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The Role of Sheikh Lotfollah Mosque's Buttresses in Prevention of its Thrust and Reasons for its Recent Re-thrust

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Abstract

Sheikh Lotfollah Mosque is one of the important mosques in Isfahan located on the east side of Naghshejahan Square. The mosque was built from 1602 to 1606 A.D. by Mohammad Reza Isfahani. The structural balance was damaged after the destruction of the school behind the mosque and later the existing bathroom and Turkish closet. Afterwards, in 1934-1938, the project to construct the buttresses began, due to the thrust movement in the north and north-west side of the mosque. Currently, deformation and movement can be observed, despite the presence of these buttresses which are examined in this research using field studies, a careful examination of the buttresses and vulnerability analysis in the area according to library studies. The results of this study verify the presence of ascending moisture caused by leakage of water and sewage pipes in the area as the main reasons for this damage. Therefore, replacement of pipes, foundation grouting and organizing the area are among the restoration project requirements.

Keywords: Sheikh Lotfollah Mosque; Buttress; Pathology; Restoration

1. Introduction

Sheikh Lotfollah Mosque has been built on the east side of Naghshejahan Square in front of the Alighapoo mansion and on an old mosque called Jelokhan alley mosque (Jaberi Ansari, 1999). There are different opinions about the usage of the mosque, but a lot of travelogues and historical sources have referred to this mosque as Sadr mosque-school and based on the same sources, it was used for religious and educational purposes (Shardan, 1993). The structural balance was damaged after the destruction of the school behind the mosque, and later the existing bathroom and Turkish

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closet; the north and northwest walls of the mosque also had deformation and movement. The architect master Maarefi, in charge of repairing the building, built four buttresses to transfer the generated thrust to the earth after the removal of the existing bathroom and Turkish closet in order to remove the disruptive factors, on one hand, and the reaction forces of the demolished buildings, on the other hand (Zargaran, 2014). Recently, some cracks have become visible on this side after a century which indicates the movement and deformation of the building, for which a thorough examination of the effective factors is the most consistent strategy. This article tries to answer the following questions:

- Did the buttresses of Sheikh Lotfollah Mosque have the appropriate response and did they have harmful volume or used weight?
- What is the main cause for the new deformations in buttresses and what strategies can be used to solve the deformation and damage of the area?

2. Geographic Location of Isfahan

Isfahan province is located on Iran's Central Plateau with an area of about 107045 square kilometers and contains about 25.6 percent of the country's total area. This province is located in central Iran between 30 degrees and 42 minutes to 34 degrees 30 minutes north latitude, and 49 degrees 36 minutes and 55 degrees 32 minutes east longitude. Isfahan city is the third largest city in Iran after Tehran and Mashhad with 51 degrees 39 minutes 40 seconds' east longitude and 32 degrees 38 minutes and 30 seconds North latitude (Shafaghi, 2002).

According to the latest country division, Isfahan province is surrounded by Markazi, Qom and Semnan provinces from north, Kohgiluyeh and Boyerahmad, and Fars provinces from south, Yazd province from east and Chaharmahal-Bakhtiari and Lorestan provinces from west. In terms of area, it has the seventh place after Sistan-Baluchestan, Kerman, Yazd, Fars, Semnan and Khorasan Razavi. The place of Isfahan on the map can be observed in Fig 1 (by courtesy of the Portal of Statistical Center of Iran, Access Date: 30 August 2015).

Fig 1 Isfahan's location on Iran's map (Electronic Portal ministry of Iran, Access Date: 30 August 2015)

3. Location of the Naghshejahan Square in Isfahan

As mentioned by Shafaghi: “Isfahan, has two natural and cultural bases which form the backbone of the city, Zayanderud in west to east direction as the natural base and Chaharbagh which is the cultural man-made base in north-south direction” (Shafaghi, 2002). The Naghshejahan Square is located near this base and on the intersection of north-eastern point meeting these two bases in the third district of Isfahans’s master plan (Fig 2). The third district marked in red dotted lines is the biggest among the twelve districts of the city with seventy five neighborhoods with an area of 51155.25 hectares (Shafaghi, 2002).

Fig 2 Boundaries of 12 districts of Isfahan (Shafaghi, 2002)

3.1. Location of Sheikh Lotfollah Mosque in the Naghshejahan Square

Sheikh Lotfollah Mosque is located on the east side of the Naghshejahan Square, in front of the Ali Qapu Palace and beside the Abbasi Grand Mosque (Fig 3). There is an inscription in the mosque sanctuary which dates back to 1028 AH and shows the completion date of the mosaic and tile. The date on the large inscription which is inside the mosque under the dome shows 1025 AH. This building has been registered in the list of the monuments on sixth of January 1932 (15^{th} of Dey) (Godar, 1989).

Fig 3 Location of Sheikh Lotfollah Mosque in the Naghshejahan Square (Source: Abbasi, 2011: 9)

4. Restorations carried out in the mosque

The idea of repair and regeneration of religious, national and historical areas was the main focus at some point in time in the first and second Pahlavi regimes. In this regard, advisors and skilled craftsmen were hired, despite the financial problems that the government was facing. This pace then became slower after the Islamic Revolution and due to the eight-year war and its consequences. More attention, however, has been paid to this matter in recent years. Sheikh Lotfollah Mosque-School is among the buildings under restoration from 1928, which can be approved by a written report in this regard with the issue number of 2411 dated 3 April 1928 (Fig 4). This document which is in the form of a report signed by a finance steward in Isfahan and which has been set under the title of Ministry of Finance, states that: “the repairing of Sheikh Lotfollah Mosque has started as ordered and Shah Square will start soon, and in case of the mosque, the start of the new building will take a few days because they are busy removing the old wall and if you order, in a few days we can hire master Jafar who is an expert in dome construction. Because if we can ascertain that the damage of dome’s back does not affect the dome, we can escape the exorbitant cost of the new building and we can spend it in a better way; and if it is needed anyway, order the needed commands to architects to achieve the best results because the cost of hiring the mentioned architect is not high and may be paid form the costs of the mosque repair in Isfahan (the aforesaid law is among public benefits). Hiring an expert architect form Europe in Tehran is useful too, but it all depends on your order”. Nevertheless, Honarfar believes that the date of starting the work is 1932 due to the conservation and restoration of the square in this year, but based on the mentioned document, 1928 can be considered as the date for the beginning of the changes such as demolition of the walls, and the period from 1933 to 1937 can be regarded as the first phase of starting the restoration (Honarfar, 1971).

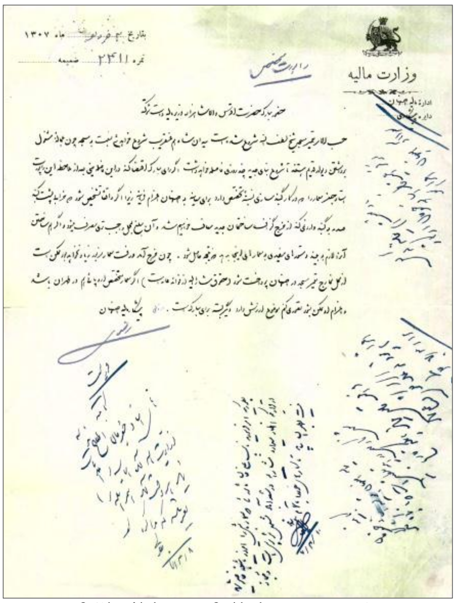
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Fig 4 Document related to the start of Sheikh Lotfollah Mosque’s restoration, National Archives, Iran, (Zargaran, 2014)

Another document refers to "score sheet of 1" as "the list of non-movable national index” which includes a brief report on construction date and registration of the building and refers to the restorations carried out in the building. In remarks which are handwritten by a reporter, this document states that: “the building is still called Sadr and Fethullah Mosque. There is an inscription inside the sanctuary which dates back to 1025. In the end, there is a large inscription above the entrance door with dates back to 1012. The lower sanctuary dates back to 1011, related to the tiles of entrance; other remains of these tiles have been installed in the basement. The toilets of the house and pools and the Turkish closet located behind the north wall of the mosque were destroyed, and long buttresses were built between 1934 and 1938. The repair and improvement of tile-work of the enormous dome of the mosque was carried out between 1937 and 1938, and the hall's floor was repaired using tiles" (Fig 5) (Zargaran, 2014).

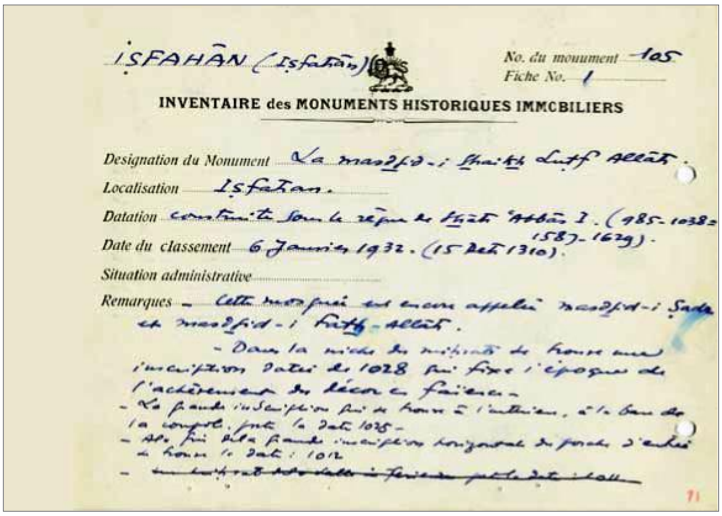
ISFAHĀN (Isfahān)
No. du monument 105
Fiche No. 1
INVENTAIRE des MONUMENTS HISTORIQUES IMMOBILIERS
Designation du Monument La masdjid-i Shaikh Lutf Allāh.
Localisation Isfahan.
Datation construite sous le règne de Shāh 'Abbās I. (985-1038 = 1587-1629).
Date du classement 6 Janvier 1932. (15 Dei 1310).
Situation administrative
Remarques – Cette mosquée est encore appelée masdjid-i Sadr et masdjid-i Lutf-Allāh.
– Dans la niche du mihrab se trouve une inscription datée de 1028 qui fixe l'époque de l'achèvement du décor en faïence.
– La grande inscription qui se trouve à l'intérieur, à la base de la coupole, porte la date 1025.
– Au-dessus de la grande inscription horizontale du porche d'entrée se trouve la date : 1012
–

Fig 5 Documentation of Sheikh Lotfollah Mosque; National Archives of Iran, Tehran (Zargaran, 2014)

The repairing of Sheikh Lotfollah Mosque started in 1933 after the order of Isfahan province's governor. The restoration work ended in 1937, and in the '50s it was restarted. The measures related to restoration work were carried out under guidance and supervision of the Department of Archaeology and by Mr. Maarefi who was the chief architect of the department and a traditional buildings skilled master. He had the responsibility of the mosque's restoration and carried out the job in four stages based on the requirements of the building.

5. Pathology of Sheikh Lotfollah Mosque's Buttresses

The person who is supposed to carry out the restoration must properly identify the damages of the building and factors causing disruptions so that it can help the building's survival in case of having proper and on time determination and provision of proper repair plans; the damages and their position in this building along with their causes must be dealt with in the first step. Aging or the frazzle of monuments is one of the factors that exacerbate the damage which leads to weakening of the mechanical characteristics, abilities and strength of materials and provides favorable conditions for other imbalances. From the authors' observation of the mosque and the area of buttresses in October, December and February 2015, damages can generally be divided in the following categories:

5.1. Damages related to Internal Factors in Buttresses

Structural damages are those types of damages which are created due to dysfunction in the structure and withdrawal of forces which form the center of the gravity of the building and creation of additional forces in the structures. Structural damages include cracks, deformation, or both.

These types of damages can be observed in the form of cracks and deformations in the north and north-western wall of the mosque.

5.2. Damages related to External Factors in Buttresses

A) Damages caused by natural factors in the long term which have mostly occurred due to moisture in the building which can be considered to be in two forms:

1. Ascending moisture which is due to the presence of surface water
2. Descending moisture

B) Damage caused in this building by human factors which are relatively high. These damages can be divided into two categories:

1. Manipulation in the building
2. Lack of proper maintenance due to mismanagement.

5.3. Pathology table of Buttresses Location

Table 1 Pathology of the examined area

Spatial elements	Damages	Imbalance	Damaging factors
Buttresses Areal wall around the building North and North West wall of the building	Degradation and erosion of materials of the wall Degradation and erosion of materials of the wall mortars' Adherence	Degradation and erosion of materials Loss of the quality of mortar	Ascending moisture Lack of Attention to the building
North and North West wall of the building	Crack and deformation	Being out of vertical mode	Ascending moisture Lack of Attention to the building Human manipulation
North and North West wall of the building	Degradation and erosion of materials of the wall mortars' Adherence	Loss of the quality of materials	Descending moisture Lack of Attention to the building
The whole area	Degradation and erosion of materials of pavements	Loss of the quality of materials	Ascending moisture Lack of Attention to the building

5.4. Cracks and Deformations in the North and Northwest wall

At that time, a thrust occurred in the north and northwest side of the building in a way that cracks with the width of 10 cm occurred in the vault of the floor under the porch, and 20 cm cracks were caused in second floor which would lead to the destruction of basement's yard and mosque's corridors. Master Maarefi believed the reason for this thrust was the existence of bath and its chimney's defect, so the action was taken to remove and eliminate these units (i.e., bathrooms and Turkish closet) and four strong brick buttresses were created behind the northern wall of the dome's porch (Beheshtian, 1976). The noteworthy point is that there are currently relatively large cracks in the floor of the hallway, cracks and deformations in the north wall of the building despite the use of an element consistent with the structure (buttresses) and the proper restoration that took place at that time which has shown a good performance in less than a century (Figs 1 to 4). The question that comes to mind is that: how much the buttresses system affects the security level of bearing capacity in Sheikh Lotfollah Mosque? Can a positive trend be observed in performance of mosque's structural systems? Are there other affective factors in these deformations and cracks?

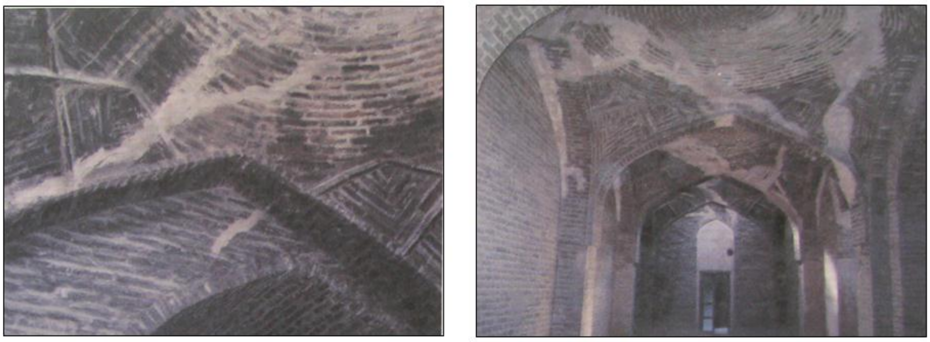

Fig 1 and 2 Cracks on the corridor of the second floor (Isfahan's Archives of Cultural Heritage)

Fig 3 and 4 Cracks on the northern side of the mosque wall

Analyzing Sheikh Lotfollah Mosque's buttresses and reviewing their structural behavior in ABAQUS software is a way to answer these questions in this section. For this purpose, first some parts of the mosque and buttresses have been measured by the authors using manual and laser meters and have been implemented using AutoCAD software (Fig 6). The details related to buttresses (such as connection of the buttress the main wall of the building, its connection to the ground and method with bricklaying) have also been examined and have been drawn manually and with the use of computer. All signs of rupture and deformation have been examined in detail in order to obtain information about the functioning of structure. The second step was transformation of required information to the software.

In the first step, the detained information about mosque's buttresses can be described in this way that the mosque has four buttresses which are almost identical in size which are located in the north and northwest without any fastening. The northwest to north buttresses have been named b1 to b4 and names r1 to r9 have been selected for corridor's ribs.

The mentioned buttresses are solid buttresses with trapezoidal plan in size of 1.47 × 1.3 × 7.94 meters and combined section (rectangle, triangle) which are clearly visible in Fig 6. Their height is 11.85 meters which are 60 cm lower than the building's roof. The section of the buttress increases by 1.5 meters at the height of 6.15 meters (the place where the roof of first floor's hallway is located) which is certainly because of thrust force of this section's vaults and increasing confidence coefficient in the structure (Fig 7). The b1 and b2 buttresses are located in along second floor and the roof's entrance hallway's main piers and b3 buttress is located along the twist of the main corridor and b4 buttress has been embedded behind the main corridor after the twist along r7 rib. The surfaces of buttresses have been constructed with bricks with dimensions of 20 × 20 × 5 cm with slope for directing rain and snow.

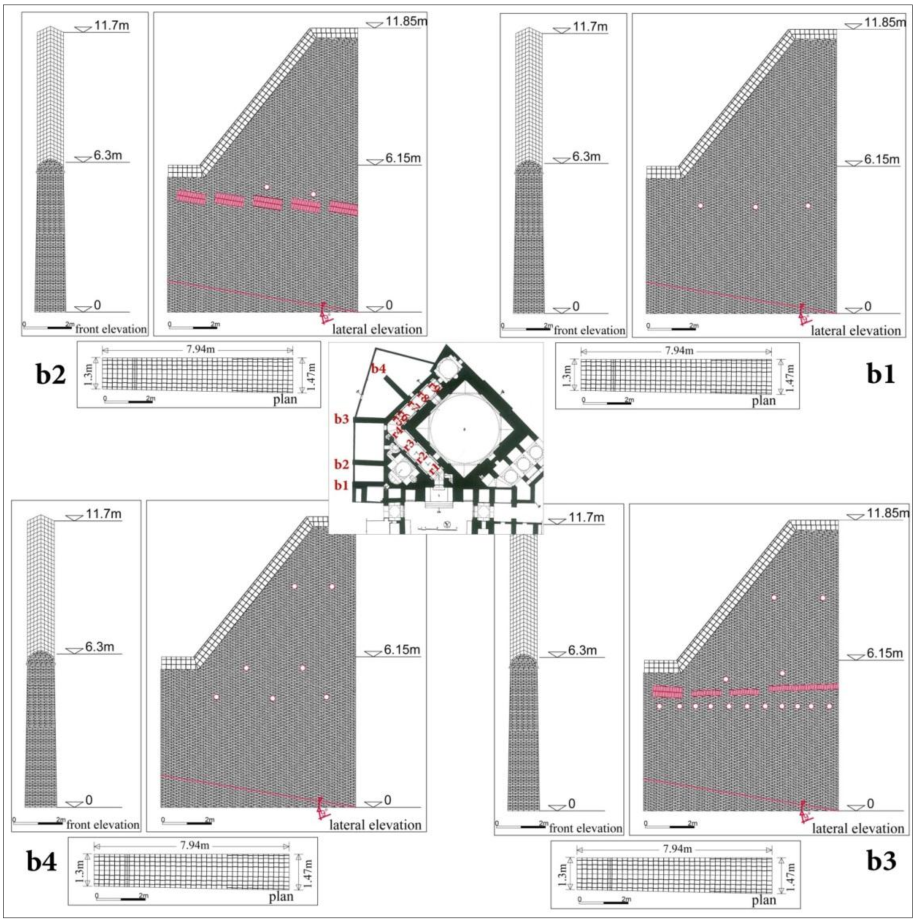

Fig 6 Plan, front elevation and side elevation of buttresses of Sheikh Lotfollah Mosque

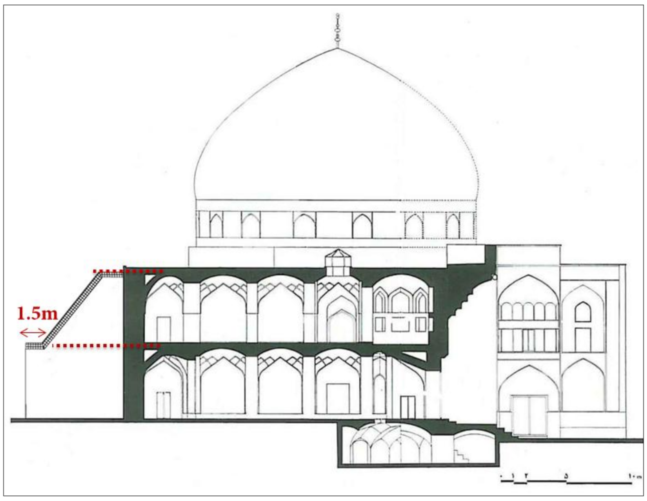

Fig 7 Increase section of the buttress where the roof of first floor's hallway is located (Isfahan's Archives of Cultural Heritage)

In the second step, information was simulated in the software. Although the single-shell dome of Sheikh Lotfollah Mosque is considered to be a dormant dome and exerts a huge thrust force but the skillful architect has been able to control thrust force with extremely low curvature of dome's bottom into the craters and designing thicken walls and two floor corridor in west and north of the mosque.

In this case, Ackerman and Pope believe that: "the dormant curvature of the dome leads to increased thrust in Oguns, but this force has been solved by increasing the thickness of walls" (Pope and Ackerman, 2008). Hejazi has also analyzed the dome of Sheikh Lotfollah Mosque using ANSYS software and expresses in this regard that: "applied tensional, compressive and shear strengths to the dome, do not pass the authorized strengths" (Hejazi, 1997). Thus it can be argued that the thrust force applied to the buttresses are not coursed by thrust force and the thrust force caused by the weight of corridors' roof (vaults and ribs) has been calculated without consideration of dome's load in order to apply thrust force in the simulated model. The force distribution in the dome can be seen in Fig 8.

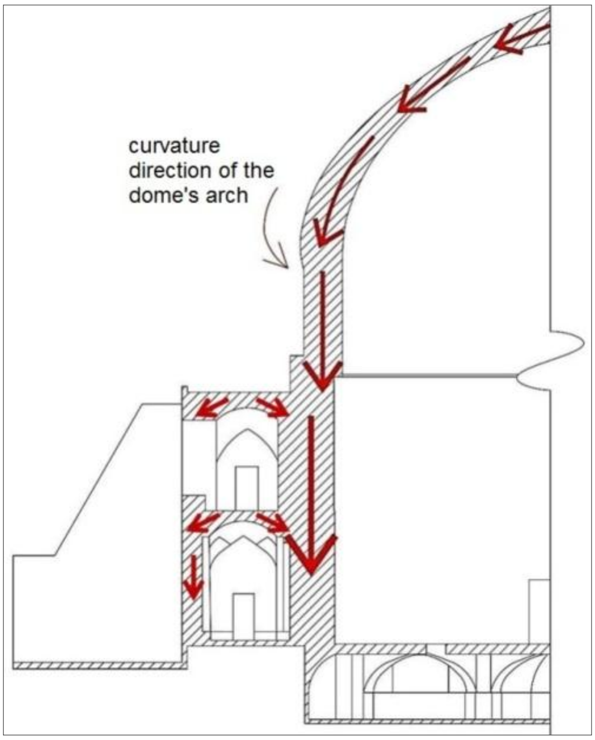

Fig 8 Force distribution and its transformation to the ground in the dome of Sheikh Lotfollah Mosque

As shown in Fig 9, the maximum tensional and compressive strengths in simulated buttress are respectively 115.7 and 35440 Newton per meter squared which are acceptable compared to allowed tensional and compressive strengths in used materials (table 2).

Table 2 Mechanical properties of materials used in buttresses (Haj Esmaieli, 2001)

Materials	Compressive Resistance (MPa)	Tensional Resistance (MPa)	Shear Resistance (MPa)
Work brick unit	0.85	0.065	0.1

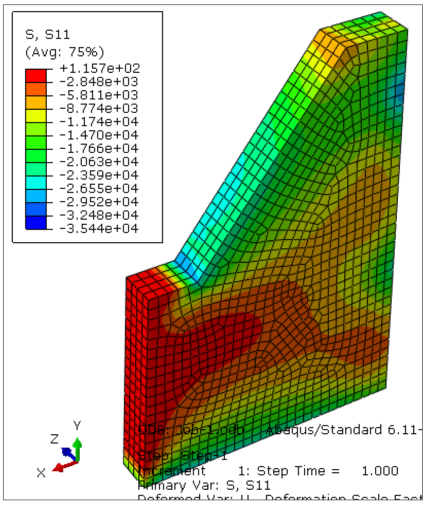

Fig 9 Tensional and Compressive contour stresses in modeled buttress without the load of dome

The thrust force caused by the dome was also added to previous forces in the modeling and the model was implemented again in order to have more reliable results. Not only has the buttress showed a positive response in the mode, but also tensional and compressive strengths do not exceed the limit until 1.2 time bigger force (Fig 10).

According to fig 10, it can be stated with confidence that the volume of used materials and the dimensions of buttresses are relatively high for transformation of thrust force and smaller buttresses with smaller dimensions would be able to bare the applied forces. In this regard, the buttresses with opening were also capable of meeting the demands of the architect and a prominent example of which is the great mosque of Yazd.

Based on the mentioned presentations, high volume and weight of buttresses will lead to subsidence of the building which indicates the theory of creation of cracks or deformation. But nearly a century passes from the construction of these walls and the subsidence is in fact a consolidation subsidence in the building which has reached to a balance at the moment. The question which can be posed is that: what is the cause of created crack and deformation? This will be discussed in the next section.

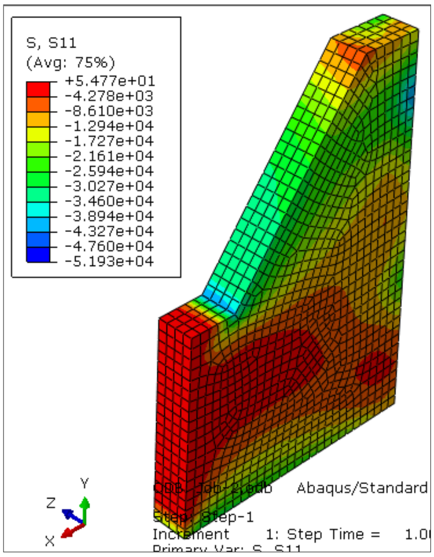

Fig 10 Tensional and Compressive contour stresses in modeled buttress with the load of dome

5.5. Erosion damage and decay of materials

The caries, corrosion and moisture in buildings in the sides of mosque's adjacent streets (Photo 5 to 8) made authors to search for an external harmful factor out of the mosque's building. The ascending moisture of sewer and water pipes leaking in the studied area were identified to be the causes of damage in conducted research and studies. According to water and sanitation experts, the design of the existing sewer plumbing in the mentioned alley is related to 1971 and its implementation has been carried out in 1972 with an inner diameter of 250 mm and a depth recorded in Fig 11 which are estimated to date back to 40 years ago and have not been reconstructed or replaced in this time period. Given that this time period is a long time compared to regional standards in a way that the determined standard in Middle East countries is 6 years and up to 17 year in Europe and their replacement, repairing and reconstruction are necessary after this time (Naddafi and Dindarlu, 2003). On the other hand, according to concluded studies: "Leakage of sewage networks in Iran is averagely nearly 59 percent in different areas every 24 hours" (Asadiany Yekta and Tabesh, 2010) which is a significant amount. It can be argued using this interpretation and with the population growing in recent years that the sewage pipes in the area under evaluation have been eroded and damaged.

Photo 5 to 8 Caries, corrosion and moisture in buildings in the sides of mosque's adjacent streets

"Erosion of sewer pipes takes place according to the chemical reaction in formulas 1 to 5" (Naddafi and Dindarlu, 2003).

$$SO_4^{--} + Organic\ compounds \rightarrow S^{--} + H_2O + CO_2 \quad (1)$$

$$S^{--} + 2H^{+} \rightarrow H_2S \quad (2)$$

$$2H_2S + O_2 \xrightarrow{Oxidizing\ Bacteria} 2H_2O + 2S \quad (3)$$

$$2S + 3O_2 + H_2O \rightarrow 2H_2SO_4 \quad (4)$$

$$Na_2S_2O_3 + 2O_2 + H_2O \rightarrow Na_2SO_4 + H_2SO_4 \quad (5)$$

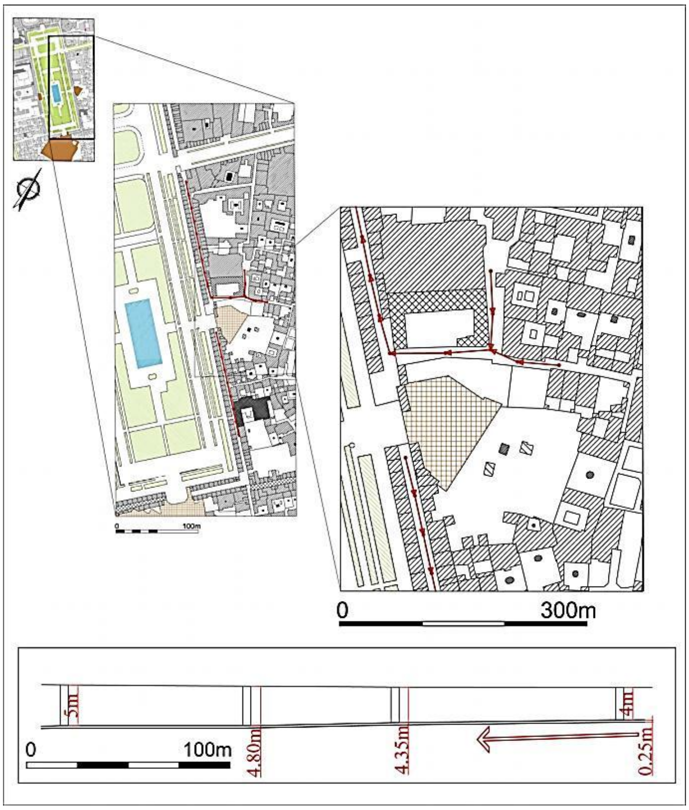

Fig 11 Tilt and depth of the sewer pipes in the mosque's adjacent alley

H2S gas enters the upper atmosphere of sewer pipes due to turbulence and the presence of moisture and oxygen provides the sulfur by oxidizing bacteria for the oxidation reaction of H2S gas. As a result, the produced sulfuric acid will cause the concrete corrosion by dissolution of calcium carbonate in the concrete. Fig 12 shows the stages of H2S gas production in sewer pipes (Naddafi and Dindarlu, 2003).

Based on the observations of corroded pipes, the corrosion is not limited to the pipe's crown and it also attacks the sides of pipes. The rate of corrosion on the left side of the pipe has been reported to be higher than other parts in calculations (Fig 13) (Naddafi and Dindarlu, 2003).

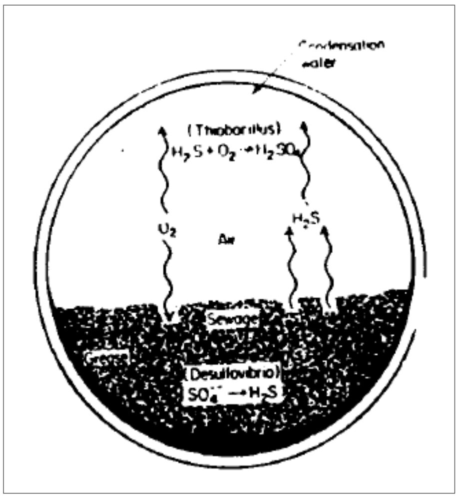

Fig 12 Method of H2S gas production in sewer pipes and corrosion (Naddafi and Dindarlu, 2003)

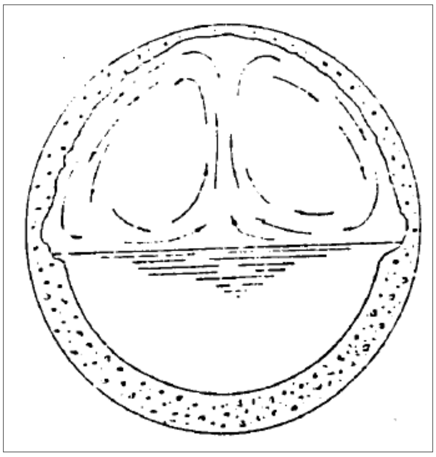

Fig 13 No equilibrium distribution of corrosion in concrete sewer pipes (Naddafi and Dindarlu, 2003)

The sewer pipe corrosion will definitely lead to leakage and penetration of salts and water the soil around the pipes. On the other hand, cations of the salts sewer pipes, absorb dipole molecules of water (Fig 14) and increases the level of soil's water absorption level. The dipole molecules of water rise up in form of capillary along with negative ions in the soil and positive evaporation occurs on the wall surface and negative ions will precipitate. The accumulation of negative loads on the surface of the wall and positive loads in the soil creates load potential difference in soil. This potential difference will cause more water to rise in the form of capillary with higher suction and increase the level of moisture in the soil and increase the possibility of having saturated soil (Massari, 1997) and this moisture will intensify the damage.

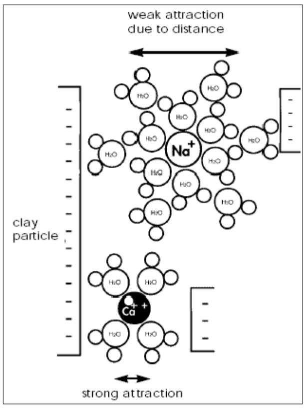

Fig 14 Absorption of water's dipole molecules in soil to existing Cations in sewage pipes' salts (Dos, 1993)

Water distribution system pipes in this area have also been created by metal pipes with an inner diameter of 100 mm which have much higher corrosion and leakage percentage compared to sewer pipes. According to concluded studies "leakage and damages of water form cracks, breaks and fittings of pipes are averagely about 40 percent" (Sarkarde and Khodashenas, 2008). This amount is also considerable due to lower depth of these pipes below the surface and water will capillary rise and shows itself. On the other hand, the permeability of the street has been taken by rigid material (asphalt) (Photo 9 and 10) and the ascending moisture is trapped and gets out form the most permeable side of the wall. The effects of moisture are visible in outer and inner bases of the wall.

Also, using materials such as stone at the base of the outer wall (Photo 11 to 13) will block the penetration location of wall's lower levels and moisture penetration into higher levels (Fig 15).

Photo 9 and 10 Use of rigid material (asphalt) in the alley

Photo 11 and 13 Use of stone and cement sand mortar in the perimeter wall of the mosque

The materials for pavement have also been damaged due to ascending moisture and lack of attention. Of course, taking the waterways of mosque, placement of rain water pipe of the mosque at the buttress's area and lack of proper slope in this area contribute to the problem in order to damage the pavements of this area.

After all of these interpretations, we can express about the reason for racks and deformations in the north and north-western side of the mosque that: the existing clay in the soil has turned into dough due to increased moisture under the soil of foundation due to leakage of water and wastewater facilities' pipes and doughy soil leads to the soil bearing capacity reduction and has caused the settling in the building. On the other hand, according to observations and conducted studies and modeling, the volume of considered buttress is high and since this buttress is solid, the overlapping of stresses' distribution of the main wall and buttresses are extremely high which has caused new cracks and settles in recent years. The cracks in the outer corridor of the second floor and the front wall of the building are considered to be active cracks showing the increase of the settle.

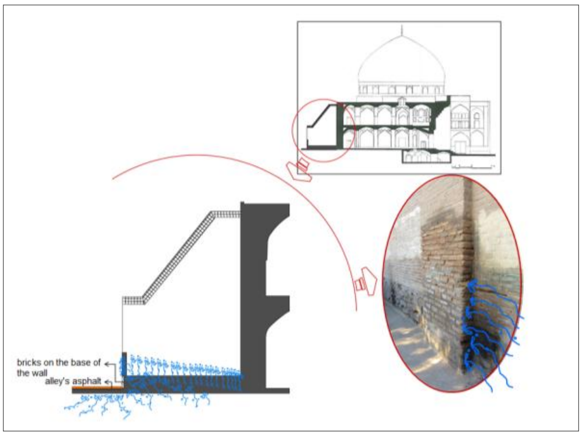

Fig 15 Method of rising moisture penetration in the base of buttresses and perimeter wall

6. Restoration plan of Sheikh Lotfollah Mosque's Buttresses

The presented restoration method in the area under study is based on preserving the authenticity of the building, using the reversible principle with minimal intervention, using innovative conservation practices with respect to the past executed repairs done by the late Maarefi.

The most basic protection scheme that can be done is collecting garbage and debris which have been accumulated by residents in the area. After that, the removal of the main cause in ascending moisture is necessary. Thus the asphalt on the alley must be removed and replacement of water and sewage network's pipes must be carried out in order to eliminate a part of damaging moisture in the area.

Since the soil moisture has reached saturation, the building will suffer from settlement after the elimination of moisture from the foundation and the body. The equation of $\sigma'=\sigma-u$ can provide a better understanding of the matter in this regard in which:

σ' is the stress applied on the soil

σ is stress caused by the weight of the building, and

u is also the stress applied on the water

u will be zero by eliminating water. Thus, $\sigma' = \sigma$ and the stress of the weight of the building will be imposed on the soil and soil will be compacted and settle occurs in it. Deformation and cracks will occur in the building over time with soil settlement. Thus the authors suggest the grouting of lime-stabilized and ash to the soil under the foundation to prevent soil compaction and its settlement in order to ward off destructive agent. “Since the lime alone has little effect on soil, there is the need for a pozzolanic material to enhance the effect of lime in the soil and its mass volume production which ash is used” (Bell, 2005).

The grouting of lime-stabilized and ash is a technique to enhance deep soils. The slurry penetrates the cavities, gaps and holes and reduces liquefaction, infiltration and soil plasticity and improves soil resistance and durability. This method is among the most economical methods of soil improvement. Factors such as soil gradation, different levels of underground water, the depth of the structure from surface and surface access to equipment are necessary for implement this method in order to determine the best method and grouting mode. Of course, since the consolidation grouting is a type of grouting in which “basic structure of the soil does not change and grouting takes place through the least pressure and increases the strength of foundation and also prevents water penetration”, it is recommended (Vailer, 1996). Fig 16 shows the parts of the building which need grouting and its implementation details.

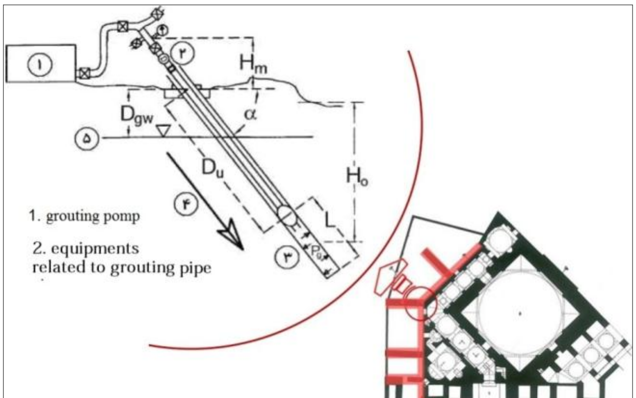

Fig 16 Parts of the building which need grouting and grouting's implementation details

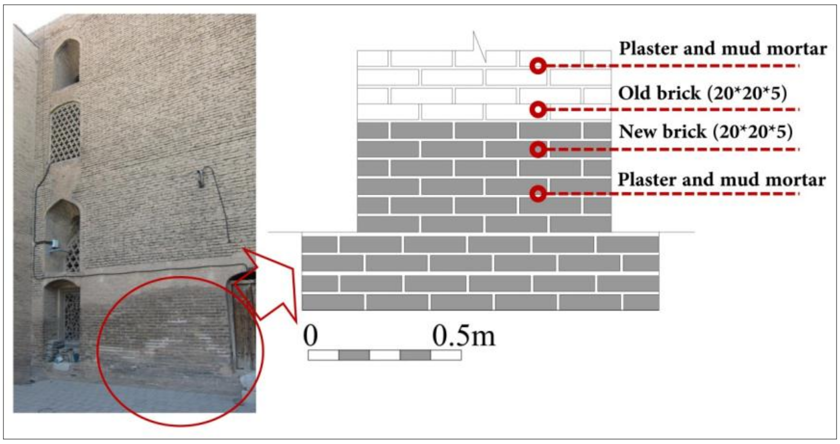

Fig 17 Replacement of new bricks and mortar and worn materials in the main wall and buttresses

Organizing the area of buttresses is necessary after grouting. The suggested plan for this section is in this form that parts of materials and bottom of the fuselage and Chinese seats which have been damaged due to moisture must be initially replaced with new and resistant materials. The intended area must be completely cleared for replacement and putting new materials in order to clean damaged mortars or debris left in it. Cleansing this part can be done by air compressor and then materials replacement be carried out. The 5 × 20 × 20 half-pressed plaster mortar brick is recommended for the main wall of the building and buttresses (Fig 17).

Since the brick paving of this part has been completely destroyed and this will absorb water and moisture during rain and directs water and moisture to the lower part of the wall, all of the brick paving of this part must be collected and the area be paved by applying the correct slop and blocked waterways in this area be opened again in order to easily direct running water from drains to the alley. The slope of this part should also be directed to the alley in order to let water of rainfall to slip on the created surface and be directed to the area. The slope of the area has been shown in Fig 18.

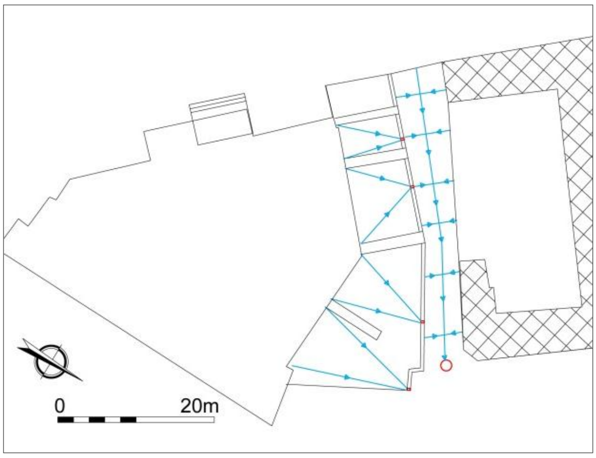

Fig 18 Slope of buttresses area and the alley

Pavement of this part has changed over time in a way that it has created a quite rugged surface. Since the floor bricks have severely suffered from displacement and settlement, maintaining it completely in the current status is not possible. The implementation of brick pavements are as follows: brick pavements are implemented with lime mortar with a little cement after the implementation of a 10-centimeter layer of limestone concrete (Fig 19).

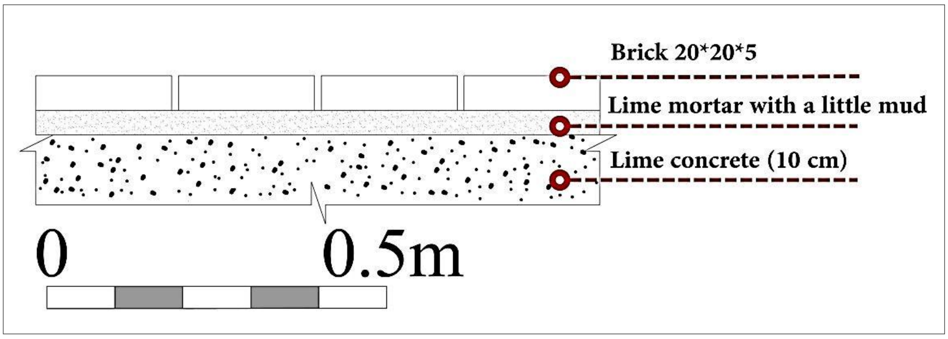

Fig 19 Area's pavement implementation

The Cutter stone is recommended for pavement alley adjacent to the mosque due to passing vehicles and motorcycles in this area. Cutter stone has been implemented in the sand and the moisture easily rises form seams between them. A water channel has been embedded in the middle of the street cement blocks in order to direct surface waters toward it. The details related to its implementation can be seen in Fig 20.

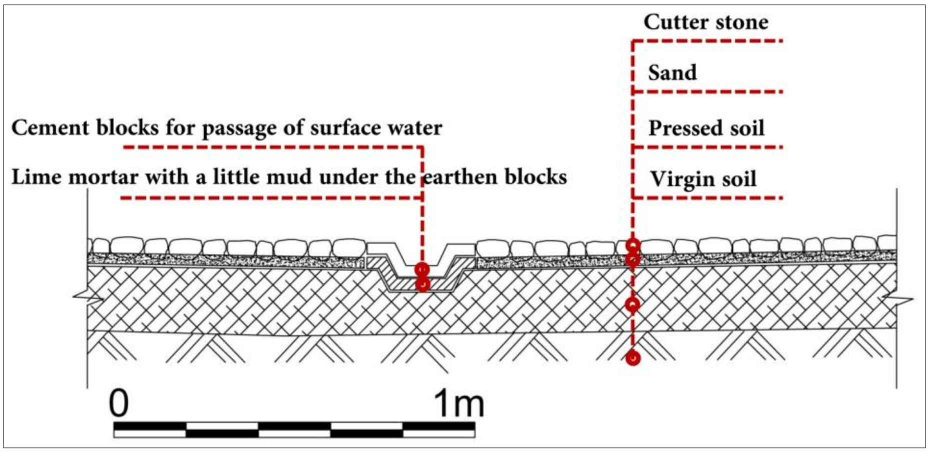

Fig 20 Details related to implementation of alley's pavement

7. Conclusion

The buttress structure of Sheikh Lotfollah Mosque has been able to fulfill the task of harnessing thrust forces during the course of its life which is almost a century despite being implemented in much larger volume. On the other hand, this structure is a part of the history of this building's restoration, maintaining and respecting it is valuable and necessary. Over time, damaging factors such as human manipulation aging and obsolescence of the building have jeopardized the implemented buttress. In the meantime, human manipulation has played an important role in the advent of damage. In a way that water pipes and sewage, lack of repair due to pipe corrosion, lack of proper slope, lack of water disposal via waterways, the use of rigid materials have prevented the rise of moisture from the surface and the foundation of building's walls. The baring capacity of the soil decreases with increased soil moisture and having doughy soil and the high volume of buttresses have also accelerated the effect of water. Thus, the solution is to act on disposal of ascending moisture through the repairing and replacement of water and sewage pipes network with restoration and use of scientific and empirical methods and help in improvement of foundation's soil by grouting of lime-stabilized and ash and organize the studied area.

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