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A Study on Shavadoon Underground Living Space in Dezful and Shooshtar Cities, Southwest of Iran: As a Sample of Sustainable Vernacular Architecture

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***Abstract*—**Shavadoon is a type of underground living space, formerly used in urban residences of Dezful and Shooshtar cities in southwestern Iran. In spite of their high efficiency in creating cool spaces for hot summers of that area, Shavadoons were abandoned, like many other components of vernacular architecture, as a result of the modernism movement. However, Shavadoons were used by the local people as shelters during the 8-year Iran-Iraq war, and although several cases of bombardment happened during those years, no case of damage was reported in those two cities. On this basis, and regarding the high seismicity of Iran, the use of Shavadoons as post-disasters shelters can be considered as a good issue for research. This paper presents the results of a thorough study conducted on these spaces and their seismic behavior. First, the architectural aspects of Shavadoon and their construction technique are presented. Then, the results of seismic evaluation of a sample Shavadoon, conducted by a series of time history analyses, using Plaxis software and a set of selected earthquakes, are briefly explained. These results show that Shavadoons have good stability against seismic excitations. This stability is mainly because of the high strength of conglomerate materials inside which the Shavadoons have been excavated. On this basis, and considering other merits of this components of vernacular architecture in southwest of Iran, it is recommended that the revival of these components is seriously reconsidered by both architects and civil engineers.

***Keywords*—**Shavadoon, Iran high seismicity, Conglomerate, Modeling in Plaxis, vernacular sustainable architecture.

I. Introduction

SHAVADOON, is one of the various types of underground living spaces formerly used by residents of two old cities in southwestern Iran, Dezful and Shooshtar. For many centuries Shavadoons were used by the people as efficiently-ventilated and comfortable spaces, with high efficiency in hot weather seasons of that area of Iran. However, by modernism movement people stopped employing several components of vernacular architecture, including Shavadoons, in their residential buildings. Nevertheless, during the war between Iran and Iraq, which lasted for eight years, the local people used Shavadoons as shelters against the bombardments. The interesting points is that no case of damage was reported in spite of several cases of air attacks to those two cities during that the war. Regarding this good strength on the one hand, and the high seismicity of Iran, on the other, Shavadoons can be considered as reliable post-disasters shelters in case of occurrence of large earthquakes. This usage can be considered as a special case of revival of vernacular architecture as well.

As Singh and colleagues (2009), [1], and Zhai and Previtali (2010), [2], have stated, in old countries with rich history, like Iran, Vernacular architecture, has several advantages of which compatibility with climate and environment, accessibility and workability of construction materials are more worth to mention. However, there are some shortcomings such as low seismic resistance in some of the traditional buildings, particularly houses in rural areas, which has discouraged the community from using that type of architecture, so that it has been totally abandoned. This is while vernacular architecture has several advantages that make it reasonable to try to resolve its few shortcomings, by architects and civil engineers, to benefit from its merits.

Some researchers have worked on revival of vernacular architecture since early 70s, and later in mid 90s, among which Rahmiyeh and Roboobi (1974), [3], and Kimura (1994), [4], can be mentioned. In recent decade revival of vernacular architecture has drawn more attention particularly in old countries with rich history, like Iran.

Mottaki and Amini (2013), [5], have studies the cultural sustainability patterns in vernacular architecture with a case study of Guilan province in northern Iran. Mentioning that global sustainable development is facing enormous challenges, and that the United Nation’s World Summit of 2002underscored economic, social, environmental, and cultural actors as the cornerstones of sustainable development, they have emphasized that traditional rural architecture represents an interaction between local culture and vernacular dwellings. They have expressed that local vernacular architecture is a cycle encompassing “life pattern”, “form pattern”, and “nature”. They have discussed that some of these vernacular heritages may have remained stable in the face of a changing world, but some others are threatened with extinction. The purpose of that study was primarily to illustrate cultural sustainable solutions in the vernacular architecture in the northern Iranian province of Guilan, bordering the Caspian Sea, and discuss a number of cultural

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solutions there, including “Dweller as Designer” and “Mutable Geometry". Their conclusion focuses on how the local knowledge of the native residents is in harmony with the environment from sustainability perspective, and also on how people can artistically overcome environmental limitations or natural catastrophes.

Another example of recent researches on revival of vernacular architecture has been conducted by Babsail and Al-Qawasmi (2014), who have worked on vernacular architecture in Saudi Arabia and have emphasized the revival of displaced traditions and using vernacular architecture components towards a sustainable future [6].

This paper presents the results of a thorough study conducted on Shavadoons and their architectural merits, and particularly, seismic behavior. For this purpose, first the architectural design aspects of Shavadoon and their construction technique were investigated. Then, by employing Plaxis powerful computer program and using a set of selected accelerograms a series of time history analysis (THA) the maximum strains created in various parts of Shavadoon were obtained numerically and the stability of this underground space was examined. The details of the study are presented in Sections II and III.

II. Architectural Merits of Shavadoons

The main usage of Shavadoon underground shelter has been preventing the habitants from the extensive heat during the summer season, in cities of Dezful and Shooshtar, which have very hot summers. However, during the war between Iran and Iraq from 1980 to 1988, Shavadoons were actually used as safe shelter against air attacks, and proved to a great extent that they are basically safe against air attacks and bombardment.

Furthermore, there is no evidence with regard to Shavadoons' damage due to earthquakes in recent history of the country. Figs 1 and 2 show longitudinal and transverse sections of a Shavadoon and its components schematically, including the main space, the ventilating shaft and the side spaces (which are called Kat by the local people) in an old house.

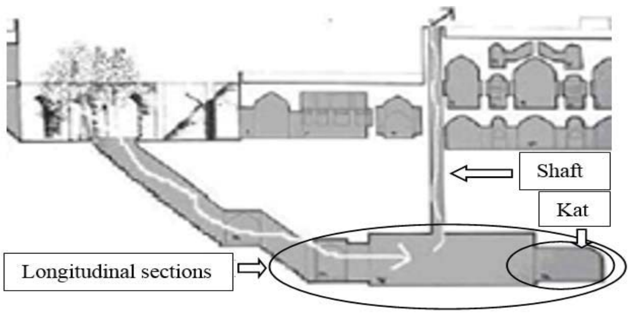

Fig. 1 Longitudinal and transverse sections of a Shavadoon and ventilation shaft and Kat space

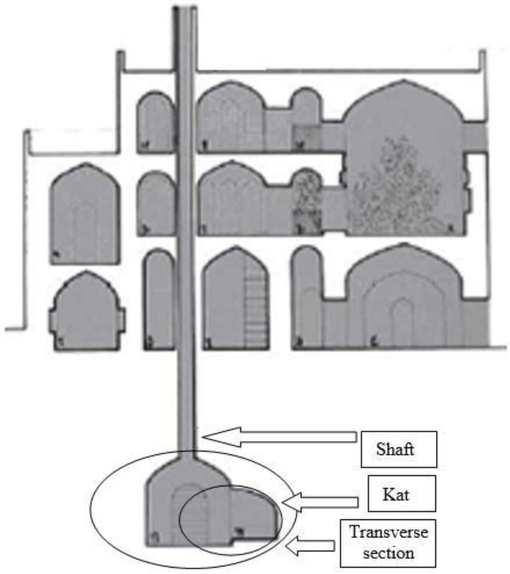

Fig. 2 Transverse section of a Shavadoon and ventilation shaft and Kat space

As the arrows show in Fig. 1, the stairs case together with the ventilation shaft create a path for air current, through which the relatively cool air of the house yard, which is mostly in shadow of the building during daytime, comes down into the Shavadoon and gets cooler there, and then after getting warmer because of the residence of the people inside the Shavadoon, goes up through the ventilation shaft. This air circulation keeps freshness of the air inside the Shavadoon. Hadianpour and colleagues in 2014 have worked on the cooling usage of Shavadoons and their potential use in contemporary architecture [7]. By using the Design Builder software for modeling, they have studied the thermodynamic performance of Shavadoons and their capability for creating the thermal comfort for the residents in past, as well as present time. Based on that study the temperature inside a Shavadoon can be up to 23 degrees lower than the outside temperature in hot summers. More description about the architectural and geometrical features of Shavadoons and related details can be found in a recent paper of the authors [8].

III. Seismic Stability of Shavadoons

To evaluate the seismic stability of Shavadoons, in this study the Plaxis powerful computer program, which is based on discrete element method, was employed. For seismic input, a set of selected accelerograms were considered and scaled and. Then a series of THA were accomplished to obtain the maximum stresses and strains, particularly tensile and shear strains, created in various parts of Shavadoon. Table I presents the used earthquakes and their specifications.

It is seen in Table I that almost all of the selected earthquakes are near-fault ones, and mostly have high to very high intensities. Fig. 3 shows the acceleration, velocity and displacement histories of Kobe earthquakes, as a sample of the considered earthquakes. The corner points at which the response values, including acceleration, stresses and strains were calculated are shown in Figs. 4 and 5, in which the geometry longitudinal section of the analyzed Shavadoon can be seen as well. Fig. 6 shows the effective mean stress distribution around the modeled Shavadoon under a typical masonry building of Dezful and Shooshtar cities.

As Fig. 6 shows the Shavadoon has been considered in a box of the surrounding soil environment, having dimensions of 1.5 times the Shavadoon's dimensions in each direction. These are the dimensions recommended for taking into account the effect of surrounding soil environment on the seismic response of an underground space or structure. It can be seen in Fig. 6 that the effective mean stress has its maximum values at two upper left and upper right corners of the Shavadoon, as expected. However, these values are much lower than the stress level tolerable by the Conglomerate materials of the environment inside which the Shavadoon has been created by excavation. It is also worth mentioning that because of the relatively high stiffness of the Conglomerate material the amount of acceleration in Shavadoon's corners are almost the same as the input acceleration as shown in Fig. 7.

TABLE I
EARTHQUAKES USED IN THA OF THIS STUDY

Earthquake	Ms*	Closest Distance to Fault Rupture (km)	PGA** (g)
Northridge P0996	6.7	8	1.285
Morgan hill P0449	6.1	0.1	1.289
Cape Mendocino P0806	7.1	8.5	1.497
Loma Prieta P0770	7.1	6.1	0.563
Kocaeli P1099	7.8	17	0.244
Chi-Chi Taiwan P1424	7.6	14.34	0.104
Coalinga P0414	5.7	9.2	1.083
Coyote Lake P0146	5.6	9.3	0.103
Kobe P1043	6.9	0.6	0.821
Palm Springs P0541	6.0	7.3	0.612
Whittier Narrow P0691	5.7	9.0	3.340
Landers P0873	7.4	1.1	0.785

*Earthquake magnitude in Richter scale based on surface waves
** Peak Ground Acceleration

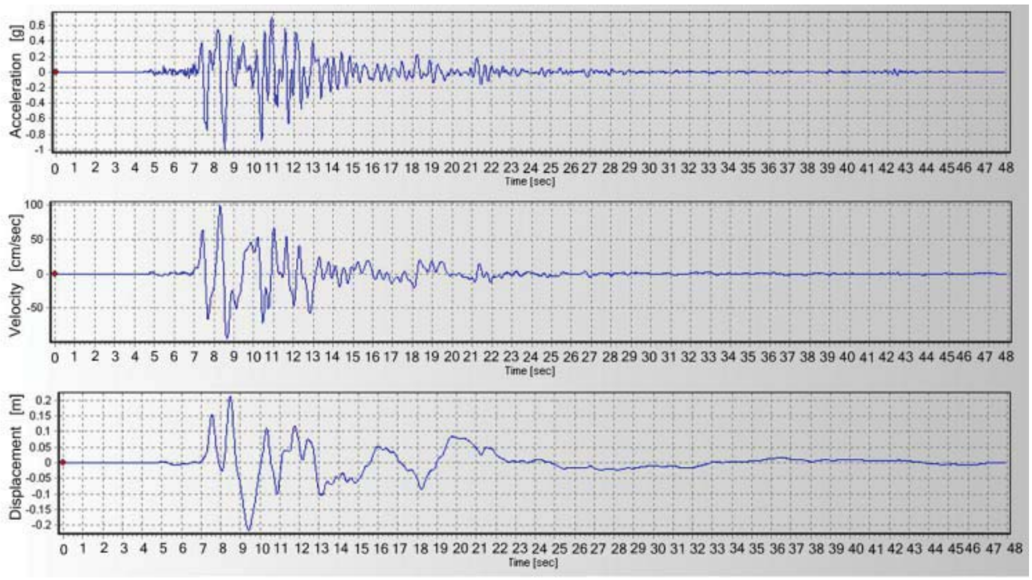

Fig. 3 Acceleration, velocity and displacement histories of Kobe earthquakes, as a sample of the considered earthquakes

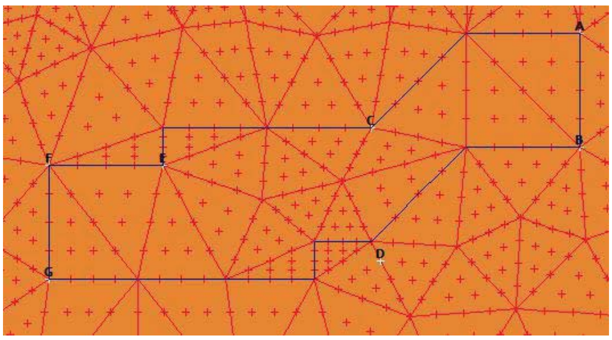

Fig. 4 The longitudinal section of the Shavadoon and the points at its left face at which stress and strain values has been calculated

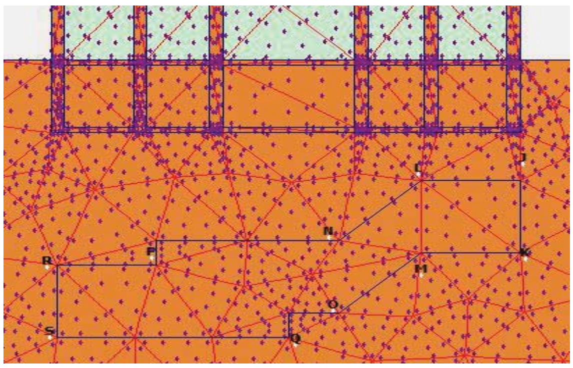

Fig. 5 The points at the right face of the Shavadoon at which stress and strain values has been calculated

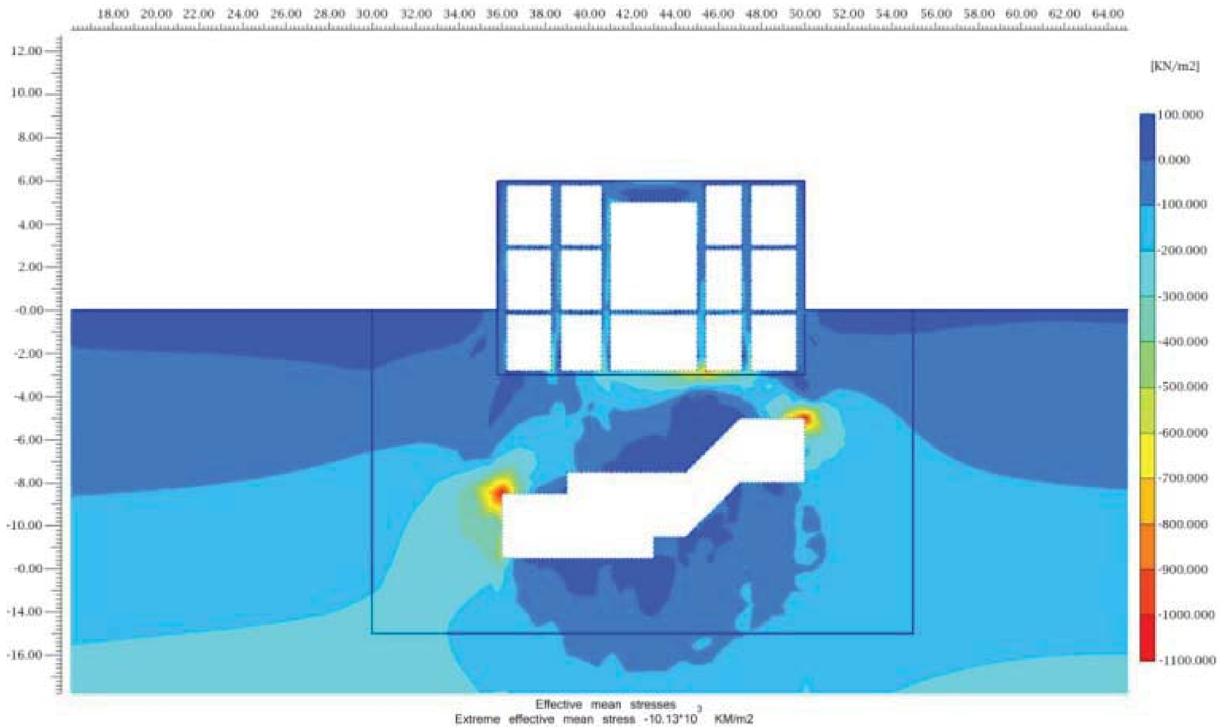

Fig. 6 Geometry of the analyzed Shavadoon and the effective mean stress values around it, subjected to Kobe earthquake

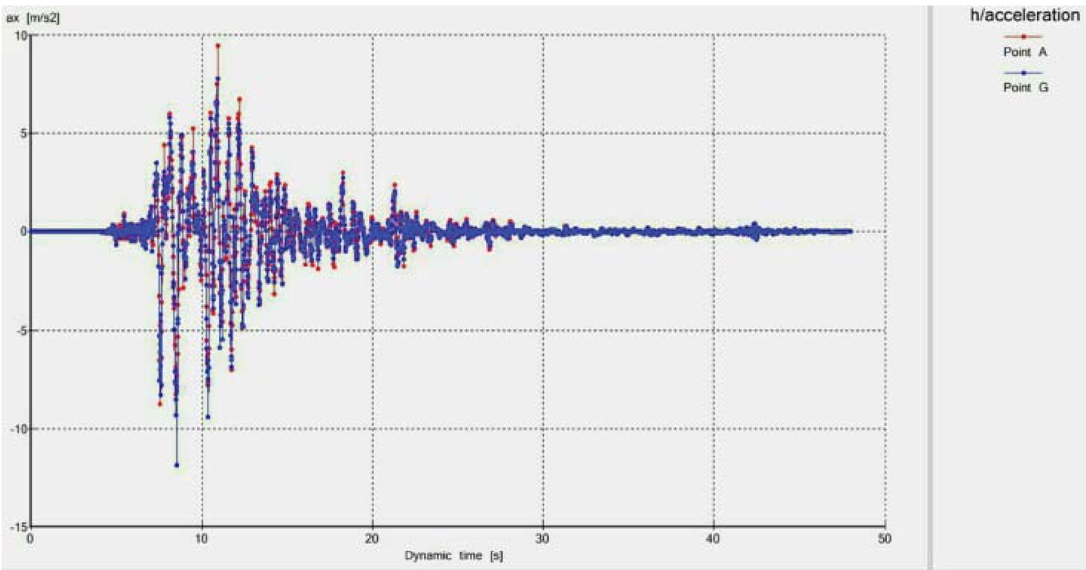

Fig. 7 Acceleration histories at two lower and upper points of the Shavadoon subjected to Kobe earthquake

As it can be seen in Fig. 7, there is only a little difference between the acceleration values at points A at the top of the Shavadoon and Q at its bottom. As other two important response values, Figs 8 and 9 shows respectively the time histories of shear stress and shear strain at various points at the boundaries of the Shavadoon subjected to accelerograms of the Kobe earthquake, as a typical sample of the considered earthquakes.

As it is seen in Fig. 9, shear strain value at each one of the considered points, after some fluctuations at the build-up phase of the earthquake, reaches a specific maximum value during the strong ground motion, and then remains constant at that maximum values till the ending instant of the earthquake. Of course, the amount of this plastic strain is much lower at points Q and S, which are at the bottom of the Shavadoon, than points R and J, which are at its upper boundary. These constant values are because of the plastic behavior of the ground material. Consequently, due to these plastic strains, some permanent deformations occur in various points of the Shavadoon, as shown in Fig. 10.

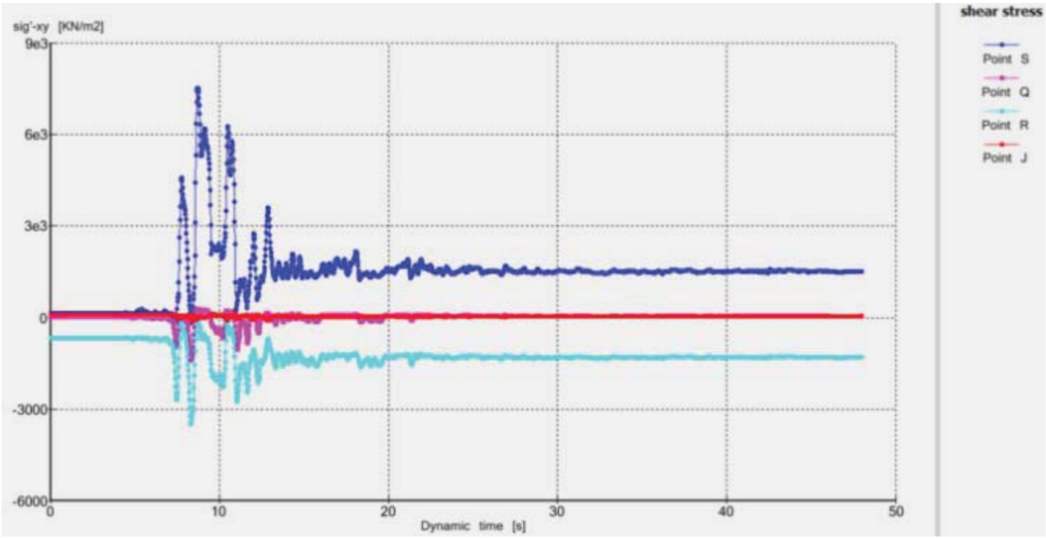

Fig. 8 Time histories of shear stress in various points of the Shavadoon subjected to Kobe earthquake

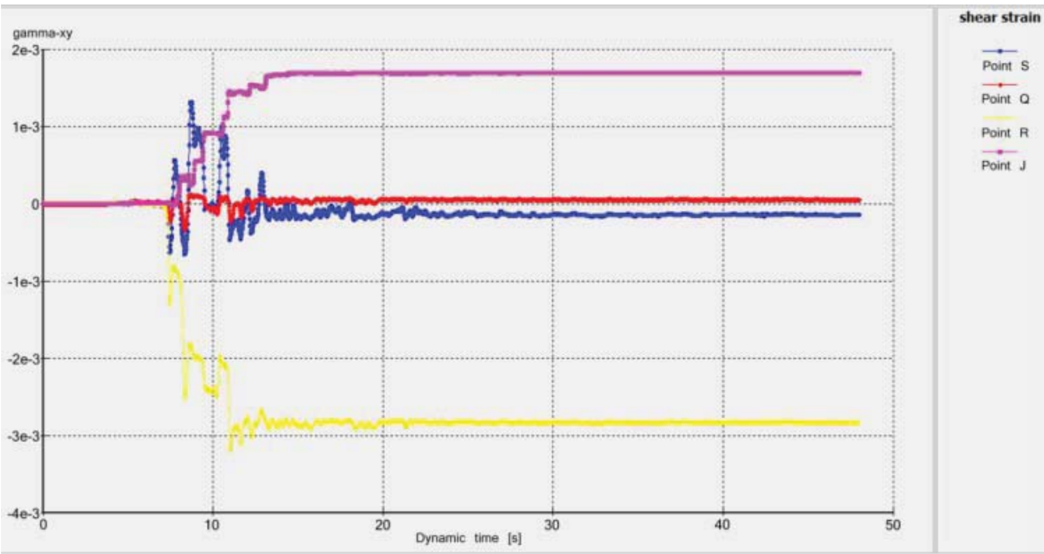

Fig. 9 Time histories of shear strain in various points of the Shavadoon subjected to Kobe earthquake

It is seen in Fig. 10 that the maximum displacement at the upper boundary of the Shavadoon is around 7 cm, which comparing to the height of the Shavadoon, which is around 11 meters, is less almost 0.6%. This amount is quite tolerable for the surrounding materials of the Shavadoon.

IV. Conclusions

Results of the THA, conducted by using several high intensity earthquake records, show that:

- Shavadoons have good stability against seismic excitations.
- This high stability is basically because of the high strength of the materials, which are mostly Conglomerate, inside which these underground spaces have been created by excavation.
- Based on this good resistance against seismic excitations on the one hand, and regarding other advantages of Shavadoons, as the very good sample components of vernacular architecture in Iranian southwestern provinces, and particularly Dezful and Shooshtar cities of Iran, it is recommended that both architects and civil engineers reconsider the revival of Shavadoons.
- Finally, it should be mentioned that this study was carried out on only one of the components of vernacular architecture in Iran. By conducting similar researches on other components of this architecture in Iran and other countries with rich history more desired aspects of vernacular architecture can be found out.

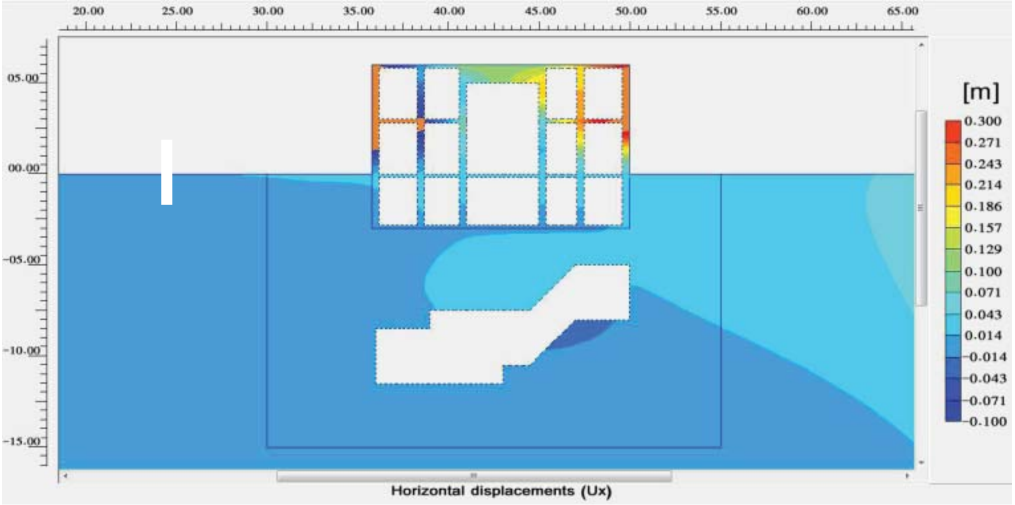

Fig. 10 Displacement time histories in various points of the Shavadoon subjected to Kobe earthquake

REFERENCES

[1] Singh, M. K., Mahapatra, S., & Atreya, S. K. (2009). Bioclimatism and vernacular architecture of north-east India. Building and Environment, 44(5), 878-888.

[2] Zhai, Z. J., & Previtali, J. M. (2010). Ancient vernacular architecture: characteristics categorization and energy performance evaluation. Energy and Buildings, 42(3), 357-365.

[3] Rahimiyeh, F. & Roboobi, M. (1974). Recognition of vernacular city and dwelling in Iran, hot and semi-humid climate, Dezful-Shooshtar, M.Sc. Thesis submitted to School of Architecture, University of Tehran, Tehran, Iran.

[4] Kimura, Ken-ichi. "Vernacular technologies applied to modern architecture."Renewable energy 5, no. 5 (1994): 900-907.

[5] Mottaki, Zoheir, and Iman Amini. "Cultural Sustainability Patterns In Vernacular Architecture: A Case Study of Gilan, Iran." GSTF Journal of Engineering Technology (JET) 2, no. 1 (2013): 106.

[6] Babsail, M. O., & Al-Qawasmi, J. (2014). Vernacular architecture in Saudi Arabia: Revival of displaced traditions. Vernacular architecture: Towards a sustainable future, 99-104.

[7] Hadianpour, Mohammad; Kordjamshidi, Maria and Mansour pour, Majid, Investigating the Cooling Usage of Shavadoons and their Potential Use in Contemporary Architecture, Bi-Seasonal Vernacular Art, Vol. 1, No. 1, Spring and Summer 2014

[8] Okhovat, H., Hosseini, M. and Zaryoun, M. (2015). Disaster-Resiliency Aspects of Vernacular Architecture: Case Study of Dezful, Southwest Iran, Proceedings of 7thIDRiM Conference, Isfahan, Iran, 1-3 November 2016.

Haniyeh Okhovat was born in Tehran in 11th of July 1984. She graduated from high school in Dezful and then entered Tabriz Branch of the Islamic Azad University (IAU), and got her BA in architecture with an average score of 16.30 in 2010. Her BA Project topic was "Architectural Design of City of Dezful's Residences". Then she continued her studies for a MSc degree in Kerman branch of the IAU and finish her MSc studies with an average score of 16.63 and her MSc thesis topic was "Design of a Residential Complex in Dezful Based on Preserving the Vernacular Values".

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