Seismic Aspects Regards Overbuilding on Masonry Heritage Buildings

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Abstract. Nowadays, masonry heritage buildings usually experience changes during exploitation. In areas of emphasized seismic risk, in cases of extensions, alterations to the original dimensions, reconstruction (the removal of bearing elements, replacement of materials, introduction of new fittings), or the subsequent erection of properties close by, with a comparison of the foundation levels change of use, refurbishment, extension, or additional building to an existing building. It is necessary to analyze the seismic aspect of such interventions in seismic prone areas. At first, we’ll focus on the legal and technical regulations. For start we’ll look back at UNESCO’s Program on Masonry Heritage, then domestic and regional legal and technical regulations and with all of that we will define the first step of the process. Next step would be a detailed registration of the current condition of the building, and also determining the characteristics of the embedded materials. The load bearing structures of the building must also be accurately identified, with all relevant measurements and, in particular, a description of the building materials and their condition. This includes all detailed maps, plans, and details of the used materials, and especially detailed record of all the damages on the structure. Even at this early stage of investigative works it may prove necessary to secure certain structural elements, or even the entire building, to prevent it from collapsing. As a rule, this requires not only the removal of the outer cladding or even of parts of a wall to determine the depth of cracks but also, if there is any suggestion of subsidence, excavations around the building or to the depth of the foundations. Calculations, based on the planned and current condition of the building, will show whether the strengthening and rehabilitation are needed for the structure. The elements that need reinforcement or conservation can be identified during the initial visit, and provision can immediately be made to take the necessary steps to relieve the load. It is necessary to do all the steps regarding technical regulations, legal regulations, methods of approach, theoretical consideration, methods of calculation, and in the end to determine the needs of that building. Theoretical consideration regarding the determined condition of structure, from all the above aspects, is the next step to be done. This also includes evaluation of the viability of these interventions, based on experience. The most sensitive issue, without doubt, is determining the condition of the foundations. This should be addressed with the utmost care with the general opinion of the building’s stability in mind.

1. Introduction
Bosnia and Herzegovina is situated in seismically active region of South-East Europe, divided in seismic zones with peak ground acceleration PGA of 0.1 – 0.2 g for 500 years return period, and even PGA of 0.30-0.35 g in some parts.
Traditional art of building includes masonry structures. Most historical buildings belonging to national cultural heritage were made of stone-masonry with robust and enduring structure. In the case of stronger earthquake motion such buildings could suffer substantial or heavy damages. Some structural elements of historical buildings, such as domes and arches, crack even in a moderate earthquake, but without the loss of stability. Generally, stone-masonry buildings in Bosnia and Herzegovina can be classified in vulnerability classes B and C according to European Macroseismic Scale EMS, where A stands for the weakest seismic structures and F for those expected to have best seismic performance. Repair and strengthening of these buildings are important and complex task for structural engineers in Bosnia and Herzegovina. Design and construction procedures for rehabilitation are presented here on examples of repair and strengthening of mosques situated in different seismic regions of Bosnia and Herzegovina. These mosques are historical stone masonry structures dating from the Ottoman period in Bosnia and Herzegovina. Traditional and contemporary materials were used for rehabilitation of these historical buildings. The challenge for structural engineers was to find equilibrium between aesthetical and structural demands and to consider seismic codes as well.[1]

Figure 1. Seismic hazard map for PGA on uniform firm rock site conditions at 10% probability of exceedance in 50 years developed during BSHAP

The PSHA for the Western Balkan Countries builds upon extensive research and database compilation carried out over the last three years by the institutions participating in the BSHAP project. Within the frame of BSHAP, it has been impossible to provide all the relevant information, even for the faults that have generated strongest earthquakes with Mw>6.5 in the region. Seismic hazard assessment was accomplished using the smoothed gridded seismicity methodology. This method defines voluminous character of seismicity within a ‘source zone’ and determines it as a spatial unit of the seismically active Earth crust. This unit can be approximated by a unified seismic regime. The seismic sources of the region modelled during BSHAP are given in Figure 1. Hazard calculations were accomplished using the OHAZ 6.0 software, a joint development of Environmental Agency of the Republic of Slovenia and the Institute of Geosciences of Albania, which was greatly improved for the BSHAP project. The seismic hazard maps were obtained by interpolation of the mean hazard curves at
specified annual frequency of exceedance. Seismic hazard maps for peak ground acceleration (PGA) corresponding to 10% probability of exceedance in 10 years (95-years return period) and 10% probability of exceedance in 50 years (475-years return period) were calculated. Figure 1 shows the seismic hazard map for PGA on uniform firm rock site conditions (average 800m/s shear-wave velocity in the upper 30 m of the crust) at 10% probability of exceedance in 50 years, corresponding to the 475-years return period. The seismic hazard maps derived for BSHAP provide a good basis to characterize the seismic hazard in the region. These maps should be improved, based on the experience from BSHAP project, in terms of seismic source characterization, ground motion prediction equations and seismic hazard assessment methodology. [2]

The range of typical expected values, which have been considered as target values when designing the models, is given below (subscript P indicates prototype masonry):

- Compressive strength: $f_{cp} = 1.5–10.0$ MPa,
- Tensile strength: $f_{tp} = 0.10–0.70$ MPa,
- Modulus of elasticity: $E_p = 1500–3800$ MPa,
- Shear modulus: $G_p = 60–165$ MPa,
- Specific mass: $\gamma_p = 1600$ kg/m$^3$.

The walls of old masonry buildings are often not tied with wall ties. As a result, the separation of walls and subsequent out-of-plane collapse typically take place when subjected to earthquake.

Classification of natural stone walls according to DIN 1053-1 and EC 6 (DIN EN 1996-1-1) is separately described. The strength characteristic of the natural stone for pressure is processed in a special subchapter because this parameter is most often used in determining the quality of the stone from which the wall is built. The existing standards and norms that deal with this issue have been analyzed. According to the nature of performance of these tests this is the simplest mechanical characteristic of the stone, however, it requires a special analysis considering the possible factors that influence the pressure resistance parameter. If we standardize some test sample parameters, such as the sample dimension, there are still many influencing factors that determine the value used in the calculation. The need for statistical analysis of the obtained results first appears because of the heterogeneous nature of the structural-textural structure of a single stone labeled as limestone, marble, gabbro, etc. Standard EN 1926 prescribes test pieces of cubic shape 50x50x50 mm or 70x70x70 mm, and the minimum number of test pieces is 10. This is sometimes an insufficient number for statistics, so a larger number of test bodies is recommended. The statistical processing procedure is given in EN 1926 and the acceptability of test outcomes depending on the number of test bodies is given in the paper. This parameter is also significant for the wall compactness coefficient (KKZ), which the author introduces into the consideration of the wall characteristics. [3]

The permitted stresses on the natural stone wall in the paper are processed in two segments, as allowed pressure stresses and allowed shear stresses. The appropriate formula is given according to DIN for the permissible shear stresses.

According to the theory of plasticity, the designer is not guided by the process of exploring the current condition of a structure but by studying how that structure can collapse. Indeed, when we want to prove the structural stability and structural ductility of a structure after an intervention, it is necessary to determine some characteristics of such structure such as load bearing capacity, width of cracks, movement etc., with the knowledge of the load transfer method, the strength of the existing materials and the increase of the resistance caused by the bonds of the materials added to the existing ones. The possibilities of analyzing masonry structures have been multiplied by using the latest software packages designed for static calculation as well as by increasing the base of experimental results. The effect of such interventions on masonry structures can be checked by computational means, but the most reliable results are obtained experimentally. There are numerous factors influencing the final decision on these measures such as the seismic zone in which a building is located, the degree of damage to the buildings and the existing resistance of the building, architectural solution, conservation conditions and so on.
The key for successful intervention is the appropriate choice of materials and techniques to be applied for them. Techniques are classified as reversible and irreversible. Materials used in reversible interventions are usually subject to strict restrictions. With irreversible interventions, we have two additional constraints, which are the compatibility of the selected materials with the original and requirement for a great durability of new material.

Many of these buildings have more serious problems with overbuilding, especially given that our regulations, and in particular Eurocodes, have limited the number of floors of such buildings. When making a final decision on overbuilding, we should not be satisfied with formal proof of the permitted loads. It is necessary to look at the constructive concept, appropriate details and the quality of the building being planned for overbuild. Restrictions on this kind of intervention on existing buildings are mainly caused by geomechanical and seismic problems. Decision on overbuilding on a building require a more detailed analysis and assessment of the safety of the existing constructive system from a constructive and economic point of view. Eurocode does not even mention the issue of overbuild in any material and thus not even masonry buildings. The problem of seismic is primarily the problem of deformation of a building during an earthquake. The amount and capacity of moving of a construction in an earthquake are practically unknown.

Calculation control in case of overbuilding on a building is usually about distribution of a certain project load on individual walls, according to some specific calculation of rigidity, and finally, we have control of the main tension stress. Control of the pressed end of the wall is not done in practice because the regulations do not explicitly require that. The algorithm of all regulations is conceived for cases of designing new buildings. The evidence of lateral stability of the supporting wall vertically to its plane are especially neglected. The regulations require that the foundations must be controlled with assumption that the limit stresses are reached at the cross-section of the pinned wall according to the capacity of the wall cross-section. The consequence could be that soil load bearing capacity is exceeded with possible development of nonlinear soil deformations, which will again lower the level of seismic load. However, since these are low-buildings and moderate earthquakes, theoretical case of possible overturning of the structure should not be expected. [4]

The overbuilding on existing masonry buildings with one or more floors, or in a milder variant-adaptation of the attic space is possible in many cases, even without major constructive interventions on the existing building, and sometimes with appropriate reinforcements, if analysis shows that they are necessary. We strive to overbuild on the buildings for which the seismic analysis has shown that with the appropriate choice of constructive system and with the application of lightweight materials we can find a solution so that additional seismic impacts on the construction of the building will be small and without any change in overall safety.

With the use of simplified procedures, the analyses have shown that the constructions have additional flexion support, and thus greater possibility of undesired shear failure, and thus more accurate methods for calculation for the overbuilt buildings are recommended, although they require more time.

Buildings which require special attention in selection for overbuilding are those: with flexible ground floors, without or with insufficient bearing walls in two mutually vertical directions, characterized with sudden change in rigidity of vertical construction, with pronounced asymmetrical distribution of vertical load bearing elements, with insufficient width of pillars between the wall openings etc.

When choosing the material for overbuilding, the advantage should be given to environmentally-friendly materials, above all those made of brick elements that can achieve a higher level of standard of living and quality of life. The selected materials should also possess the relevant characteristics stated in regulations.

Procedures that need to be implemented before making a decision on overbuilding are:

- Review and analysis of the original documentation
- Detailed review of the existing building to determine the actual condition
- Decision on the type of needed interventions
• Designing project documentation and execution with quality control

All the above indicates that such interventions on masonry structures should be approached according to the selection principle, with the necessary verification of geomechanical and seismic properties of the terrain.

Let us not forget the vibrations caused by the traffic, especially if the traffic changes several times during the exploitation of the building. Some of the prominent authors even claim that the condition of the building is more affected by changes in the terrain over time compared to the aging of the structure.

One part of the planned actions is either already realized or its realization is in progress, and most often this is in buildings with a massive masonry constructive set. Such massive masonry systems have to be analyzed for the needs of the mentioned interventions from the point of view of increasing the weight and increasing the height of the building, given the specificity of the site (soil bearing capacity and seismic zone).

Preliminary analysis and decision-making regarding the overbuilding for the described constructive system can be divided into masonry structures without reinforced concrete vertical (and horizontal) ring beams and masonry buildings with vertical reinforced concrete ring beams. These two types of masonry buildings are subject to restrictions regarding the number of floors, in accordance with the regulations on construction in seismic areas. Buildings that have a basement are far more favorable for overbuilding, considering the issue of their foundation in relation to increasing stress in the soil. [5]

2. Overbuilding on heritage masonry buildings examples

2.1. IRIS Building, Sarajevo

This building, which originated as a characteristic classical building from the Austro-Hungarian period, experienced its transformation after World War II.

The designer, Josip Vancaš, was an architect with great talent and he worked in the Austro-Hungarian period, realizing an exceptionally large number of buildings.

It is a building that has always had an administrative function and existed in a space close to the electrical power station in Sarajevo. Its primary form was transformed into a building that only attempted to follow its original form in its new form, but it certainly experienced a kind of deterioration because it was converted into a cubic building without distinct stylistic features from its original symmetrically structured shape, pyramidal positioned in relation to its horizontal division (Fig. 2).

The change of form probably occurred due to the need for increased space in the interior, which ultimately resulted in the change of the walkways, emphasizing of the entrance that did not exist before, and of course the roof structure, which ultimately gave the building a completely different character.

2.2. The railway station building in Bistrik, Sarajevo

This railway station building belongs to a group of buildings that were constructed in BiH during the rule of the Austro-Hungarian Empire as the accompanying typical buildings along the railway lines. It should be emphasized that these buildings were built in a free alpine style and that at that time and later they were built throughout the Austro-Hungarian Empire, in all the places where this Empire built railways. Of course, this is a narrow track railway line, remains of which are almost nonexistent today. What has been partially preserved are the railway stations, which are either abandoned or experienced a kind of transformation, as is the case with the railway station in Bistrik (Fig. 3).
Figure 2. Upgrading of the IRIS Building

This building experienced a change as the original disposition was changed by setting up a porch that was built when the function of the building changed. At the moment when the narrow railway was abolished and when the main road was built close to this building, the building was given a new purpose and it was used by tenants who turned it into a living space which led to this specific horizontal overbuilding that occurred on the ground floor. Next to this railway station there is a very well preserved and authentic fuel tank that exists today without any intervention. Like the building above, its experienced deterioration through destruction of the surrounding environment, and this intervention, freely chosen, disrupted its integrity and significance within the framework of the architectural heritage.
3. Aspect of the increase of weight

In terms of weight increase due to overbuilding, stress load analyses for the soil as well as stresses in the walls must be performed. For buildings where weight increase due to overbuild is 10-15% it is not required to undertake works on foundations because of the reserve in the soil load bearing capacity due to consolidation.

This aspect also implies an analysis of stress increase in the walls, where for buildings that had stress up to 10% less than allowed before overbuilding, there are sufficient reserves of load bearing capacity for another floor and the attic, provided that the existing building is not in such a condition that it can suffer from earthquake even without an overbuilding. All other cases imply a more detailed analysis of the load bearing capacity of the walls (contact wall and foundation).

The analysis of the building with overbuilding should be done taking into account the following necessary works:

- Identification of the constructive system of the building before and after the overbuilding, including a constructive system of the foundations.
• Determining the real weights of structures between floors and walls and defining the moving loads
• Calculation of appropriate seismic loads affecting the building
• Perform a synthesized dynamic stress that is a combination of intensity and character obtained by spectral analysis and coefficients defined by the procedure of quasi-static analysis
• Determination of the stress levels of the construction caused by simultaneous activity of mentioned loads
• Determination of the resistance of the structure in relation to the prescribed failure coefficients

Masonry buildings with vertical reinforced concrete ring beams

For buildings with larger overbuilding (more than a single floor and an attic) it is to be assumed that it will be necessary to: strengthen foundations, increase the thickness of walls with the same material with interconnections, set reinforcement grids on both sides with joint anchors with torcte concrete, insert stiffening reinforced concrete elements, etc. After the analyzed cases of overbuilding from the aspect of load bearing capacity it seems that in most cases overbuilding is possible for existing masonry buildings where we build an additional floor and an attic, because there is no change to the existing condition of stresses in such structure. This is certainly valid if the new design does not change the structural system of the existing building, or the vertical loads on the building.

In the case of such interventions on existing buildings, it is necessary to underline the problem of foundation. Foundation problems arise due to the weaker technical level of the existing building, changes to the existing construction due to overbuilding, previous interventions on the building, and possible changes in the soil of the foundation.

Changes in the foundation soil over time are very diverse and occur due to the impact of the building or changes in its environment, such as the subsequent introduction of different installations, construction of structures that adversely affect groundwater conditions, and subsequent deep excavations.

The investor is obliged to provide the appropriate geotechnical supporting documents and in order to develop them it is necessary to carry out some of the usual procedures, such as: prior testing, field tests of the soil content and condition of the soil, geometry and condition of the foundations, geo-mechanical tests in the laboratory, and geo-mechanical calculation for adopted profiles and models of the soil. As a result of overbuilding on old buildings, it is common to have significant deformations of individual structural elements, uneven deformation in the foundation soil, and reallocation of loads to the elements with greater rigidity, resulting in uneven pressure on the soil.

If we want to determine the interaction between the structure and the foundation soil, it is necessary to determine some of the essential properties of the foundation soil, such as deformability in the condition of actual humidity and behavior in changing humidity and tension status on the samples taken as cubes cut in the soil rather than by pressing the cylinders into soil. [4]

4. Experiments and test results

Besides traditional technologies, such as the tying of the walls with steel ties, the strengthening of the walls by injecting cement grouting and applying reinforced cement coating, which have been developed decades ago, the methods based on new materials and technologies have been also proposed for upgrading the seismic resistance of old masonry buildings. Although the requirements of preservation of cultural heritage limit the application of such materials and technologies, modern technologies often require minimum intervention in the existing structural system while providing substantial improvement in seismic behavior at the same time. Recently, experiments to investigate some aspects of seismic isolation and possibility of tying the walls of old masonry buildings with CFRP laminate strips instead of steel ties, have been carried out at Slovenian National Building and Civil Engineering Institute in Ljubljana. Experiments and test results will be presented and discussed in this contribution.

Experiments have shown that seismic isolation alone is not enough to improve the seismic behavior of old masonry buildings without wall ties. Experiments have also shown that a simple dampproof course in the form of PVC sheet installed in the mortar bed joint cannot be considered as seismic
isolation. However, the shaking table tests of models, confined with horizontal and vertical CFRP laminate strips and strengthened with diagonally placed strips at the same time, indicated significantly improved seismic behavior. The CFRP laminate strengthened models did not collapse even when subjected to ground accelerations which by more than three times exceeded accelerations causing the collapse of the models without wall ties.

The experiments indicated the possibility of replacing the steel ties, which are installed at floor levels of old masonry buildings as one of the usual seismic strengthening measures, by CFRP laminates. When placed vertically and diagonally, CFRP laminate strips additionally strengthen the structure, if properly anchored into the foundation system at the ends. Although the model earthquake, used to drive the shaking table in the particular study, cannot be considered as typical design earthquake, the experiments also confirmed the long-known fact that seismic isolation of rigid masonry structures represents an efficient way to reduce seismic loads. However, the experiments have shown that the usual measures to ensure structural integrity, such as tying the walls with wall ties, should not be omitted.

The experiments indicated high efficiency of contemporary technical solutions when applied to old masonry buildings. However, they also pointed out that technological details, crucial for the efficiency of such methods, need to be resolved before the methods are widely applied to old masonry buildings. Namely, adequate solutions related to bonding and efficient interaction between the materials which have so extremely different mechanical characteristics as CFRP laminates and masonry, need yet to be found. [5]

5. Technical solutions

Based on the needed collected data (appropriate design of the building and its structure, detailed examination of all visible damage and their documentation, data on the materials and their condition, geo-mechanical properties of the soil ...), it is necessary to perform detailed static-constructive analyses and calculations on the basis of which the assessment is done to discover the causes that led to the unsatisfactory condition of the load bearing structure of a building. The results of the analyses should be compared with the condition of the damaged building established on the spot. If the results of the analysis match the condition of the building, we can consider that the idealized construction model corresponds to the real condition of the building. In this case, the results of the analysis can be taken as a realistic basis for the choice or adoption of a technical solution for remediation. The technical solution for repair must provide the load bearing capacity and durability of the structure, at least for all the impacts that can be realistically applied to them, regardless of the load bearing capacity of the structure when it was built. Consequently, damage to the structure could have been caused by the fact that the original structure did not take into account the loads that caused the damage, which could actually arise and should be foreseen (except for extraordinary loads, such as the impact of warfare that exceeds the forces for which building should be safe). [6]

Finding a technical solution for the repair of a structure is a more complex and delicate job compared to a design of a new building. This especially stems from the fact that, sometimes, some important structural elements cannot be identified without any possible surprises occurring in the execution.

Due to the delicateness of the repair itself, a responsible expert (engineer) should preferably be doing the whole job of collecting data, analyzing, developing a technical solution and performing the work. When appropriate, relevant experts from other areas should be involved.

6. Conclusions

According to the Venice Charter of 1964, Historic Buildings and Monuments are valuable structures that bear witness to the culture and tradition of the people over the past centuries. It is our duty to guard them, protect them and preserve them intact for the generations to come.
When traditional techniques are shown to be inadequate, the consolidation of historical buildings can be achieved using modern techniques for conservation of structures, efficiency of which has been proven through scientific research and can now be said to be empirically proven. [7]

Upgrading an existing historical building may be of crucial importance for such building, but it should, if possible, be avoided and applied only when the analysis shows that the desired goal cannot be achieved by restructuring the interior space. Such overbuildings should be designed in such a way so as to be clearly distinguishable from the existing building and so that the properties defining the building are not radically changed, damaged or destroyed. Irrespective of the cause, the cross-sections of heavily damaged constructive elements and hence the elements themselves, if the number of such cross-sections is sufficient to transfer the system into a mechanism, which depends on the static scheme, are brought to the condition of boundary load bearing capacity and usability, or at least close to that condition. Starting from such a presumption, it is important to take special care of the following during repairs. Residual stresses which, when it comes to the elements exposed to bending (which is the most common case), are of no importance as residual tensions at the new tension level are self-balancing, which is not the case with axially stressed elements. Residual deformation (i.e. curvature), which may affect the usability of these elements, especially if they are overloaded compared to the original design load. Even though regulations have stipulated that calculations must be carried out according to boundary conditions, the permitted tension method is highly effective and reliable, especially in cases of need for preliminary dimensioning and tension and deformation control. Works on the execution of overbuilding must be carried out with special attention, with the control and participation of the designer. Caution on the construction site should be increased compared to construction of a new building, due to possible (always possible and unexpected) surprises that may arise because of previously accepted data on material and other construction elements (hidden parts of the structure that are only available during the execution of works).

When designing new elements, or converting existing ones which are significantly damaged, the designer must also take into account the financial capacity of the investor, capabilities of the contractor, as well as the condition in the market of materials that are intended for installation. Taking all these into account, it can be stated that there are no universal solutions in such interventions, although in the overbuilding works there are, as a rule, problems that can be categorized as trivial, for which procedures that are very much standard and verified exist. A favorable circumstance of the appearance of certain high-quality tested materials with high tensile strength (carbon fiber, etc.) should also be added to the above, as they are increasingly applied in repair works, because, in addition to the above qualities, they enable fast, economical and efficient installation, and the implementation is almost routine. All this, as can be seen from the aforementioned, should also include taking into account the work involved in the design of the overbuilding project as well as selection of the contractor, which should be an organization with experience in this work with experienced designers.

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[5] The research presented in the paper was carried out within the framework of research project L20691 and research program P20274, financed by the Ministry of Higher Education, Science and Technology of the Republic of Slovenia and co-financed by rubber industry, Sava Company Ltd., program Construmat from Kranj, Slovenia. CFRP laminates and
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