PRESERVATION AND RESTORATION OF THE ARCHITECTURAL HERITAGE IN VIEW OF THE STRUCTURAL ENGINEERING PERSPECTIVE

Gasimzade Azer- professor, Doctor of Science, AzUAC, Baku, Azerbaijan, azer@omu.edu.tr
Serra Danish- PhD Student, department of Civil Engineering, Ondokuz Mayis University, Samsun
Nematli- Emin PhD Student, department of Civil Engineering, Ondokuz Mayis University, Samsun,

Abstract. Evaluation of the current building situation, which is one of the priority stages of the preservation and restoration - repair and strengthening (P&R-R&S) of historic buildings, so as not to damage the originality of the structure, using the non-destructive Operational Modal Analyzes-OMA method is on target. That is also the fundamental method for calibrating (estimating the current state of the structural, material, soil interaction, etc.) the finite element model of the structure. On the other hand, applying materials with high strength and as light as possible in these studies is efficient, such as Carbon Fiber Reinforced Polymers-CFRP. Another importance of using this material is that it is more resistant to corrosion and has a long service life. These properties have caused CFRP to have a vast and fundamental place in structures P&R-R&S. In the presented work, with the aforementioned methods, the project of repairing and strengthening the old tobacco factory and transforming it into a modern shopping center is shown, which was implemented in 2011. Afterward, the application limits of these studies to the historical buildings in the East Zangezur and Karabakh regions, which were liberated from the occupation, are explained on the historical building examples in the mentioned region.
Keywords: Preservation and Restoration with CFRP, Operational Modal Analysis, Performance Based Design

Introduction. Building structures lose their performance due to various reasons (atmospheric, biological, and chemical factors, overload, delayed effects, etc.) (Nowak et al., 2013). When checking a building structure's performance, using an observational method can be very misleading. A bridge that looks healthy may have an invisible problem, and a bridge that looks very old may be structurally intact (Kasimzade et al., 2021). Considering this, the evaluation of the current building situation is one of the priority stages of the conservation and restoration - repair and strengthening (P&R-S) of historical buildings.

By using nondestructive operational modal analysis-OMA (Kasimzade, 2007; Kasimzade and Tuhta, 2007, 2017, 2018) we can evaluate the performance of historical buildings without damaging their originality. That is also the fundamental method for calibrating (estimating the current state of the structural, material, soil interaction, etc.) the finite element model of the structure (Kasimzade and Tuhta, 2005a, 2005b, 2012; Kasimzade et al., 2006a, 2006b, 2018, 2021; Kasimzade, 2006, 2007).

Performance Based Design-PBD (Kasimzade, 2021; Kasimzade et al., 2018a, 2018b, 2020) determines the building's performance capacity during and after an earthquake. When this design approach is followed while evaluating the current and post-retrofit performance of the building, financial resources are used more effectively, and those who do not have technical knowledge about the project have a vocabulary that allows them to discuss the performance target with professionals (FEMA, 2006). Suppose it is concluded from the data obtained by the operational modal analysis that the structure should be strengthened. In that case, it becomes necessary to strengthen the elements without increasing the structure's mass as much as possible (Kasimzade and Tuhta, 2021). The modulus of elasticity of CFRP (2.3×10^5 MPa) is about ten times greater than the modulus of elasticity of concrete (2.8×10^4 MPa) and about 15% greater than the modulus of elasticity of reinforcing steel (2.0×10^5 MPA), and its mass is negligible compared to others. Another importance of using this material is that it is more resistant to corrosion and has a long service life. These properties have caused CFRP to have a vast and fundamental place in structure conservation and restoration applications (Kasimzade and Tuhta, 2011, 2017; Lee and Jain, 2009).

In the presented work, with the aforementioned methods, the project of repairing and strengthening the old tobacco factory and transforming it into a modern shopping center is shown, which was implemented in 2011(Kasimzade and Tuhta, 2011). Afterwards, the application limits of these studies to the historical buildings in the East Zangezur and Karabakh regions of Azerbaijan, which were liberated from the occupation on 08.11.2020, are explained on the historical building examples in the mentioned region. The examples are shown according to the state of the buildings in this region immediately after the occupation (Şuşa the Cultural Capital of Azerbaycan, 2022) and their state before the invasion (Chronicle of Karabakh Centuries, 2016) and during the occupation period (Karabakh: Yesterday and Today in Photos, 2007; Ministry of Culture and Tourism Republic of Azerbaijan, 2008; Ministry of Foreign Affairs Republic of Azerbaijan, 2007) are taken into account. Mainly located in Shusha; The House of Khan's Daughter Natevan, The House of Cahangir Khan Hacı's son Nuribəyov, The House of Mir Mövsüm Nawwab, The House of Cabbar Qarayagdi, The Building of Realni School, The Hospital Building, the Çol Qala Mosque, The House of Mesedi Qara, The House of Mesedi İbis and on many similar building examples are explained.

On the subject of the current study, to ensure interdisciplinary (architectural, structural, material, and so on) engineering understanding, the current work is presented in the following sections (by giving brief summary information about each section):

1. Applications of non-destructive OMA method and the calibration of Finite Element Model of the building;
2. Properties of CFRP and the contribution of its application to the elements and structure;
3. Structural Repair-Strengthening with CFRP Example: Tobacco Factory Case;
4. The CFRP applicability limits explanation on The House of Khan's Daughter Natevan, The House of Cahangir Khan Haci's son Nuribəyov, The House of Mir Mövsüm Nawwab, The House of Cabbar Qarayagdi, The building of Realni School, the Hospital Building, the Çol Qala Mosque, The House of Mesedi Qara, The House of Mesedi İbis and many more;
5. Checking the performance of the Repaired-Strengthed structure (Performance Based Design-PBD in the direction of the relevant guidelines)

Applications of the non-destructive OMA method and the calibration of the finite element model of the building. To ensure interdisciplinary engineering understanding these review steps are explained under the following sub-headings, mainly in visual illustration form (Fig. 1- Fig. 12).

Building response measurement and evaluation in the example of reinforced concrete structures.

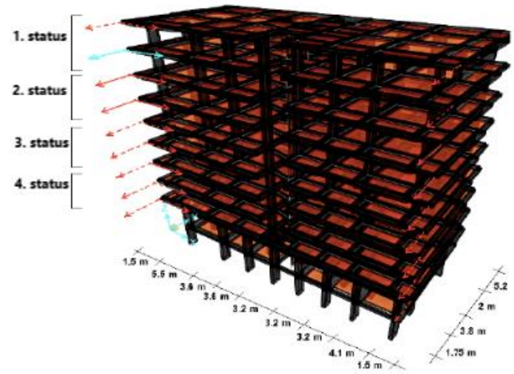


Figure 1. Numerical (finite element) model of structure and experimental model devices (accelerometers) layout (red and green marked lines are the roving and reference accelerometers respectively) (Kasimzade Archive)

Figure 2. Experimental (real) model of structure and layout of the devices (accelerometers) on it (Kasimzade Archive)

Figure 3. Installation details of devices (accelerometers) on the 1-11 floors, seismometer on the ground floor, checking the operability of devices on the computer respectively (Kasimzade Archive)

2.2 Definition of the structural parameters by comparing of numerical (FEM model, blue line) and experimental (real model, red line) models responses - mode shapes

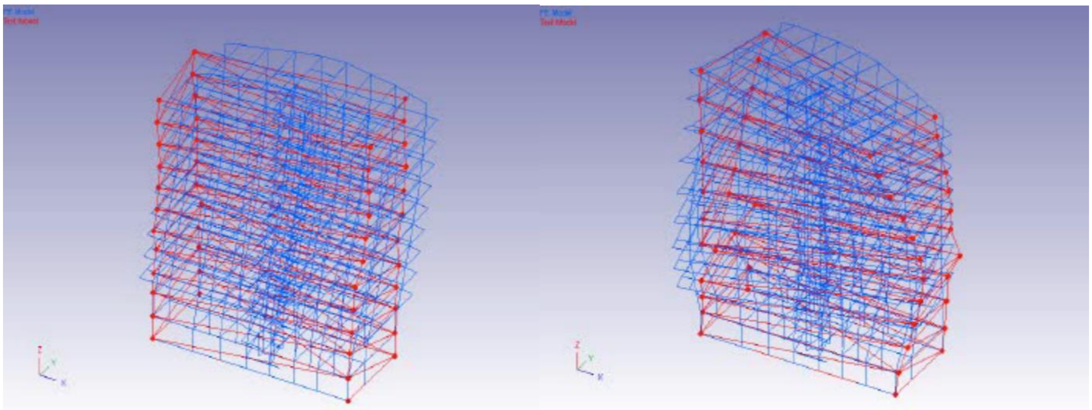


Figure 4. Installation some vibration modes of the numerical (FEM) and experimental (real) models of structure (Kasimzade et al., 2006).

a. Building response measurement and evaluation in the example of reinforced steel structures

Figure 5. Mobile structural monitoring system, steel frame benchmark structure, outside and inside of the mobile laboratory (Kasimzade Archive, (Kasimzade et al., 2006,2007,2012)

Figure 6.
a) Formation of steel model bridge test structure; *b)* Placing the triaxial accelerometer at node (Kasimzade et al., 2021)

2.4- Building response measurement and evaluation in the example of wooden structures

Figure 7. *a)* Wooden structure; *b)* Response measurement and evaluation; *c)* Structure support modelling for test model; *d)* Layout of the reference device; *e)* Test model of structure (Kasimzade Archive)

Building response measurement and evaluation summary in the example of historical masonry (stone) structures

Properties of CFRP and the contribution of its application to the elements and structure. As was mentioned Carbon Fiber Reinforced Polymers are commonly used for the construction, repair and strengthening as it has many advantages in terms of lightweight, noncorrosive, exhibit high specific strength, and specific stiffness, are easily constructed, and can be tailored to satisfy performance requirements (Lee and Jain, 2009).

Evaluation results of CFRP application in beam bending. During the following experiments (Kasimzade and Tuhta, 2011), to observe the effect of CFRP the maximum load and moment capacities obtained from numerical (Figure 14.a) and experimental analyzes (Fig. 13.a, Fig. 14.b, Fig. 15) were evaluated for the specimens without CFRP and wrapped in 1 layer and 2,3,4 layers of CFRP. 15 reinforced concrete specimens without CFRP and with suitable for 1, 2, 3, 4 layers CFRP (CF-130) have been tested towards bending and following conclusions based on experimental. Analytical, numerical investigation can be drawn:

— CFRP strengthened reinforced concrete beams increased failure load and moment approximately 70-120 percent depending on the CFRP layer’s number.

— For getting maximum fruitfulness of CFRP strengthening, it is necessary fitting observance direction for covering specimens

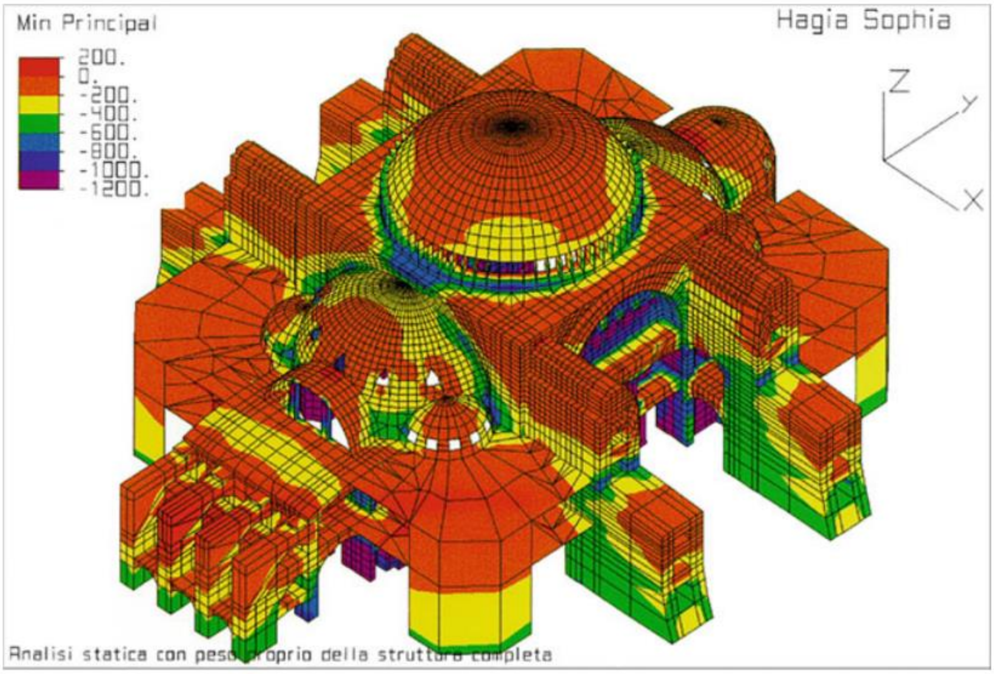


Figure 8. Maximum principial stress under gravity loading in the calibrated FEM model of the Hagia Sophia (Kasimzade et al., 2018)

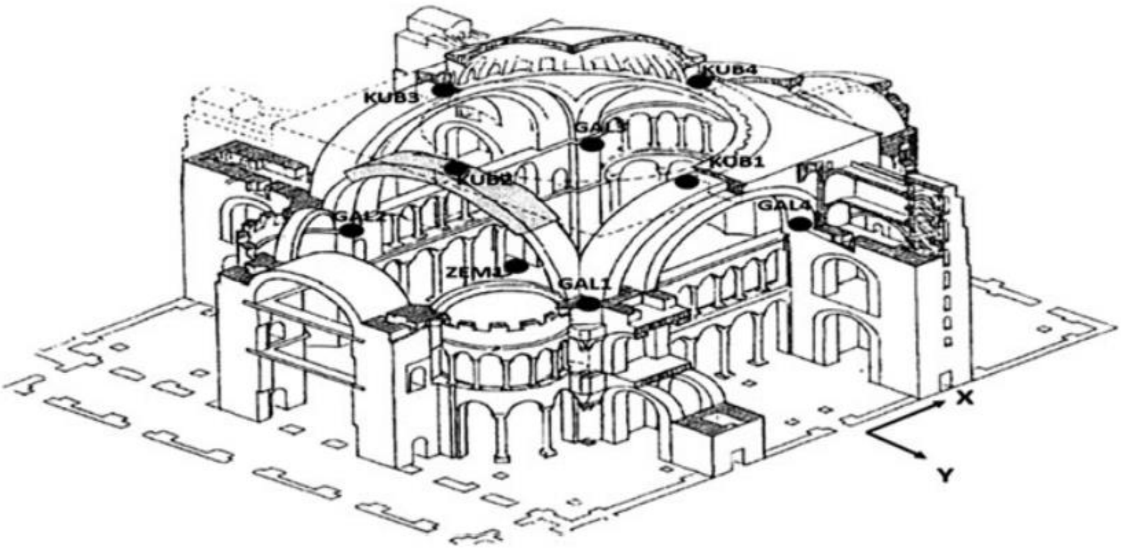


Figure 9. Accelerometers layout in Hagia Sophia (Kasimzade et al., 2018)

Figure 10. Scaled model of Hagia Sophia on the shake table (Kasimzade et al., 2018)

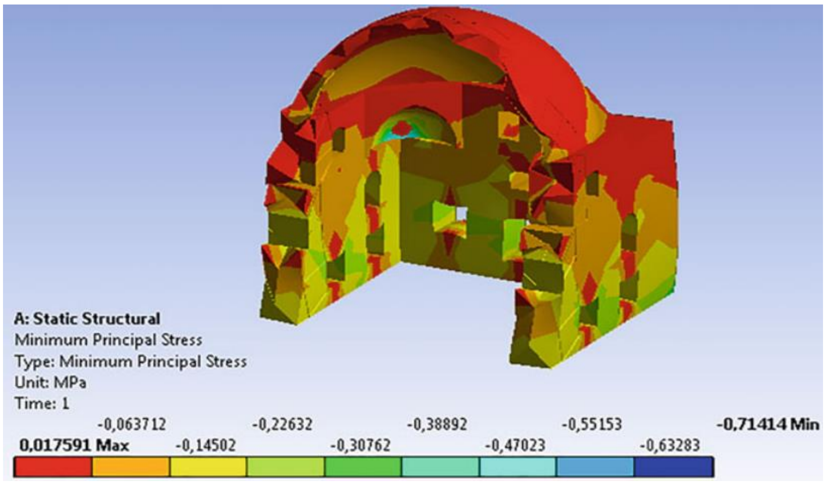


Figure 11. Minimum principial stress under gravity loading in the calibrated FEM model of the Merzifon Döner Taş Mosque (Kasimzade et al., 2018)

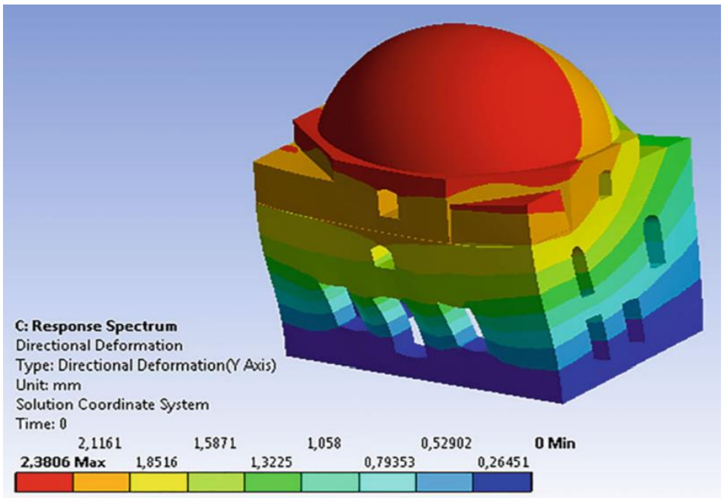
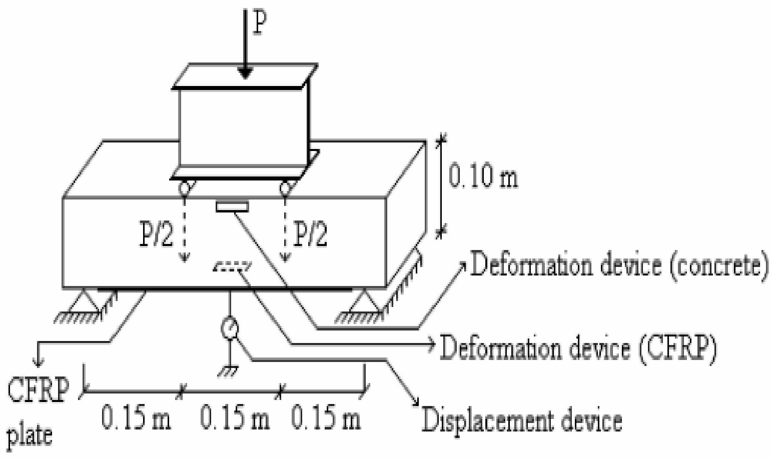


Figure 12. Response spectrum-Deformation of the Merzifon Döner Taş Mosque in Y direction (Kasimzade et al., 2018)



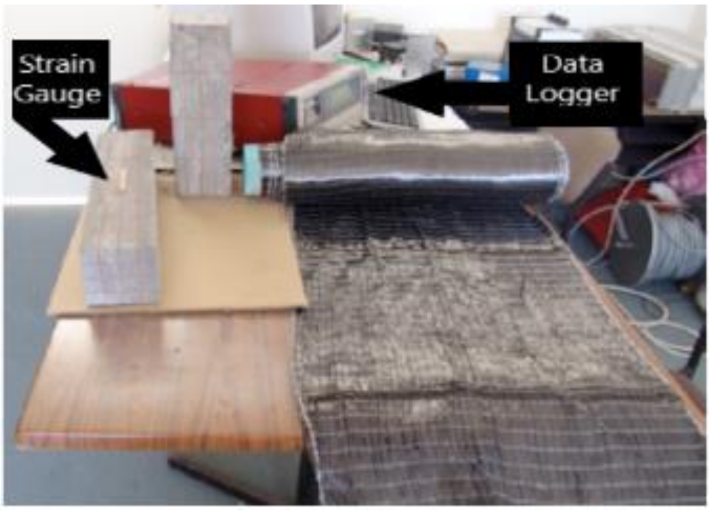
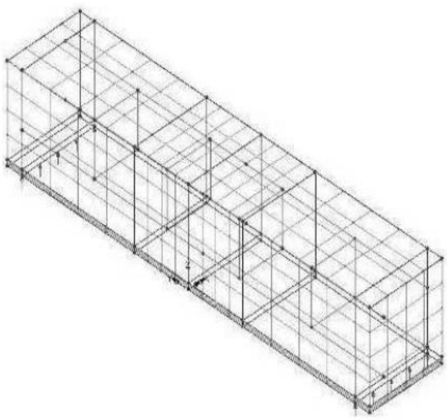


Figure 13.

a) Specimen measuring devices and loading layouts;
b) b) CFRP fabric and strain gauge embedded beam
c) (Kasimzade and Tuhta, 2011; Kasimzade Archive)



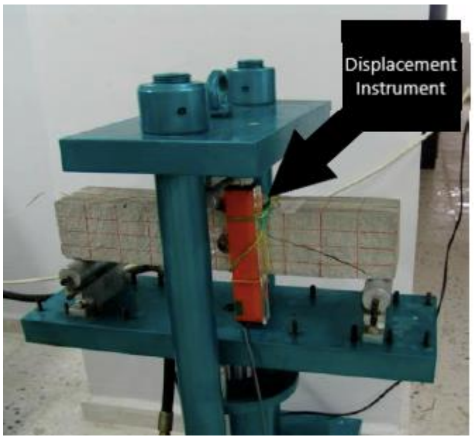


Figure 14.

a) Specimen numerical (FEM) analysis model; *b)* Specimen experimental analysis model (Kasimzade and Tuhta, 2011; Kasimzade Archive)

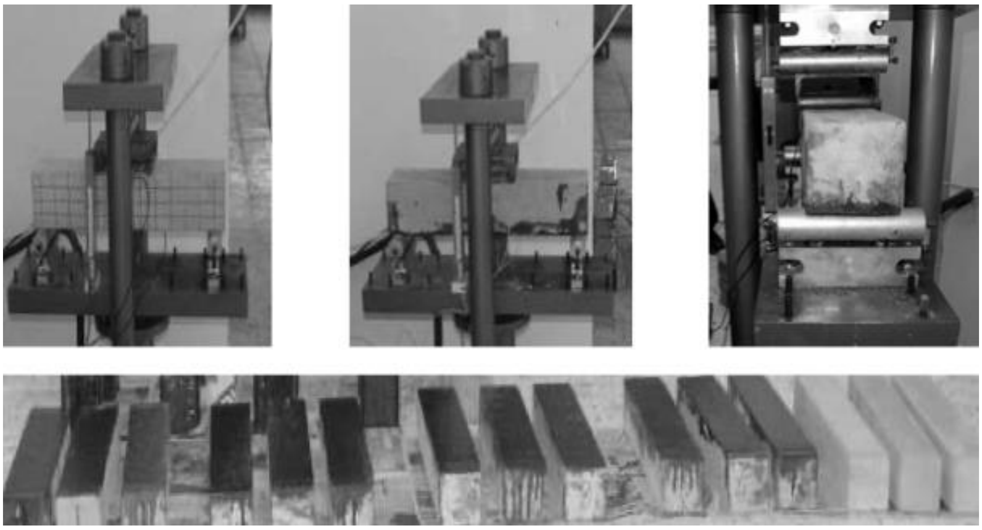


Figure 15. Specimens without and with CFRP during of experiment (Kasimzade Archive)

Structural strengthening evaluation. The mentioned evaluation is effectively explained in a very simple example (Kasimzade and Tuhta, 2017a, 2017b).3 accelerometers used to record microtremor data in the x and y directions, and one of them is assigned as the reference sensor, indicated by red arrows. Others are used as roving sensors, indicated by black arrows and the response of the steel structure measured for the two data setups (Fig. 16, 17).

- The results of the experiment show that the modal frequency difference lies in the interval of 32.963%-61.204% for existing and retrofitted cases and it provides the increase of frame structure stiffness by about 34.43%; for the retrofitted model, using CFRP applied to beams only.
- The investigated results ensure and confirm the possibility of using the recorded microtremor data on the ground level as ambient vibration input excitation data {at investigation and application of Operational Modal Analysis (OMA) on the bench-scale earthquake simulator (The Quanser Shake Table) for retrofitted structures and shed light on the development of related research.
- The conclusion of the experiment strongly suggests that the retrofitting should be very efficient to increase stiffness and natural frequencies.
- In this study, it is shown that OMA may be used to evaluate the period and rigidity of the retrofitted structures.

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Structural repair- strengthening with CFRP example: Tobacco factory case. Samsun (Turkey) Tobacco Factory, which was established in 1887 and served as factories for the country's economy for a long time, is planned to contribute to the national and regional economy by transforming them into shopping malls with a new approach with an investment of 50 million Euros within the scope of the Bulvar Shopping Mall project (Fig.18).

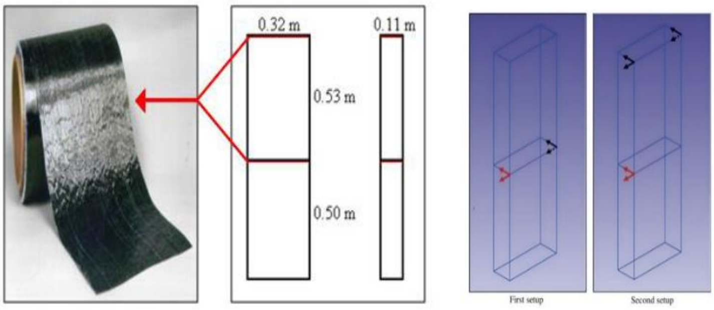

Figure 16. *a)* CFRP aplication details;
b) Accelerometers location of experimental model in the 3D view (Kasimzade and Tuhta, 2017a, 2017b)

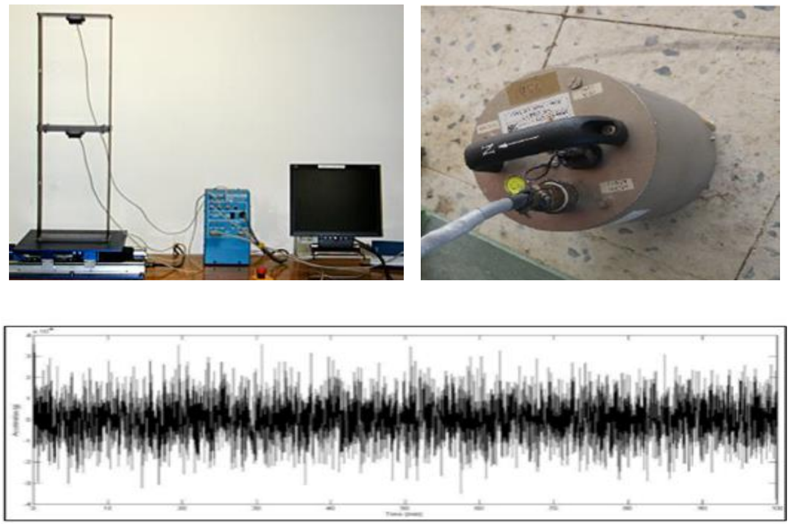

Figure 17.
a) Model steel structure, shake table; *b)* Seismometer for ambient vibration recorder;
Recorded microtremor data on ground level which was used as ambient excitation in the shake table test (Kasimzade and Tuhta, 2017a, 2017b)

Figure 18. Site Plan (Kasimzade Archive)

Some of the Samsun Tobacco Factory buildings were built with the masonry technique by the French in 1887, and in the following years, some additions were made, such as the B2 Block, which was built in 1950 by trying to resemble the old building. The buildings were designed as wooden masonry, columns, and floors, except for the B2 block which was built later. Within the scope of the project, exterior facades will be protected and the carrier system will be completely changed except B2 block, the existing floors will be removed and the wooden carrier system will be renewed with steel construction. Since only B2 Block has a reinforced concrete carrier system, reinforcement in this building will be made with CFRP fabrics. In addition, B1 block masonry walls will be reinforced with CFRP fabrics. Some images of before (Fig.19, Fig.20) and after (Fig. 21, Fig. 22) the implementation of the project is presented.

Figure 19. A-block view before repair and strengthening; *b.* C and D-block view before repair and strengthening; *c.* B block view before repair and strengthening (Kasimzade Archive)

Figure 20. *a.* View from street; *b.* Courtyard view (Kasimzade Archive)

Summary of reinforcement applications with CFRP in C1 block. In the B2 block, the slabs, beams and columns has been reinforced with CFRP without changing the system.

Figure 21. a) Condition of B2-Block before CFRP repair and strengthening application; *b)* Preparation of the elements to be repair and strengthening in block B2; *c)* Preparation of the elements to be repair and strengthened in block B2 (Kasimzade Archive)

Figure 22. *a)* Column beam and floor repair and strengthening with CFRP Fabric in B2 Block; ***b)*** Masonry walls repair and strengthening in B2 Block (Kasimzade Archive)

The CFRP applicability limits explanation on the in-situ selected monumental houses of Shusha City of Azerbaijan Republic. In historical buildings, it is extremely important to preserve the originality of the building. For this reason, this method is recommended if the structural elements are at a level of performance that can be strengthened. The structures in the city of Shusha that can be strengthened with CFRP are selected and presented in Fig.23 - Fig.43 in terms of preserving the architectural structure and originality. In the in-situ selection studies, the buildings that give the opportunity of architectural preservation of the outer walls are given priority.
Below the CFRP applicability limits explanation was illustrated on the in-situ selected monumental houses such as: House of Khan's Daughter Natevan, The House of Cahangir Khan Haci's Son Nuribəyov, The House of Mir Mövsüm Nawwab, The House of Cabbar Qarayagdi, The Building

of Realni School, The Hospital Building, The Çol Qala Mosque, The House Of Mesedi Qara, The House Of Mesedi Ibis.

Figure 23. The House of Khan's Daughter Natevan, after the occupation (Şuşa the Cultural Capital of Azerbaycan, 2022)

Figure 24. The House of Khan's Daughter Natevan, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 25. The House of Khan's Daughter Natevan, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 26. The House of Khan's Daughter Natevan, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 27. The House of Khan's Daughter Natevan, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 28. The Khan's Daughter Nateva's house, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 29. The House of Cahangir Khan Hacı's son Nuribəyov*, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)
*(*Some parts of my school years passed in this house; its memory is cherished)*

Figure 30. The House of Cahangir Khan Hacı's son Nuribəyov (before the occupation) (Karabakh: Yesterday and Today in Photos, 2007; Ministry of Culture and Tourism Republic of Azerbaijan, 2016)

Figure 31.
The Building of Realni School, Shusha, after the occupation (Şuşa the Cultural Capital of Azerbaycan, 2022)

Figure 32. The Building of Realni School, Shusha, before the occupation (Karabakh: Yesterday and Today in Photos, 2007; Ministry of Culture and Tourism Republic of Azerbaijan, 2016)

Figure 33.
The Building of Realni Hospital, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 34.
The Building of Shusha Hospital, after the occupation
(Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 35. Col Qala Mosque, Shusha, after the occupation
(Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 36. Col Qala Mosque, Shusha, after the occupation
(Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 37. The House of Mesedi Qara, Shusha, after the occupation
(Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 38. The House of Mesedi Qara, Shusha, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 39. The House of Mesedi Ibis, Shusha, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 40. The House of Mesedi Ibis, Susa, after the occupation (Shusha the Cultural Capital of Azerbaycan, 2022)

Figure 41. M.P. Vagif's Tomb (Kasimzade Archive, 1972)
*(*The person under the monument is A.A. Kasimzade)*

Figure 42. M.P. Vagif's Tomb (authors: Ə.V. Salamzadə and E.I. Kanukov 1977-1982)

Figure 43. M.P. Vagif's Tomb, 7.11. 2020, after the occupation,
(https://www.wiki.az-az.nina.az/Shusha.html)

Checking the performance of the repaired-strengthed structure (Performance-Based Design-PBD in the direction of the relevant guidelines). As it is known, the examination of the structures must be done with the performance-based design method in line with the demands of the relevant guidelines and references (FEMA, 2006; Kasimzade et al., 2018a, 2018b; Kasimzade, 2021). Performance-based design ensures that the behavior of the structure before and after the earthquake is within the expected criteria in relation to the intended use of the structure (Fig.44).

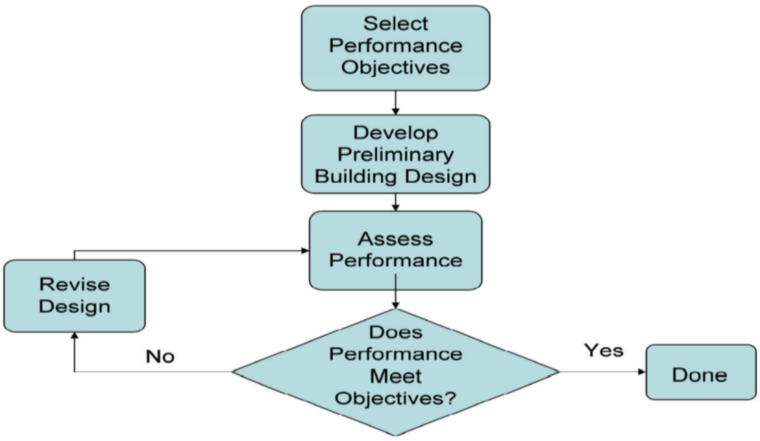

Figure 44. Performance-Based design flow diagram (FEMA, 2006)

Based on examples from references (Kasimzade et al., 2020; Kasimzade A. A., 2021), the Table 1 and Figures 45,46 are illustrating the important key steps of the PBD method.

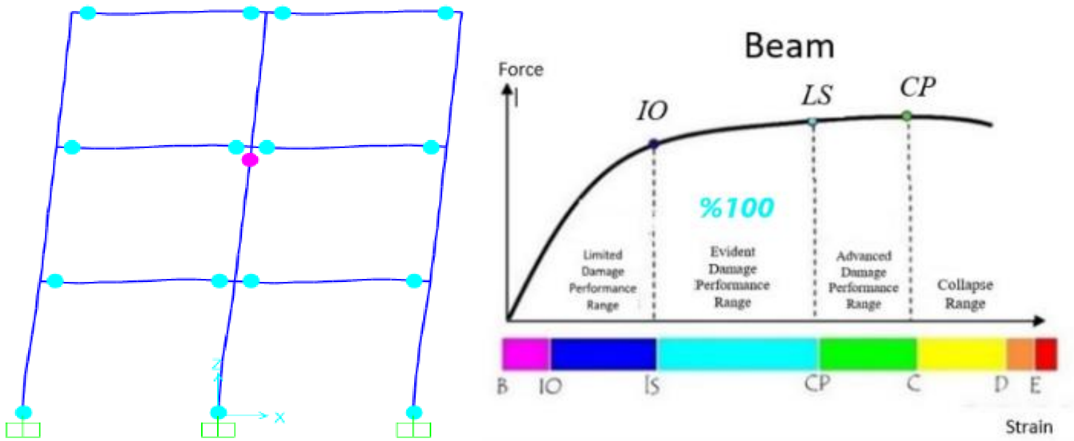

Figure 45.
Plastic hinges formed in the structure as a result of the Pushover Analysis (Kasimzade et al., 2018; Kasimzade, 2021)

Table 1. Performance levels of the plastic hinge formed in the structure (Kasimzade et al., 2018; Kasimzade, 2021)

Plastic Hinge Performance Levels					Total number of plastic hinges
B, Pink	IO, (Navy blue)	LS, (Blue)	CP, (Green)	C, (Yellow,Red)	
1	0	15	0	0	16

All of the plastic hinge formed in the beams to the Force-Strain curve has passed into the Evident Damage Performance Range. Other Carrier elements (Columns) consist of 25% Limited Damage

Performance Range and 75% Evident Damage Performance Range. As a result of the analysis with the PBD method, structure ensures LS performance level. For this case, the carrying capacity of the structure was obtained as Vt=188.176 kN, as seen from the base shear and maximum displacement curve (Fig. 46).

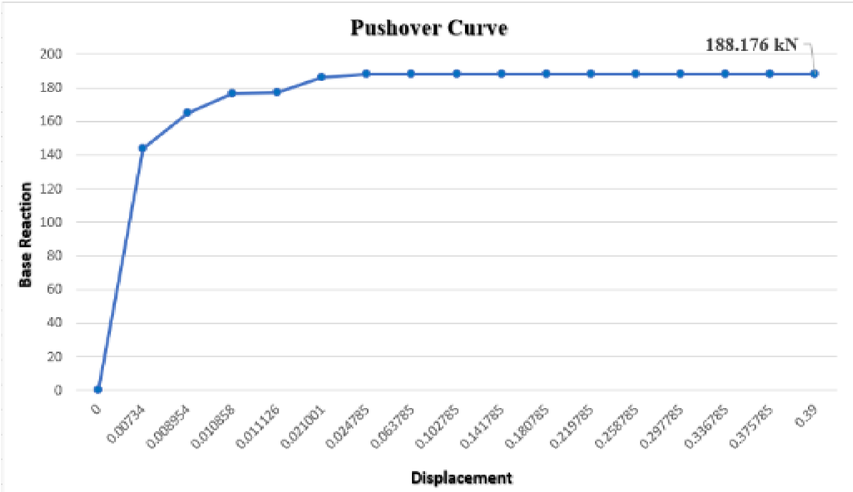

Figure 46. Base shear force on the structure as a result of the Pushover Analysis (Kasimzade et al., 2018; Kasimzade, 2021)

Conclusion. In this Context; Main steps of the preservation and restoration of the architectural heritage in view of the structural engineering perspective was presented. In this presentation was shown that CFRP reinforced concrete beams increased the breaking load and moment by approximately 70 percent, even with only one layer. Consequently, it can be concluded that CFRP, whose weight is negligible compared to other strengthening methods, is a good alternative for historical buildings as it does not harm the originality of the building.

From the same point of view nondestructive Operational Modal Analysis Method, which is used to evaluate the current situation of structures, can also be recommended. The shopping center, which was converted from Tobacco Factory by following these methods, is now the heart of the city where it is located. It is recommended to strengthen the historical buildings in Karabakh and East Zangezur regions of Azerbaijan by following these methods.

The structures in the city of Shusha that can be strengthened with CFRP are selected. In the in-situ selection studies, the buildings that give the opportunity of architectural preservation of the outer walls are given priority. The CFRP applicability limits explanation was illustrated on the in-situ selected monumental houses such as: House of Khan's Daughter Natevan, The House of Cahangir Khan Haci's Son Nuribəyov, The House of Mir Mövsüm Nawwab, The House of Cabbar Qarayagdi, The Building of Realni School, The Hospital Building, The Çol Qala Mosque, The House of Mesedi Qara, The House of Mesedi Ibis.

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