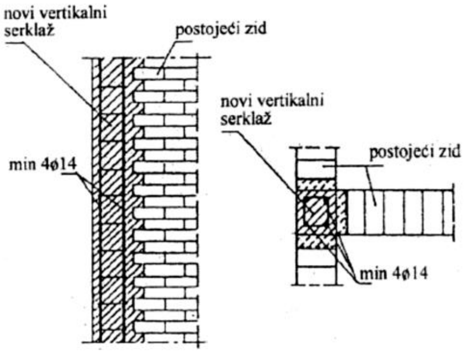

Fig. 2. Construction of vertical RC element in masonry wall

FRP composites can be used to strengthening entire wall or only certain wall segments. Figure 3 shows typical examples of strengthening masonry columns (part of a masonry wall between openings), which in the case of rooftop extension are often the most critical part of a masonry structure. Strengthening schemes include FRP strips placed horizontally, vertically and diagonally, as well as a combination of vertically positioned FRP strips and horizontally positioned FRP bars.

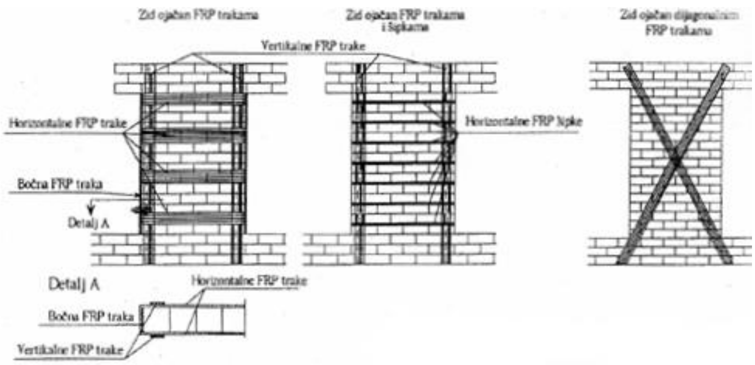

Fig. 3. Strengthening schemes of part of wall between openings using FRP composite

4. PROCEDURES AND METHODS OF FLOOR STRENGTHENING IN CASE OF ROOF EXTENSION

One of the main reasons for the poor seismic behavior of existing masonry buildings is the lack of rigidity of the floor structures in its plane and/or the lack of a proper connection between the floor structures and the structural walls. In the case of modern masonry structures, horizontal reinforced concrete elements are provided along each structural wall at the level of each floor. RC elements connect the intermediate structures to the walls and the structural assembly acts as a monolithic unit during an earthquake. When well anchored into the walls, rigid floor structures and horizontal RC elements ensure synchronous oscillations of the walls, prevent excessive wall deflections out of plane and, at the same time, allow seismic forces to be distributed to individual walls in proportion to their stiffness.

In older masonry buildings, a floor structure usually consists of wooden planks placed over wooden beams. This type of construction is not good for horizontal loads because it does not have sufficient rigidity in its plane. Wooden floor structure can be stiffened by adding new wooden boards directly to existing floorboards. Each new plank must be bonded to each existing plank over which it is placed with sufficient nails in order for the two planks to work together as a horizontal diaphragm. A significant increase in load-bearing capacity and stiffness can be achieved by placing new boards diagonally (at an angle of 45°), forming a stiffness in the form of a horizontal grid. It is also possible to stiffens a wooden floor structure with a thin layer of concrete placed over an existing wooden structure. The additional concrete slab is usually 4-6 cm thick and is reinforced with mesh reinforcement (Fig. 4).

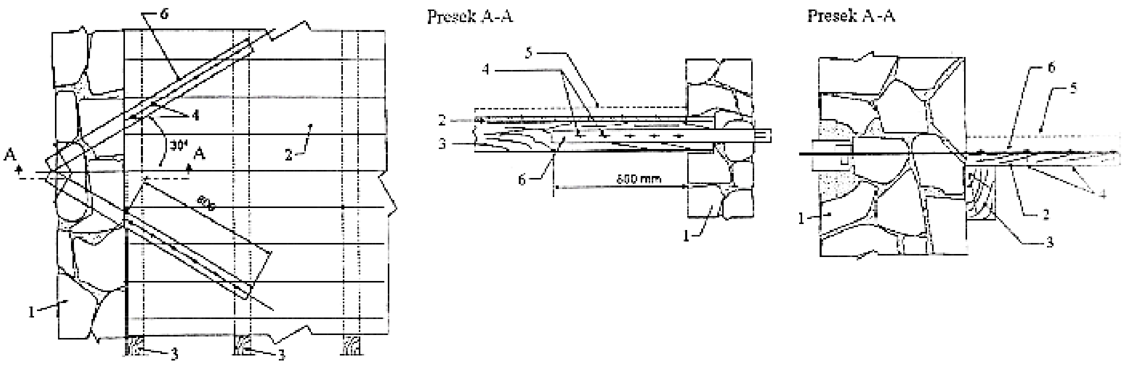

Fig. 4. Connecting the wooden floor to the masonry wall; 1 – existing wall, 2 - Existing wooden planks, 3 – Existing wooden beams, 4 – Nails, 5 – New concrete slab, 6 – Steel strip

Wooden floor constructions can be stiffened with horizontal and diagonal clamps (16-24 mm in diameter), which are placed directly below the floor structure. For this solution, reinforced bars with specially machined threaded ends are used. The bars are anchored over steel anchor plates placed at the ends of the walls. Horizontal clamps are placed symmetrically on both sides of the wall in grooves 4-5 cm wide, cut into mortar cladding.

The durable wooden floor structures can be replaced with reinforced concrete or prefabricated slabs, with perimeter framing. Regardless of the type of structure used, a minimum of 15 cm of support should be provided on the supporting wall, where the connection between the floor structure and the walls should be ensured by intersecting the walls at a distance of at least 1.5 m.

5. CONCLUSIONS AND RECOMMENDATIONS

- Masonry buildings are generally very vulnerable to earthquake effects, especially if they are with rooftop extension, which is particularly evident in earthquakes of maximum intensity. The seismic resistance of existing masonry buildings must be assessed on the basis of a review and analysis of the existing structural system and condition of the building. If it is shown that an existing facility is not properly constructed, adequate strengthening of that building should be provided, regardless of whether the provided interventions formally meet or do not meet all the provisions of the Rulebook on Technical Standards for the Construction of Buildings in Seismic Areas (Official Gazette SFRJ no. 31/80, 49/82 and 29/83).
- The presence of "rigid" floor structures is crucial for the aseismicity of masonry buildings. Therefore, if an object is to be upgraded, it is imperative to form floor structures that are able to provide a uniform distribution of seismic influences on the vertical structural members.
- When upgrading masonry structures, special attention should be paid to existing vertical load-bearing structural elements - masonry walls. Depending on the type of walls, the quality of the material from which they are made, the level of vertical and horizontal loading or their possible damage, appropriate strengthening of those walls should be provided.

- Existing foundations of masonry structures, in the case of rooftop extension, must transfeer both existing and additional vertical loads. This additional load originates from the mass of the upgraded section as well as from seismic impacts. Therefore, due consideration must be given to the condition of the foundation, the calculation and the implementation of the necessary strengthening.

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