Seismic Evaluation and Rehabilitation of the Historical Masonry Structure of Arg Gate in Semnan

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SUMMARY:
Semnan province was one of sixteen divided of Avesta in the ancient era whole of the duration for government of medes and achaemenid. This province accounted as one of the biggest state for partians. This state had good development in Sasani era. Seman after the periods of Isalm was a part of historical regions of Ghomes or Komesh. Arg Gate (Darvazeh Arg) was constructed during the reign of Naseredin Shah, in the years 1300-1305 AH. The gateway has been made of brick and stands to an elevation of over 7 m. The ceiling of the chambers resembles a barrel, but the main rooms have ceilings covered with shallow domes. The master-piece of this structure is the door way, worked with pieces of seven-colored tiles depicting a scene from the myth of Rostam and the white monster. In this paper, an evaluation of the capacity of the gateway to withstand lateral loads together with the expected demands from seismic actions is provided. The effects of two techniques of repair and strengthening on the behavior are then investigated in order to evaluate the effectiveness of these techniques in retrofitting historical buildings. The advantages and disadvantages of these techniques are discussed.
The first method, base isolation, separates the structure from the ground and is efficient in dissipating and damping the seismic vibration to the structure. This technique reduces the requirement of intervening directly on the structure itself for seismic strengthening, but will require a major intervention on the surrounding field. The second method, utilizing post-tensioned steel reinforcement within the walls and minarets, replaces and enhances old elements that had been supplied in the original structure, and was found to improve the structural seismic response. This technique is troubling but can be installed in such a way that it is hidden from view.

Keywords: Seismic evaluation; rehabilitation; historical structure; masonry gate, Semnan.

1. INTRODUCTION

Historical buildings, obviously, are a reservoir of human history and culture, and preserving them means respecting the previous generations. Furthermore, the old historical buildings in a city would accentuate the culture and characteristic of that city. It has been well documented that the preservation of historical structures can be an economic development tool for cities. Heritage tourism is a key component in the renewal of several cities economies. One of the main purposes of this development is to guarantee sustainable economic, social and cultural development combined with preservation and active enhancement of cultural resources. Iran is a country with vast cultural and historical attractions which draw in landmark number of tourists in different seasons of the year. Its attractions and beauties are scattered in different parts and cities of it. One of the most attractive tourist cities of Iran is Semnan.

The province of Semnan is in the north-east of the central plateau of Iran, and its capital is Semnan. It stretches along the Alborz mountain range and borders to Dasht-e Kavir desert in its southern parts (Fig. 1). The province is divided into two parts: a mountainous region, and the plains at the foot of the mountains. The former offers a scope for recreational activities as well as being a source for minerals, whereas the latter encompasses some ancient cities of Iran as one of the capitals of the Parthian Empire was located here (Karimi 1997).

Semnan province in terms of having a lot of old historic buildings and monuments in its place, each with numerous beauty and attraction is. Semnan can be divided into sixteen sectors from the old days of Avesta. During the Median (Medes) and Achaemenid periods, it accounted for being one of the largest satrapies (provinces) of the empire. During the Islamic era, Semnan was part of the historical region of *Gomess* or *Komesh*, and The Silk Road paved its way from the midst of this region.

Figure 1. Location of Semnan Province

The Cultural Historical Heritage Organization of Iran lists 470 sites of historical and cultural heritage in Semnan. One of the main landmark of Semnan is Arg gate. Arg gateway can be among the most beautiful and magnificent works of one of the tourists to know that after years of calls (Fig. 2).

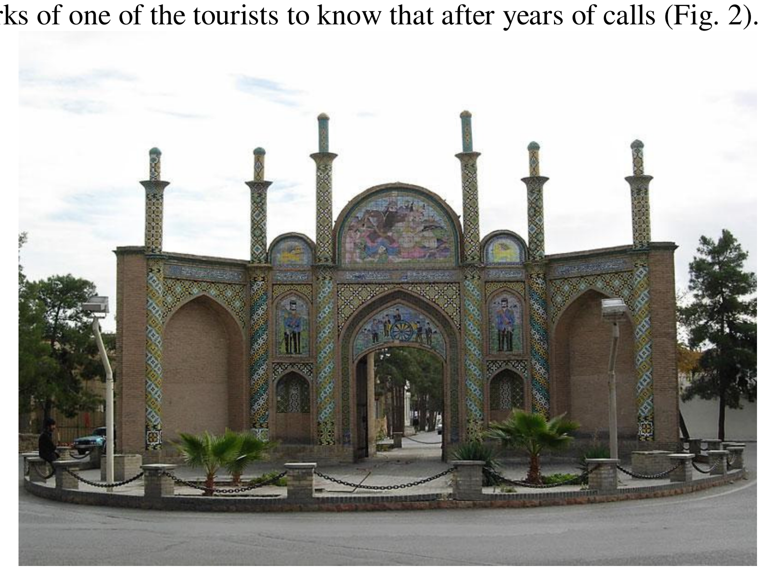

Figure 2. The bird view of Arg gate

Semnan Citadel, a large public buildings and places of the city is required at the time of the Persian month Bahman, son of Fath Ali Shah built. North Gate of the old city of Semnan Citadel is the only survivor at the time of Reza Shah during construction and street widening and construction of new buildings remains. The gateway of Arg has been established during the Naseredin shah Ghajar rea (Kheirabadi 1991).
North view of the Citadel gate with both north and south of the northern facade has two rooms on either side of the mirror each other, two Rahrvry small porches in front of the room and the main entrance of the site traffic. This is part of the brick facade and the main hall with a square plan less prone to lead to the dome. North view of the interesting inscriptions decorating the main entrance to the semi-circle above the yellow line calligraphy field is azure tiles. The use of geometric designs and mythological role of the journalist in front of the southern facade of the entrance gate to the city is remarkable. One of the outstanding parts of this historical building is the significant door way which the historical legendary fight between Rostam and white demon depicting with pieces of seven colored tiles. The doors of the gateway has made by thick planks with iron spikes.

Figure 3. The southern façade of Arg gate

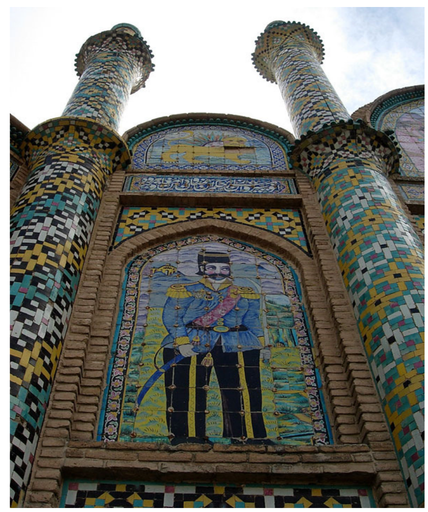

Figure 4. The lion and sun motifs Qajar officers on the southern façade of Arg gate

Tile decoration of this facade is a symmetrical shape and the lion and sun motifs Qajar officers are depicted. Gate wall scrolls in a row, five rows of white on the blue line caligraphy exists in the lines and leaf arabesques seen the plan. The original building of the gate has been built by bricks with the height of over 7 m. Highest minaret is 11.5 m. The surface of these minarets has built with tile.

Past studies have demonstrated these historical structures are susceptible to damage, and prone to partial or total collapse, under earthquake loads, sometimes due to non-respectful restoration (Ramos and Lourenço 2004). As a matter of fact, repairs and retrofitting techniques should always respect the original existence; any intervention not respectful of it could also create incompatibility with the original structural behavior. Masonry buildings are generally able to carry the vertical loads in a very safe and stable way, while they are rather sensitive, from a structural point of view, to horizontal loads. The high seismic vulnerability of this type of building is due both to the particular configuration and to the mechanical properties of the masonry. If in principle, the prediction of the structural response of monumental buildings is not different from that of other constructed facilities (e.g. a bridge) it is an even more challenging task for several reasons (Carpinteri *et al.* 2005). In brief, monumental historical buildings are by definition buildings that it's difficult to reduce to any standard structural scheme because of the uncertainties that affect the structural behavior and mechanical properties. The above considerations explain the need of specific modelling and analysis strategies for historic masonry constructions.

In this paper, starting from a single case study, a contribution to the issue of modelling and analysis of a historical gate under seismic action is provided: a relevant case study that demonstrates the careful use of numerical analyses to face practical engineering problems in the field of historical construction is presented. An evaluation of the capacity of the structure to withstand lateral loads together with the expected demands from seismic actions is also given.

2. SEISMICITY OF SEMNAN REGION

The portion of Alpide belt from Iran in the west to Burrma in the east, seismically, is one of the most active intercontinental regions of the world. Semnan region is part of the Iranian plateau that is subjected to many tectonic activities, including active folding and faulting, and volcanic eruptions. It is also known for its long history of disastrous earthquakes. Not only have these earthquakes killed in thousands but they have also led to waste of valuable natural resources. Since 1900, over 120,000 fatalities have been resulted from earthquakes in Iran.

Semnan is located in the north of Great Kavir. The gravity survey by Dehghani and Makris (1983) indicates that the crust beneath the Great Kavir is in isostatic equilibrium; it is thus unlikely to be undergoing broad uplift or downwrap at present, apart from the northern fringe adjoining the actively rising Alburz Mountains. However, the Kavir basin with the associated Garmsar, Semnan and Damghan basins are areas of considerable active faulting and fault-related seismicity, particularly along the faulted basin margins (Fig. 5).

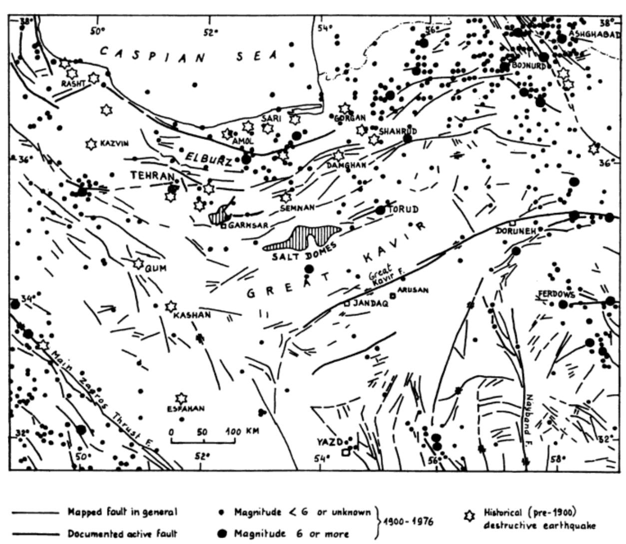

Figure 5. Map of major fault traces and earthquake epicentres in northern and central Iran

The historical context of earthquakes in this region has been compiled by Ambraseys and Melville (2005). First-motion data indicate that these earthquakes are almost all generated by reverse slip and subsidiary strike-slip movements (Dehghani and Makris 1983). The strike-slip component of deformation probably has a complex origin. Earthquakes are characteristically shallow, of large magnitude but are discontinuous, with long recurrence periods (Berberian 1977). For the central Kavir, the mean return periods of about 22, 170 and 1150 year have been determined for earthquakes of magnitude 5.5, 6.5 and

7.5, respectively. The northern Kavir is more active, with return periods of 5, 30 and 250 year, respectively (Nowroozi and Ahmadi 1986). Historical records show that nearly every larger town near the Kavir border, including Semnan has been severely damaged by the earthquakes in the past. In 1927, an area of 280000 Km^2 was shaken by an earthquake centered at the western side of the Kavir (Ambraseys and Melville 2005). Qumes (Ghoomes) city hill is located 35km to the southeast of Semnan. In the old Islamic literature, Semnan, Damghan, Bastam and Gorgan have been named as being part of Ghoomes (Haghighat 1990). Many historians mentioned a high-magnitude earthquake (Io=X, Ms 7.9) on 22 December 856 in this region which wiped off the Qumes civilization from the face of the earth. At least 200000 fatalities were reported (Haghighat 1990). Fig. 6 shows a recent seismicity map for Iran which includes Semnan region.

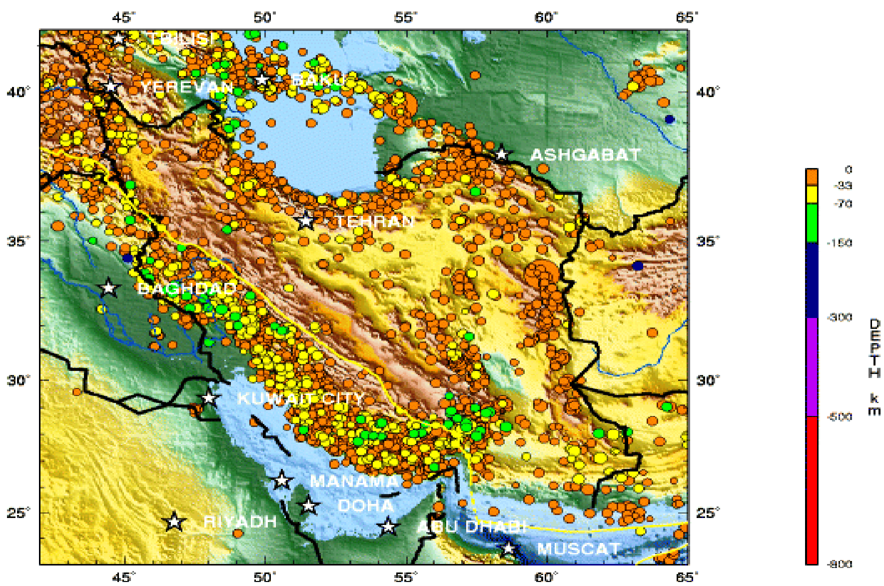

Figure 6. Seismicity of Iran, 1990-2006

3. SEISMIC ANALYSIS

Earthquake codes and regulations are not valid for the assessment of the seismic vulnerability of historical buildings which are made of materials that have aged and which have already suffered damage (Mortezaei *et al.* 2011). To obtain the dynamic response of this masonry structure, four different types of earthquakes (El-Centro, Bam, Tabas and Manjil) with a maximum input acceleration of 0.35g are applied. The selected sets of earthquake records are chosen in order to investigate the nonlinear structural response to an excitation with different frequency content and duration.

In order to reduce the computational effort, the finite element (FE) model of the gateway has been updated posing gap elements around the areas where cracks are present (Fig. 7). The seismic analyses carried out on the nonlinear 3D FE model have allowed evaluation of the ultimate strength capacity of the gate. Some load combinations that were used in transversal and longitudinal seismic directions allowed a direct, though approximate, assessment of the seismic safety level of the gate. Square root of sum of squares (SRSS) technique has been used for the load combination. The most severe load combination for the building turns out to be the seismic load acting to the lower level of the gateway which has low integrity and stiffness. For this load combination, the demand vs. capacity (about 11 % of seismic load) confirms the susceptibility of this type of buildings to extensive damage and possibly to collapse, as has frequently been observed during earthquakes. As a matter of fact, building collapses for a seismic load equal to about 7.5 % of external load would be due to the failure of the minarets of gateway in which the first mode takes place. Comparing the effects of different loads used in the seismic analyses, shows that the gateway is especially vulnerable at the support level, due to low integrity and stiffness and the presence of cracks in this level.

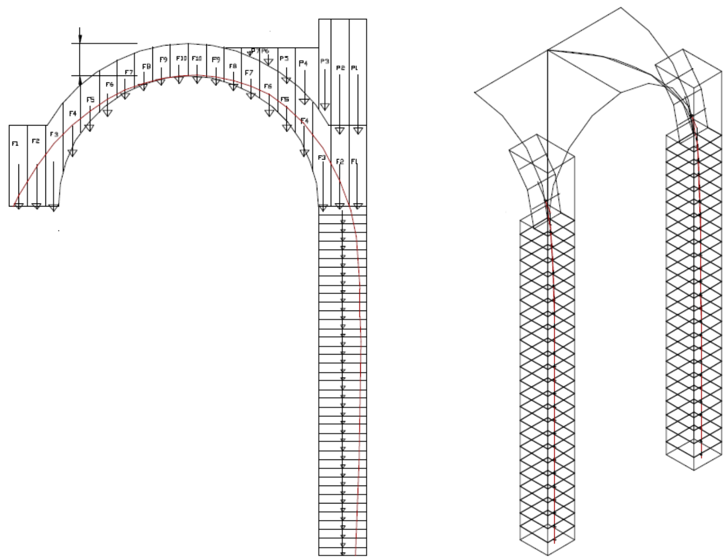

Figure 7. Finite element modeling of the gateway

4. STRENGTHENING SCHEM

The analysis of the seismic behavior of the gateway structure has permitted us to point out two main weaknesses of the building. With respect to the state of cracking patterns at the gateway structure, it's then possible to suggest a strengthening retrofitting technique with respect to the architectural aspects.

There are some cracks in the gateway structure, which are limited to the surface of the inner rooms. Regarding these cracks, injections of aerial mortar (grout) can be used. The aim of this technique is to close the cracks and to improve the connections of the wall. This strategy not only can restore some of the lost strength capacity, but it can address the separate vibration of masonry elements created after the appearance of the cracks. After the injection, the effects of two techniques of repair and strengthening on the behavior, i.e. base isolation and post-tensioned steel reinforcement, are investigated in order to evaluate the effectiveness of these techniques in retrofitting historical buildings. The advantages and disadvantages of these techniques are discussed.

4.1. Post-tensioned steel reinforcement

The structural success of masonry depends on its ability to overcome its intrinsic low tensile strength, which is controlled by the adhesion between the mortar and masonry unit. An unreinforced masonry system can resist overturning loads with the weight of the masonry itself, but this approach may not be the most economical method for designing multiple story structures (Fig. 8).

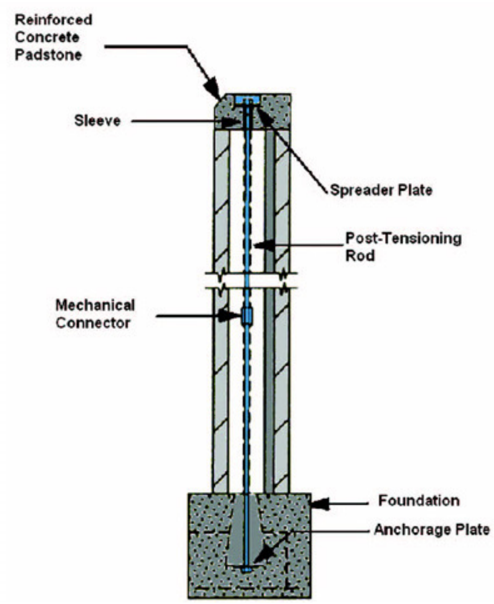

Figure 8. Schematics show of typical post-tensioned masonry systems

In order to improve the behavior of masonry gateway under the action of seismic forces, one of the strengthening methods is utilizing post-tensioned reinforcing steel.

Two procedures exist for supplying the pre-stressing force to the steel: pre-tensioning and post-tensioning. In post-tensioning, tendons are tensioned against the masonry after it is placed and achieves target strength. Between these two methods, post-tensioning is preferred for masonry because of its construction ease. In addition, stress loss from elastic deformation during the pre-stressing process is minimized. Post tensioned provides several economic advantages in the building process over traditional reinforced masonry and other materials.

A great benefit of using load-bearing masonry is attributed to its capability of incorporating architectural elements, such as partitions and non-load-bearing walls, into structural design without adding significant material or cost to the structure. This feature eliminates the coupled need in modern construction of a load-bearing frame and architectural accessories, thus offering structural advantage and cost effectiveness. Full grouting is not necessary for post-tensioned, which results in material and labor cost savings, when compared to conventional reinforced masonry. Selective grouting of bond beams and grout plugs achieve much greater economy and efficiency than full grouting. Also, when compared with conventional masonry construction, the number and spacing of bars is minimized. Because of these aspects of post tensioned, there is the potential for a shorter construction schedule, depending upon the manner in which the post-tensioning operation is scheduled relative to other construction tasks.

Because of the applied compressive stress, the shear strength of the system is enhanced to the point that shear reinforcement may be eliminated in many cases. Flexural behavior is enhanced, and ductile response is observed through large displacement capacity and the tendency for the structure to return to its initial state after loading. This self-righting nature of post-tensioned masonry is of great importance when seismic resistance is considered.
A structural advantage can be obtained through anchorage at the top and bottom of the wall. These anchorages can provide fixity at the base and effective connections between walls and diaphragms. Controlling the cost of post-tensioned hardware and minimizing the amount of restraint necessary to provide structural integrity are key ways of keeping this construction procedure economical.

Post-tensioned steel reinforcement is placed at critical areas to compensate for the lack of tensile strength and ductility and to increase the stiffness of walls and minarets. Steel ties avoid separate vibration of the masonry elements formed after cracking occurs. Horizontal bands are provided at different levels in order to ensure "box-like" action of masonry buildings and to reduce the possibility of "out-of-plane" failures. Roof level of the gateway consists of a system of arches, vaults, and minarets that do not provide adequate continuity among the supporting walls and minarets. The original wood banding within the walls and minaret has in many instances rotted away and the cavity left can be utilized for the insertion of steel ties and injection of grout. This is an advantage to this technique in that it can be hidden from view after it has been installed.

The strengthened model was subjected to the above mentioned four different types of records for the purpose of comparison of the effectiveness of the applied method of strengthening. The response of the strengthened model was considerably different from that of the original model. The capacity curve of the strengthened model show higher strength and ductility in comparison with the original model (Fig. 9). The results of comparison obtained from the original and strengthened model are as bellow:

1. The structural response to the acceleration levels up to a_{max}=0.18g was elastic. After 0.18g, the first cracks occurred in the original model, whereas the strengthened model remained elastic.
2. Below a_{max}=0.35g, the original model suffered severe damage and was near to the failure; where this level of demand represented the elasticity limit and beginning of nonlinearity for the strengthened model.
3. The FE modeling shows the amplification of acceleration at the top of the minarets.
4. The type of failure mechanism was different in the strengthened model. The strengthened model does not suffer separation of bearing walls and vertical crack, but the failure occurs in the lower zone and results in diagonal cracks.

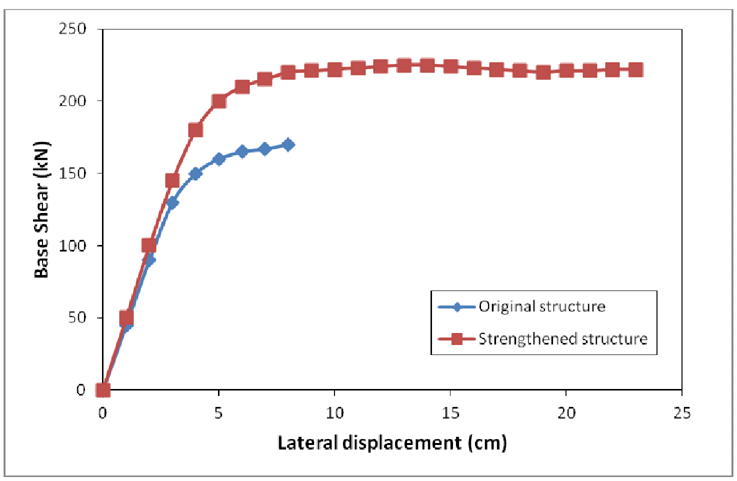

Figure 9. Capacity curve of original and strengthened structures

4.2. Base Isolation

Base isolation is a technique developed to prevent or minimize damage to buildings during an earthquake. A fixed base building, i.e. the building that is built directly on the ground, will move with the motion of earthquake and can sustain extensive damage as a result. When a building is built away (isolated) from the ground, resting on flexible bearings known as base isolators, it will only move a little or not at all during an earthquake. Base isolation technology can make masonry structures capable of withstanding earthquakes, protecting them and their occupants from major damage or injury. A base isolated structure is supported by a series of bearing pads which are placed between the structure and its foundation. A variety of different types of base isolation bearing pads have now been developed. For example, lead-rubber bearing is made from layers of rubber sandwiched together with layers of steel (Fig. 10). In the middle of the bearing is a solid lead plug. On top and bottom, the bearing is fitted with steel plates which are used to attach the bearing to the building and foundation. The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction.

With base isolation, the earthquake energy that would have been transferred to the structure gets absorbed at the base level. In addition, the period of the isolated structure is increased which typically results in a reduction in seismic demands. In these ways, ductility demand to the structure is greatly reduced.

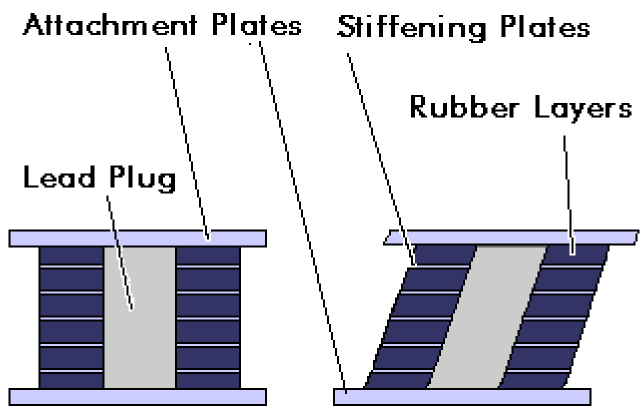

Figure 10. Base isolation

For another method of strengthening, base isolated model were subjected to the same records of ground motion as before. Every base isolation was placed under the every minaret. Due to the base energy dissipation characteristics of the base isolated model, the models analyses were continued at higher loading levels. The results showed different trend that are as following:

1. A comparison between input acceleration and output acceleration show that the amplification is reduced due to the application of the base isolators.
2. There is insignificant amplification of the output acceleration at the top of the minarets that is approximately 1/5 that of the model without base isolators.
3. The displacement at the top of the base-isolated model relative to the original structure is greatly small. For the acceleration input of 0.35g, relative displacement top is 17 mm for the base isolated model and 32 mm for the strengthened model.
4. The failure mechanism of the base isolated model is totally different from the original models.

5. CONCLUSION

In order to assess the structural behavior, and to evaluate the seismic vulnerability of a Qajar gateway the behavior of a case study, Arg gate of Semnan, has been analyzed under seismic loading. For this purpose a 3D numerical model of the gateway has been constructed. Some nonlinear analyses have been made in order to assess the seismic vulnerability. A crucial task in masonry building modelling is the evaluation of the mechanical properties. In this work, concerning this step, conservative values already available from similar experience are assumed. In order to gain an understanding of the actual deterioration state of the structure the model has been identified taking into account the actual cracking path.

By a comparison between the stresses and the strains due to the seismic shocks acting in the horizontal direction, it was observed that the minarets of gateway is especially vulnerable in this direction, due to low stiffness and the presence of cracks in the wall arranged parallel to the seismic action (the wall responsible for counteracting the seismic loads). The comparison demand (seismic loads) vs. capacity (material and topology strength) confirms the susceptibility of this type of building to extensive damage and possibly to collapse, as frequently observed.

In this regard, the effects of two techniques of repair and strengthening on the behavior of masonry gateway are then investigated in order to evaluate the effectiveness of these techniques in retrofitting historical buildings. The advantages and disadvantages of these techniques were discussed.

The first method utilized post-tensioned steel reinforcement within the walls. Post-tensioning can allow a significant reduction in building weight versus a conventional masonry building with the same number of floors. This reduces the foundation load and can be a major advantage in seismic areas. Post-tensioning enables masonry to be used for its greatest advantage, compressive strength. By increasing the tension using post-tensioning tendons, the masonry units are placed in compression. This limits the flexural action of the structure, thereby dramatically increasing its strength. Post-tensioning enhances the resistance to flexure as well as shear and tension. The governing criterion for post tensioning forces is the limitation of the crack width, besides the masonry strength in general. The ultimate load level mainly depends on the deformation of the entire wall between anchorages.

The second method, use of isolators, prevent the structural damage and limit the maximum lateral deformations and accelerations of the stories of the buildings and guarantee the protection of non-structural components and equipments. The results showed that a base isolation is a very powerful concept to improve the seismic safety of historical monuments.

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