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Evaluation of Mineralogical Characteristics and Erosion of Tous Historic Mud Wall, Ne of Iran

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Abstract: As time passes, ancient buildings are exposed to different types of erosion. Tous historic mud wall is a part of Tous castle, the oldest building in Mashhad plain, northeast of Iran. This paper deals with evaluation of mineralogical characteristics of the wall construction materials and essential reasons for erosion of this great wall. First of all, the different types of erosion which were observed on the wall were investigated. Then XRD analysis was carried out in order to determine the types of minerals and XRF analysis was done to find out the types and amounts of various elements and oxides in the wall materials. 16 samples were tested in this regard. These specimens were collected from different parts of the wall.

Key words: Ancient buildings, Tous historic wall, XRD, XRF, erosion

INTRODUCTION

Mixture of soil and water has been the essential material of historic building industry in the Middle East and many parts of Iran as well. Many researches have been done on mud bricks (Pineda-Pinon, 2005, Binici *et al*., 2005a, Binici *et al*., 2005b, Yetgin *et al*., 2006, Degirmenci, 2007, Demir, 2007, Kouakou and Morel, 2009, Calabria *et al*., 2009). Iranian masons and architects had learned different properties of soils and different ways of mixing them during the last centuries. This can be proved by great and splendid masonry buildings which had been constructed throughout the country. The best example is Arg-e-Bam, the largest mud brick complex in the world which was unfortunately destroyed in 2003 during Bam earthquake (Ramazi and Soltani Jigheh, 2006).

On the other hand, various factors such as climatic conditions, wars, earthquakes, passing the time as well as not paying enough attention to conservation of them, have led to their erosion.

One of the important ancient buildings in the northeastern part of Iran which is dated more than 17 centuries ago is Tous Castle. Tous wall with more than 7 km length is a part of Tous Castle. Tous region is a part of Mashhad plain in Khorasan Razavi province. It is located on northwest of Mashhad city, the second largest city in Iran with a population about 3 million (Fig. 1). Kashafrood is the main drainage system in the plain and Tous castle is situated on north side of this river. The average annual precipitation in the region is about 250 ^{mm} and generally it has a semi-arid to arid climate as suitable condition for this type of structures. There are two different mountain ranges in Mashhad plain, Koppet Dagh on north and Binalood on south. Tous region is located on alluvial fan deposited from Koppet Dagh mountain erosion.

The region is classified as moderate to approximately high risky areas for earthquake. There are different active faults around Tous region (Fig. 2). The last violent earthquake in Mashhad city goes back to 1682. It caused severe damage and serious injuries.

In the area, depth of ground water level is high due to overexploiting of ground water in the last decades (Lashkaripour *et al*., 2007). The map of groundwater decline for a period of 30 years in Mashhad plain is presented in Fig. 3. As shows in the map, Tous region has suffered from the maximum values of groundwater draw down in the Mashhad plain.

Tous Historic Wall:

Tous historic castle (Tous historic city in Iranian literature) is the oldest ancient building in Mashhad plain, northeast of Iran. This castle was surrounded by a great wall in order to be protected and safe. This splendid wall with more than 7 ^{Km} length and over 9 ^{m} height had a basic diameter of about 5 to 6 ^{m}. There were at least 4 entry gates along the wall; on north, south, east and west. They were called Razan gate, Roodbar gate,

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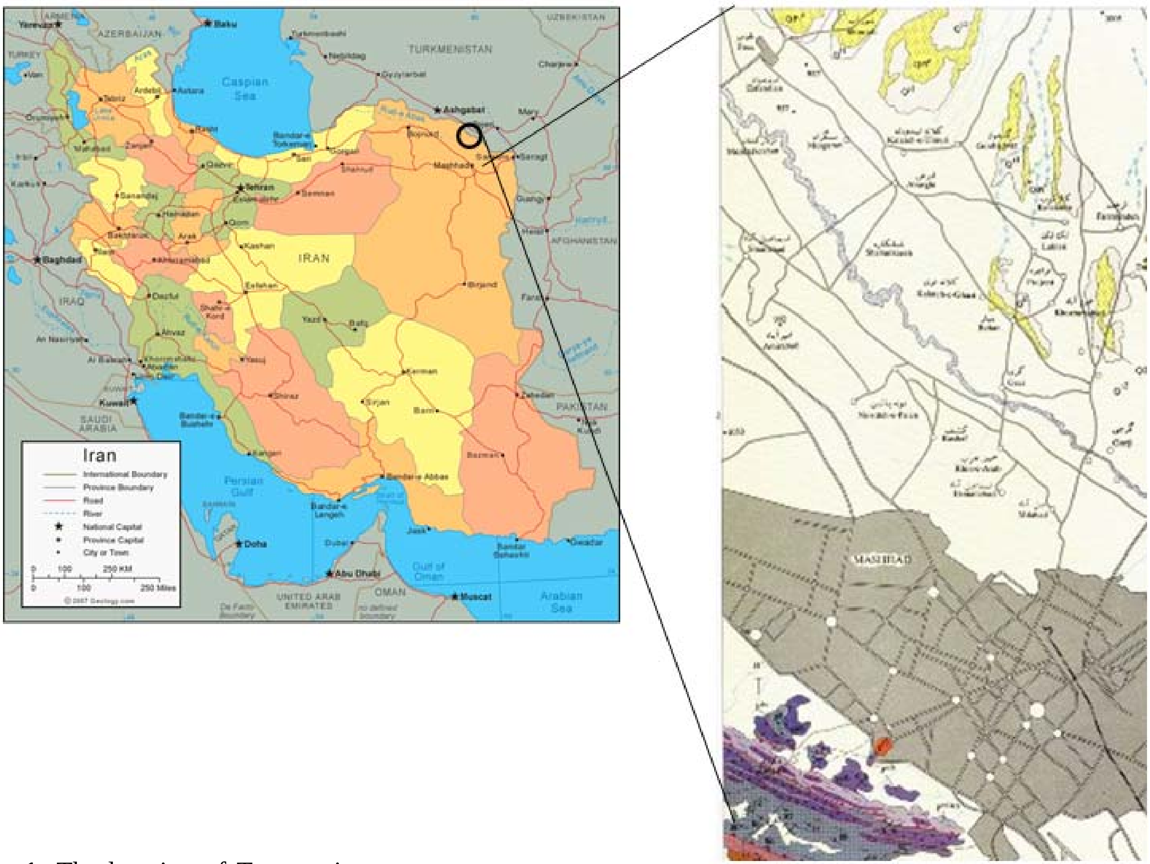

Fig. 1: The location of Tous region.

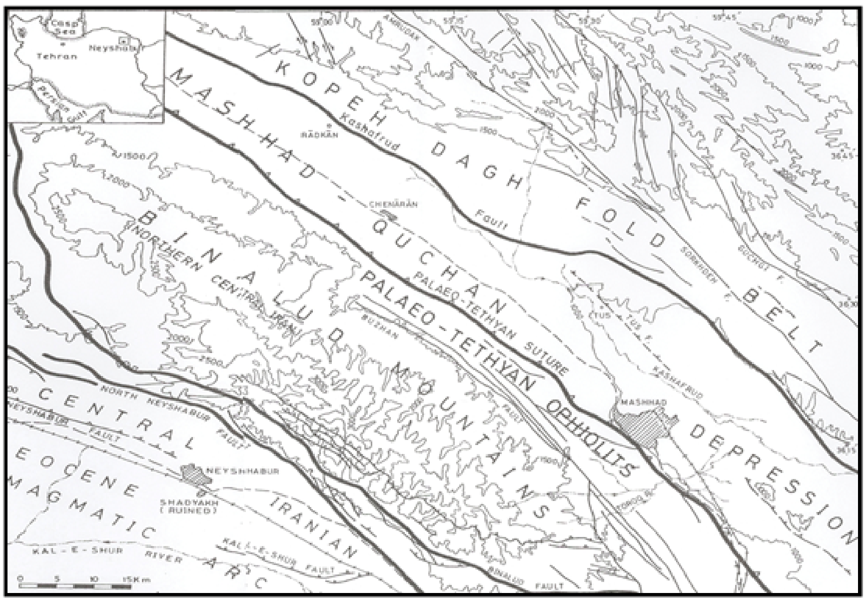

Fig. 2: The map of faults around Tous region (Berberian, 1981).

Marv gate and Neyshaboor gate respectively. The wall was mainly constructed with mud bodied called in Persian, Cheeneh. Of course some parts of it were subsequently repaired by using adobes. There is no accurate time for the construction period of the wall but archaeologists believe that it goes back to more than 17 centuries ago. Unfortunately, nowadays, there are just separated parts remained.

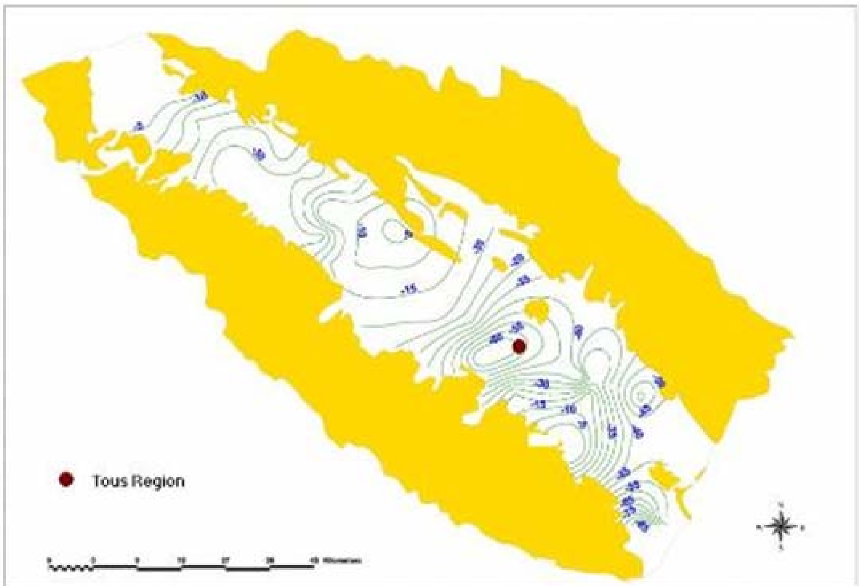

Fig. 3: The map of groundwater decline for 30 years in the plain.

Wall Erosion and Failure:

Different types of erosion and decay affect earth structures. The same mechanisms of erosion which affect other building materials, operate on earth ones but the effects generally are very much faster. Warren reported that the general agencies of failure in earth structures are as follows: 1) water penetration 2) plant growth 3) human agencies and animals 4) wind (Warren, 1999).

The same as other historic buildings, Tous wall could not be safe from decay. The failures observed on the wall are as follows (Nasseh, 2010):

Failure induced by upward water infiltration (Fig. 4): High ground water table can cause such failure but Tous region has a low ground water table. It seems that the main factor which has led to such failure is the lack of a convenient drainage system at the bottom of the wall. Run-off water can penetrate into the wall and consequently induces different cracks at its bottom. Applying a proper drainage system can reduce the consequences of run-off water.

Failure induced by downward water infiltration (rainfall) (Fig. 5): Despite a mixture of clay and straw coating, Tous wall has a rough top surface. This is definitely caused by raining and snowing. It seems that applying a coating of high quality can decrease the damage caused by rainfall.

Failure induced by rat and termite activities (Fig. 6): Termites can survive in places with sufficient water and organic matter such as straw. Small animals leave less evidence of their depredations but can be more damaging. In the region, termites have created burrows through the wall structure. These burrows can provide a suitable place for water infiltration and also can cause the loss of wall bearing capacity. The same but much larger burrows have been created by rats in the wall. Animals contribute actively to the decay of earth structures but of all erosive agencies, they are the most easily controlled. Rats can be controlled by using traps and special poisons. There are special poisons for reducing termite population too. Moreover, physical and chemical protectors can be useful (Ghayoorfar *et al*., 2008).

Failure induced by wind accompanied by rain (Fig. 7): Wind can cause rain drops erode the wall surface. This problem can also be decreased by a resistant coating or covering.

In addition to the mentioned failures, during its long life, different wars, earthquakes and human activities have led to more decay in the wall.

Test Methods:

Different types of clay minerals play different roles in clay soil erosion and decay. In order to identify the clay mineral, different analyses such as x-ray diffraction (XRD) and x-ray fluorescence (XRF) can be conducted. XRD is a method for identifying the mineral type when XRF is an approach for determining the types and amounts of various elements and oxides. In this paper, XRD and XRF analyses were carried out in

Fig. 4: Failure induced by water penetration down upward on Tous wall.

Fig. 5: Failure induced by water penetration up downward on Tous wall.

Fig. 6: Failure induced by rat activities on Tous wall.

Fig. 7: Failure induced by wind accompanied by rain on Tous wall.

order to evaluate the mineralogical properties of construction materials in Tous wall. For this purpose, 16 samples were collected from different sides of the wall. Fig. 8 shows the sample locations.

RESULTS AND DISCUSSIONS

XRD analysis was carried out on the collected samples in order to identify the mineral types of the wall construction materials. Table 1 shows the results of XRD analysis. Based on the results, none of the samples

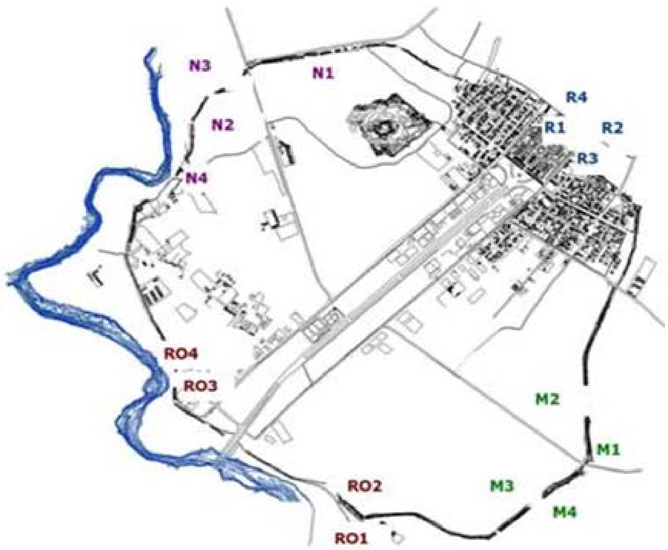

Fig. 8: Relative locations of different samples.

includes montmorillonite which could be problematic. Montmorillonite can be expanded by absorbing a lot of water and because of that, causes many cracks and failures. The clay type of samples is illite that is not so problematic. Also chamosite from chlorite group is not so harmful.

XRF analysis was conducted in order to determine the types and amounts of elements and oxides in the wall materials. The results of principal oxides and chlorine are presented in table 2. The XRF results of samples are so similar to each other that show the similar source of materials of the tested samples. The values of LOI (loss on ignition) in the samples are high which is due to unbaked materials as well as high amounts of $CaCO_3$. The presence of calcite in XRD results, verify this matter. SiO_2 involves in composition of different silicates when heating over $700^{\circ c}$ (Sanchez Ramos *et al*., 2002). But as the wall materials are not baked, it is expected to have quartz instead of high-temperature silicates in the results. As it is expected, the XRD results, show quartz in the main phase. Moreover, considerable concentrations of CaO and MgO in the samples may indicate a dolomitic and calcareous source for the raw materials. The sediments resulted from Koppet Dagh mountain erosion which have been deposited near Tous region, are marl-calcareous. It is likely that these sediments had been the source of raw materials for constructing Tous historic wall.

Table 1: XRD analysis results

Sample No.	Qtz. Maj. Ph	Cal. Maj. Ph	Ab. Maj. Ph	Or. Maj. Ph	Ill. Min. Ph	Cham. Min. Ph	Or. Min. Ph	Dol. Min. Ph	Gyp. Min. Ph	Hal. Min. Ph	Syl. Min. Ph	Hem. Min. Ph
R1	*	*	*		*	*	*	*	*	*		
R2	*	*	*		*	*	*	*	*	*	*	*
R3	*	*	*	*	*	*		*	*			
R4	*	*	*		*	*	*	*				
M1	*	*	*		*	*	*	*			*	
M2	*	*	*		*	*	*	*				
M3	*	*	*		*	*	*	*				
M4	*	*	*		*	*	*	*		*	*	
N1	*	*	*		*	*	*	*				
N2	*	*	*		*	*	*	*				
N3	*	*	*		*	*		*				
N4	*	*	*		*	*	*	*		*		*
RO1	*	*	*	*	*	*		*				
RO2	*	*	*		*	*	*	*		*		
RO3	*	*	*		*	*	*	*				
RO4	*	*	*	*	*	*		*		*		

In order to evaluate some of the reasons for Tous wall erosion, a comparison was made between the amounts of principal oxides in a typical china clay and the same amounts in Tous wall; because heating process does not affect the amount of elements and oxides and merely changes the types of minerals as well as LOI (Cultrone *et al*., 2001). Percents of principal oxides in a typical china clay are presented in Table 3.

Table 2: XRF analysis results

oxideEl. No.	SiO_2 %	Al_2O_3 %	Na_2O %	MgO %	K_2O %	TiO_2 %	MnO %	CaO %	P_2O_5 %	Fe_2O_3 %	SO_3 %	Clppm	LOI %
R1	35.8	7.6	4.28	4.48	1.55	0.58	0.1	17.67	0.17	5.05	1.93	10793	19.69
R2	37.74	8.22	2.72	4.21	1.67	0.6	0.1	18.55	0.18	5.2	1.16	6025	19.04
R3	41.5	8.79	1.47	3.88	1.75	0.62	0.1	18.43	0.14	5.28	0.9	963	17.04
R4	44.43	9.46	0.93	3.84	1.86	0.69	0.11	17.62	0.12	5.81	0.05	62	15.07
M1	36.5	9.59	1.02	3.87	2.09	0.6	0.1	18.41	0.18	5.83	0.06	5202	21.23
M2	35.11	8.96	1.77	3.71	2.04	0.59	0.11	19.45	0.16	5.69	0.38	5042	21.52
M3	37.19	9.49	1.22	4.05	2.13	0.65	0.12	17.72	0.21	6.22	0.22	2583	20.54
M4	35.46	9.32	3.6	3.96	1.98	0.58	0.1	16.75	0.16	5.52	0.1	17238	20.76
N1	38.95	9.01	1.05	3.7	2.12	0.58	0.09	19.13	0.32	5.12	0.18	2223	19.54
N2	35.82	7.98	1.73	3.56	1.94	0.57	0.1	20.68	0.34	5.04	0.48	4724	21.3
N3	35.21	9.11	0.7	3.48	2.07	0.53	0.09	21.09	0.19	5.06	9.09	1783	19.22
N4	37.76	9.38	1.33	3.77	2.01	0.62	0.11	18.58	0.18	5.7	0.1	5837	19.9
RO1	40.1	9.63	0.68	3.65	2.17	0.62	0.11	18.57	0.23	5.68	0.07	238	18.47
RO2	36.5	9.52	0.85	3.3	2.13	0.6	0.11	17.67	0.19	5.72	0.11	3302	22.97
RO3	41.29	9.94	1.01	3.72	2.03	0.61	0.1	16.96	0.21	5.44	0.11	2879	18.28
RO4	38.77	9.37	4.53	3.38	1.93	0.63	0.1	16.51	0.17	5.42	0.05	13488	17.79

Existence of Na ion in the soil is the main factor of dispersion potential in fine-grained soil. As it can be seen from table 4, the value of Na_2O in a typical china clay is much less than the same values in the wall samples. So, high values of Na_2O in the wall materials might have been one of the reasons of its erosion. Furthermore, the amount of salt in the wall materials can be another factor in erodibility of the wall. In order to evaluate this factor, the amount of chlorides was calculated for each sample. The calculation method was based on the following equation:

$$(\text{Cl (ppm)}/10^6) \times 100 = \text{Cl\%} \times 2 = \text{Chloride\%}$$

Where Cl (ppm) is the amount of chlorine based on XRF results.

In the above equation, after calculating the amount of chlorine in percent, the same amount is taken from Na_2O for halite and from K_2O for sylvite and is added to the percent of chlorine. That is why chlorine percent has been multiplied at 2. NaCl is the chemical formula for halite and KCl is for sylvite. The weight ratio between Na or K and Cl is 1:1. The calculation results are shown in table 4.

Table 3: Percents of principal oxides in a typical china clay (Worrall, 1986).

Composition	SiO_2	Al_2O_3	Na_2O	MgO	K_2O	TiO_2	CaO	Fe_2O_3	LOI
%	46.29	38.38	0.15	0.59	0.51	0.02	0.61	0.30	13.59

Table 4: The amount of chlorides in the samples.

Sam. No.	R1	R2	R3	R4	M1	M2	M3	M4	N1	N2	N3	N4	RO1	RO2	RO3	RO4
Chloride%	2	1.2	0.18	0.012	1	1	0.4	4	0.4	0.8	0.4	1.2	0.04	0.6	0.6	2

As it is shown in Table 4, the amounts of chloride in some of the samples are considerable. This might have been the other factor in increasing erodibility of the wall.

Conclusions:

Based on the results of this research, the main factors of failure on Tous historic wall are as follows:

1. Failure induced by upward water infiltration
2. Failure induced by downward water infiltration
3. Failure induced by rat and termite activities
4. Failure induced by natural phenomena such as wind, rain and earthquakes
5. Failure induced by human activities and wars.

Based on XRD analysis, it can be concluded that the swelling potential is not so problematic because there is no montmorillonite in clay mineral contents of the samples.

The results of XRF analysis on the wall samples are as follows:

1. The XRF results are so similar to each other that show the similar source of them.

2. The values of LOI in the samples are high which is due to unbaked materials as well as high amounts of $CaCO_3$.
3. Considerable concentrations of CaO and MgO may indicate a dolomitic and calcareous source for the raw materials just like Tous nearby sediments which had been eroded from Koppet Dagh Mountain.
4. Higher values of Na_2O in the wall materials rather than in a typical china clay can be one of the factors involved in the wall erosion.
5. The considerable amounts of chloride salts in some of the samples might have been the other factor in increasing erodibility of the wall.

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REFERENCES

Berberian, M., 1981. Active faulting and tectonics of Iran. In: Gupta, H.K. & Delany, F.M., (eds), Zagros-Hindukush. Himalaya Geodynamic evolution. Am. Geophys. Union and Ged. Soc. Am., Geodynamics Series, 3: 33-69.

Binici, H., O. Aksogan, M.N. Bodur, E. Akca, S. Kapur, 2005a. Thermal isolation and mechanical properties of fibre reinforced mud bricks as wall materials, Construction and Building Materials, 21: 901-906.

Binici, H., O. Aksogan, T. Shah, 2005b. Investigation of fibre reinforced mud brick as a building material, Construction and Building Materials, 19: 313-318.

Calabria, J.A., W.L. Vasconcelos, A.R. Boccaccini, 2009. Microstructure and chemical degradation of adobe and clay bricks, Ceramics International, 35: 665-671.

Cultrone, G., C. Rodriguez Navarro, E. Sebastian, O. Cazalla, M.J. De La Torre, 2001. Carbonate and silicate phase reactions during ceramic firing, Eur. J. Mineral., 13: 621-634.

Degirmenci, N., 2007. The using of waste phosphogypsum and natural gypsum in adobe stabilization, Construction and Building Materials, 22: 1220-1224.

Demir, I., 2007. Effect of organic residues addition on the technological properties of clay bricks, Waste Management, 28: 622-627.

Ghayoorfar, R., Poor S. Mohammadi, L. Hasan Abadi, M. Saffar, 2008. Biologic agents in historic buildings decay, The Organization of Cultural Heritage Publications, Yazd, Iran, (in Persian).

Kouakou, C.H., J.C. Morel, 2009. Strength and elasto-plastic properties of non-industrial building materials manufactured with clay as a natural binder, Applied Clay Science, 44: 27-34.

Lashkaripour, G.R., M. Ghafoori, A. Bagherpour, L. Talebian, 2007, Mashhad ground water table draw down and its effect on ground settlement, Proceeding of The First Applied Geology Congress, Iran, 2: 916-922, (in Persian).

Nasseh, S., 2010. Identification of a proper resource for supplying fine grained construction materials in order to renovate Tous historic wall, M.Sc. thesis in Engineering Geology, Ferdowsi University of Mashhad, Iran, (in Persian).

Pineda-Pinon, J., J.T. Vega-Duran, A. Manzano-Ramirez, J.F. Perez-Robles, H. Balmori-Ramirez, M.A. Hernandez-Landaverde, 2005. Enhancement of mechanical and hydrophobic properties of adobes for building industry by the addition of polymeric agents, Building and Environment, 42: 877-883.

Ramazi, H., H. Soltani Jigheh, 2006. The Bam (Iran) earthquake of December 26, 2003: from an engineering and seismological point of view, Journal of Asian Earth Sciences, 27: 576-584.

Sanchez Ramos, S., F. Bosch Reig, J.V. Gimeno Adelantado, D.J. Yusa Marco, A. Domenech Carbo, 2002. Application of XRD, XRF, thermal analysis and voltammetric techniques to the study of ancient ceramics, Anal Bioanal Chem., 373: 893-900.

Warren, J., 1999. Conservation of earth structures, Butterworth-Heinemann Publications, 1st edition.

Worrall, W.E., 1986. Clays and ceramic raw materials, Elsevier Applied Science Publishers, 2nd edition.

Yetgin, S., O. Cavdar, A. Cavdar, 2006. The effects of the fiber contents on the mechanic properties of the adobes, Construction and Building Materials, 22: 222-227.