

Mohammad Mehdi MASOUMI¹**SHAHR-I SOKHTA AND ITS MASONRY WALLS FROM STRUCTURAL AND SEISMICITY STANDPOINT****Abstract**

Shahr-I Sokhta, Burned City, located in the south of Zabol, Sistan where founded circa 3200 BCE and some part of the city was burnt. Marvelous finds such as the world's earliest known artificial eyeball, the first animation in the world, the oldest known backgammon, with its dice and so forth all in this city. Their expertise was merely not in handicrafts. In this work provided evidences which Burned City's walls are highly resistance against seismic loads and has engineering aspects, a wall was simulated by a finite element software and seismically considerations was approve the walls minimal deformation even after circa five thousand years.

Keywords

Shahr-I Sokhta (Burned City), masonry walls, structural and seismicity viewpoint on the masonry walls.

1 INTRODUCTION

In Sistan Province on the way of Zabol-Sistan, about 65 km south of Zabol Shahr-I Sokhta is located, one of leading archaeological sites and the most significant Bronze Age site in the west of Iran with great antiquity nearly 5200 years old, with a total area of 151 ha. [1, 2] and with Spanning more than 300,000 hectares [3]. This city is founded near a branch of the Helmand River in 3200 BCE, being currently parched. The city abandoned approximately a millennium later. The historical name of the site is unknown so far, however, S. Sajjadi (head of archeologist is Burned City) is said to be two ideas among archaeologists, first is Aratta is the Sumerian name refer to Shahr-my Sokhta [5, 6] that might have been located at Shahr-I Sokhta [7], but other archaeologists don't believe [5]. The name has to part in Persian which "Shar" and "Sokhta" respectively mean city and burnt". This name was given when a great of burnt material found on the surface [4] regarding to the last report of S. Sajjadi this city was burnt least three times [8].

Outstanding archaeological finds at Shahr-I Sokhta

In Shahr-I Sokhta, Burned City, metallurgy has developed such as smelting improvements developed into the disc ingots and round slag-cakes, in the third millennium [9]. There was a center for the production of bronze tools and objects [2]. The first animation in the world, a drawing on a pottery has shown in five pictures of a goat as it goes toward a tree step by step[8, 10] a primitive dice found there which look like belong to early backgammon game [11]. In Burned City there has been signs of the first brain surgery and other surgical operations, for instance, cesarean section and procedures to treat breast cancer in ancient Persian civilization [12]. In 2006, the world's earliest known artificial eyeball was discovered [13]. In first excavation at Shahr-I Sokhta pottery pipes found, with water supply or sewer role. It was the fault of archaeologists that they had not determined the liquid inside the pipes [5, 6]. A further premier feature of Shahr-I Sokhta is city division that S. Sajjadi believed this is unique among that era. All foremost finds at Shahr-I Sokhta just excavated

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from a few parts of the city. Most archaeological potential focused on cemetery part, due to from an archaeological point of view, cemetery has taken precedence over other parts [5].

City Layout

The grid pattern, the most patterns expanded across the world, with straight streets intersecting others at right angles which was the major pattern in Mohenjo-Daro Harappa [14] and Burned City. The grid is probably the simplest form of planned settlement design [15]. Burned City layout showing in Figure 1, Burned City or Shahr-I Sokhta, were divided into some close quarters such as, craftsmen quarters in the northwest, monumental quarters in the north part, graveyard located in the south and the north of flint and chert production area, and major residential quarters in the east where some houses had burnt, moreover, settlement parts cover most of the other parts, in addition a small part in the southeast, all were depicted in figure 1 which S. Sajjadi represented in his reports.

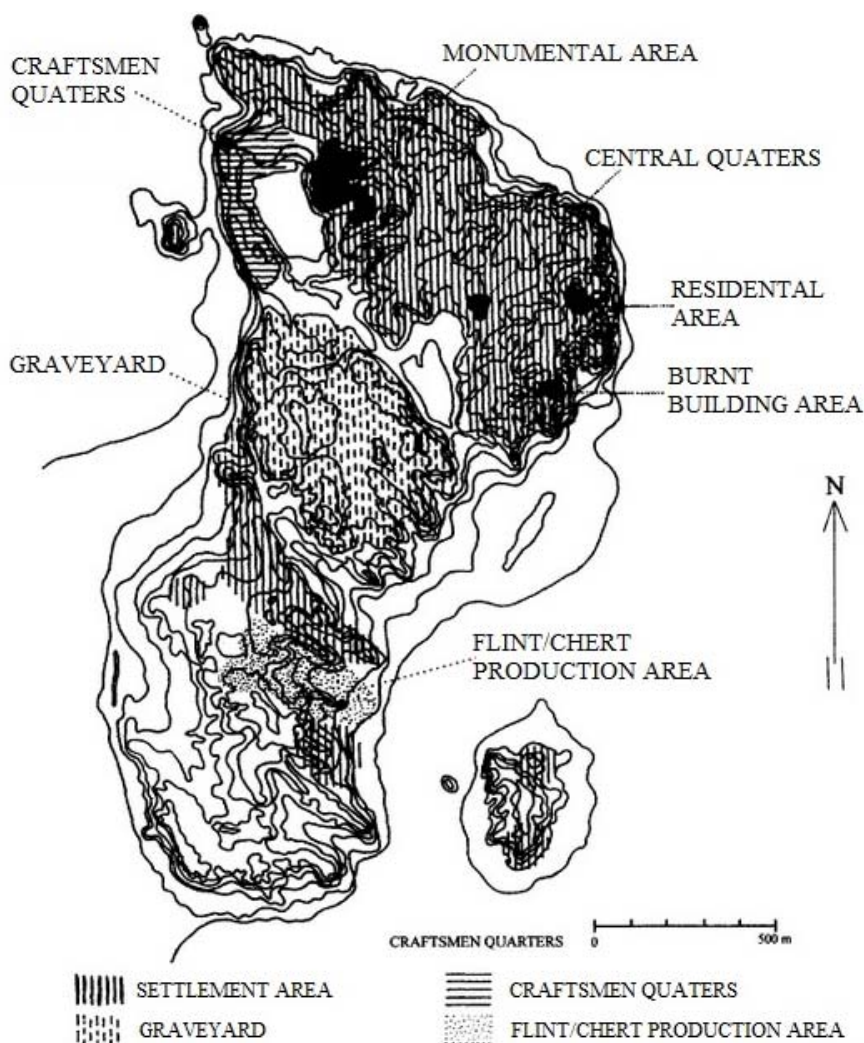


Figure 1: The city quarters [16]

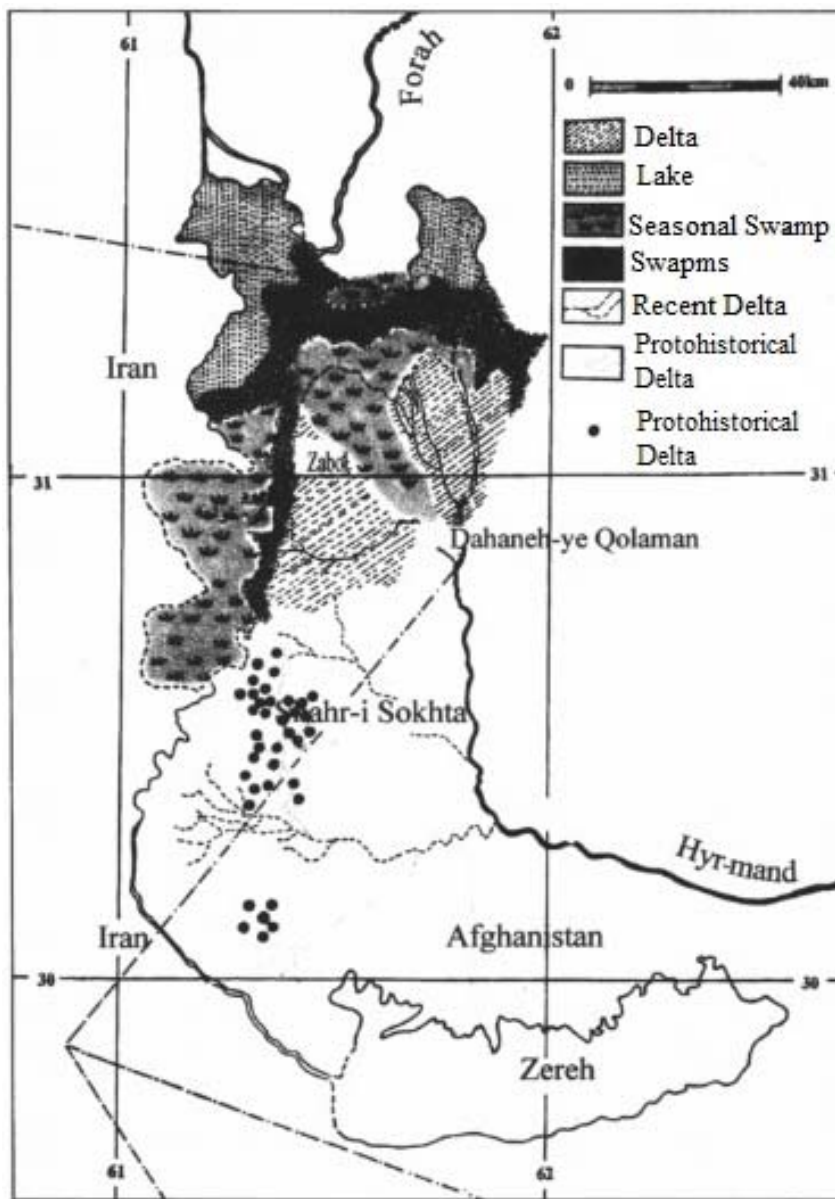


Figure 2: The city geographical location [16]

Figure 2 portrayed early geographical location of Burned City. When most ancient cities were highly depended to the nearest water reservoir, especially cities located close to the basin of the rivers or lakes and deltas due to agriculture. From more or less archaeological point of view the cities had abandoned when the river basin changed and even when the river was arid such as what had happened to Shahr-I Sokhta led to forsake circa 2100 to 1900 BCE. Before deserting the north of the city where was Hamun Lake, fed by the Helmand River, their locations pictured in Figure 2. Consequently, with juxtaposing Figure 1 and Figure 2, cogently inferred that the north of Burt City is more populated because of its proximity to the lake and in all probability that is why the central part of the city, the residential quarters, and the city monumental quarters were located at the north of Burned City. One of the major crafts was the pottery which needed to water to make, which caused the location of craftsmen quarters at the north, where the lake located. S.Sajjadi said that most

important part for excavation is the grave yard which took priority to other quarters and that is why the residential quarter has not properly been excavated so far.

This paper attempts to show the masonry walls of Shahr-I Sokhta regarding to all aspects such as structure of the masonry, seismicity and structural viewpoint of thinness wall of the city made with header course of adobes. Although the adobe mechanical behavior is highly depend on the type of soil used in. Analyzing of the adobe behavior represent a demanding numerical modelling with the respect to lack of material properties and information. Regarding to the earthen and pottery finds was conjectured building materials were clay.

2 MASONRY WALL DESCRIPTION

The grid plan of the rectangular adobes had pivotal roles. However, Burned City is an earthquake prone-zone, the buildings walls were structurally sound except some parts, such as animals burrowing and soil erosion expectedly. Furthermore, substantial regions of the city filled with sand because of seasonal sandstorms. All walls in the city had been made with adobes and cob or mud used as mortar and wall plaster Figure 3, 4A and 4B. The adobe dimensions, $10_{\text{cm}} \times 20_{\text{cm}} \times 40_{\text{cm}}$ which was the same adobes in Indus Valley Civilization. Figure 5 shows a simple well-shaped adobe which used in the same concurrent civilization, Harappa. Therefore, the adobe perception is derived for this study.



Figure 3: The wall made by adobes and some parts were plaster



Figure 4: A and B Rehabilitation of walls [8]



Figure 5: Abode perspective [17]

2.1 The Bonding of Wall Structures in Burned City

A principle of adobe arrangement which no vertical prepend aligns in two consecutive ways. The walls between rooms were the thinnest with mostly the header arrangement while the major walls range between two to four course and rarely five course. In this study the thinnest wall had been taken into account and analyzed with finite element software in order refrain from disfiguring the city's wall.

3 ENGINEERING DATA ASSUMPTION AND APPROACH

By nature, all walls were the unreinforced masonry structure were analyzing regarding to other studies of these structures. In this study Elasticity Modulus, Poisson Ratio, density and compressive strength for adobe respectively are 230 MPa, 0.2, 2040 kg/m³, 1.44 MPa [18]. Compressive strength obtained when the partial of sample wall by universal testing machine and tensile strength supposed 5% of compressive strength [19] moreover elasticity modulus, Poisson ratio, density and compressive strength for cob (mortar) are 216 MPa, 0.2, 1900 kg/m³, 1 MPa to 2 MPa. As, the walls remain sound for long time it is inevitable to conceive that in this study the peak compressive strength was assumed for this study. Static Structural, Transient Structural approaches were assumed for the analyses of the study. In Table 1 succinctly showed all material properties. During the earthquake, some part of the wall compressed and other side stretched, some deformation, that is why the material properties is necessary to know about stress and strains.

Table 1: Material properties

	<i>Elasticity Modulus MPa</i>	<i>Poisson Ratio</i>	<i>Density kg/m³</i>	<i>Compressive Strength MPa</i>	<i>Tensile Strength MPa</i>
Adobe	230	0.2	2040	1.44	0.072
Cob	216	0.2		2	0.2

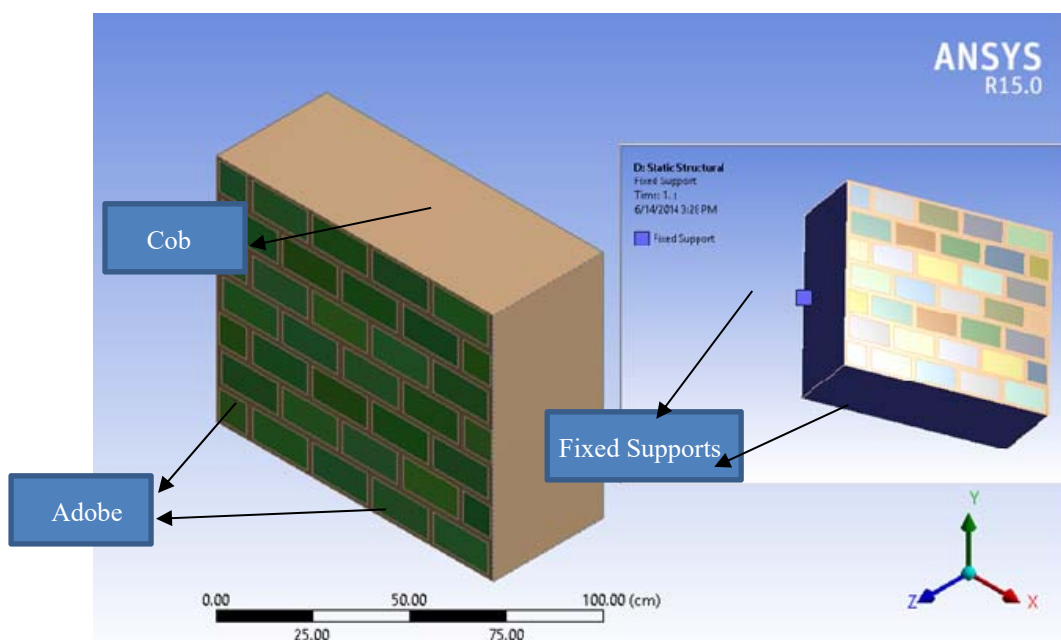


Figure 6: Supports and header course of adobes (green part)

In this study the simulated wall was gone by all above information, with following dimensions $100 \times 85 \times 40 \text{ cm}^3$ portraying in Figure 6 which the adobes are the same size of the city's adobes, with 2 cm mortar thickness which adhered adobe to adobe. All adobes being confining with at least a one-centimeter mortar cover. The wall was fixed at the left side and the bottom, moreover in the software an acceleration was imposed to the bottom of the wall.

4 RESULT AND DISCUSSION

All magnificent findings in Burned City implied a perception that they were highly competent to the extent that their skill had shown in wall structures which had variety thickness at least 40 cm to 100 cm, regarding to the adobe size and the walls. They learned about earthquake and could have constructed a building resist against earthquakes especially in comparison with Indus Valley Civilization where whole city was damaged and leveled by natural hazards several times, such as flood.

The simulated wall was analyzed with modal and transient structure on Z-direction. All the six modes of the wall and their maximum Z-directional deformation showed in Table 2.

Table 2: Modal modes and deformation

Mode	1	2	3	4	5	6
Frequency (Hz)	40.261	89.842	95.751	114.74	116.21	141.24
Deformation (mm)	3.69	0.15	2.85	0.16	3.43	0.28

In transient structure analysis the acceleration direction was parallel to Z-axis, on the face of the wall. The acceleration details was shown in Figure 7. In fact the acceleration data was obtained from peak partial of PEER NGA STRONG MOTION DATABASE RECORD, KOBE 01/16/95 2046, TAKARAZU [20]. The table shows that peak ground acceleration for this research maximum approximate is 0.693g, the magnitude of 8 according to Mercalli intensity scales, it is severe and destructive.

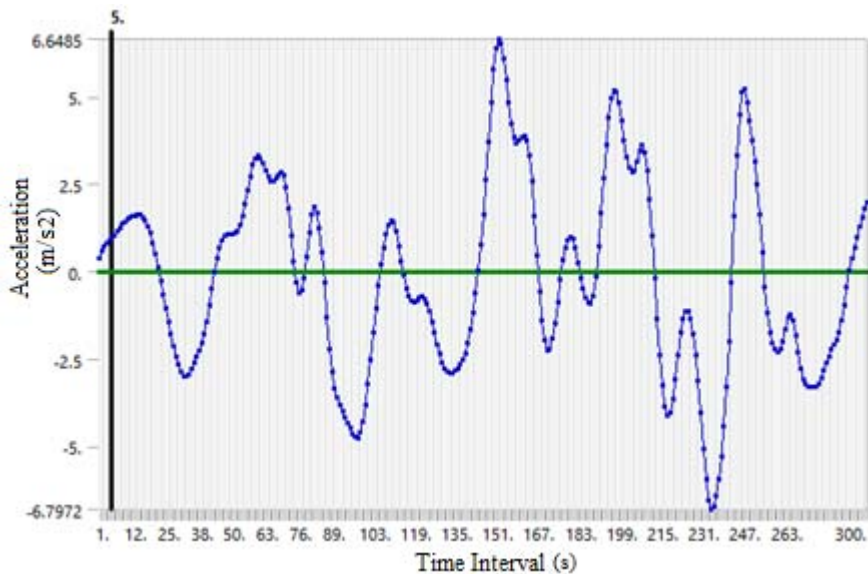


Figure 7: Graph of 300-step acceleration with a time step of 0.1

The wall deformation was taken into the account respect to the acceleration diagram and the result shown in the Figure 8. Minimal deformation of the simulated wall indicates the reason why the walls remains after five thousand years on the structural lateral load viewpoints.

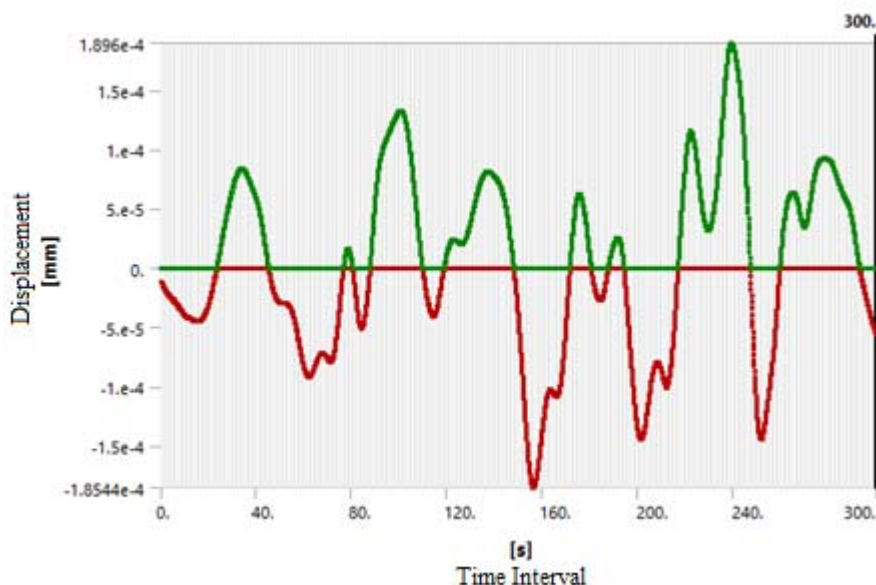


Figure 8: The wall deformation

The maximum stress of the walls was not exceeded 1.85×10^{-5} MPa and 2.64×10^{-6} MPa for normal stress and maximum shear stress respectively, hence the walls have been withstanding against all seismic loads.

5 CONCLUSIONS

One of amazing and mysterious civilization with impressive findings and city structure in the world had constructed highly resistant masonry wall. This study showed how the walls of the Burnt City have been remained for circa five thousand years against earthquakes has been happening. Furthermore, the walls structures manifests that they are more resist even against severe earthquake.

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