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Investigation of GRC Retrofitting Effect on Masonry Dome Using FEM

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Abstract – Historical buildings are the cultural heritage of the world. Preservation of historical buildings is important in the past and today. In particular, material fatigue, environmental vibration effects and natural disasters that occur over time cause great damage to historical structures. It is thought that many historical buildings will not reach the next years due to neglect. In order to prevent this situation, historical buildings should be maintained and strengthened if necessary. In addition, historical buildings should have sufficient stiffness to prevent collapse against pre-disaster situations. Masonry domes are often seen in historical buildings. Many masonries dome historical structures are frequently encountered today. In order for masonry dome in historical building to be transferred to the future, care should be taken and they may need to be strengthened periodically, especially after disasters. For all these reasons, in this study, the GRC retrofitting method, which is one of the retrofitting methods of buildings, is mentioned. Thus, the effect of the GRC retrofitting method applied on an exemplary historical masonry dome on modal parameters has been demonstrated. In this comparative study, it was observed that the stiffness of the masonry dome increased with the GRC retrofitting method. As a result of this study, it is suggested to retrofitting masonry dome with the GRC retrofitting method, taking into account the state of the historical building and environmental factors.

Keywords – Masonry Dome, GRC Retrofitting, Modal Analysis, Retrofitting

I. INTRODUCTION

Many types of structures are damaged as a result of natural disasters (such as floods, landslides, earthquakes). According to the degree of damage received, loss of life and property occurs with the collapse. In some structures, collapse does not occur as a result of disasters, but damage is observed [1], [2], [3], [4]. Various reinforcement methods are applied in such structures. Thus, the structures are restored to their former bearing strength and stiffness, thus avoiding possible collapse. Various proven popular retrofit methods are available to solve such problems. The use of GRC retrofitting is one of these retrofit methods which popular method.

Domes; They are positive Gaussian curvature systems built to pass large openings and serve as space covers. They occur when an arch rotates 180° around its axis of symmetry. Throughout history, both in Islamic and Western architecture, designers have tried domes in various geometries and combinations. The dome, which sometimes means the roof where the whole congregation gathers, sometimes symbolizes the authority and power of the state. Historical domes are made of masonry materials with low tensile strength such as adobe, brick and stone. Contrary to the general belief that they only work on pressure, they are exposed to severe tensile stress, especially in the horizontal axis, in the skirt regions. Domes are damaged or even collapsed due to static and dynamic loads (earthquake, etc.). As it is known, the load-bearing system in ancient structures built with the masonry system is quite different from the skeleton system in reinforced concrete structures. All elements used here form part of the carrier system. For example, in a dome where stone was used as the material, the stones in the lower row carry the weight of the top keystone. Each stone transfers its load to the stone below it one row. Thus, the whole system finds the possibility of monolithic operation [5]. Elements that make up the dome; under bending, compressive and tensile stresses. In the assumptions made to simplify the solution, bending stress can be neglected due to the geometrical feature of the dome [6]. Since each element in the domes transfers its load to the element in the lower row, it would not be wrong to say that these structures operate completely under pressure stress in the vertical axis. However, the same cannot be said for the horizontal axis. Contrary to popular belief, especially the skirt areas combined with the pulley receive tensile stress. On the horizontal axis, the upper third of the dome's height is subjected to compression, while the remaining two-thirds of the lower part is subjected to tensile stress [7]. As can be seen from the studies, domes receive tensile stress and the region where these stresses are most intense; skirt region. Therefore, it is inevitable for the dome to displace in the skirt region as it tends to open. In order to prevent this, engineers have developed various solutions in the past. The flying buttresses we encounter in gothic cathedrals and the half-dome combinations developed by Mimar Sinan can be given as examples [8].

Glass fibre reinforced concrete (GFRC) is a type of fibre-reinforced concrete. The product is also known as glassfibre reinforced concrete or GRC in British English [9]. Glass fibre concretes are mainly used in exterior building façade panels and as architectural precast concrete. Somewhat similar materials are fibre cement siding and cement boards. Glass Fiber Reinforced Concrete, also known as Composite Cement, CCV, Fiber Concrete, Fiber Reinforced Concrete and Glasfaserbeton (GFB), GRC and GFRC in various parts of the world, is a mixture of cement, fine aggregate, water, chemical additives and alkali resistant glass fibers. Glass Fiber Reinforced Concrete is a material that makes great contributions to economy, technology and construction aesthetics all over the world today. Glass Fiber Reinforced Concrete has been continuously developed since it was first produced in 1960, 50 years ago, and today's construction designers have a choice of matrix modifiers such as acrylic polymer, quick-drying cement and various additives to improve the long-term stability of the material depending on performance needs. Extensive independent testing and performance data are available on all elements of the matrix formula. In the production of prefabricated products produced in the factory, generally 2-5% alkali resistant glass fiber is used by applying spraying method or conventional concrete casting methods. This material is also used in the reinforced factory fiber in the form of a mixture applied in the field at a rate of 1-2%, as well as preventing cracking due to plastic shrinkage. In the GFRC production method by pre–mixture and casting, cement matrix is firstly produced and pre–cut glass fibers, between 2–4 % (usually 3.5 %) weight, are then mixed. The length of the pre–cut fiber is usually 6–12 mm, however, longer fibers lead to restrict to the mixture workability. Respectively, the matrix is produced in a high–shear mixer and chopped fiber strands are incorporated in a low–speed mixing regime because of maximum workability. This facilitates their dispersion at the highest practical volume content with a minimum damage to the fibers. Production with pre–mix GFRC may involve several procedures such as injection and vibration, pressing, or shotcreting [10].

Researchers have carried out many studies using both the retrofitting and the finite element method. Researchers have conducted studies [11], [12], [13], [14], [15], [16], [17] about masonry dome which also contributed to this study. Also, researchers have conducted studies [18], [19], [20], [21], [22], [23] about GRC and GRC retrofitting which also contributed to this study.

The aim of this study is to contribute to the retrofitting of masonry dome according to their pre-disaster and post-disaster stiffness conditions. It is known that there are many retrofitting methods available for the masonry dome to regain their former stiffness. In this study, the effects of the GRC retrofitting method on masonry dome periods and mode shapes are investigated.

II. Materials and Method

In this study, masonry dome model was created and modal analysis was carried out with the finite element method. The masonry dome model was retrofitted with GRC retrofitting and two masonry dome model was created for comparison. Variables on the model should be minimized in order to better see the reinforcement effects. Therefore, it was emphasized that the models should be designed simply and symmetrically. Thus, it is aimed that the only variable between both models is the retrofitting method. In the application of the finite element method, the SAP2000 package program, which is used in the field of academic and engineering applications all over the world, was used.

A. *Description of Masonry Dome Model*

The model masonry dome is designed as masonry stone. The masonry dome model has a hemispherical cross section with a diameter of 10 m. Height is 5 m. The wall thickness is 0.15 m. The mechanical parameters of masonry stone in model are; poisson's ratio: 0.2, modulus of elasticity: 2 GPa, density: 20 kN/m^3. The masonry dome finite element model was created using the SAP2000 software. The finite element model of the masonry dome is given in fig. 1.

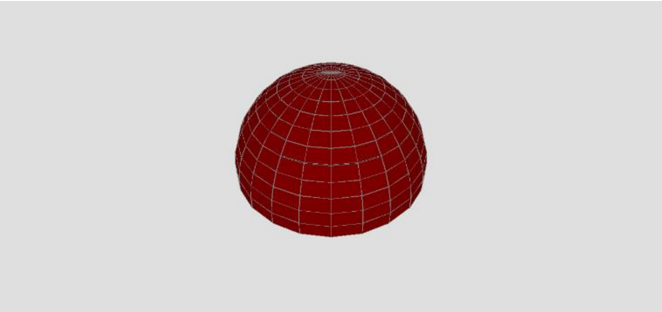

Fig. 1 3D Finite element model of the masonry dome

B. *Description of Masonry Dome Retrofitted Model*

0.025 m GRC retrofitting process was applied to the out surface of the existing masonry dome model. Mechanical properties of the applied GRC materials; poisson's ratio: 0.24, modulus of elasticity: 15 GPa, density: 20 kN/m^3.

III. Results and Discussion

Masonry dome model and masonry dome retrofitted model were analysed using SAP2000 software. The period and mode shapes obtained for both models are obtained for each mode.

A. *Results of Masonry Dome Model*

The modal analysis of the masonry dome model was performed with FEM. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 2,3,4,5,6 as periods and mode shapes.

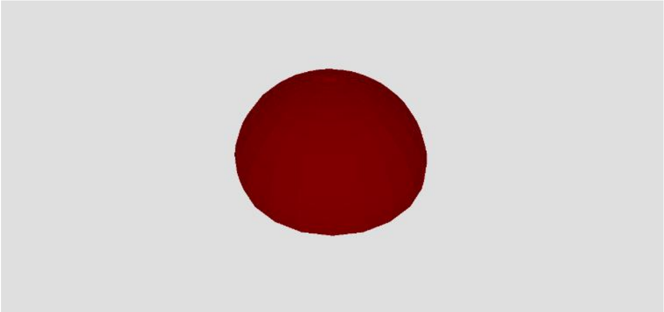

Fig. 2 Mode shape (Period value = 0.052 s)

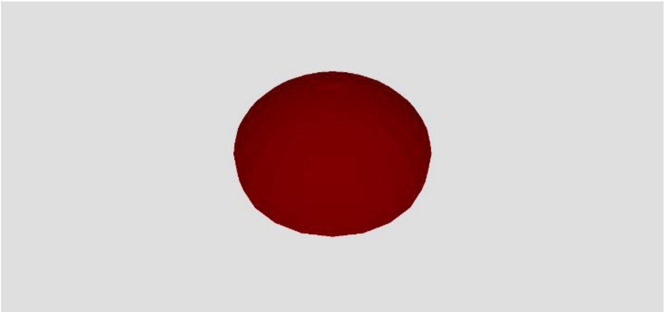

Fig. 3 Mode shape (Period value = 0.039 s)

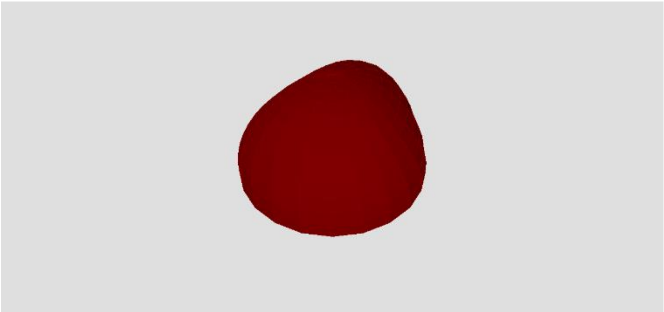

Fig. 4 Mode shape (Period value = 0.034 s)

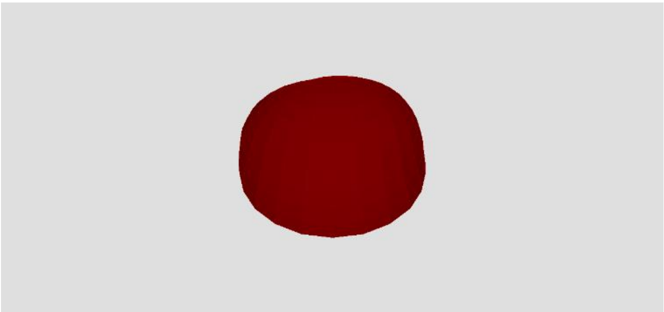

Fig. 5 Mode shape (Period value = 0.033 s)

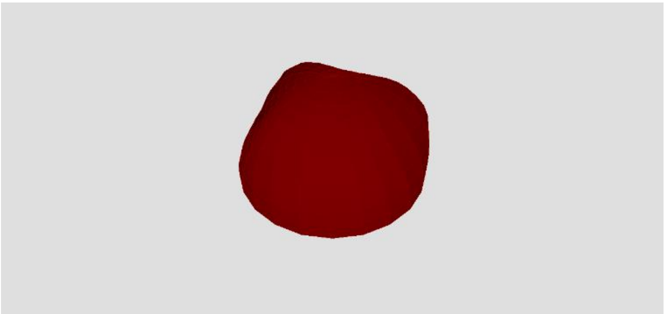

Fig. 6 Mode shape (Period value = 0.032 s)

B. *Results of Masonry Dome Retrofitted Model*

The modal analysis of the masonry dome retrofitted model was performed with FEM. The first 5 modes were taken into account in the analysis. Obtained results are presented in figures 7,8,9,10,11 as periods and mode shapes.

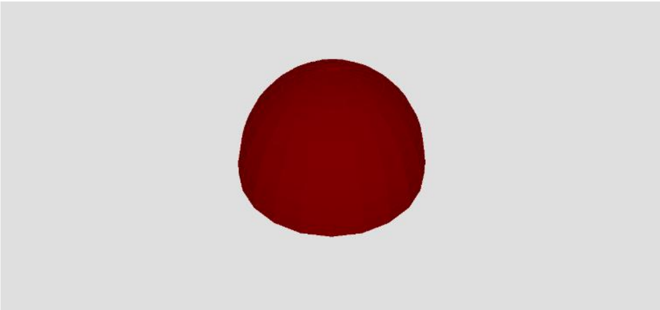

Fig. 7 Mode shape (Period value = 0.037 s)

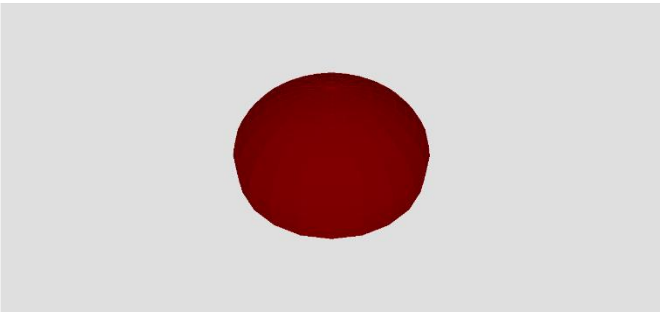

Fig. 8 Mode shape (Period value = 0.028 s)

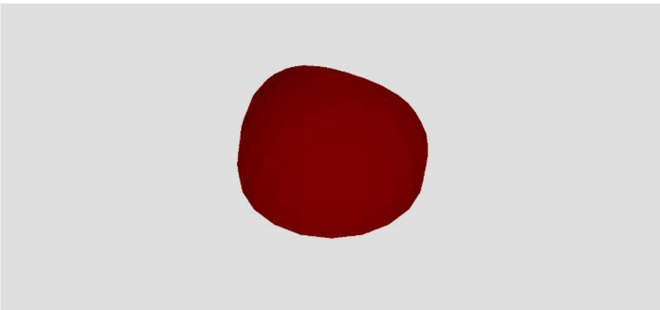

Fig. 9 Mode shape (Period value = 0.024 s)

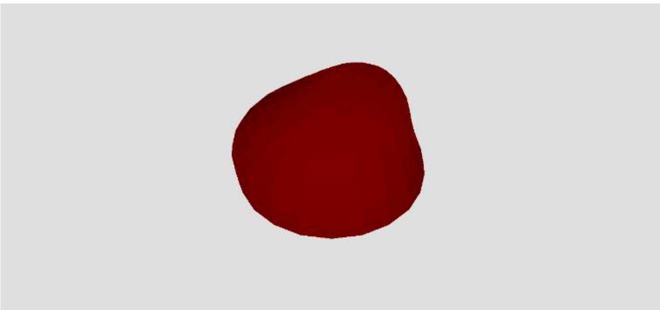

Fig. 10 Mode shape (Period value = 0.023 s)

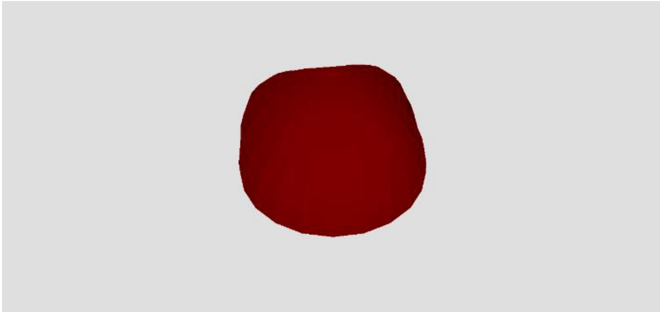

Fig. 11 Mode shape (Period value = 0.022 s)

C. *Comparison of Modal Analysis Results*

The comparison of periods of the model non-retrofitted and retrofitted are given in Table 1.

Table 1. Comparison of period values

Mode	**1**	**2**	**3**	**4**	**5**
Non-retrofitted	0.052	0.039	0.034	0.033	0.032
Retrofitted	0.037	0.028	0.024	0.023	0.022
Difference (s)	0.015	0.011	0.010	0.010	0.010
Difference (%)	28.85	28.21	29.41	30.30	31.25

With the retrofitting, some minor change in translation and torsion was observed.

IV. CONCLUSION

In the mode 1, the period difference between non-retrofitted and retrofitted status was obtained as 0.015 s. The effect of period retrofitting with GRC retrofitting as a percentage was determined as 28.85.

In the mode 2, the period difference between non-retrofitted and retrofitted status was obtained as 0.011 s. The effect of period retrofitting with GRC retrofitting as a percentage was determined as 28.21.

In the mode 3, the period difference between non-retrofitted and retrofitted status was obtained as 0.010 s. The effect of period retrofitting with GRC retrofitting as a percentage was determined as 29.41.

In the mode 4, the period difference between non-retrofitted and retrofitted status was obtained as 0.010 s. The effect of period retrofitting with GRC retrofitting as a percentage was determined as 30.30.

In the mode 5, the period difference between non-retrofitted and retrofitted status was obtained as 0.010 s. The effect of period retrofitting with GRC retrofitting as a percentage was determined as 31.25.

With the retrofitting, some minor change in translation and torsion was observed. It is thought that these changes are not very important.

In the light of all these results, it is clearly seen that the stiffness of the masonry dome model increases by retrofitting the masonry dome model with GRC retrofitting. The fact that the period decrease percentages in the modes are close to each other is thought to be due to the geometry of the masonry dome. In the 1st mode, in other words, there is a decrease of 28.85 percent in the dominant period value. It is known that this is a positive situation in terms of retrofit. The maximum decrease in period values was observed in the 5th mode. The lowest period decrease was seen in the 2nd mode with approximately 28.21 percent. It can be said that the drop value obtained in this period is quite positive in terms of the increase in model stiffness. As a result of this study, the masonry domes can retrofit with the GRC retrofitting method.

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