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A STUDY ON FAILURE PATTERN OBSERVED IN MASONRY BUILDINGS DURING 8TH OCTOBER HAZARA-KASHMIR EARTHQUAKE IN PAKISTAN

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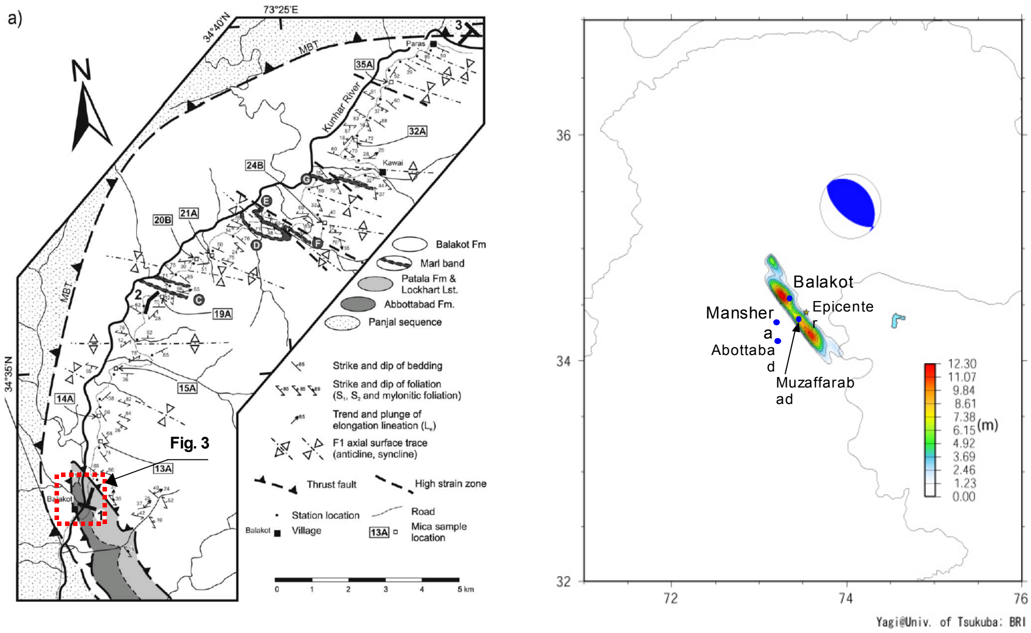
ABSTRACT

An earthquake measuring 7.6 on the Richter scale struck Mansehra, Muzaffarabad, Garhi Habib Ullah, Balakot, Bagh, Battagram, Battal, Allai, Naran valley, Neelum valley, Jhelum valley, Islamabad, Lahore etc. on 8th October 2005 at 0852 PST. The epicenter of the earthquake was located near Muzaffrabad. As per official figures, about 74000 are dead, 70000 are injured and 2.5 million families have been displaced. The heaviest damage was observed in Muzaffarabad, Bagh, Allai and Balakot area where entire villages were destroyed. The local traditional stone / block / Brick masonry structures in the area were not designed to withstand the earthquake of such magnitude. This caused considerable damage including major cracks to complete collapse in load bearing members. Unreinforced masonry (URM) structures were damaged commonly due to poor construction practice of load bearing walls. The damage level depended on the distance from surface faulting. Most of the destroyed villages were subjected to the full intensity earthquake vertical and shear motion with negligible attenuation since they were very near to the ruptured zone. This paper attempts to evaluate the behavior of masonry structures based on the type of masonry used in places like Balakot, Bagh, Muzaffarabad and several other places. Quite a few masonry buildings had used earthquake resistant features like lintel bands and corner reinforcements. The cracking and failure patterns of such buildings have also been examined and recommendation for future type of structures will also be proposed in order to educate the local population to adopt suitable earthquake resistant construction practice in the area which could ensure least life as well as property damage.

Key Word: Seismic activity, Stone/block/brick Unreinforced Masonry, Structural Damages, Crack Pattern

1- Introduction

On 8th of October 2005 northern areas including Azad Kashmir were struck by the most devastating earthquake of Pakistan's history measuring 7.6 on Richter scale. The earthquake severely damaged the large number of cities in Northern Areas of Pakistan. An intense earthquake (M 7.6) shocked severely the North Eastern Frontier Area of Pakistan (Epicenter: 34.493°N, 73.629E), about 90 km NE of Islamabad at 8:52 local time, Oct. 8, 2005. The focal depth was reported to be 26 km (USGS). Earthquakes in the northern mountainous areas of Pakistan and adjacent parts of India and Afghanistan are the result of the movement of the Indian plate sub-ducting north beneath the Eurasian plate at a rate of 40 mm/year (USGS) as evident from and the area affected by this earthquake is a foreland of Hindu-Kush ranges including the highest peaks in the world. The epicenter and contour showing slip on the fault surface are shown in Fig. 1(b).



(a) **(b)**

Figure 1: (a) Geological map of Kaghan Valley, Hazara-Kashmir Syntaxis, Pakistan (after Yani Najman, 2002) showing the fault line in the area.
(b) Contours show the slip on the fault surface (Source Process of Pakistan earthquake)

In the recent earthquake, majority of structures were damaged / collapsed which need to be repaired / reconstructed specially a variety of concrete block, stone and brick masonry structures suffered damage during the recent 8th October Kashmir-Hazara earthquake. Some of the traditional masonry structures had no earthquake resistant features and suffered considerable damage. Unreinforced masonry structures are the most vulnerable during an earthquake. Normally they are designed for vertical loads and since masonry has adequate compressive strength, the structures behave well as long as the loads are vertical. When such a masonry structure is subjected to lateral inertial loads during an earthquake, the walls develop shear and flexural stresses. The strength of masonry under these conditions often depends on the bond between brick and mortar (or stone and mortar), which is quite poor. This bond is also often very poor when lime mortars or mud mortars are used. A masonry wall can also undergo in-plane shear stresses if the inertial forces are in the plane of the wall. Shear failure in the form of diagonal cracks is observed due to this. However, catastrophic collapses take place when the wall experiences out-of-plane flexure. This can bring down a roof and cause more damage. The adversely affected areas like Balakot, Muzaffrabad and Bagh were so close to rupture zone that the vertical component of earthquake wave was very much dominating and uplifted the structures and the shear component completed the collapse of the structure. Masonry buildings with light roofs such as tiled roofs are more vulnerable to out-of-plane vibrations since the top edge can undergo large deformations. It is always useful to investigate the behavior of masonry buildings after an earthquake, so as to identify any inadequacies in earthquake resistant design. Studying types of masonry construction, their performance and failure patterns helps in improving the design and detailing aspects. After the 8th October Kashmir-Hazara earthquake that rocked the vast areas of Pakistan, causing large scale destruction in the Muzaffarabad, Balakot, Bagh, Battagram and large areas in Naran, Neelum, Jhelum, valleys. The authors visited the affected areas twice to study the damages to masonry buildings. Fig. 2a&b are showing the devastating damages in Balakot and completely collapsed building of Muzaffrabad Uniuversity.

(a) **(b)**

Figure 2: (a) View of devastating damages in Balakot
(b) View of completely destroyed Muzaarabad University

2- Damages Observed in the Masonry Structures

The major damages observed in the masonry structures are summarized below:-

2.1- Shear Cracks

Shear cracks appeared in the load bearing and masonry infill due to severe ground motion during the earthquake. The load bearing members and masonry infill at the right angle to the direction of ground acceleration showed shear cracks due to accumulation of shear stresses in the member. Fig.3a shows the shear cracks in load bearing wall as the wall was in the perpendicular direction with respect to earthquake motion. Fig.3b shows cracks in the masonry infill.

(a) **(b)**

Figure 3: (a) Shear cracks in masonry load bearing wall (Muzaffrabad University)
(b) Shear cracks in masonry infill in shopping plaza at Abbottabad

2.2- Cracks due to in Plane Movement.

Flexural as well as shear cracks were observed in most of the building due to excessive stresses induced by in plane vertical and horizontal forces. As the affected area was very close to the fault surface the vertical and shear component of the seismic wave had combined significant affects on most of the buildings. Figure 4(a) & (b) shows the horizontal flexural and shear cracks in brick masonry load bearing wall due to in plane movement caused by earthquake vertical and horizontal forces.

(a) **(b)**

Figure 4: (a) Flexural & shear cracks alongwith separation of wall from wall connection
(b) Shear & flexural cracks alongwith separation of wall from roof

2.3- Collapse due to Settlement.

Failure of masonry structure was also observed due to settlement. Most of the buildings were constructed without any prior soil investigation and situation got worsened by constructing the structures on the fill land with shallow and improperly designed foundation. In the eve of the catastrophic earthquake the earth shaking destabilized the soil beneath the structures and they collapsed. Figure 5(a) & (b) shows the collapse of brick masonry building due to settlement due to shear / settlement failure of soil beneath the foundation.

(a) **(b)**

Figure 5: (a) Collapse of masonry building in Muzaffrabad due to settlement
(b) Collapse of masonry building in Balakot due to settlement

2.4- Out of Plane Failure of Wall leading to Collapse.

Collapse of buildings due to out of plane movement was also observed in the affected areas. All the walls having less flexural strength and minimum stiffness in the perpendicular direction of seismic waves were collapsed causing the failure of complete structure. Figure 6(a) & (b) shows the collapse of load bearing stone masonry wall due to out plane earthquake forces.

(a) **(b)**

Figure 6: (a) & (b) Collapse of load bearing wall due to out of plane loading

3- Behavior of Masonry Structures during the Earthquake

As the affected areas were very close to the rupture zone and being shallow earthquake, the vertical component of the seismic wave was very dominating and this component of force severely damaged the buildings and the shear component completed the collapse. The behavior of different types of masonry structures observed during the visit is given as under:-

3.1- Unreinforced Brick Masonry Structures

The performance of brick masonry structure was interestingly satisfactory despite its known brittle behavior. The reason for this satisfactory behavior is due to fact that these were small two storeys box type structures with light roofing system. However, considerable shear and flexural cracks appeared in all most all the buildings but none of the building was totally collapsed.

3.2- Unreinforced Stone Masonry structures

Stone masonry structures performance was very poor and all most all the masonry stone structures completely collapsed or severely damaged. Most of the stone masonry schools, colleges, universities, old hospitals and official buildings collapsed completely causing considerable losses in the terms of lives and property despite the fact that all the stone masonry buildings have the light weight wooden roof trusses. The main causes observed was the old age, poor construction material, proper designing and poor skillmanship.

3.3- Unreinforced Concrete Blockwork Structures

The performance was very poor and most of the buildings were collapsed or damaged severely. The main cause of this behavior was heavy R.C roof with improper joint connection. The poor material quality and skillmanship also contributed considerably in the failure of structures.

4- General Reasons of Damages in Masonry structures studied during the Visit

The visit of the affected areas reveals that mostly the damage occurred due to the following reasons:-

4.1- Most of the structures built with round river bed stones were found to be collapsed completely.

4.2- Liquefaction of soil, occurrence of soft pockets or settlement of soil results in inadequate foundation support. This leads to the structural failure of rather sound structures. Shallow foundations fail earlier during an earthquake

4.3- Poor quality of construction, like the use of weak materials, poor workmanship, inadequate skill in bounding units, improper connection between the members, etc., results in the failure of the structures in the damaged structures.

4.4- Unsymmetrical geometry, both in plan and elevation and big openings for door and windows in the walls are found to be some of the main factors responsible for the damage.

4.5- Failure of connections between wall and wall, roof and wall and foundation and wall may cause failure of structure. Heavy weight of roof and poor connections with other elements may result in severe damages.

4.6- Mostly in stone masonry huts, the poor maintenance of timber roof failed as a result of termite attacks. Moreover, the affected timber components of the roof were supporting thick mud layers, which enhanced the damage due to its heavy self weight.

4.7- Ground conditions were not taken into account during construction of the structures which caused major damage.

4.8- The slope instability, due to earthquake shaking, was identified as another major cause of collapse in many structures. In such cases, deep pile foundations would have avoided the failure.

5- Recommendation / Suggestion for Future Construction of Structures.

After visiting the affected areas following suggestions / recommendations are rendered to be adopted for future construction and to minimize the devastating effects of any future earthquake in the area which seismically active zone:-

5.1- During an earthquake, the loss of human lives is mainly due to the collapse of kucha type of structures. These structures can be regarded as non-engineered as their design does not follow the standards to resist the lateral earthquake forces. Pakistan as well as most of the earthquake-prone developing countries has a serious problem with these non-engineered structures. Unfortunately, this problem is increasing rather than decreasing because of growing population, poor economic conditions, scarcity of wood, cement and steel, lack: of understanding of earthquake features, etc.

5.2- Uniform Building Code 97 has placed most of the areas in Pakistan in zone 2A. However, after this recent strong 8th 2005 Kashmir-Hazara Earthquake there is strong need felt to consider re-zoning of the area. According to re-zoning of the area the proper local building codes should be formulated. In the absence of any local building code it is suggested to follow the international building codes for future construction.

5.3- It was observed during this visit that a number of masonry structures were damaged due slope failure and improper foundations. It is strongly recommended to carry out proper soil investigation and proper footing type according to soil investigation. Construction on unstable slopes should be avoided; otherwise it is necessary to stabilize the slope before constructing any structure. Mat/Raft foundation should be made mandatory for residential buildings or pile foundations and unstable slopes will be the most appropriate solution.

5.4- The properly engineered, having good construction material, well constructed and designed structures have performed well during this earthquake

5.5- The construction of properly designed light weight single storey or double storey buildings will be safe in the area and construction of multistory buildings without proper seismic design should be avoided. The residential structure can consist of mat foundation with reinforced brick or block masonry walls having light weight wooden roof truss. For commercial buildings it is strongly recommended to have reinforced concrete beam column arrangement with brick or block masonry infill walls with wooden roof truss or R.C roof slab. Shallow R.C mat footing on stable strata and in case of unstable slope/strata proper slope stabilization measures should be ensured to provide appropriate lateral soil support and to avoid differential settlement. Further, R.C columns should be tied at lintel and floor levels. The main aim of seismic design of a structure should be to avoid complete collapse to save the life at any cost. The partial damage of the structure may be allowed by having ductile arrangements which can be repaired after the tremor.

5.6- Horizontal lintel band should be provided to reduce the effects of lateral forces and to make the box type of structure and to reduce the unsupported length for less slenderness effect. Proper reinforced connection should also be provided to improve the seismic behavior of the masonry structures.

5.7- All multi-storey buildings must be properly designed for the earthquake loading. Detailing of steel must also be carried out according to the code provisions.

5.8- The building must be regular and symmetrical in shape. The geometric and mass centroids must coincide to avoid torsional moment. Further, shear walls must be symmetrically placed.

5.9- Reinforcing bars should be provided at the corners and the junctions of the walls.

Connection between wall and roof should be made carefully. Corners and junctions of the walls should be strengthened by providing wood planks, steel bars, wire mesh, etc. Cantilevers, free standing walls and free standing columns must be avoided besides irregular geometry of the structure.

5.10- All the near by buildings should be of same size and height to avoid buffeting together along with sufficient gap between two adjacent structures. This is necessary to have same mode of vibration at a time.

6- Conclusion

There are many lessons that have been learnt from Kashmir-Hazara earthquake. Based on these lessons, some short and long term measures have been recommended to be adopted in other seismic prone areas of the world. The massive destruction caused by the earthquake is attributed largely to unprecedented devastating nature of seismic waves, tough / rugged mountainous terrain, improperly designed seismic resistant structures and our own faulty construction practices. Catastrophes are the real test of the nations but positive aspect is that it surfaces the mistakes and teaches to rectify them and not to repeat the mistakes. Moreover, it unites the nation to combat the devastating effects of catastrophe. In the report it is endeavored to highlight the mistakes committed during construction and other factors causing the large scale devastation and to rectify the faults during future construction by following the suggested methods. Any arrangement that utilizes mostly the locally available material and involves the local inhabitants in construction will prove to be the most economical, easiest and quickest measure.

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