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Original Research Article

Revising the Problem of the Transverse Vault of the Arch of Alishah in Tabriz*

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Abstract

Problem statement: The Arch of Alishah is the only surviving part of the Taj al-Din Alishah Tabrizi's Mosque complex. Although Mustawfi's report and Matrakchi and Grelot's paintings of Alishah Mosque indicate the presence of a brick transverse vault, an ahistorical approach to architectural studies has claimed it as a Safavid structure without a vault. This argues that hive technique walls could never bear the weight of an arch. This is contrary to the ruin of a brick vault, reported by Mustawfi, and can be seen in Matrakchi and Grelot's painting, which was documented during the 1971 archaeological excavations.

Research objective: The conservation plan of the Arch of Alishah uses the results of technical analyses of the type and dimensions of its transverse vault.

Research method: This research has three methods: history, field measuring, and structural technical calculations, which were carried out in three stages: In the field phase, the structure of Arch of Tabriz was technically surveyed using a 3D laser scanner, and in the third phase, the data from the previous two phases were modeled and analyzed using Revit and Diana FEA software using two linear and nonlinear static analysis methods.

Conclusion: The left and right walls of the Arch of Alishah were indeed able to bear the weight of a large and tall arch with a span of 28.4 m at the arch's springs and to restrain its tensile and compressive stresses, and these stresses were not the main cause of its collapse. Certainly, the Arch of Tabriz still had a pointed arch until 1721. Such a pointed arch, with a height of 58.25 m from the floor of the building and 28.25 m from its springs, was the tallest and largest arch in the history of Iranian architecture, the Islamic lands, and the pre-modern times as well.

Keywords: *The Arch of Alishah in Tabriz, Pointed arch, Parabolic arch, Linear static analysis, Nonlinear static analysis.*

Introduction

The historic monument known today as the Arch of Alishah in Tabriz is the only remnant of the mosque complex of Tāj al-Din Alishah (TĀJ-AL-DĪNʿALĪŠĀH) of Tabriz. The function of this remnant changed to the Fort of Tabriz during the second round of the Russo-Iranian wars (Ajorloo & Nemati-Babaylou, 2014). This religious complex, built by the order and investment of Ḵᵛāja Tāj-al-Din ʿAlīšāh vizier, in 1318-1324, is one of the five Ilkhanid Abwab-al-Berrs, along with the observatory of Maragheh, Rabʿ-e Rashidi,

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Ghāzānīya, and Solṭānīya. Historically, the complex remained incomplete after the death of ʿAlīšāh vizier in 1324 (Ajorloo & Mazhari, 2023). Archaeological excavations have documented that the present-day iwan in the Arch of Tabriz is the remnant of a larger structure that was formed by the joining of two earlier northern and later southern structures, the southern annex behind the mosque, being the mausoleum of Tāj-al-Din ʿAlīšāh vizier, famous as the Tavūs Khāneh (Ajorloo & Mansouri, 2006; Ajorloo & Mazhari, 2023). Despite the observations of H. Mustawfi (1919) recorded in his 1340 book of Nuzhat-al-Qulūb and later 1537 and 1673 paintings of the mosque of Alishah in N. S. B. Matrakçi (1976) travelogue of Beyān-i Menāzil-i Sefer-i Irākeyn-i Sultān Süleymān and G. J. Grelot in Voyage en Perse by J. B. Chardin (1711), all indicate the existence of a brick arch (Fig. 1). Several studies in the late 2010s based on a non-historical approach have claimed this monument as a Safavid structure with neither an arch nor a covering. Such studies, in terms of technical calculations, claim that the left and right walls, which were built by the hive technique, could never bear the load of an arch. They referred to the present-day health and stability of these walls as evidence of the absence of such an arch. This means that the walls would have collapsed if there was an arch (Kamali & Moradi, 2021; Mizāb et al., 2021; Moradi & Mizāb, 2019; Moradi et al., 2019; 2021; Moradi & Omrani, 2019). This claim was made while archaeological excavations in 1971 documented the same brick arch debris that Mustawfi (1919) observed and reported on, as depicted in Grelot's painting (Fig.1). The present authors argue that the terrible earthquake of April 26, 1721, in Tabriz, which left 80,000 dead (Melville, 1981), was the final fatal blow to the tall Arch of Alishah. M. M. H. Zonūzi (2019) has reported this earthquake in his Riāz-al-Jannat, 1801. Accordingly, the present authors hypothesized a pointed arch to answer their question concerning the transversal covering of the Arch of Alishah's form and stability. According to their argument, measurement by the 3D laser scanning verified that the size of the opening of the iwan ranged from 31. 40 to 28. 40 m at the springs of the arch (height: 36 m), which was applied by reducing 50 cm for every 12 m of increase in the height of the east and west walls. Architecturally, such measures indicate that the hypothesis of the existence of an arch is reasonable.

Research Background

The research background on the Mosque of Alishah can be categorized into two groups: archeology and architecture. The archeological group includes excavations under A. A. Sarfaraz in 1971 and B. Ajorloo in 2016. They recorded the southern iwan as the remains of Tāj-al-Din ʿAlīšāh's mausoleum, which is famous as the Tavūs Khāneh (Peacock House), and the northern part as his mosque, although only the plan of the old northern building remains (Ajorloo, 2017; Ajorloo & Mansouri, 2006; Ajorloo & Mazhari, 2023; Ajorloo & Nemati-Babaylou, 2014). In the second group, architectural studies on the Arch of Tabriz and the works of A. U. Pope (1939), Wilber (1955), Kleiss (1981; 2015), Qiyasi (1997), O'Kane (2021), and Mazhari (Ajorloo & Mazhari, 2023) are notable for their efforts to recreate the Alishah Mosque complex. Moreover, in the 2010s, based on a non-historical approach, architectural studies were directed toward the date and structure of this monument, which represented it as a Safavid architecture with neither a coverture nor a vault (Kamali & Moradi, 2021; Mizāb et al., 2021; Moradi & Mizāb, 2019; Moradi et al., 2021; Moradi & Omrani, 2019).

Theoretical Framework and Methodology

Theoretically, this research is to criticize and rethink the former ahistorical approach to the Arch of Alishah's architectural studies. Therefore, the authors' historical approach has applied the congruence of archaeological records and historical accounts, where their authenticity and validity are once again tested by technical calculation methods. It should be noted that the ahistorical approach leads to a kind of de-historization that misleads the systematic restoration of historical monuments (Ajorloo & Mazhari, 2023).

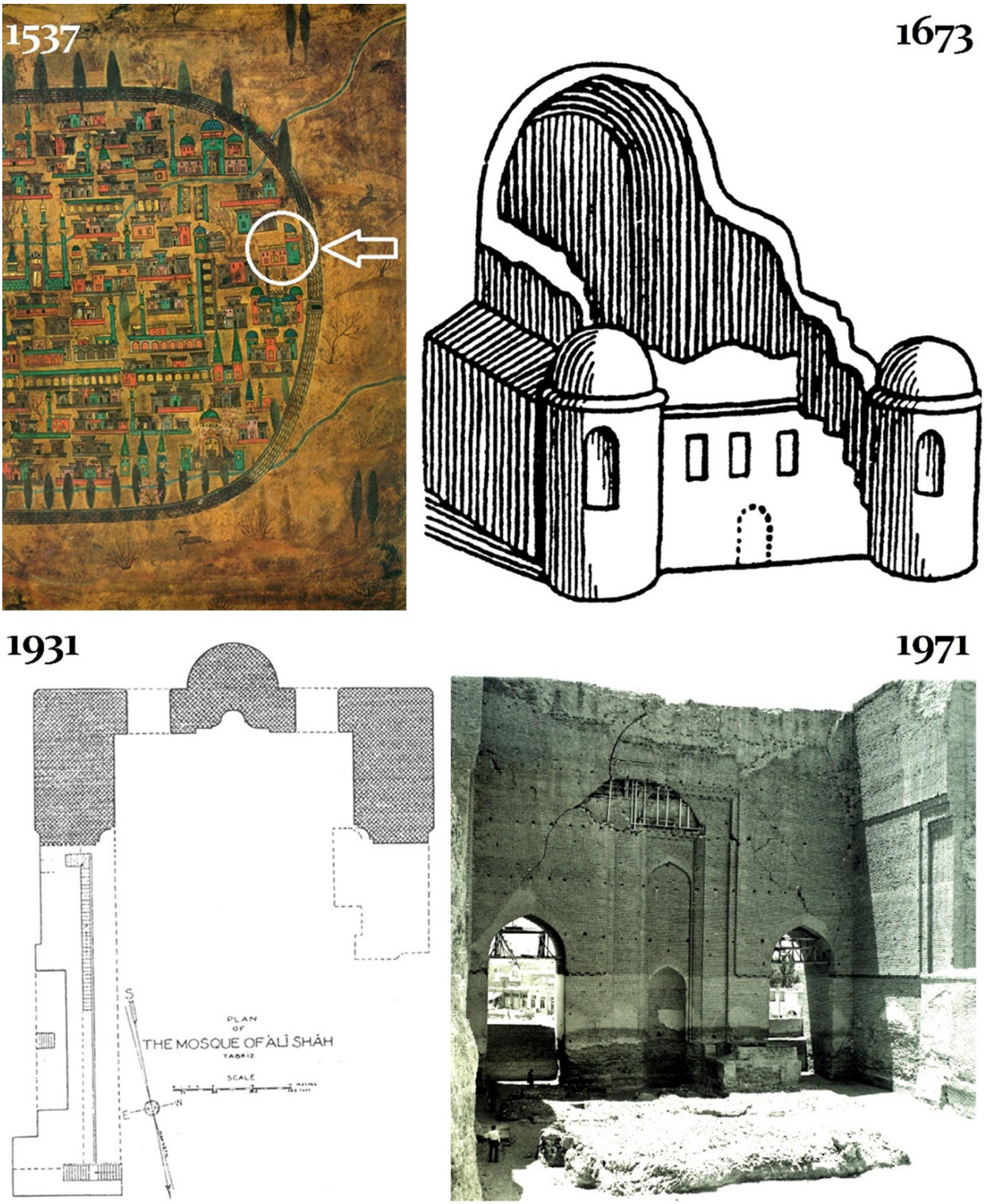

Fig. 1. Archaeological findings and historical documents of the structure, plan, vault, and ruins of the arch of the Alishah's Arch: Matrakçi 1537, Grelot 1673, P. Baggs 1931, and Sarfarāz 1971. Source: Ajorloo, 2017; Ajorloo & Mazhari, 2023.

Methodologically, this research has applied three methods of historical sources, field survey, and technical calculations of the structure, which were carried out in three stages: In the historical stage, the initial historical reports about the Alishah Mosque and the archaeological excavations of 1971 and 2016 were reviewed again. In the field stage, the structure of the iwan of the Arch of Tabriz or the remnant of the Tavūs Khāneh was technically surveyed using a Stonex X300 3D laser scanner (Fig. 2). The data obtained from the previous two stages were modeled and analyzed using Revit and Diana FEA software in the third stage. The analyses performed in this modeling were both linear and nonlinear static under the influence of the building weight. In this modeling, the structural support was fixed and integrated at the floor of the building, and the load force was also considered dead, that is, dead weight, the weight of the building itself. The grid was arranged in a quadrangular shape with dimensions of 50 cm.

Discussion

The iwan, well known as the Arch of Alishah, is a U-shaped brick structure (Fig. 1). The structure was 65. 5 m long before being destroyed in 1981 (Ajorloo & Mazhari, 2023). According to the 3D laser scanner measurements, it remains only 20. 30 m. Other outputs of the 3D laser scanner measurements are (Safiri, 2025): the width of the structure from the southern façade is 52. 20 m, the width of side walls is 10. 40 m, the depth of the iwan is 13 m, the depth of the Mihrab wall is 7. 30 m, and the width and height of the doorways on the sides of the Mihrab - known as the windows - are 5. 5 and 16 m, respectively. The maximum existing height of the building from the floor of the basement of Tavūs Khāneh to the top of the Mihrab is 33 m. The tall tower behind the Mihrab has a diameter of 11. 80 m and a height of 30 m, including a height of 27 m from the cellar of Tavūs Khāneh to the top of the banquette. The field surveys of the authors, during their 3D laser scanning, reconfirm that the architect of the Arch of Alishah used the hive technique to lighten the weight of the brick structure of its iwan. For this purpose, the architect built the side walls hollow with boxes/frames made of bricks 2. 75 m wide and 20 m deep, beginning from the top of the banquette. The 7. 65 m widths of these walls are left solid from the building's base to the top of the banquette, which turns around the Mihrab and its side walls. Such information is the basis for the present researchers' modeling using the Diana software (Fig. 3).

The findings of the archaeological excavations under Ajorloo (2017) confirmed that the side walls of the northern (earlier) building, to which the southern (later) building was annexed, were 80 meters long and 12 meters wide, which is 1. 60 meters more than the southern building's walls (Fig. 4). In the northern building, traces of a wall with the same width as the side walls of the southern building are seen, which has a Mihrab-like niche and is aligned with the Mihrab of the southern building/ Tavūs Khāneh, which indicates that this wall must be the Mihrab wall of the northern building or the Alishah's Mosque, which A. A. Sarfaraz called the Hājeb (retaining) wall, in 1971 (Fig. 5).

In the modeling of the Arch of Tabriz, the selected arches were also designed in two forms: parabolic, similar to that of the Sassanid Palace of Ctesiphon, and pointed, common in Iranian architecture during the Ilkhanid period. Notably, the architectural stylistics of the Ilkhanid period require the pointed type of discussed transverse arch. The existing arches of the Mihrab and its side doorways are of the pointed type. Nevertheless, Grelot's 1673 painting shows it as similar to the parabolic type and to that of the Palace of Ctesiphon. The Ilkhanid historical sources also state that the architecture of the Alishah Mosque was inspired by the architecture of the Sassanid Palace of Ctesiphon, which has a parabolic arch (Ajorloo & Mansouri, 2006). Consequently, the present authors decided to

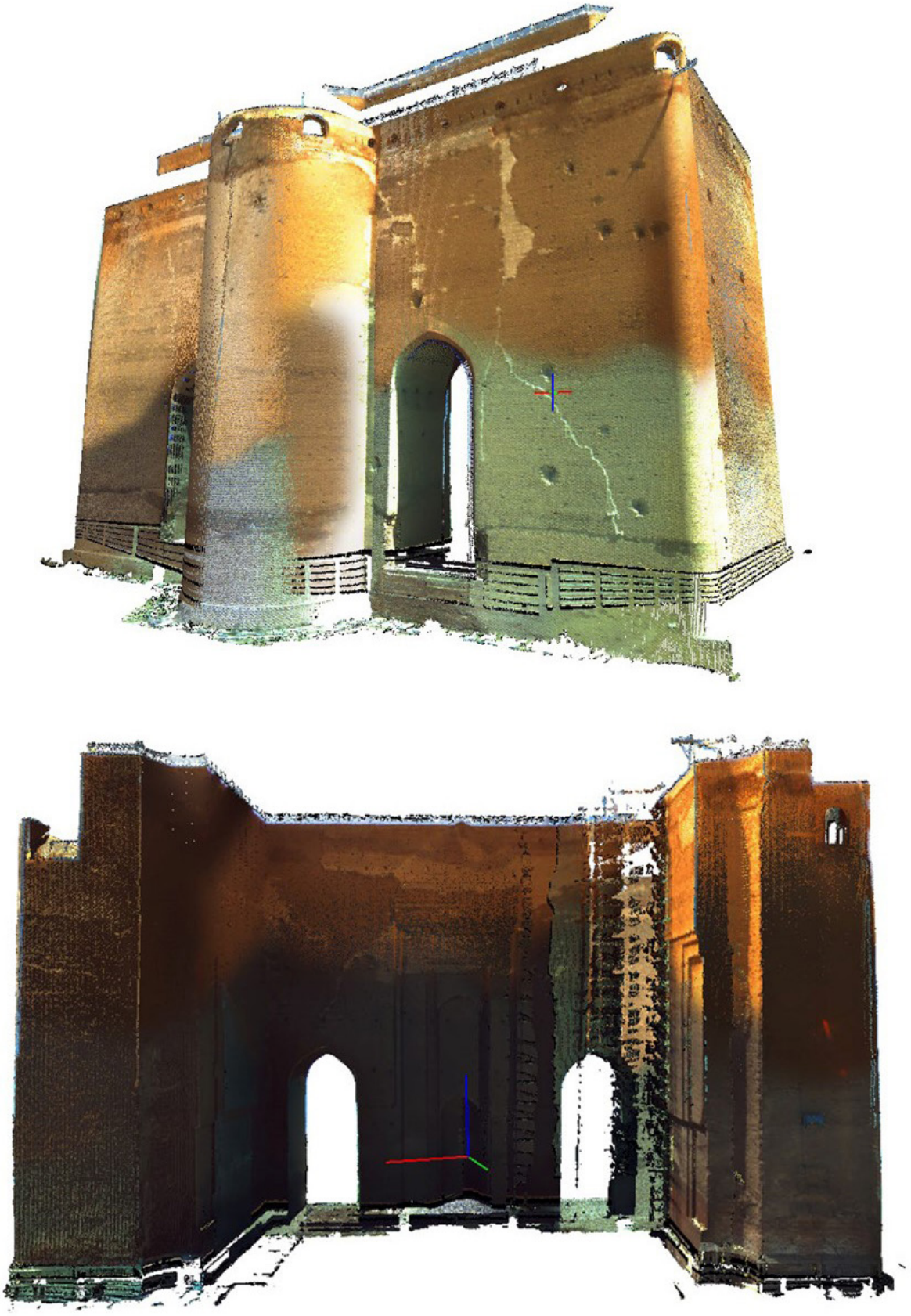

Fig.2. Two samples of the documentation of the southern and northern facades of Alishah's Arch using a 3D laser scanner. Source: Authors.

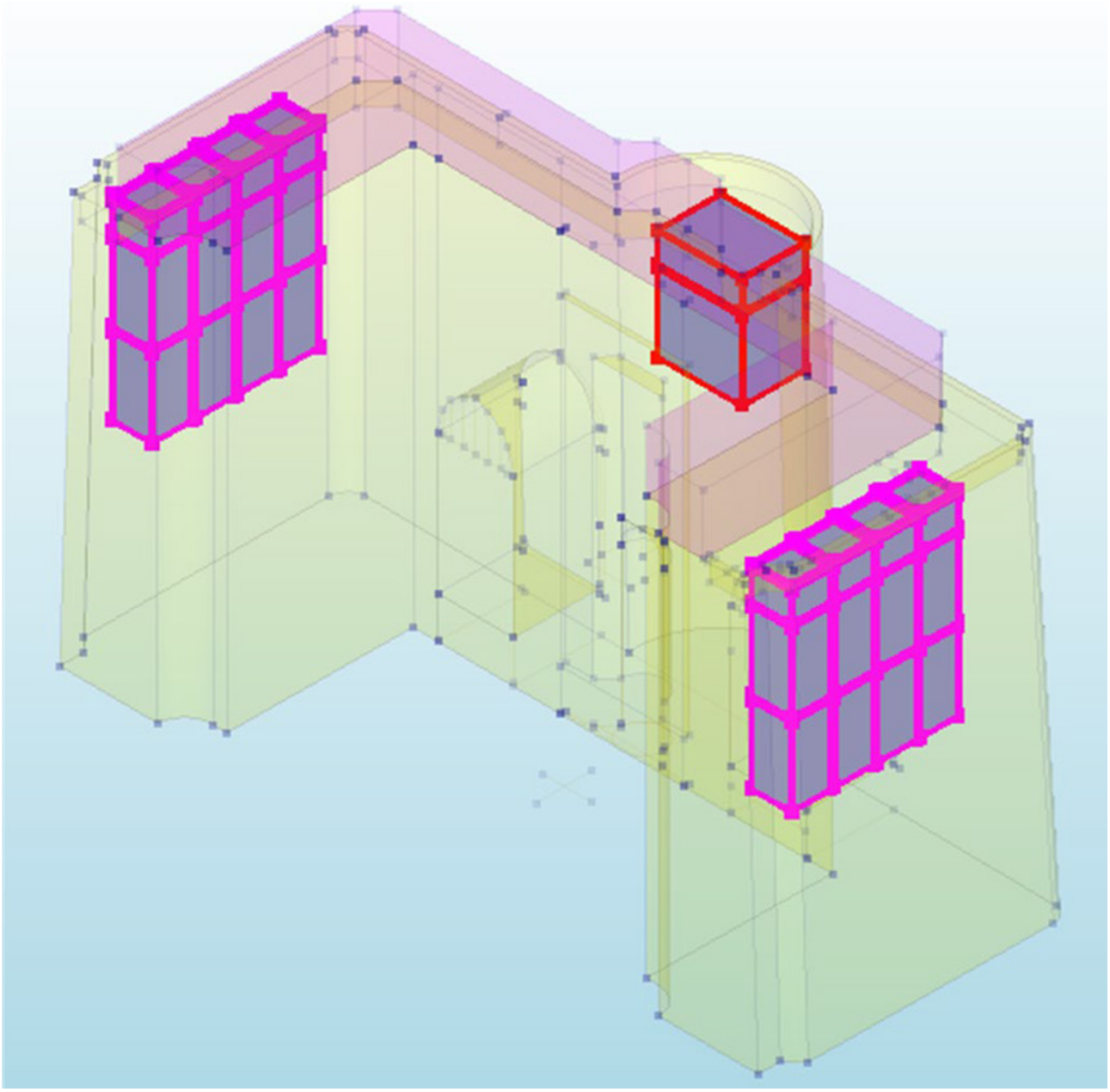

Fig. 3. Modeling of the side walls of the Arch of Alishah, showing the hive and solid parts. Source: Authors.

Table 1. Mechanical specifications of the Arch of Alishah extracted from the NTC 2018 system. Source: Authors.

Poisson's ratio	Weight (Kg/ m3)	Elastic modulus (Mpa)	Tensile Strength (Mpa)	Compressive strength (Mpa)
0/25	1835	1200	0/25	2/5

model both types of arches. According to software calculations based on field data, the following information was obtained (Fig. 6): The parabolic arch should have been 61 meters high from the floor of the building, 31 meters high from the springs, and 2.5-4. 5 meters thick. The pointed arch should have been 58. 25 m high from the floor of the building, 28. 25 m high from the springs, and 1.5– 4 meters in thickness. These figures and dimensions are unparalleled throughout the history of Iranian architecture and the world as well (Fig. 7). The data output from linear static analyses for the maximum compressive and tensile stresses for the parabolic type are as follows: Min: -0.58N/

Fig. 4. A photo depicting the foundation and 80 m wall remnant of the Alishah Arch, unearthed by the archaeological excavation, 2016. Source: Ajorloo, 2017.

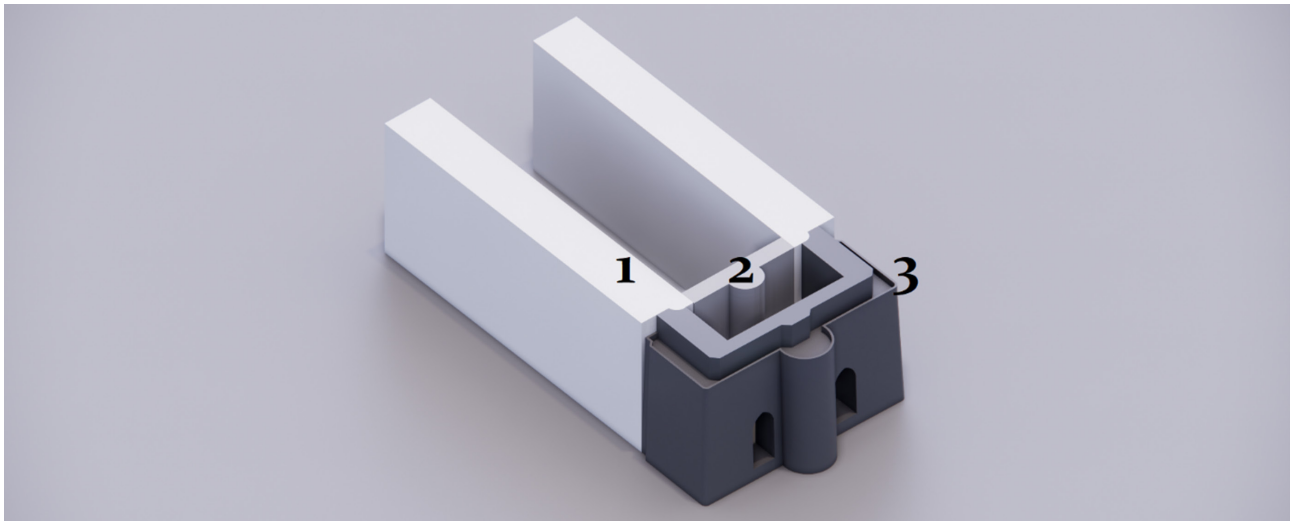

Fig. 5. A Revit 3D modeling of the Arch of Tabriz showing the position of the retaining wall or the Mihrab wall of the earlier northern building next to the later southern building: 1. The 80 m wall of Alishah's nave, which was unearthed by the 2016 archaeological excavation, 2. The retaining/ Mihrab wall, 3. Tavūs Khāneh or Alishah's mausoleum. Source: Safiri, 2025.

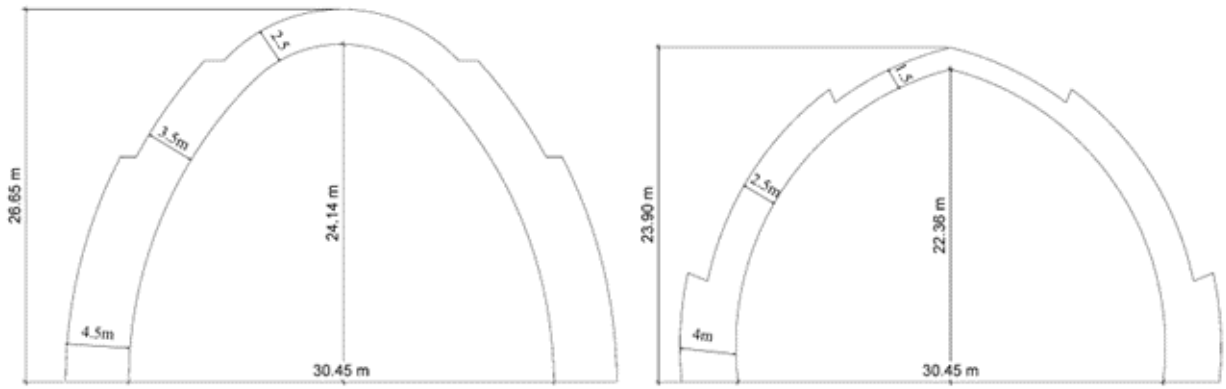

Fig. 6. Modeled dimensions of the opening, height, and thickness of the proposed pointed and parabolic arches of Alishah's Arch. Source: Safiri, 2025.

mm² and Max: 1. 00 N/mm², and Min: -2.11N/mm² and Max: 0. 22 N/mm², respectively. These outputs indicate the parabolic type bearing capacity. The data output from linear static analyses for the maximum compressive and tensile stresses in the same building reconfirms the bearing capacity of the pointed type: Min: -0.51N/mm² and Max: 2. 57 N/mm², and Min: -2.79N/mm² and Max: 0. 21 N/mm², respectively (Fig. 8).

The data output from nonlinear static analyses (under the influence of the building's weight) for the maximum compressive and tensile stresses for the parabolic type are: Min: -0.61N/mm² and Max: 0. 78 N/mm², and Min: -2.11N/mm² and Max: 0. 22 N/mm², respectively. Such analyses reconfirm the side walls' ability to bear the weight of a parabolic arch, which is also verified for a pointed arch. The data output from nonlinear static analyses (under the influence of the building's weight) for the maximum compressive and tensile stresses for the pointed type are: Min: -0.51N/mm² and Max: 1. 70 N/mm², and Min: -2.46N/mm² and Max: 0. 21 N/mm², respectively. These verify that the architect of the Alishah Mosque complex was confident that the side hive walls had the strength to bear the weight of such an arch (Fig. 9). As a result, the maximum tensile stresses in the transverse vault range from 0 to 0. 15 MPa. Considering that the tensile strength of the building is considered to be 0. 25 MPa (Table 1), it is inferred that the tensile stress in the transverse vault is less than the tensile strength of the building, which indicates that the side walls of the building had enough ability to support the weight of both types of arches. It should be noted that throughout the structure of the Alishah Mosque, only in the upper parts of the Hājeb/ retaining wall (the Mihrab wall of the northern building) do tensile stresses exceed the defined resistance, because this wall actually had a tensile function to be able to counteract the arch's thrust. Also, in this case, the output of both linear and nonlinear static modeling, the force transmission path indicates the bearing capacity and stability of the walls (Figs. 10 & 11). It is remarkable that, despite the tensile stresses present in the upper part of the retaining wall, it was expected that cracks would appear in this section. The output of the analysis also confirmed this inference (Fig. 12).

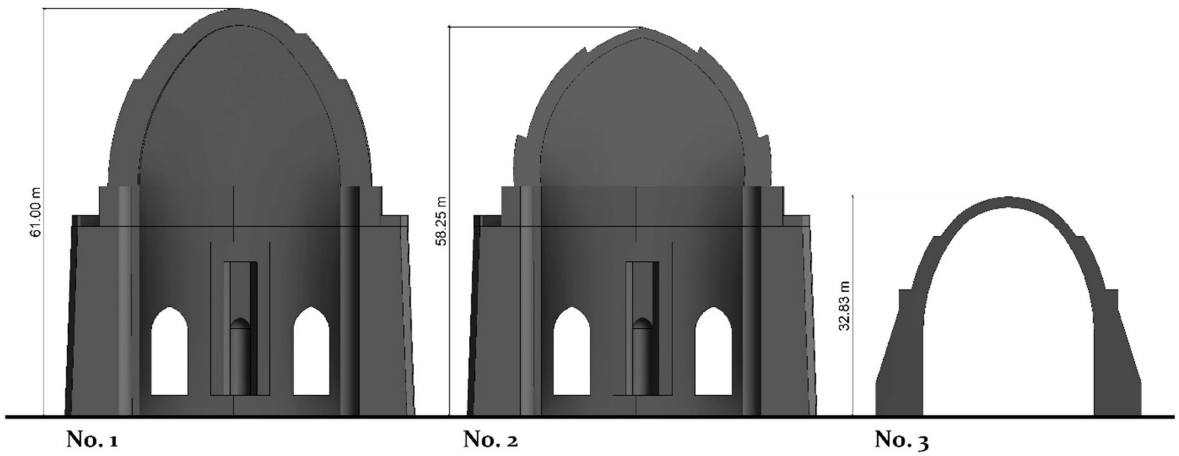

Fig. 7. Modeled comparison of the height of the Arch of Alishah with two assumed pointed and parabolic transverses compared to the parabolic arch of the palace of Ctesiphon: 1. Parabolic transverse of Arch of Alishah 61 m, 2. Pointed transverse of Arch of Alishah 58.25 m, and 3. Palace of Ctesiphon, 32.83 m. Source: Safiri, 2025.

Table 1. Mechanical specifications of the Arch of Alishah extracted from the NTC 2018 system. Source: Authors.

Poisson's ratio	Weight (Kg/ m3)	Elastic modulus (Mpa)	Tensile Strength (Mpa)	Compressive strength (Mpa)
0/25	1835	1200	0/25	2/5

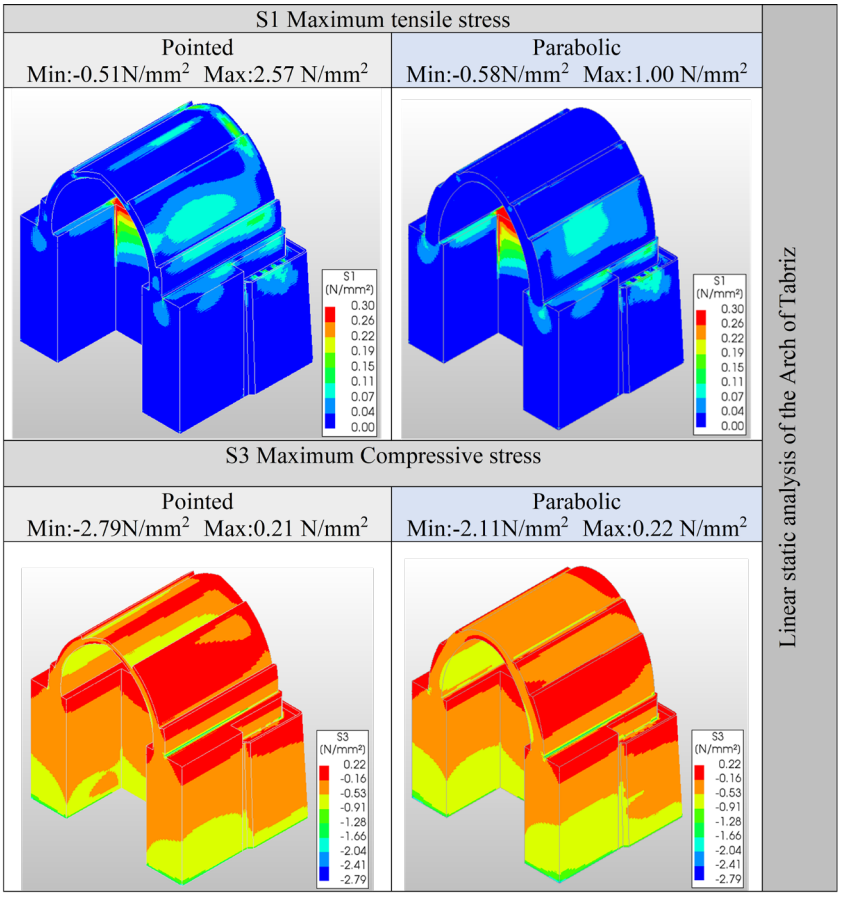

Fig. 8. Diana modeling of linear static analyses of tensile and compressive stresses of the transverse of the Alishah's Arch in two assumed cases of pointed and parabolic arches. Source: Safiri, 2025.

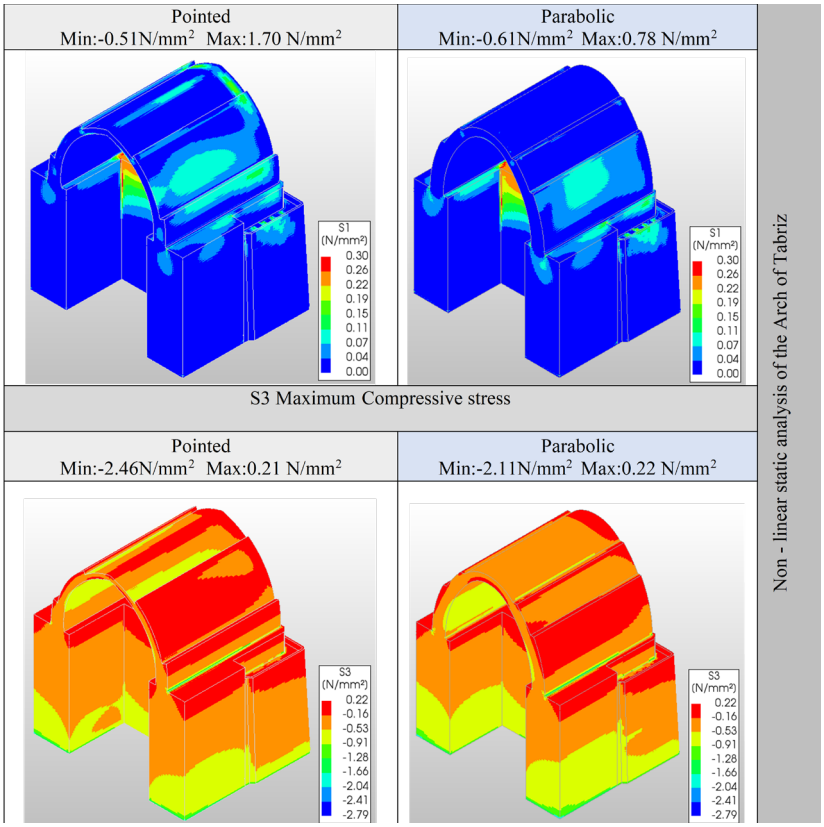

Fig. 9. Diana modeling of nonlinear static analyses (under the influence of the building's weight) of tensile and compressive stresses of the transverse of the Alishah's Arch in two assumed cases of pointed and parabolic arches. Source:Safiri, 2025.

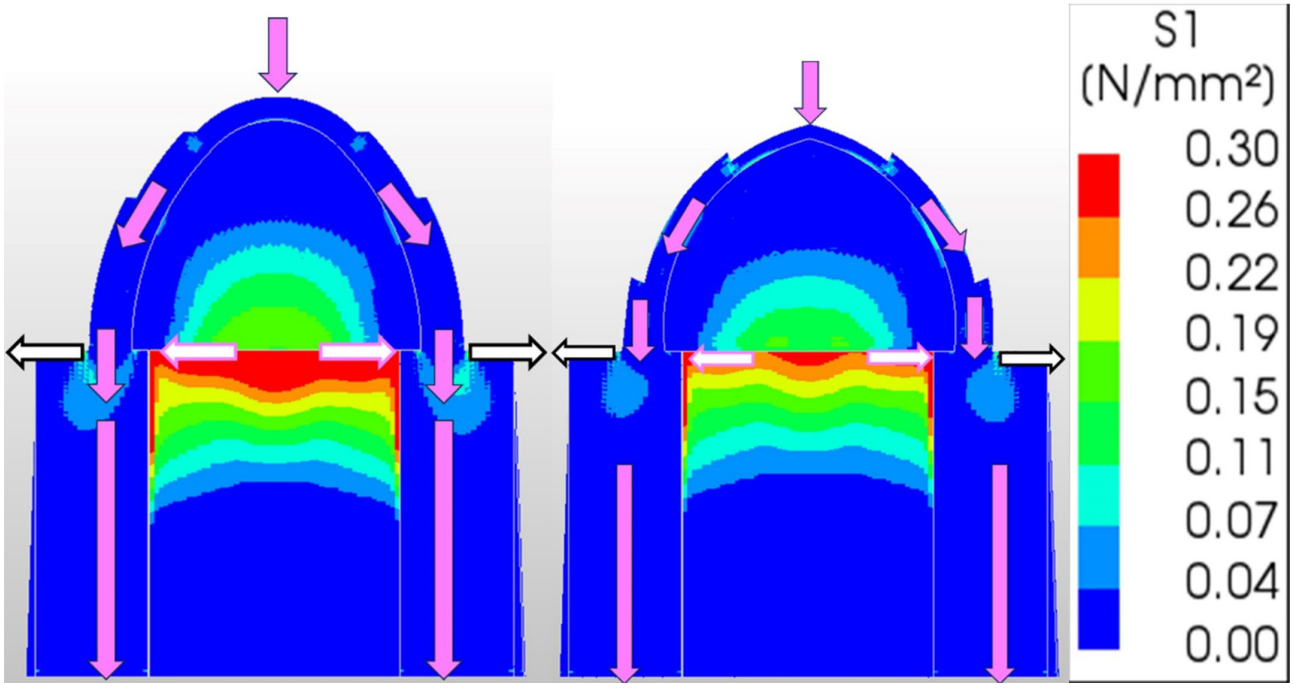

Fig. 10. Linear static analysis of the transverse force transmission path and the performance of the retaining wall of the earlier northern building as a tensile part in both pointed and parabolic arches, using Diana software. Source: Safiri, 2025.

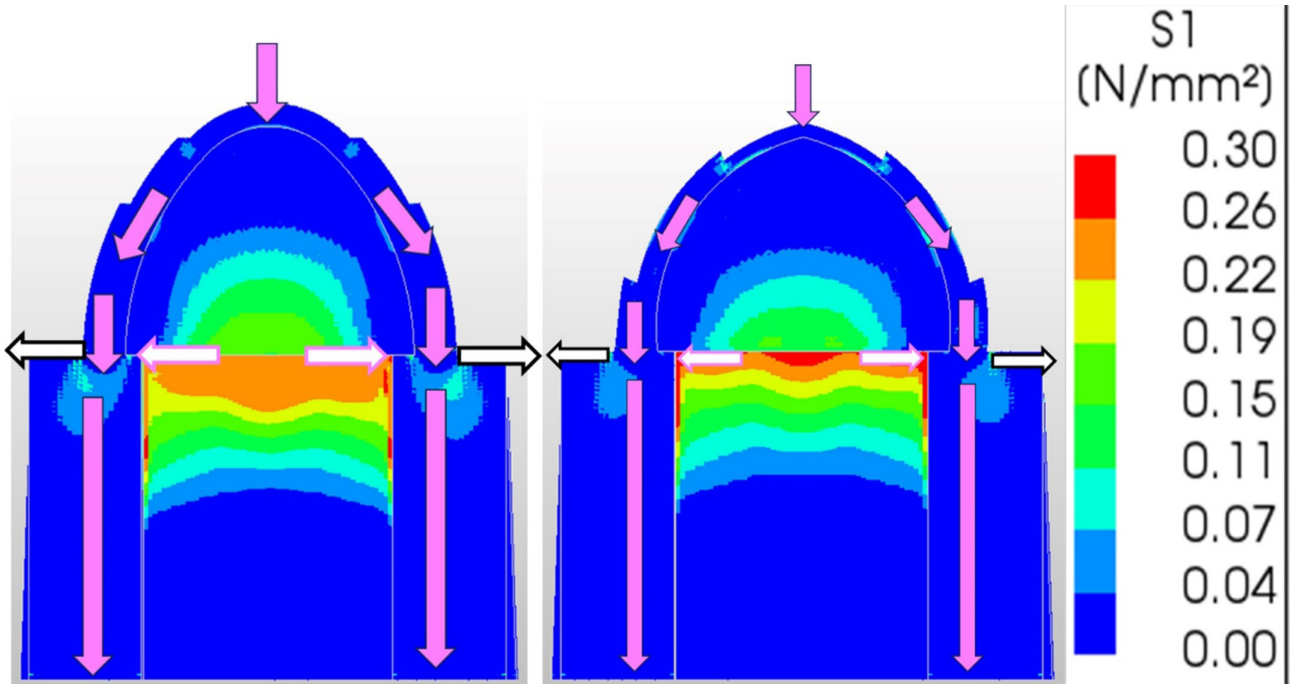

Fig. 11. Nonlinear static analysis (under the influence of the building's weight) of the transverse force transmission path and the performance of the retaining wall of the earlier northern building as a tensile part in both pointed and parabolic arches, using Diana software. Source: Safiri, 2025.

Conclusion

The hypothesis of a transverse vault with either type of parabolic and pointed was tested by software modeling based on collected data from archaeology and 3D laser scanning of the Arch of Tabriz. The output of this software modeling confirms that the side walls of the Arch of Alishah actually had the strength to bear the weight of a large and tall vault with a span of 28. 4 m at the springs and to restrain its tensile and compressive stresses. However, such tensile and compressive

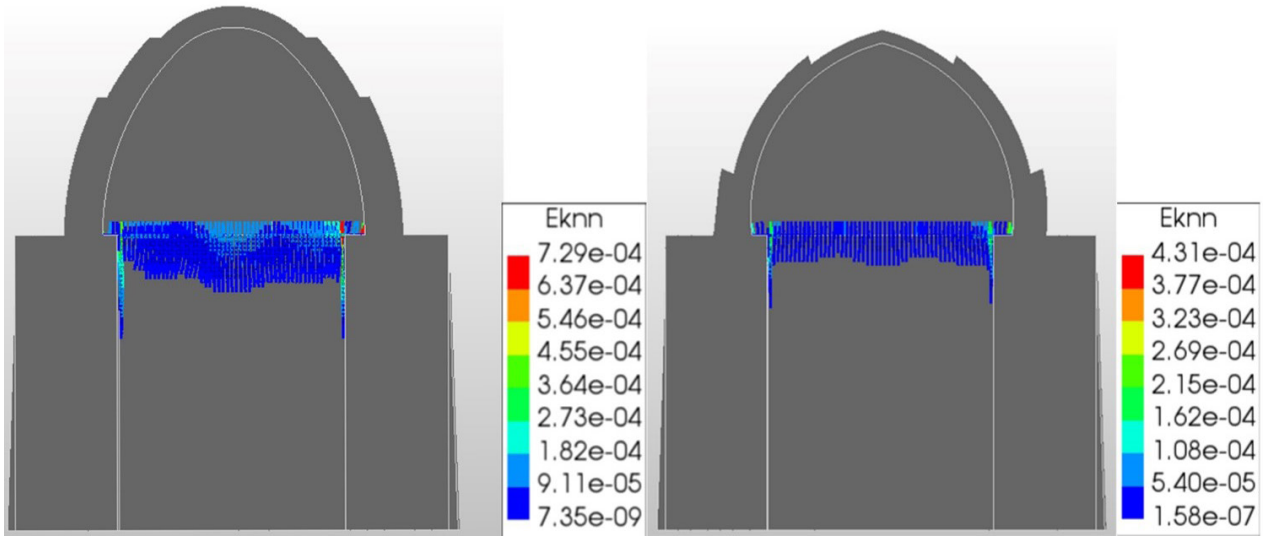

Fig. 12. Cracks in the upper part of the retaining wall of the earlier northern building, caused by the presence of tensile stresses in both assumed pointed and parabolic arches, using Diana software. Source: Safiri, 2025.

stresses were not the main cause of the collapse of that vault. Rather, its main causes may be the same rush in construction that H. Mustawfi has highlighted in his Nuzhat-al-Qulūb, 1340. The 1721 terrible earthquake in Tabriz was also effective. In Chardin's travelogue, Grelot's 1673 painting is the last visual report showing the half-collapsed vault of the Arch of Alishah. Therefore, there is no doubt that the Arch of Tabriz still had a vault until the spring of 1721. Regarding the type of arches of this building, it should be noted that both pointed and parabolic arches can be verified in software modeling supported by architecture and history. Nonetheless, in terms of architectural stylistics and the fact that the arches of the 30 m tall Mihrab and its side doorways/windows have pointed forms, it is reasonable that the vault that still existed until 1721 should have been pointed as well. In this case, the pointed arch of the Arch of Alishah, with a height of 58. 25 m from the building's floor and a height of 28. 25 m from the springs, was the tallest and largest transverse vault in the history of Iranian architecture, Islamic lands, and even pre-modern times.

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