Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 9, Issue, 02, pp.46953-46959, February, 2017

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

ANALYSIS OF OBSERVED SEISMIC DAMAGES ON HISTORIC ADOBE-MUD BRICK STRUCTURES OF BAM CITADEL, AFFECTED BY THE 2003 BAM EARTHQUAKE

*Jafar Rouhi, Bianca Gioia Marino and Aldo Aveta

University of Naples Federico II, Italy

ARTICLE INFO

Article History:
Received 17th November, 2016
Received in revised form
19th December, 2016
Accepted 25th January, 2017
Published online 28th February, 2017

Key words:

Adobe-Mud Brick Structures,
Seismic Damages,
Bam Citadel,
2003 Bam Earthquake.

ABSTRACT

From past to the present, lessons learned from structural behaviour of buildings during destructive earthquakes have been used to advance construction techniques, and more recently, such lessons have fostered the development of methods and techniques to have more engineering interventions and preservation disciplines on historically or culturally important structures. Generally, post-earthquake damage assessments will offer an opportunity to understand why historic buildings fail, and will provide information that can serve as the basis for their seismic improvement. The tragedy of December 26, 2003 Bam earthquake, and what happened over the Bam Citadel, as a result, entails the need to evaluate the seismic vulnerability of historic adobe structures. Therefore, documentation of the actual damages resulting from strong ground motions are essential to understand how historic adobe buildings perform, or in fact behave at the time of earthquakes. In this case, survey about structural behavior of this vulnerable type of construction material, analyzing its seismic weakness, which may help in preventing social, cultural and economic losses against a subsequent earthquake that may happen in the near future. Therefore, in this paper to have better insight about the possible seismic damages on historic adobe-mud brick structures, the damages on seismically destructed Citadel of Bam are analyzed in details, the possible damages that the consciousness of their occurrence can result in better anti-seismic intervention on historic adobe structures.

Citation: Jafar Rouhi, Bianca Gioia Marino and Aldo Aveta, 2017. "Analysis of observed seismic damages on historic adobe-mud brick structures of bam citadel, affected by the 2003 bam earthquake", *International Journal of Current Research*, 09, (02), 46953-46959.

INTRODUCTION

Adobe is the name for a style of building construction that uses bricks made from mud (National Park Service, 2011). Mud is one of man's oldest building materials and most ancient civilizations used it in different forms. Adobe-mud bricks (often called adobe bricks) is a Spanish word that originally derives from the Arabic word "al-tob" meaning "sundried or unbaked brick"; the term has its roots in Egyptian hieroglyphs. However, today the term of adobe is used in English as an "earthen construction" to describe all types of construction techniques using mud or soil raw materials. This versatile building material is widely available and in some parts of the world, especially in remote areas, it is the only material available over there (Adam and Agip, 2001). The use of sun-dried blocks dates back to approximately 8000 BC., and until the end of the last century it was estimated that around 30 % of the World's population lived in earth-made constructions (Houben and Guillard, 1994). In the first world, cities like Jericho, Catal Huyuk and Babylon were constructed out of adobe bricks. Materials obtained from soil served for erecting common houses, but also for great monuments such as Arch of Ctesiphon in Iran, or Pharaoh's Tombs in Egypt. It is significant that the oldest surviving examples of this building form are in the treeless landscapes and in the most arid areas of the world (Sruthi, 2013). However, buildings made up of adobe-mud brick are common in the Latin America, Australia, North Africa and Middle East, South Asia, China and Interior Asia, East Europe and Sub-Saharan Africa. In Egyptian hieroglyphics document, biblical accounts refer to early use of adobes and the use of mud-bricks for construction in the ancient world. As a ubiquitous form of construction material, adobe-mud brick structures are still built up in many regions of the world with hot/arid climate conditions because of their low costs of manufacturing, transportation and on-site workmanship, simple and unsophisticated construction technique and excellent thermal properties. Approximately 50% of the population in developing countries, including the majority of the rural population and at least 20% of the urban and suburban population, live in earthen dwellings (Houben & Guillard, 1994). As a worrisome situation, adobe-mud brick structures pertaining to their antiquity and vulnerability, commonly in earthquake are presenting asthenic behavior during moderate to strong ground motions. During an earthquake, adobes are exposed to extreme tensile strength,

Corresponding author: Jafar Rouhi,
University of Naples Federico II, Italy.

and are unable to function well structurally. As Cancino *et al*. (2009) stated, "Adobe, typically used to build thick and massive walls, is a low-strength building material that is able to resist compression, but is weak in response to tensile forces. The stresses absorbed by an adobe wall during an earthquake normally exceed the wall's tensile strength. The building dissipates the energy released by the earthquake through crack formations that divide the wall into isolated blocks that pound against each other until the structure suddenly collapses." About the extent of earthquake damage to an adobe structure, Tolles *et al*. (1996) pointed out, "it is a function of (a) the severity of the ground motion, (b) the geometry of the structure, i.e., the configuration of the adobe walls, roof, floors, openings, and foundation system, (c) the existence and effectiveness of seismic retrofit measures, and (d) the condition of the building at the time of the earthquake." Elsewhere, Dowling (2004) also expressed that the seismic capacity of an adobe house depends on the mechanical properties of the materials (blocks and joints), on the global structural system (structural geometry, connections, etc.), on building foundations, and also on the quality of the construction and maintenance. Generally, adobe structures have a brittle behavior and may collapse without warning (Blondet *et al*., 2006); even there is not enough time for evacuation. That's why, adobe structures, the only earthen structures listed in the 1998 European Macroseismic Scale (Grunthal, 1998), according to which, together with rubble stone, are the most vulnerable structures to earthquakes (NIKER, D3.1, 2010).

For centuries, lessons learned from earthquakes and other natural disasters have been used to advance construction techniques, and more recently, such lessons have fostered the development of the engineering and historic preservation disciplines, as well as the testing and review of current building codes and disaster management policies and procedures (Cancino *et al*., 2012). Generally, post-earthquake damage assessments will offer an opportunity to understand why buildings fail, and will provide information that can serve as the basis for the seismic improvement of buildings. For describing and comparing the relative damage rates sustained by buildings following Bam earthquake, it is useful to have a definite set of categories that describes the intensity of damage in different classifications. Owing to abnormal seismic behavior of adobe buildings and their non-compliance behavior to a certain principle, as well existence of differences in their construction practices from region to region, it is so difficult to render a general standard for their seismic behaviors. Therefore, studies about these types of structures are region specific. Based on the observed damage data from the Bam earthquake, the result indicated that damages on Bam Citadel were initiated at an earthquake intensity of VIII on EM-98 intensity scale and were classified into Grade D and Grade E on EERI 1994 standard.

To survey the damage typologies of adobe monuments in Bam Citadel, it has been tried to provide descriptions, figures, and photographs of damage failures observed in adobe walls, arches, vaults, and domes after the December 26, 2003 earthquake in Bam city. The more common types of damages can be summarized in four groups, each of which has been surveyed separately: (I) Damage on Adobe Surface Coating; (II) Damage on Adobe Walls; (III) Damage on Adobe Roofs; and (IV) Damage on Adobe Towers.

Methodology

This research is a part of the Author's PhD dissertation entitled,"Conservation and Restoration of Adobe Architectural Heritage of Bam Citadel (Iran), Affected by the 26 December 2003 Bam Earthquake: Problems and Issues". In this thesis, different aspects to have an efficient anti-seismic intervention work on historic adobe-mud brick structures arestudied in details. However, since in order to preserve and protect historical buildings and monuments from the potential impacts of earthquakes, the first phase is to understand how ancient monuments act during an earthquake, as a result, entails the necessity for conducting a study on one seismically endangered adobe case. Therefore, in this research the ancient city of Bam "Bam Citadel", the largest extend adobe complex in the world, is recognized as a suitable case to make a conceive-known and close scrutiny about factors affecting on severity of seismic damages on adobe monuments of the Citadel of Bam. It should also be mentioned that in August 2015, the Author had a site visit from Bam Citadel, during which it was tried to provide a complete pictorial report from activities that have been executed on the main monuments of Bam Citadel. Therefore, to find the required data of the study focus groups, in-depth individual interviews and review of primary and secondary sources and documents were employed.

Origins of Cracks in Adobe-Mud Brick Structures

At first, to survey the damage typologies of adobe-mud brick structure, it would be worth to have a glance at the origins of cracks in adobes, and the mutual impact of their dimensions on the structural damage. In adobe structures, cracks may be caused by the expansion and contraction of materials, inadequate foundations or differential settlement, moisture invasion, wall movement from a collapsing roof structure, lateral loads from pitched roofs and openings, removal of an earthen roof, or by poorly constructed walls and more seriously with seismic motions. As Blondet *et al*. (2006) mentioned, "During earthquakes, the ground shakes in all directions and generates inertial forces that earthen materials should be able to withstand. Since the compressive strength of adobe is much higher than its tensile strength, significant cracking starts in the regions subjected to tension." However, it is important to determine the structural integrity of the wall (Cornerstones Community, 2006). In 1992, Weaver in his book entitled "Conserving Buildings, Guide to Techniques and Materials", generally categorized structural cracking into two groups (see table, 1): first, no effect on the structure, other than aesthetic and second, effect on use and serviceability of the building. The first category, which includes four classes (between 0.1 mm (very difficult to see) to 2.0 mm (can be seen in clear light from a few meters), is one in which the cracking has no serious effect on the structure, or at least only with an aesthetic effect. These cracks can be caused mostly by natural expansion/contraction cycle that is daily and seasonal. The second category also consists of four classes (between 2.0 to 5.0 (visible) to more than 25.0 mm (easily discernable from distance), in which the first three classes are related to serviceability and the fourth class is in a dangerous condition.

Damage on Adobe Surface Coating

Crack is a typical feature of historic adobe buildings, and occurs constantly throughout the life cycle of an adobe building. Due to the expansion of adobe materials after drying

Table 1. The origins of cracks in adobes, and the mutual impact of their dimensions on the structural damage (Source: Weaver, 1992)

Categories	Originate of cracks	Cracks size (mm)	Visibility of the faults or cracks	Effects of cracks on the structure
First	These cracks caused by initial shrinkage in new materials orthermal expansionand contraction overa long period	Less than 0.1	Very difficult to see	No effect
		0.1 to 0.3	Hairline cracks	Not serious
		0.3 to 1.0	Can be seen closely	In large numbers will have aesthetic effect
		1.0 to 2.0	Can be seen in clear light from a few meters	Aesthetic effect
Second	Penetration of water, serious or extremely serious structural damage, structural movement, settlement of columns, footings or bending of beam or trusses	2.0 to 5.0	Visible	Cracking of arches
		5.0 to 15.0	Easily discernable	Jamming of doors and windows, cracking of walls, shear diagonal cracking in ceilings, falling plaster, collapsing arches, breaking of plumbing and pipes
	Sudden change orremoval of the supports, mining subsidence, collapsingexcavations	15.0 to 25.0	Easily discernable, Cracks are grouped, Visibility of distortions with naked eye	Collapse of masonry arches, walls, chimneys Distortions of bearing elements
		More than 25.0	Easily discernable from distance	Dangerous structure, structural collapse without warning

and their exposure to environmental changes, as a reaction to accommodate by surrounding changes, cracks occur both at the macro and micro levels in the adobe materials. However, there are some generic reasons, which can cause movement and lead to the development of different types of cracks in adobe materials, such as foundation failure, thermal movement, decay of superstructure, moisture movement, inherent defects, deflection under loads and ground movement. Generally, cracks in adobe buildings can be characterized to be reversible or irreversible in character. However, in areas where the material strength is exceeded in either shear or tension, earthquake will produce more superficial cracks on adobe façades, so sometimes the result as the reversible crack's damages would appear as distortion and failure in adobe surface coatings. In addition, it should be noted that adobe surface coatings have a large thickness, and the gravity of these materials and the quality of their mortars have a main roles in the level of damage during an earthquake.

Figure 1. Damage on adobe surface coating in the Mirza Na'im School of Bam Citadel (Source: personal archive of Prof. Luigi Marino, 2007)

Damage on Adobe Walls

In historic adobe-mud brick structures some damage types are usually slight, but they may become serious if the structure is subjected to greater displacements resulting from an earthquake with a longer duration together with a large number of aftershocks, or repeated earthquakes, particularly when no intermittent corrections and repairs have been carried out. It should be considered that in most cases, different types of damages do not act independently, but rather in combination. In fact, the combination of several damage typologies can cause other types of damages. In general, although there are simple relationships between some type of damages, but in other cases they might have a very complex relation.

Out-of-Plane Wall Damage

During an earthquake, one of the most typical failure mechanism in adobe building is due to out-of-plane flexural damage. The adobe walls are very susceptible to cracking from flexural stresses where the cracks initiate as vertical cracks at the intersection of perpendicular walls, and later extend vertically or diagonally and running horizontally along the base between the transverse walls (Tolles *et al*., 1996; Varum *et al*., 2014). Then over time the wall rocks out-of-plane, outward and inward, rotating round the horizontal cracks at the base. If adobe walls by embedding such elements as buttressed walls have been prevented from overturning, the extent of damage will be reduced.

Gable-end Wall Collapse

In historic adobe buildings, the gable-end wall collapse is a specific type of out-of-plane failure. For long adobe walls without intermediate lateral restraint, this type of damage occurs when the wall panel is inadequately connected with lateral structural elements. In this typology of damage, the wall-foundation interface behaves as a pin connection, which has little resistance to overturning when an out-of plane force is applied (Dowling, 2006). Then by detachments that occur in the wall-wall connections and wall-roof connection, because of lack of edge resistant on three sides, the wall panel will generally overturn outward due to the outward force exerted by the roof in the absence of an adequate roof diaphragm. This type of failure frequently results in collapse of building, as commonly observed in Bam Citadel in 2003.

Out-of-Plane Flexural Cracks and Collapse

During a seismic event, one of the first cracks that appear in the freestanding adobe wall, without any lateral restraints and supports along its length, is out-of-plane flexural cracks.

During prolonged ground motions, because gravity is constantly working in combination with earthquake forces, the bending about the vertical axis first causes a splitting-crushing cycle generating vertical cracks, and then by bending about the horizontal axis, the upper part of wall panel will overturn. In fact, the probability of out of plane flexural cracks and collapses in non-load-bearing walls are more than load-bearing walls due to lack of fixed ending. In Bam Citadel, numerous examples of out-of-plane flexural damages have been observed in Citadel's surrounding fortification.

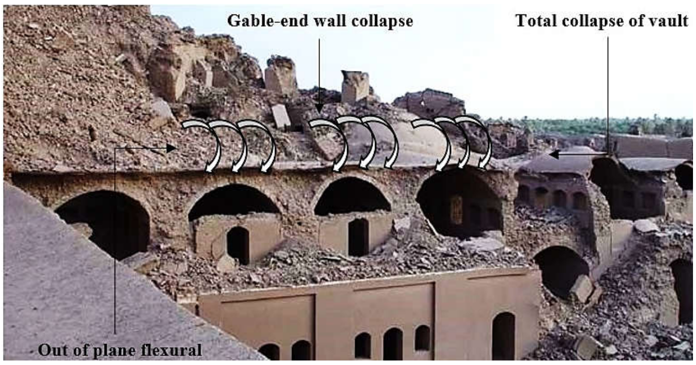

Figure 2. Different types of out-of-plane damage on the Barrack of Bam Citadel (Source: archive of ICHHTO, 2003, designed by Author)

Mid-Height, Out-of-Plane Flexural Damage

A particular case of out-of-plane flexural damage occurs when the adobe wall have low thickness ratios (L= $\frac{\text{l = length}}{\text{d = width}}$). When the load-bearing and non-load bearing adobe walls are long and slender, by development of horizontal cracks along the base and their combination with vertical cracks, the mid-height, out-of-plane flexural damage might occur.

In-Plane Shear Cracks

Lateral seismic forces acting within the plane of the walls generate shear forces that produce diagonal cracks, which usually-but not always-follow stepped patterns along the mortar joints (Varum *et al*., 2014). The diagonal cracks are typically the results of in-plane shear forces which often start at the corners of openings, such as doors and windows, and develop in walls between openings where the concentration of tensile stresses cause cracks with approximately 45° relatively to the horizontal.

Figure 3. Mid-height, out-of-plane flexural damage in second wall of Bam Citadel (Source: archive of Gettyimages, 2004. Source: http://www.gettyimages.it/immagine/bam-citadel?, designed by Author)

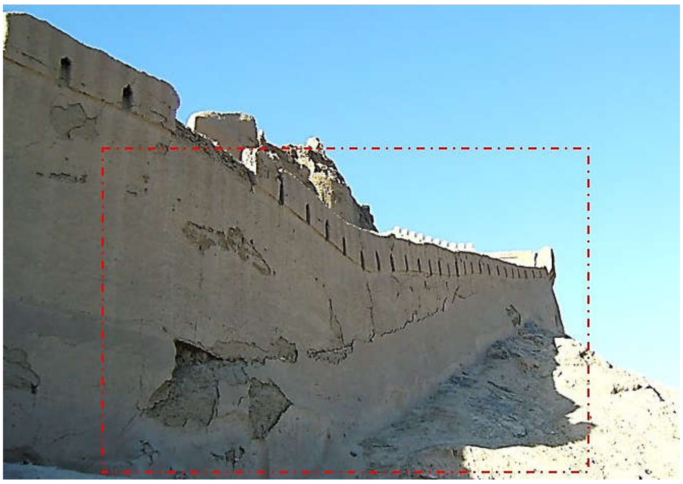

Figure 4. Mid-height, out-of-plane flexural damage without collapse in third defensive wall of Bam Citadel. Fortunately as can be seen, the horizontal and vertical cracks across the length of wall could not cause to detachment of wall, if the seismic motion had been more prolonged, the total collapse of wall might have occurred (Source: archive of ICHHTO)

The X-shape in-plane cracks occur when the sequence of ground motions cause the shear forces to go in one direction and then go in the opposite direction. In this case, later when the adobe walls have cracked, the continuation of seismic movement might exacerbate the damage and cause independent collapse of the walls in an out-of-plane mode. More severe damage to the structure may occur when an in-plane horizontal offset occurs in combination with a vertical displacement (i.e., when the crack pattern follows a more direct diagonal line and does not stair-step along mortar joints) (Tolles *et al*., 1996).

Figure 5. The in-plane shear cracks in Bam Citadel after the 2003 Bam earthquake (Photos by Rouhi, 2015)

Intersection of Perpendicular Walls

This damage often occurs as vertical cracks or gaps appear in the wall connections at the intersection between the façade walls and the perpendicular walls, where the connections between components are too weak to withstand against the earthquake demands. In this case, while the perpendicular wall remains very stiff in plane, one of the connected walls rocks out of plane. During large ground motions, this process triggers the walls to the post-failure overturning of the wall panels. This type of damage is one of the most inevitable collapse mechanism of adobe walls under seismic motions. Observations made after the Bam earthquake have shown that the magnitude of damage suffered by the monuments in Bam Citadel was directly related to quality of the connection, and the damages had been more significant where large cracks were associated with damages that occurred in roofs.

Figure 6. Intersection of perpendicular walls in Bam Citadel after the 2003 Bam earthquake (Photos by Rouhi, 2015)

Corner Damage

Cracks caused by seismic motions often occur in locations with high stress concentrations. Cracks in corners of an adobe building are very common because relative response is largest at the wall's interfaces. That is why the probability for occurrence of cracks at the corners of buildings during an earthquake is more than other parts. A thin adobe wall may become unstable soon after the initiation of cracks through the wall. However, a thick-walled adobe building is still a long way from losing its stability after the first cracks develop (Tolles *et al*., 1996). The extent of damage caused in a building will depend on the width of the crack generally characterized as hairline cracks, fine cracks, moderate cracks, extensively damaged cracks and structural cracks (Varum *et al*., 2014). It should be noted that, since adobe materials have high adhesion properties, any cracks could not cause serious damages.

Figure 7. High adhesion of seismic damaged adobe wall in the Bazzar of Bam Citadel (Photos by Rouhi, 2015)

As Tolles *et al*. (1996) cited, corner cracks in adobe walls can be categorized in three sections:

- Vertical cracks at corners: vertical cracks often develop at corners during the interaction of perpendicular walls and are caused by flexure and tension due to out-of-plane movements. This type of damage can be particularly severe when vertical cracks occur on both faces allowing collapse of the wall section at the comer.
- Diagonal cracks at corners: diagonal cracks that start at the top of a wall and extend downward to the corner are caused by in-plane shear forces. This type of crack results in a wall section that can move laterally and downward during extended ground motions. This type of damage is difficult to repair and may require reconstruction.
- Combinations with other cracks or preexisting damage: the combination of diagonal cracks and vertical cracks can leave an adobe wall severely fractured with several sections of the adobe wall susceptible to large offsets and/or collapse. The diagonal cracking at that location is at the southwest corner of the buildings leaving the cracked wall sections free to move outward. Corners may be more susceptible to collapse if vertical cracks develop and the base of the wall has already been weakened by previous moisture damage.

Figure 8. Different types of cracks in Mirza Naem School of Bam Citadel after the 2003 Bam earthquake (Photo by Rouhi 2015)

Cracks at Openings

An opening in a frontage constitutes a vulnerable point in the event of deformation of the adobe frame. The cracks of the front walls are found in the contours of the openings, where the stresses are most significant and in particular close to the re-entrant angles (NIKER, D3.1, 2010). Since more often during seismic motions, cracks occur in locations that stress concentrations are high, the openings are deep interested in cracks phenomena. Usually, these cracks start at the top or bottom corners of openings and develop vertically, diagonally and horizontally to the tops or bases of the walls. In adobe building, cracks over the openings may be hazardous to occupants if they are dislodged. The best way to control cracks at openings is keeping the openings in the walls small and well-spaced.

Figure 9. Crack at opening of Bam Citadel after the 2003 Bam earthquake (Source: (Left) personal archive of Prof. Luigi Marino; and (Right) Auroville Earth Institute "BAM AND ARG-E-BAM", after the 2003 Bam earthquake)

Damage on Adobe Roofs

Damage Analysis of Vaulted Roofs

As a general remark, the vaulted roofs system have limited stability under static conditions, so when the stability of this type of roofs is satisfied that the line of thrust (LT) remains in the middle third of the side's roofs and walls. In term of LT's placement in vaults, when LT goes to the intrados side and/or outside the extrados side of the middle third, the tension stress will increase in the vault. On the other hand, in term of LT's placement in walls, when LT goes to the outer middle third, the bending and shear tension might cause severe damage to the adobe walls. During the 2003 Bam earthquake, due to the dynamic character of the seismic motions, most of LT went outside of inner third. However, surviving vaulted roofs could be seen all over the Citadel even in areas where the greatest damages were observed. However, there were some vaults that showed good behavior even when the direction of the movement was perpendicular to their generators. Apart from some cracks, minor failure and separation from side's walls, this type of roofs performed satisfactorily. In this case, the observed damages and failures were mainly concentrated in areas in the vicinity of the intersection line of the vaults with the end of their triangular transition sections where the roofs are connected to adobe wall. Although it is difficult to know the main reason for good dynamic behavior of still standing adobe vaults in Bam Citadel, it can be noticed that differences in the thickness of roofs and the quality of the site's soil may also be responsible for this behavior. In most cases, the vaults in Bam Citadel together with other structural components of adobe buildings have suffered complete collapse. The sequence of such failure usually starts with excessive deformation of load bearing walls, and later separation of roofs from walls in buildings without adequate wall-to-roof connections often lead to complete building collapse. However, in some cases, the failure of roofs did not follow wall's destruction, while the walls remained relatively intact, the roofs faced total collapse. The reason for such failure can be found in heavy weight and weak connection of adobe vaults. Apart from that, the high vertical acceleration component of this earthquake also increased the probability of complete collapse of the adobe roofs; some people of the city of Bam who survived from 2003 Bam earthquake, in their description about earthquake said that at the time of earthquake it seemed that all of the buildings were exploding from their upper parts.

Figure 10. (left) damages on vaulted structure in the east part of Bam Citadel after the 2003 Bam earthquake; and (right) a set of vault roofs survived during the 2003 Bam earthquake in the Barrack of Bam Citadel (Photos by Rouhi, 2015)

Figure 11. Total and partial collapse in the Barrack of Bam Citadel after the 2003 Bam earthquake (photo by Ahmadi and Boroomandi, 2003. Source: archive of ICHHTO, designed by Author)

Damage Analysis on Domed Roofs

Unlike the vaulted roofs that have shown variable damage typologies by the earthquake, most of the domed roofs in Bam Citadel faced complete destruction, and a small number of domes faced low failure in their façade. An example of such total destruction can be seen in the Stable of Bam Citadel, where almost all of its domes totally collapsed. As Langenbach (2004) pointed out, "the collapse of the domes throughout the complex, many simply may have followed their bursting supporting walls to the ground. Others that collapsed inwardly, such as the icehouse, probably suffered from the effect of the intense vertical vibrations on the weak unfired brick masonry. The momentary doubling of the weight of the domed structures was probably more than they could handle. The bricks themselves were simply too small and weak to form enough of a resisting arch."

Figure 12. Damage on domed roof in the Stable of Bam Citadel after the 2003 Bam earthquake (Source: archive of RPBCH, designed by Author)

Damage on Adobe Towers

During the earthquake, the Citadel's towers with their destruction marked one of the greatest cultural heritage losses, even 13 years after earthquake and with all the efforts made, the absence of towers in the first gate, stable, governor's house and etc. is largely felt. The circular structures, such as the turrets on the ramparts, fared worse than the long straight walls and rectangular structures (Langenbach, 2004). Bam Citadel was composed of a set of 49 towers, in which by the 2003 earthquake, most of them suffered a severe range of damage from 70% to tottal collapse.Because of long height and insufficient strength of their materials, adobe towers are extremely unstable to the earthquake. However, seismic motions by moving over the body of adobe towers can cause failures in their different parts. In Bam Citadel, the horizontal, vertical and diagonal cracks and rupters could be seen on the

Figure 13. The condition of east-south tower of the Stable of Bam Citadel in different periods before and after earthquake (Sources: archive of ICHHTO, before the 2003 Bam earthquake; and Rouhi, 2015)

façade of towers. In most cases, by development of cracks, the towers were subject to detachment in their connection with side walls. Here due to the large vertical acceleration of the earthquake, the upper portion of most towers were substantially damaged.

Conclusion

The term ‘damage’ is used to describe a situation in which a structure has lost some or all of its bearing capacity, a condition that can lead to failure and collapse (Croci, 1998). To address the damage typology of a special type of structures, there are different vulnerability assessment methods, which are presented in various published technical literatures. These methods can be divided into four groups; empirical methods, judgment-based methods, mechanical methods and hybrid methods. Among these methods, the first two are qualitative, whereas the last two are quantitative methods. Although the use of known numerical and modeling analysis techniques would approximately estimate the dynamic behavior of individual adobe structures in an ideal condition, but they cannot exactly show the real seismic function of an adobe building. The main reason for this can be that the earthquake can significantly increase the internal reactivity of the adobe materials, which have been exposed to many deterioration factors over time, but for those numerically or experimentally analyzed there are no considered deterioration factors. Therefore, the result from direct observation of seismic damages would be more accurate, as far as through knowing the concentration of seismic tensions in different parts of the adobe structure and exploring of the possibility of possible failures, which may happen during a seismic eventon historic adobe structure, we will be able to propose an efficient seismic retrofitting operation.

REFERENCES

Adam, E.A. and Agip, A.R.A. 2001. Compressed stabilised earth blocks manufactured in Sudan, United Nations Education Scientific and Cultural Organisation (UNESCO). Retrieved from www.growingempowered.org/wp.../Compressed-Earth-Building-Block-Guide.pdf

Blondet, M., Neumann, J.V. and Tarque, N. 2006. The Peruvian Building Code for Earthen Buildings. Los Angeles (C.A): Getty Seismic adobe Project, pp. 45-51. https://www.getty.edu/conservation/publications_resources/pdf.../gsap_part2a.pdf

Cancino, C. *et al*. 2009. Damage Assessment of Historic Earthen Buildings after the August 15, 2007 Pisco, Peru Earthquake. Los Angeles (C.A): The Getty Conservation Institute.

Cancino, C. *et al*. 2012. Seismic Retrofitting Project: Assessment of Prototype Buildings, Volume 1. Los Angeles (C.A): The Getty Conservation Institute.

Cornerstones Community. 2006. Adobe Conservation: A Preservation Handbook. New Mexico: Cornerstones Community Partnerships.

Croci, G. 1998. The Conservation and Structural Restoration of Architectural Heritage. Southampton: WIT Press.

Dowling, D. 2004. Adobe housing in El Salvador: Earthquake performance and seismic improvement. In: Rose, I., Bommer, J.J., López, D.L., Carr, M.J., & Major, J.J. (eds.), Geological Society of America Special Papers, pp. 281–300.

Grunthal, G. 1998. European Macroseicmic Scale (EMS-98), Cahiers du Centre Européen de Géodynamique et de Séismologie 15. Luxembourg: Centre Européen de Géodynamique et de Séismologie.

Houben, H. and Guillard, H. 1994. Earth Construction – A Comprehensive Guide. London: ITDG Publishing.

Langenbach, R. 2004. Soil Dynamics and the Earthquake Destruction of the Earthen Architecture of the Arg-e Bam. Iranian *Journal of Seismology and Earthquake Engineering, JSEE (Special Issue on Bam Earthquake)*; 5-6 (4-1): 133-151.

National Park Service. 2011. Adobe and Our Visitor Center, NDRI (Natural Disasters Risk Index). Retrieved from http://www.preventionweb.net/english/professional/maps/v.php?id=14169

NIKER, D3.1. 2010. Inventory of earthquake-induced failure mechanisms related to construction types, structural elements, and materials. Coordinator: Università di Padova, leader: POLIMI. Retrieved from www.niker.eu/.../D3.1%20-%20Annex2%20-%20Contributions%20of%20Partners.pdf

Sruthi, G.S. 2013. MUD ARCHITECTURE. Proceedings of International Conference on Energy and Environment-2013 (ICEE 2013), *International Journal of Innovative Research in Science, Engineering and Technology*, 2(1): 47-52.

Tolles, E.L., Webster, F.A., Crosby, A., Kimbro, E.E. 1996. Survey of Damage to Historic Adobe Buildings After the January 1994 Northridge Earthquake, GCI Scientific Program Report 1996. Los Angeles (C.A): The Getty Conservation Institute.

Varum, H. *et al*. 2014. Structural Behaviour and Retrofitting of Adobe Masonry Buildings. In: Costa, A., Guedes, J.M., Varum, H. (eds.), Structural Rehabilitation of Old Buildings, Building Pathology and Rehabilitation 2, Springer-Verlag Berlin Heidelberg, pp. 37-76.

Weaver, M.E. 1992. Conserving Buildings, Guide to Techniques and Materials. New York: John Wiley & sons.

****