Retrofitting of Masonry Structures Considering the Architectural Perspective: A Case Study in Foca, Izmir

Ertugrul Turker Uzun [1], Ilker Gucu [1], Tolga Arslan [2], Sevket Onur Kalkan[2]

[1] Izmir Institute of Technology, 35430, Gulbahce Campus, Izmir, Turkey
[2] Izmir Katip Celebi University, 35620, Balatcık Campus, Izmir, Turkey

ertugruluzun@iyte.edu.tr

Abstract. Masonry structures have been preferred for centuries in most of the countries across the world because they are easy to build and economical due to the use of local materials in their construction. As a result of high usage volume, masonry structures that created the architectural section of history and culture constitute an important part of the current building stock despite the developing and diversified construction techniques nowadays. The protection of these structures, which are important both in terms of their cultural values and their transfer to future generations, is of great importance in the architectural point of view. For this purpose, a masonry structure from Foca is selected. The material properties and architectural plan of the structure are determined in accordance with the original one. The structure is modelled by using a software program under seismic effects. Displacement and stress values for each acceleration record are obtained. Besides, an evaluation is made in the direction of the analysis results and it is determined according to the seismic performance of the structure. After that, the structure is retrofitted according to the current design codes and without distorting the architectural perspective. This study aims to increase the structural strength of the case building by using conventional and modern techniques for the recovery of the structure.

1. Introduction

Natural stone is one of the oldest building materials and it is especially preferred in the constructions that are thought to be permanent. The reason for the widespread use of stone in historical buildings is that it can be easily supplied in almost everywhere and on land. In Turkey, natural stones are produced in nearly every region. The most important indicator of Turkey’s diverse and rich natural stone reserves is the historical buildings around the country. The most well-known and preferred natural rocks in historical building blocks are basalt, granite, andesite, sandstone, limestone, tuff, marble, slate, and diabase. These rocks are abundant in many parts of Anatolia. These stones are usually named and recognized according to the region in which they are found; such as Unye stone, Küfeki stone, Armutlu stone, Can stone, Nevsehir stone, Kesan stone, Saray stone, Kirsehir stone, Foca stone, Urfa stone, Ayazin stone etc. [1]. The volcanic rocks in the Foca region are generally formed by tuffs. Foca volcanite, represented by tuffs, are whitish-yellowish-greenish [2,3]. This material, known as "Foca Stone" due to its region-specific characteristics, has been used for a long time in the area and widely chosen in the construction of stone houses. Its soft character makes it easy to chop and shape. The tuffites, which present a distinct stratification, are volcano-sedimentary. These stratigraphs are evident in the transitional contact between the volcanic rocks and the continental sedimentary rocks.

Although natural stone materials are preferred majorly, they are very vulnerable to the external effects. In order to protect and provide sustainability for this structures, retrofitting process will be necessary as time goes. The most important points in strengthening of masonry structures are identifying the used materials and preventing the architectural texture. The selected strengthening method should be compatible with aesthetic, building function and original structure [4]. The existing damage to the structure must be well specified before selecting the strengthening method and material to be used. Therefore, determinants such as thermal analysis, moisture analysis, and conductivity analysis and field investigation put into practice. Increasing the carrying capacity of the building elements, as well as the overall capacity of a masonry structure, is the main purpose of the strengthening process [5]. In order to perform retrofitting and strengthening in masonry buildings, tensile capacity, shear capacity, ductility, bending capacity or strength can be increased since it will raise the degree of the carrying capacity [6]. For this purpose, many strengthening methods are used to strengthen masonry structures such as surface treatment, covering and injection the cracks, external jacketing, external reinforcement, use of fiber reinforced polymer (FRP) materials, adding RC or steel frame, post-tensioning etc. [7], [8]. Applicability because of the location of the structure and economic conditions should also be taken into account when selecting the appropriate strengthening method [9].

In addition to strengthening the structures, architectural perspective is also a significant parameter for the historical and local structures since these buildings are concrete examples of the culture and one of the most important elements that link from past to present. The preservation of these structures in order to understand the past and transfer them to the future is of great importance. For this reason, damaged or worn old structures need to be repaired. All the repair process of these structures is called restoration. In other words, it is the fix of the worn-out structure by protecting its original form as much as possible. Over time, different regulations have been introduced in various parts of the world against increasingly inadequate and bad restoration works. Carta Del Restaurant [10], one of the oldest of these regulations, was released in Italy in 1931. In this regulation, there are various rules such as restoration, reuse, and functioning of historical buildings. In case of traditional methods are insufficient for the restoration of a traditional building, the possibility of using contemporary methods is described in Carta Del Restaurant. Another important international regulation is Carta di Venezia [11] adopted in 1964. This regulation mentions the importance of documenting the processes carried out during the restoration and the rules about the detailed investigation of the changes that the structure undergoes during its lifetime. In the regulation, it is emphasized that the modern restoration processes that will be applied to the structure must have been scientifically proven.

In this study, an example of stone masonry structure which is located in Foca, İzmir is investigated. Construction samples are gathered from nearby the structure and analysed to determine material properties of the stone. After that, 3D finite element model is created and examined under the strong ground motion. Then, by considering economic reasons and architectural perspective, stone masonry structure is retrofitted and analysed. The results are given comparatively with and without performing retrofitting process.

2. Description of the building

The examined structure is constructed by using stone material that is easily found in Foca region. The structure has two floors that can be described as basement and ground floor. The story heights are 1.3 m for the basement and 3.5 m for the ground floor. This is given in Figure 1 illustrating 3D and front view of the structure with dimensions.

(a) (b)

Figure 1. (a) 3D and (b) front view of structure

Moreover, the ground floor plan of the structure is given detailed in Figure 2. All dimensions are given as cm. The thickness of outer and inner walls are 60 cm and 12 cm respectively. The seating area of the structure is approximately 697000 cm2.

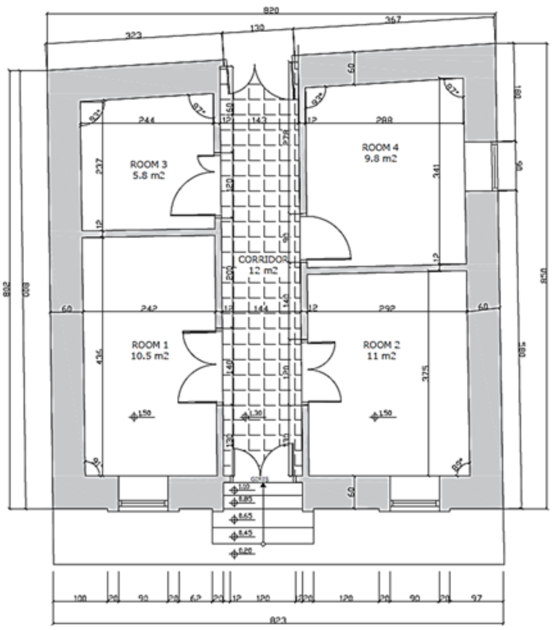

Figure 2. Ground floor plan of structure.

3. Determining material properties of the structure

Evaluating the structural bearing system in terms of structural engineering mechanical properties such as unit weight, pressure and tensile strength and modulus of elasticity must be detected. For this purpose, the uniaxial compressive strength test is mostly used in the classification of rock mass and strength of rock material samples with cylindrical shape. The test specimens are cores in the form of regular circular cylinders. The side surfaces of the samples are fairly flat and smooth. The amount of sample moisture during the test can have a considerable effect on the compressive strength test results. Because of that reason, the samples are allowed to stand at room temperature and atmospheric conditions for 15 days from the time of preparation until the experiment. Then, the samples are dried to constant weight at 105°C.

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10 cored specimens are taken over the Foca-stone sample taken from the site and specimens are given in Figure 3. Due to the difficulty of taking the core in the uniaxial pressure resistance test made on the tuffs, some samples are subjected to the L = D rule and some correction formulas are used to determine the uniaxial compressive strength value.

(a)

(b)

Figure 3 (a) Examined structure constructed material (b) test specimens

Common correction formula used in practice:

$$\sigma_c' = \frac{\sigma_c}{\frac{b}{h} x\ 0.24 + 0.88} \tag{1}$$

where; ‘σ_c’ is uniaxial compressive strength measured during the test (kg/cm^2), ‘$\sigma_{c\ I}$’ is corrected uniaxial compression strength value (kg/cm^2), ‘b’ is the diameter of core (cm), and ‘h’ is the height of core (cm).

The following formulation is used in determining the splitting tensile strength of the core samples;

$$T = \frac{2P}{\pi DL} \tag{2}$$

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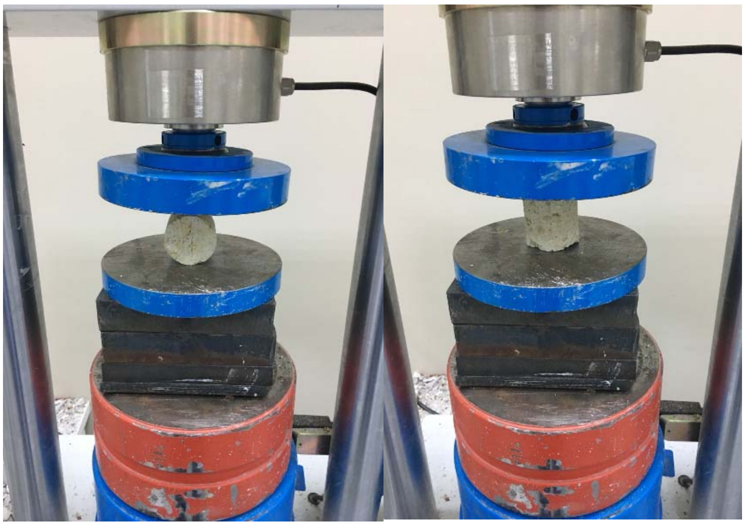
The ratio of mechanical stress to strain in a material when that material is being compressed; it is the modulus of elasticity applied to a material under compression: modulus of compression = compressive force per unit area/change in length per unit length. In Figure 4, analysed specimens are given as split tensile and uniaxial compressive tests respectively.



(a) (b)

Figure 4. (a) Split tensile test (b) uniaxial compressive test

The general characteristics of the Foca Stone found in the area are given in Table 1. After the analyses, modulus of elasticity "E" is calculated as 9635 MPa or 9.6 GPa.

Table 1. General characteristics of Foca Stone.

Unit Volume Weight	1839 kg/m^3
Specific Gravity	2.21 gr/cm^3
Porosity	38.02 %
Compressive Strength	5.95 N/mm^2
Splitting Tensile Strength	2.03 N/mm^2
Water Absorption	33.12 %

4. Analysis of structure

Observations should be made to determine the current state of the building carrier system in advance. Then, the structure must be modelled as it is to determine the current level of security. It will be decided whether it needs to be repaired or strengthened. After these steps, the structure should be modelled in the calculations that will be done. The same method must put to use in the analysis of both cases. This procedure is accurately used to analyse the examined stone masonry structure.

4.1. Structural modelling

The 3D finite element model (FEM) is developed by using ETABS [12] and shown in Figure 5. The geometrical simulation is done by using shell elements and the discretization of the finite element mesh is assigned entirely flat quadrilateral and triangular elements. Material properties are defined by using experimental results. Then, the created model is used to analyse the structure.

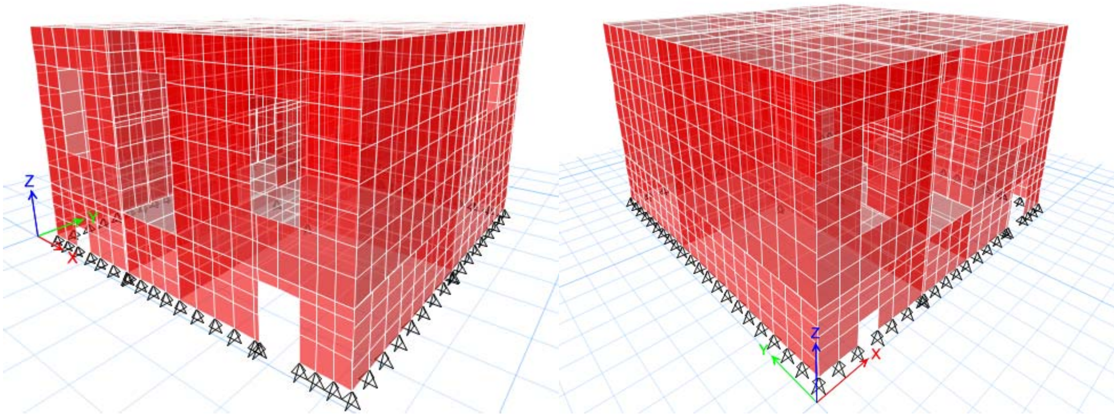


Figure 5. 3D finite element model (FEM) of the stone masonry structure.

4.2. Properties of applied seismic ground motion

It is known that masonry structures are brittle properties and these structures are vulnerable to strong earthquake shaking. Therefore, it is important to determine and improve the seismic behaviour of the masonry structures. In order to investigate structure seismic performance, nonlinear response history analyses are conducted for each modelled. Since the examined stone masonry structure constructed in Izmir is located in the 1st seismic region, a strong ground motion is selected from Düzce recordings of Kocaeli Earthquake, which has the highest value of acceleration. In Figure 6, earthquake time-acceleration graph is given.

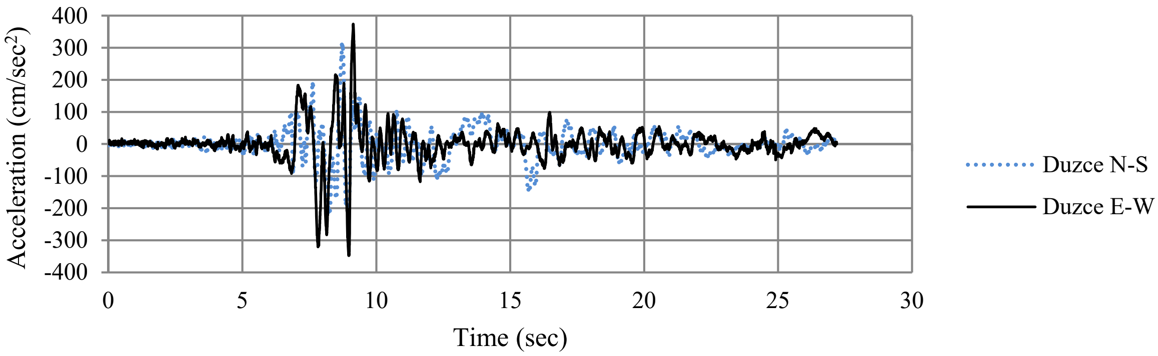


Figure 6. Strong ground motion from Düzce station

According to TSC 2007 [13], it is selected that the seismic zone is 1st seismic zone and soil class is Z4 type. In order to simulate the possible elastoplastic behaviour of the stone masonry structure, it is assumed that the seismic load reduction factor "R" for the structure is taken as 2. A 4 % damping ratio on the modal shapes are selected as suggested in the literature [14].

4.3. Deciding retrofitting process

After the observations and analysis of modelled structure are done, retrofitting or repaired type should be decided. At this stage, in addition to the original materials made from the repair or reinforcement of historical structures, there are many materials that can be used such as high strength steel, stainless steel, epoxy resin, various types of cement, GFRP, CFRP [15,16]. According to the Venetian Constitution [11], it is necessary to demonstrate that traditional materials are inadequate in order to use such materials in construction.

For this structure, after carried out of the experiments, it is decided that traditional stone material have low strength capacity. In addition to this, observations show that the structure doesn't have any damages at critical points. Therefore, high strength steel material (modulus of elasticity "E" is 210 GPa, minimum yield stress "Fy" is 440 MPa, and minimum tensile strength "Fu" is 550 MPa) is selected to retrofitting process of the stone masonry structure adhering to Venetian Constitution [11] and TSC 2007 [13]. 200 mm steel rods are applied to the vulnerable parts of the structure and retrofitted structure is also examined the same method with the original structure. Applying points of the masonry structure for the retrofitting are selected after the nonlinear response spectrum analysis is realized. These points are also given in Figure 7.

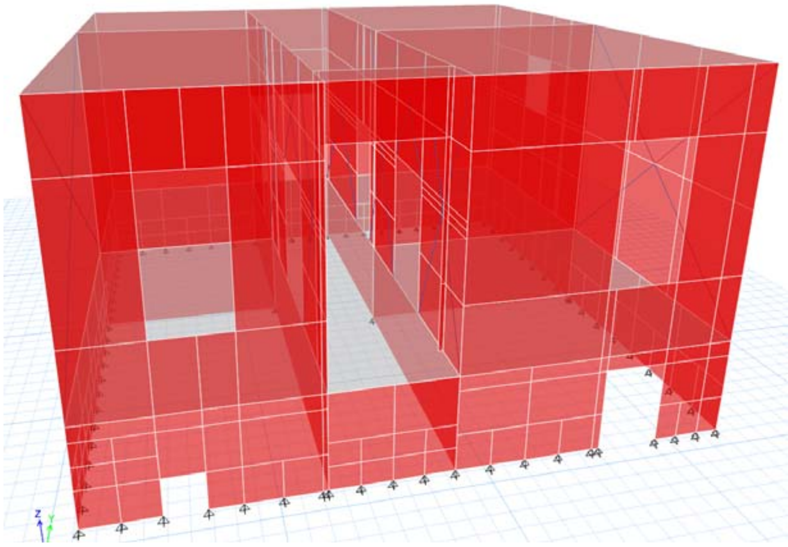


Figure 7. Finite element (FE) model of the retrofitted stone masonry structure

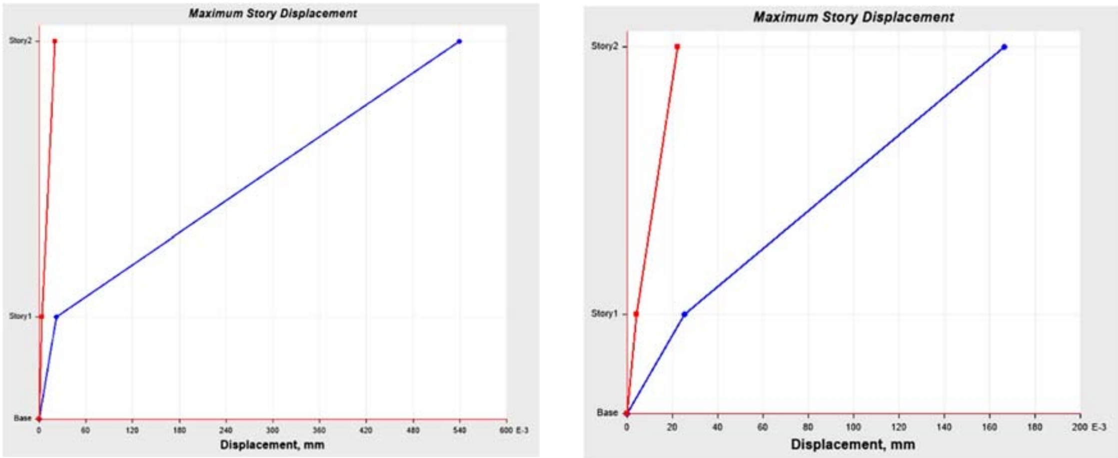
Interior walls of the structure for the retrofitting are tried to select because of the considering architectural perspective. In this way, the structure has been tried to be strengthened by choosing the minimum number of elements that can be selected and the inner perspective is tried to be preserved. Also, outer appearance of the structure is protected.

5. Results

Static analysis under dead load is performed on the model to determine the stresses that are due to its own weight. As a result of this analysis, the structure can safely carry the maximum stresses due to its own weight.

Nonlinear response history analyses are performed both X and Y direction of structures separately. Since E-W (X-direction) component of ground motion is strong, all of the results are given by considering this component of the ground motion. According to analyses results, the structure isn't safe against the strong earthquake motion.

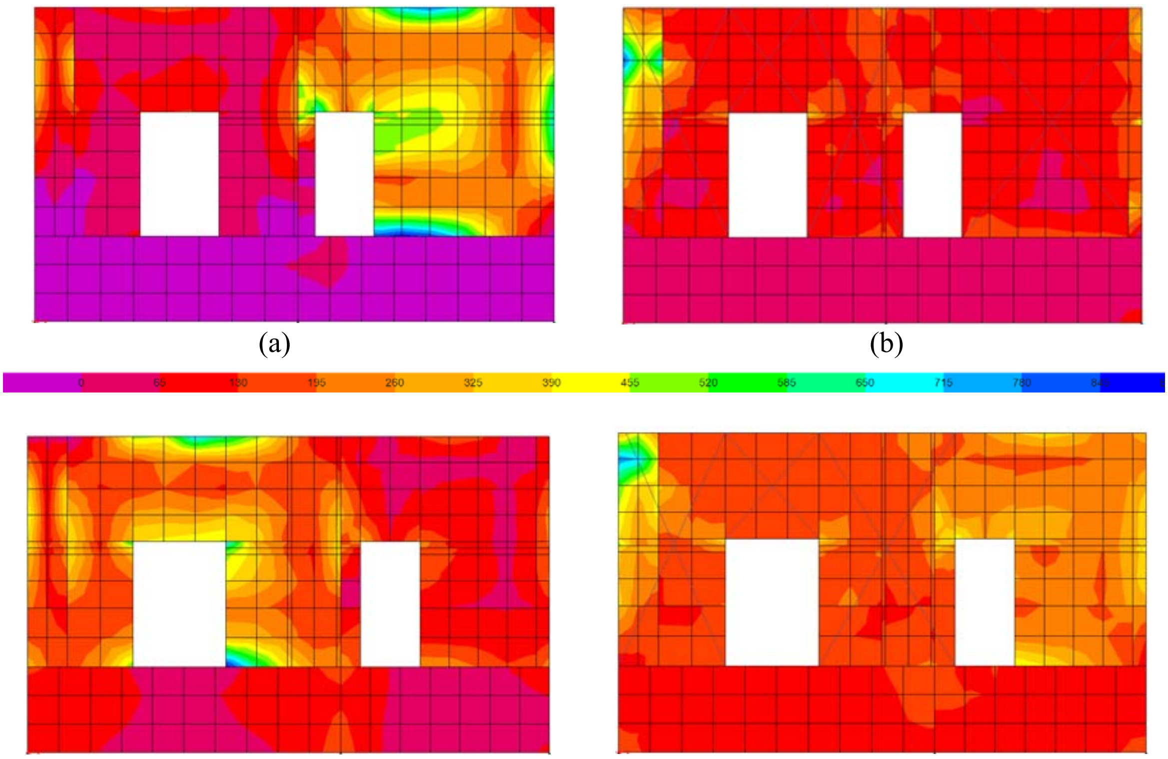
In this process, maximum story displacements of the structures are given in Figure 8 comparatively. Blue and red graphs represent x-direction and y-direction displacements in turn. With using proper and effective retrofitting, examined structure maximum story displacements for top point of the structure are decreased 68.5 % for x-direction. For y-direction, the original structure is analysed and any retrofitting processes in this direction are not applied because of the satisfying limit cases.



(a) (b)

Figure 8. Maximum story displacements for (a) original structure (b) retrofitted structure.

Moreover, occurred maximum shell stresses on the walls because of the ground motion are given in Figure 9. According to these results, vulnerable two different wall parts of the stone masonry structure are selected and retrofitted. After the retrofitting process, shell stress values in the wall are decreased considerably.



(b) (d)

Figure 9. Maximum shell stress (a) (c) original structure (b) (d) retrofitted structure.

6. Conclusion

In this study, 2 story stone masonry structures are selected and examined under the strong ground motion. After the analyses, structure is retrofitted by taking into consideration the architectural perspective because of the requirement. Results obtained from retrofitting stone masonry structure are summarized as follow:

- It is concluded that stone material used as construction material in Foca region exhibit insufficient in order to construct structure under the strong ground motion.
- Before deciding the retrofitting process, it is necessary to decide structure behaviour and vulnerable parts of the structure. According to this, structure can be economically retrofitted and architectural perspective can also be protected.
- Since examininig one type of structure cannot give the detailed information about the seismic vulnerability of the structures in the region under the strong ground motion, more buildings should be investigated in order to protect the region.

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