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Stabilization and Strengthening the Foundation of the Two Entrance Gates of the Holy Shrine of Imam Reza (PBUH)

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Abstract This paper presents the structural analysis and constructional method for the stabilization and strengthening of the foundation of the two entrance gates in Holy Shrine of Imam Reza (PBUH). The holy shrine of Imam Reza (PBUH) is a great complex in the city of Mashhad in Iran. It was founded nearly 1000 years ago and has developed and become extensive through the times. There are several entrances and wide courts around the oldest section in the centre of the complex. Recently, the extension scopes of this complex, required excavation and construction in the basements near the two main gates, called Saat and Naghareh Khaneh Edifice. These activities, near the 400 years old edifices, needed special mobilization, like, monitoring the historical buildings and strengthening their foundations. A deep study was performed, which pursued two purposes. The first purpose was to strengthen the foundation of the buildings and the second was to make a tunnel through the foundation of the buildings because of some operational benefits for the client. At the first glance these two purposes, seemed contradictory, but finally, a new structural system for the foundation were designed and built, which was able to carry the superstructure loads to the ground while a wide tunnel was constructed as well. Special scheduled sequences of construction were prepared, which was flexible and sufficiently reliable so as to overcome any undesirable circumstances and obstacles. Monitoring the buildings behaviour during the constructional phase was conducted to assist the execution directions. This project was carried out successfully and it is in use.

Key Words: Historical buildings, stabilization method, Naghareh Khane Edifice, Saat Edifice

Introduction

Increasing the rate of visitors and pilgrims of the holy shrine of the Imam Reza (PBUH) in Mashhad city of the Islamic Republic of Iran in recent years is a serious problem for the responsible directors of the complex. Providing the convenient places for pilgrims essentially is not easy because of the limitation of extensions in the centre of a crowded urban area so they decided to develop the underground spaces where ever it would be possible. Developing the underground spaces and excavating near existing building especially the old and historical ones is a sensitive operation and needs a comprehensive study.

This paper reviews the studies which have been done and the constructional method which has been used for stabilization of the two huge edifices while constructing the basements along the both side of their foundations and making wide tunnels through the existing foundations to connect the basements. Other complementary studies on the superstructures for seismic rehabilitation are presented in other papers.

In Fig.1 the situation of the two edifices has been shown in the holy shrine of the Imam Reza (PBUH) complex. The courtyard between the edifices and the two other corridors behind them are the where the underground spaces have developed and basements have constructed. Now, three wide tunnels connect the basements under the edifices.

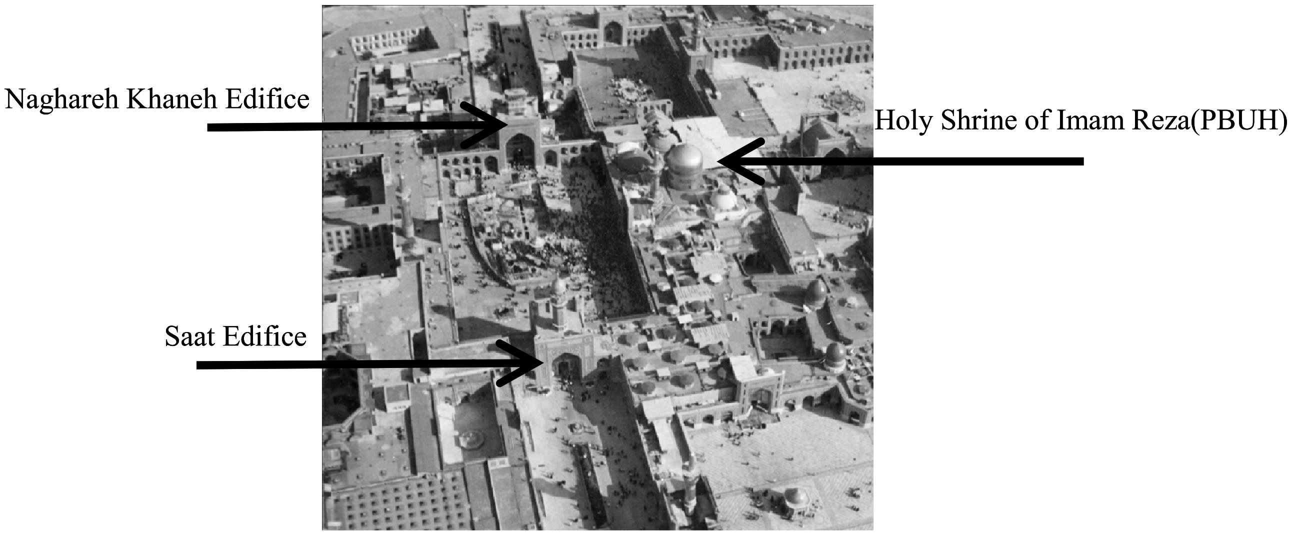


Figure 1: Position of edifices in Imam Reza (PBUH.) Holy Shrine Complex

Preliminary Studies

At the first glance, the advantages of making basements and tunnels in the location of the two edifices for the operational goals are clearly obvious and it was not surprising that the employee insisted on the project, but from the structural point of view it seemed a risky project in constructional procedure and it was not recommendable for the probable increase in the vulnerability of the structures against earthquakes. So the preliminary studies started in a doubtful atmosphere. A programming for the exploration and recognition of the existing building condition has been prepared. Then some parallel activities were started to gather the sufficient information about the soil, the structures, and also their history. To discover the accurate condition of the foundation of the edifices it was decided to dig some wells inside their foundations. The locations of the wells were selected in a way that the wells be useful for both of the explorations phase and the probable further construction phase, so the efficient pile location around the main load carrying masonry pillars were determined and then the exploration started.

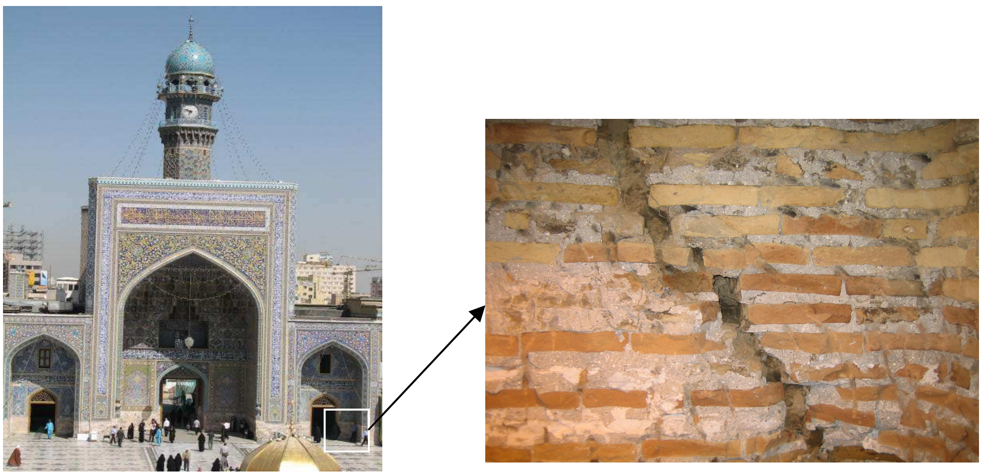


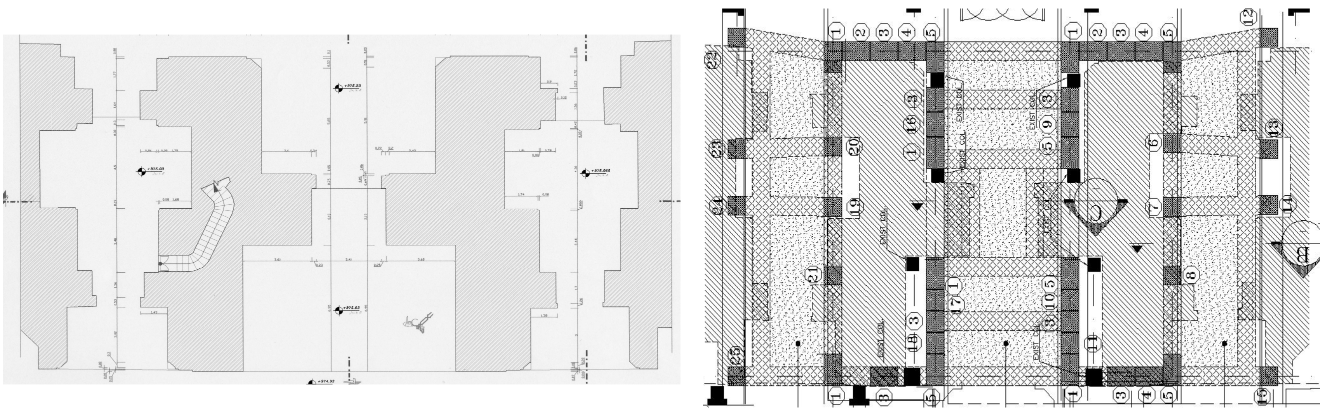
Figure 2: (a) Saat Edifice and the position of the crack, (b) Crack in the foundation

During this phase a noticeable crack were discovered in the foundation of one of the edifices and it proved that the edifice needs to become strengthened even no basement constructed next to it. This damage has been shown in Fig.2 and the Fig. 3(a) shows the general form of the masonry mat foundation. The reason of the damage was found in the documentary studies and a record of a settlement was found which it has the best conformity with the crack pattern.

This defect in the edifice turned the idea of constructing the tunnel through the foundation of the edifices to an opportunity for the strengthening their foundations by adding piles and changing the load transferring system of the foundation.

Comprehensive Studies

The general information which was obtained in the preliminary studies was used for the conception design. In the comprehensive studies the complementary information about the soil bearing capacity (Fang 2002) “Foundation Engineering Handbook”, stiffness and strength of the various types of the foundation systems and the appropriate methods of construction were reviewed. It was clear that a new system for the foundation should be constructed and it should be able to repairs the foundation deficiencies and also strengthen it to prevent the settlement in spite of constructing the tunnels under the edifices. To find an efficient and practical configuration of the new system it was very important to consider the relevant sequence of construction. So several constructional methods and systems with their constructional scenarios considered and the advantages and disadvantages of them were compared. (Bostenaru 2004)
The results of the studies lead to choose a special deep foundation system for the buildings. As it is shown in Fig. 3, a system consisted of two groups of adjacent piles all around the two main load carrying pillars were chosen. In this way, three tunnels along the foundation of the edifices would be built instead of a one big tunnel. The two groups of piles form the two boxes which can confine the soil under the pillars and will not allow any settlement during the constructing of the tunnels and also these boxes can increase the load bearing capacity of the soil (Mandara and Palumbo 2004) and transfer the surcharges to the lower layers of the soils. The piles around the boxes also form the walls of the tunnels.



(a) (b)

Figure 3: (a) ground floor plan of the edifices, pillars are hatched, (b) Piles layout around the pillars

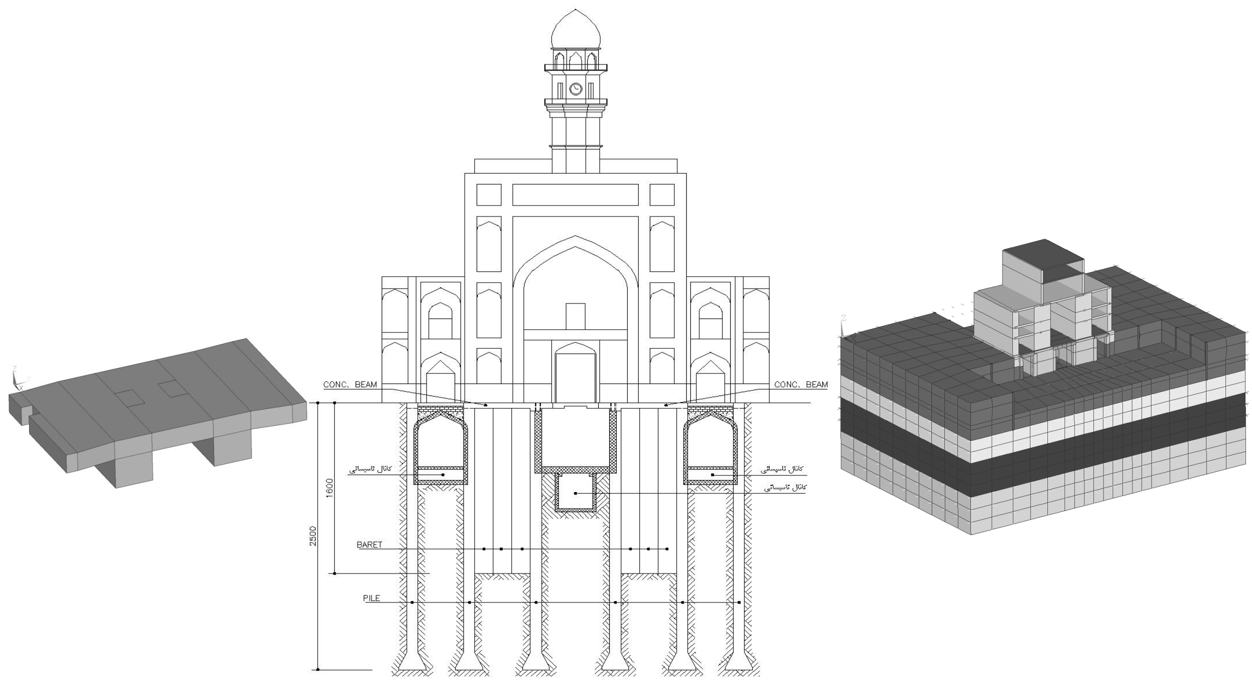
Structural Analysis and Design Strategy

It is improbable to have a perfect structural model without any uncertainty especially for a historical structure. Simplifications in the mathematical models of the structure and material behaviours cause inaccuracies in the analysis. In this situation, a reliability analysis may be a useful method, but for the historical buildings it is not only time consuming but also a very complicated method because of the fuzziness of some of the variables such as the lack of the probability information of the old material characterizations, qualitative assessments of the existing damages and disintegrations in the structures. So for this case, an engineering bias estimation was used and a group of multi-scenario analysis performed to find the envelope of the demand of the structures. Linear static analysing method was used for designing of the piles and other structural elements of the foundation. It should be mentioned that the superstructure was studied by both linear and nonlinear methods which are

presented in another paper. In the analytical model, soil were modelled by the Winkler springs models and the stiffness of the springs were varied ±%30to find the extreme limits of the responses.

Construction Method

It had been ordered that the individual in-situ piles were dig manually similar to the traditional method for Qantas (aqueduct wells) to minimize the impacts and vibrations of the activities and smoothen the transferring of the load path between the original masonry foundation, soil and piles. It is believed that the speeding up of the operations in such cases may cause a sudden accident, reciprocally; slowness brings everything under control. By digging each well for a pile, a part of the original mat foundation were cut and then were replaced by a reinforced concrete element. In fact after constructing all of the concrete piles and finishing the boxes around the soil under the pillars, the 10000 KN weight of the edifice were transferred to the soil inside the boxes and the other parts of the old foundation between the boxes were released from the loads, so these parts could be removed or excavated and used as the tunnels.
After constructing all of the concrete piles, concrete diaphragms were built to connect the top of the boxes to each other and to the side piles. These slabs made the roof of the tunnels. In Fig.4 the vertical section of the superstructure over the new foundation system has been shown. Another feature of this structural system is the capability for sustaining the superstructure against the liquefaction phenomena which is probable due to the characterization of the site soil. The deep foundation prevents non-uniform settlement.



(a) *(b)* *(c)*

Figure 4: (a) Schematic model of the original masonry mat foundation,(b)Vertical section of the superstructure over the new foundation system(c) Schematic model of the superstructure, basements and the tunnels

Monitoring of the Structure

In spite of the numerous analyses, there was a deep anxiety about the safety of the historical edifices. Monitoring the behaviour of the structure during the constructions is a useful way to overcome to this anxiety in such an intricacy of the condition. So, a set of monitoring instruments was installed on the edifices to sense every movement of the buildings during the constructional phase. A set of pressure cells was installed at the end of the piles to monitor the changing of their

pressures. Four extensometers also were used to study the deformations of the piles. Movements of each structure were recorded by five joint meters between the edifices and the adjacent buildings, and two tilt meters which were installed on the top of the structures were used to control the vertical alignment of the buildings. This network of the instruments helps the executive group to understand the behaviour of the building and modify their methods (P&M O of Iran 2002). As an example, the speed of digging the wells was increased gradually without any timidity, based on the information executed by instruments. The efficiency of the monitoring system came into view when it revealed that the structure twisted around the vertical axis while they have been excavating in one of the side tunnels of the Nagharee Khaneh Edifice. Immediately, they stopped the excavating in that tunnel and started to excavate in other side tunnel. In this way, they could control the twisting movement of the edifice. The data base of the recorded movements and pressures of the structural elements and piles has been developed from the start of the project until now and it is still is used for controlling the conditions of the buildings. In Fig. 5 a part of the monitoring results has been presented.

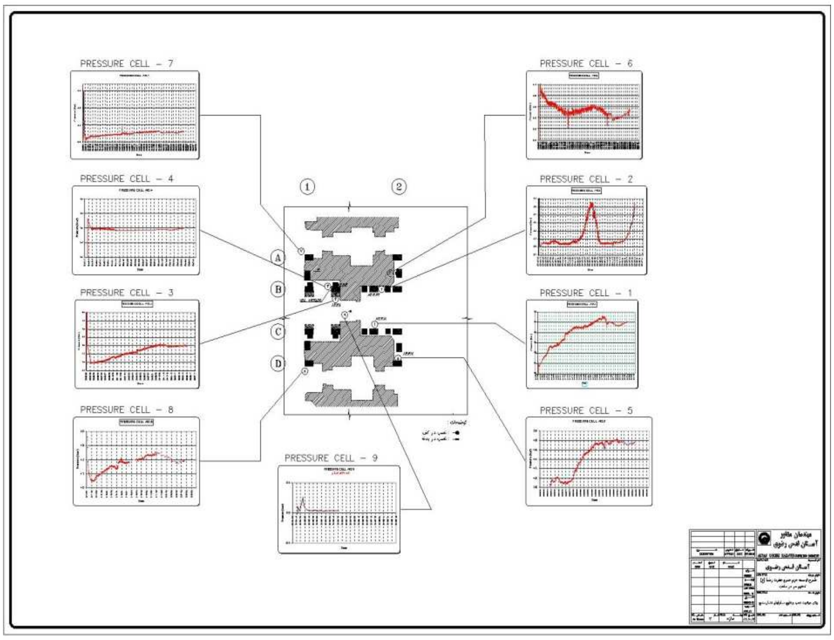


Figure 5: position of the pressure cells and the graph of the records

Some parts of the results should be noticed to understand the behaviour of the buildings and some parts should be eliminated for the errors of the recording. Generally can say, in the set of the instruments of a project, all of the results should be interoperated together to achieve the reliable results. After filtering the errors of the records, the differences between the calculated pressures through the mathematical modelling with the reality were determined. Relative change rate of the pressure in piles are more interested than the absolute values, because the differences in the rate of the relative changes show the imbalance of the structure.

(a)

(b)

Figure 6: (a) Final form of one of the side tunnels, (b) Final form of the middle tunnel

In Fig.6, the finishing of the constructed tunnels under the Saat Edifice between the two basements have been shown.

Conclusion

The methodology of choosing the structural system, analyzing and constructing the selected system for stabilization of the foundation of the two large edifices were reviewed in this paper. It has been explained that a multi-scenario analysing with engineering bias estimation is a practical method to solve the complicated cases in the structural analysis and design procedure. The importance of the monitoring of the structure during and after the constructional phase was discussed. It is explained that the results of the analysing the mathematical models of the structure shows great differences with the data which has been recorded by the monitoring system. Particularly in this study, the comparisons between the analysing and monitoring results show that the maximum difference in the absolute value of the results is %80 and in the relative values is %30. Safety of the two historical edifices after the constructing the tunnels through their original foundation show the capabilities of the chosen methods.

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