Proposal for the retrofit of the world heritage site of Arge Bam after earthquake damage

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ABSTRACT: An earthquake of magnitude 6.5 on the Richter scale with a maximum intensity value of 9 EMS on 26 December 2003 resulted in almost complete destruction of the ancient town of Bam, Iran, and the surrounding area of Baravat, approximately 800km south-east of Tehran. Out of a population of 180,000 the official government report on 29 December 2004 announced a loss of more than 30,000 lives with 50,000 injuries. Damage beyond repair was caused to about 18,000 homes and hundreds of businesses. The historical monument of Arge Bam, parts of which date back 2000 years, was severely damaged.
The construction of Arge Bam was based on a traditional method known in the region as chineh, a layer technique, and spread to Arabia and Africa. The materials used were comprised of a mixture of stone, aggregates, clay, lime and pozzolan layered with sun dried blocks of mud clay (khesht).
This paper focuses on the investigation work carried out within the context of proposing a sympathetic restoration method for the historic fabric of Arge Bam (a world heritage site). The proposed method considers the seismic strengthening of the remaining structure with the least possible change within the context of long term maintenance of this historic site.

OBJECTIVES

This paper investigates and proposes a sympathetic restoration method for an acceptable seismic strengthening approach with the least possible alteration to the remaining original structure and the historic fabric of Arge Bam.

BACKGROUND

The earthquakes recorded during the last 25 years are: 250 km southeast of Bam on 22 February 2005 of magnitude 6.4 Mw with a loss of 600 lives and 125km southeast of Bam on 11 June and July 28, 1981 of magnitudes 6.6 and 7.3 Mw with a loss of 4500 lives.

The historic monument of Arge Bam which is around 220,000 m^2, includes 25 distinct monuments, comprises residential, social, educational and commercial buildings, a military camp, mosques, bazaar, school, prison, sports centre, ice house, and the governor's section and is surrounded by 2,000 m of walls, Figure 1.

The height of the walls and towers in the Citadel varies from 6 to 18 m, with the base width ranging from 2 to 6 m. Outside and along the walls, there are defensive trenches of 1.4 m. Arge Bam was inhabited until around 1910 when it was used as a Ghajar military camp and is listed as world heritage site by UNESCO.

The oldest part of the Citadel was built on rock and later areas were built on surrounding lower soft alluvial soil.

Each layer of the chineh is defined and enveloped by a continuous render coat that is taken up and over it (Walls 2003). The height of 40 cm relates to the length of a builder's arm when kneeling on top of a wall and reaching down the sides to apply the render coat. The layers are staggered and are usually about 5m long. The advantage of the technique is that it does not need scaffolding.

The horizontal joints between the layers are smooth to allow some relative movement between layers horizontally, also dispersing the vertical cracks from earthquakes, settlements and shrinkage through vertical joints at 5m spacing. This dispersion absorbs the energy from earthquakes, therefore decreasing the damage on the structure.

Each layer of chineh was allowed to dry for a week to complete its shrinkage cycle before placing the above layer. A few courses of khesht were also laid in between every successive, five or so layers. A number of walls or abutments of khesht supported roofs made of domes or arches.

DAMAGE FROM EARTHQUAKE

The soil in the lower part of the hill was silt, therefore the monuments located in the southern part of the site, such as the main entrance were more vulnerable to the seismic forces, Figure 2.

The main entrance was coated with heavy clay and lime gypsum render restricting movement joints in the chineh. This rigidity of the rendering resulted in severe compression and external buckling of the earthen walls, Figure 2. In a number of cases the surface rendering separated from the ancient wall in large chunks.

In previous restorations of the Ice House, a stepped dome was built on the existing walls after 1974. The aerial photographs for The National Geographic Magazine in 1974 show that the dome was not reconstructed at the time of that aerial survey (Langenbach 2004). This additional loading

may have resulted in increasing the damage to the inner part of the internal wall as well as initiating vertical structural cracks near its entrance, Figure 3.

The layered earth walls were weakened by the presence of termite infestation which also caused hollow narrow tunnels which undermined the strength of the palm tree trunk roof joists. In later restoration, mud clay straw surface render was applied to a number of monuments which also attracted a larger population of termites.

Extensions in later periods during the expansion of the Citadel, and restorations in the second half of the 20th century with little architectural and engineering input were the reason behind the scale of destruction of Arge Bam during the earthquake of 2003, Figures 2& 3.

CONSERVATION CHARTERS

Most international Conservation Charters for cultural heritage strongly recommend minimal structural intervention to preserve the original fabric of the monument while accepting the need to provide long term structural integrity to provide a safe site.

The Venice Charter (1964) is the cornerstone for the conservation intervention of historical monuments, but nevertheless has some ambiguities and contradictions in its statements regarding the future structural safety of monuments.

The Burra Charter (1999) categorized the concepts of preservation, restoration, and reconstruction as follows:

Preservation is to maintain the historic fabric in its actual state while controlling its decay. Any seismic retrofit work should be carried out with the least possible irrevocable alteration to the historic structural system .

Restoration is to return the historic fabric to its previous state without introducing new materials.

Reconstruction is to return a place as much as possible to its previous known stage and its main difference with the above two is the inclusion of new and ancient materials in the historical fabric. Reconstruction is appropriate when a place is incomplete due to damages and modifications and where through this method it recovers the cultural value of the monument. It outlines that this may be limited to a place and does not have to constitute the major part of the fabric. This should be restricted to the reproduction of physical or documental evidence and must only be differentiated from the original when closely inspected (Daniel et al. 2006).

CONSTRUCTION MATERIAL

The potential benefits of lime mortar in construction are well-known in the field of building conservation technology but have not been adequately explored in terms of its effects on seismic performance (Hami 1967).

Lime, clay and pozzolan mortar mix has successfully been used in Iran for making unfired bricks as well as for mortar bedding over the past two thousand years. Masonry bedded in mortar with low cohesion contributes to a type of "ductile" behaviour.

In Kashmir, a system of interlocking horizontal timber runner beams was used, without vertical wood columns, to hold the rubble, masonry and soft mud mortar buildings together on the silty soil. Historical reports confirm that these buildings withstood earthquakes better than the nearby unreinforced brick palace and government buildings (Langenbach 2004).

It is worth considering Kashmiri experience, which may prove to be an appropriate concept for walls subjected to earthquake forces. In Kashmir, the weak mortar used combined with the overall flexibility of the building structure and restraint provided by the tie timber beams, may prove to be more resistant to catastrophic fracture and collapse by allowing the cracks to be distributed throughout the wall.

The flexibility and internal damping of the layered and khesht walls can also serve to change the building's response, reducing the out-of-plane forces in the walls while the timber acts to keep the weaker layered units in place when the wall deforms. Use of fired clay brick should be prohibited in the reconstruction of Arge Bam.

Alternative fibre polymer reinforcement may be investigated as a replacement to the traditional use of straw which attracts termites. Termites, found in warm climates, feed on the straw and to a lesser extend on the roof joists, although the needles on the surface of the trunk of palm trees slows their infestation.

RESEARCH

The objectives of the research are to establish a sound basis for the preservation of historic layered and unfired brick masonry. The research project would consider

- Providing safe access to each monument with minimal interruption to the exiting debris and remaining structure, and method statements and detailed plan of intervention for each monument.

- Temporary supports, shoring, needling and propping of the remaining structure.
- Management and use of the debris produced by the earthquake at each monument.
- The study of the effects of mortars of varying strength and constituents and the post-elastic in-plane strength and behaviour of layered walls.
- Data collection of the archaeologically important aspect of Arge Bam (material properties, architectural configurations, building technologies,) to determinate the original structural configuration.
- Investigation of the seismic behaviour of earthen structures using finite element models including the model stiffness static and dynamic loading , and the softening and destabilising effect of loads on the earthen wall.
- An overall study of stiffness of the earthen walls.

CODES OF PRACTICE

There are disagreements between the historic preservation documents which recommend using the weakest and most lime-rich ASTM formula (K) 1 unit cement to 2.25-4 units lime for restoration work in the Uniform Building Code (ASTM 2006), which prohibits the use of mortar weaker than the three strongest categories, known as ASTM types M, S & N: 1 unit cement to 0.25-1.25 units lime for any mortar used in structural masonry which includes most historic masonry walls (Langenbach 2004).

Iranian Seismic Code IS2800 generally excludes use of lime mortar and earth walls. Use of hydraulic lime mortar as well as use of earth structures which has in certain cases demonstrated durability comparable to cement block walls, needs to be investigated (Hami 1967 & Hydraulic Lime Mortar 2003).

While the Codes are developments based on the performance of the wall under load at its design strength at construction stage, the preservation documents aim at maximizing the long-term durability of walls with relatively weaker material in responding to the environment. It is worth comparing the long-term performance of ancient masonry and modern masonry to understand the benefit of the softer, high lime mortars.

IS2800 does not cover the behaviour of masonry when it is cracking and yielding in an earthquake. The code is for present-day construction such as steel and reinforced concrete and is based on linear elastic calculations using reduced forces to approximate post-elastic actual behaviour, but designers often give very low values to masonry because of its lack of material ductility. However, as a system, there is substantial remaining capacity in a wall which has begun to crack before it becomes unstable.

The adoption of IS2800 for Building Conservation to allow improvements to existing historical buildings requires a thorough investigation covering the specific needs of historical buildings in relation to the varying period, region and design of the historical building. This development of the code would minimize disagreements over what future strengthening would be necessary for historic buildings.

CONCLUSION

Understanding both the behaviour of layered (chineh) and unfired brick (khesht) construction can guide us towards those methods which are least destructive for the original fabric. Some of these methods may even be more effective over the long-term, not only because they build on what already exists, but also because they are developed from local social and economical conditions and have been tested by the previous earthquakes.

The objective of historic preservation is to preserve continuity within the slow evolution of building traditions while providing the most effective lasting resistance to movement over time, the gradual settlement of the foundations, the slow erosion of the lime, as well against the future earthquakes.

Local seismic faults are now active and regular earthquakes are reoccurring in this region. The seismic strengthening should also provide safety for the large number of visitors to the monument.

An Italian team of conservationists from Universities of "Politeconico" of Milan, Parma, Florence and Parda who appreciate the importance of maintaining the historic fabric were approached by the management of Bam site to develop a project for repair and restoration of a typical building (Mirza Na'him). Meanwhile, this group has been adopting techniques which could provide solution to more general reconstruction of the whole area of the Bam Citadel (Binda et al. 2006) .

Reconstruction of monuments such as Arge Bam may take many years and consume a substantial budget .

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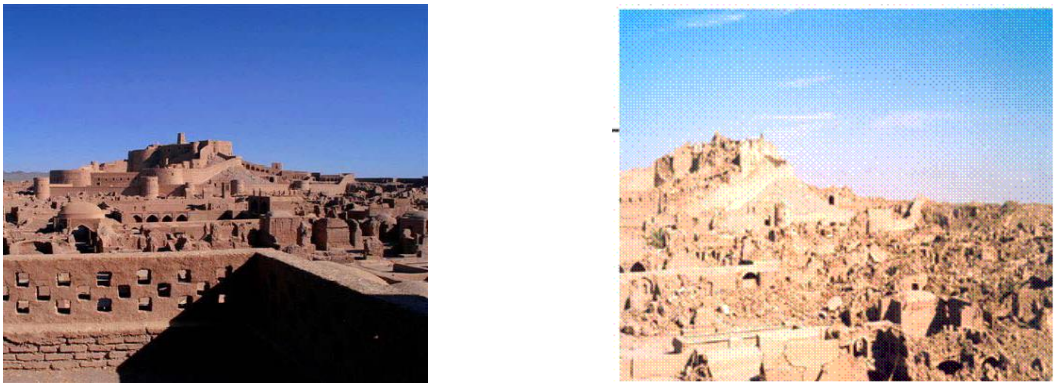

Figure 1. The picture on the left was taken two months before the earthquake of 26 December 2003 (left). The main building of Citadel after 26/12/03 (right).

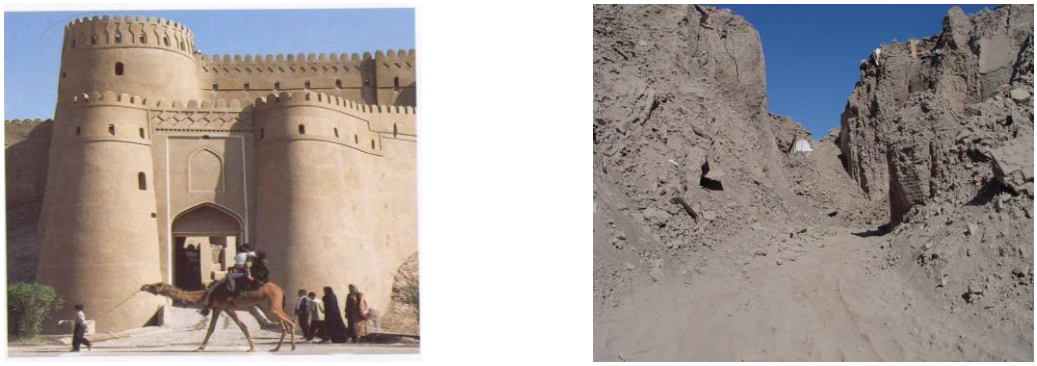

Figure 2. Main chineh entrance to Arge Bam located on the south side of the compound has been restored (left) with mud straw render restricting layered movement joints.

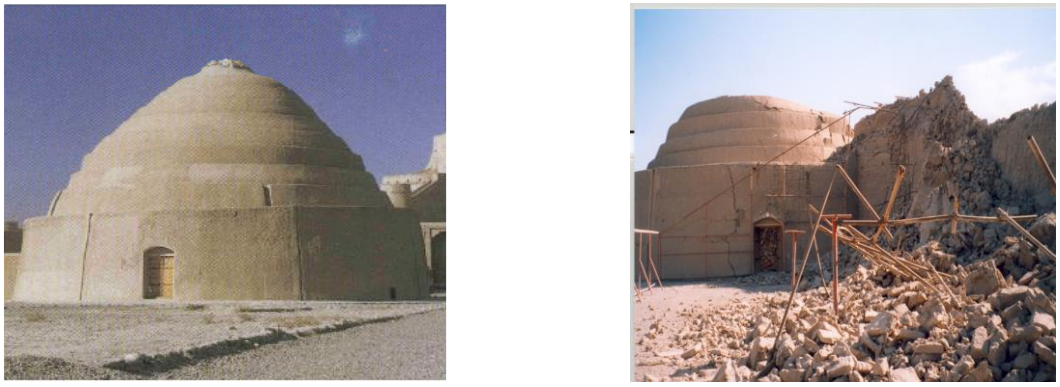

Figure 3. The Ice House with the reconstructed dome before (left) and after 26/12/03 (right)