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EVALUATION OF DESIGN AND CONSTRUCTION PRACTICES
-- A LESSON LEARNT FROM KASHMIR EARTHQUAKE --

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ABSTRACT: An intense earthquake of magnitude 7.6, known as Kashmir Earthquake, jolted northern areas of Pakistan and Pakistan administrated Kashmir on October 8th, 2005. The affected area has a rugged mountainous terrain with extreme weather conditions and was never exposed to such a serious seismic activity in the recent history. Therefore, the event was responsible for the destruction of buildings, infrastructures and earth slopes. The authors have been surveying the devastated areas to assess the damage pattern, proposed methods for improved design/construction and lack of their practices.

Key Words: Kashmir Earthquake, design and construction practices, damages, lack of application, lessons learnt

INTRODUCTION

An intense earthquake of magnitude 7.6, known as Kashmir Earthquake, jolted northern areas of Pakistan and Pakistan administrated Kashmir at 08:50 (03:50UTC) on October 8th, 2005. The epicenter of the earthquake was located at latitude of 34.493°N, longitude of 73.629°E and focal depth of about 26 km (United States Geological Survey (USGS)). This is the location, around 90 km north-northeast of Pakistan's capital, Islamabad and 20 km northeast of Muzaffarabad, local capital of Pakistan administrated Jammu and Kashmir. The highest numbers of aftershocks (122) were recorded on October 9th, 2005 with a significant drop of aftershocks in subsequent days. The total aftershocks were 1778 at the end of 2005 (Pakistan Meteorological department, 2006). The earthquake resulted in more than 86,000 fatalities, 10500 people injured, 400,000 houses destroyed and 2.8 million people left homeless in northern Pakistan and Azad Jammu and Kashmir (EEFIT mission, 2006), and is by far one of the deadliest in the sub-continent.

This earthquake was resulted from reactivation of northwest-striking fault, later defined as the Balakot–Bagh fault (Figure 1). The surface expression of the causative fault extends between Bagh and Balakot through Muzaffarabad (Geological Survey of Pakistan (GSP), 2006). The fault has reverse separation with northeast side moved up which has been verified by high crustal deformation from satellite data and fault modeling. The earthquake caused a widespread destruction in a wide belt along the total length of the fault. The area is characterized by its rugged mountainous terrain with limited communication structures connecting the sparse settlements. The devastated area is also recognized by the severe environmental conditions (especially very cold winter) and the residential structures were constructed with heavy roofs and thick walls to ensure the survival in these extreme environmental conditions. Due to the poor economical conditions, settlements in the mountainous ranges are the first choice for common people as compared to the flat land, which is more expensive. Moreover, the important/official structures were not designed properly for such an intense shake while the common residential dwellings were constructed without any design provisions. The earthquake was severe enough to destroy these structures. The city of Muzaffarabad and Balakot town were the nearest settlements to the epicenter, and they were the most heavily damaged (Figure 2).

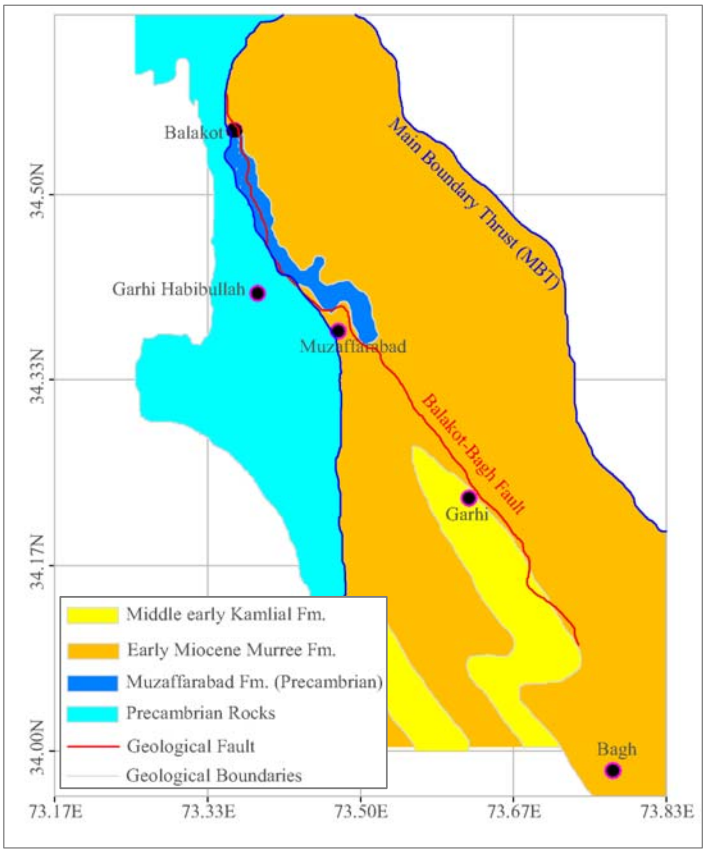

Fig. 1 Simplified geological map of the devastated area with overlaid fault map (Kazmi et al., 2010 after Ahmed et al. 2009). The major devastated cities are Muzaffarabad, Bagh and Balakot.

The authors have been surveying the devastated area since the occurrence of the Earthquake and have summarized their findings into three stages along the time scale. First stage comprises of two months after the earthquake. In this stage, the damage contributed by earthquake is evaluated; the damage to buildings, residential houses, non engineered structures and geotechnical structures is discussed. Second stage comprises of two years after the earthquake. This stage summarizes the work presented by different researchers for proper site selection and design/construction methodologies to develop safe settlements. Establishment of different governing bodies for reconstruction and rehabilitation of infrastructures and measures taken by these societies are summarized in this stage. Third stage comprises of two year after the earthquake to date, emphasizing the change in construction type, improvement in construction techniques in the local society, and concern of seismic safety during construction. All the three stages are summarized in detail in the following sections.

Fig. 2 Devastation caused by Kashmir Earthquake in Muzaffarabad and Balakot cities

STAGE-1: TWO MONTHS AFTER THE EARTHQUAKE

Kashmir Earthquake was different in many aspects as compared to other historical earthquakes. Although, there were known active faults (Muzaffarabad and Tanda faults, mapped by Nakata et al. in 1991, later comprehensively defined as Balakot-Bagh fault (Figure 1)) in the region, there is no history of intensive ground shaking in the preceding few decades. In most of the developing countries, disaster response is event driven instead of being preemptive. Similarly, citing the dormant seismic history of Kashmir region, there was no concept of seismic safety either at administrative or individual levels. The affected area has a rugged mountainous terrain with extreme weather conditions. Therefore, the residential dwellings were developed considering only their environmental vulnerability.

Extent of Damage

The strong ground shaking caused a variety of damages including infrastructure damages, extensive landslides and damage to residential houses and other structures. Close to 400,000 houses were fully destroyed and damaged leaving about 2.8 million people without shelters (EEFIT mission, 2006). Out-dated design codes without seismic consideration, poor construction materials, poor site-selection and non-engineered structures were the prime reasons of extensive damage to residential buildings.

Damage to buildings and residential houses

As is discussed, the devastated area has a rugged mountainous terrain with very limited flat terraces. These flat terraces are well congested and the land price is beyond the approach of majority. Therefore, a fair number of population lives along the hill slopes (Figure 3a), building their dwelling against the natural slopes (Figure 3b) or on the soft deposits. These sites are vulnerable and have the tendency to magnify the earthquake effects. A large number of houses, with their back walls against the hill slopes, have been damaged during the earthquake due to increased pressure from the soil behind (Figure 4).

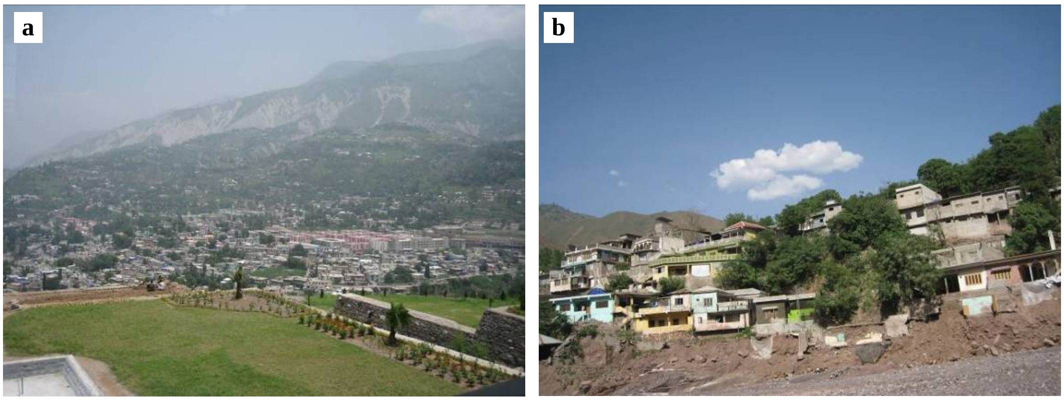

Fig. 3 a) A view of the Muzaffarabad city showing that a considerable number of population is living along the hill slopes behind flat terraces b) A typical example of the poor site selection, a common construction approach along the hillside (Photos by Kazmi, 2007)

Fig. 4 Houses collapsed during the Kashmir earthquake with their rear walls damaged by increased earth pressure from the hill slope.

In addition to the poor site selection, lack of seismic considerations in design and construction was a prime reason for this massive devastation and death toll. Use of locally available stone and concrete blocks in construction is a state-of-the-art approach for construction of houses. Majority of the residential houses were made of stone or hollow concrete block masonry with corrugated iron roofs resting on timber trusses. The primary load bearing members were the masonry walls. Complete structural collapse was observed due to failure of such walls in out-of-plane bending and in-plane shear. Majority of the public structures (schools, colleges, hospitals etc.), which are supposed to be designed for a higher level of service and importance factor, also had similar structural systems as that of the residential houses. The ground shaking was large enough to partially or fully collapse all such constructions (Figure 5). A death toll of more than 15000 school children witnesses the extent of damage to school and colleges.

Landslides and slope failures
Strong ground shaking triggered a large number of landslides and slope failures. The total number of landslides identified by using SPOT 5 images counted to be 2424 (Sato et al, 2006). The largest

example is the Hattain Bala landslide (Figure 6a), an 85 million m^3 soil mass (Dunning et al., 2007) that moved down the slope flushing the whole village settled on it and killing almost 200 people. The soil mass blocked two tributaries of Jhelum River and created a huge landslide dam, which later breached in 2010 and caused flooding to its downstream. In addition to such huge landslides, suficial slope failure appeared in wide belt along the total stretch of Balakot-Bagh fault (Figure 6b). This slope failure created a huge amount of debris material which moved down the creeks during the heavy rains of monsoon and hit the inhabitants along the valleys.

Fig. 5 Girls Degree College Rawalakot (left photo) and Boys Degree College Hajira (right photo) were totally collapsed during the earthquake. The structural system for both the buildings was load bearing stone masonry walls with different roofing system (Photo by Kazmi, 2006)

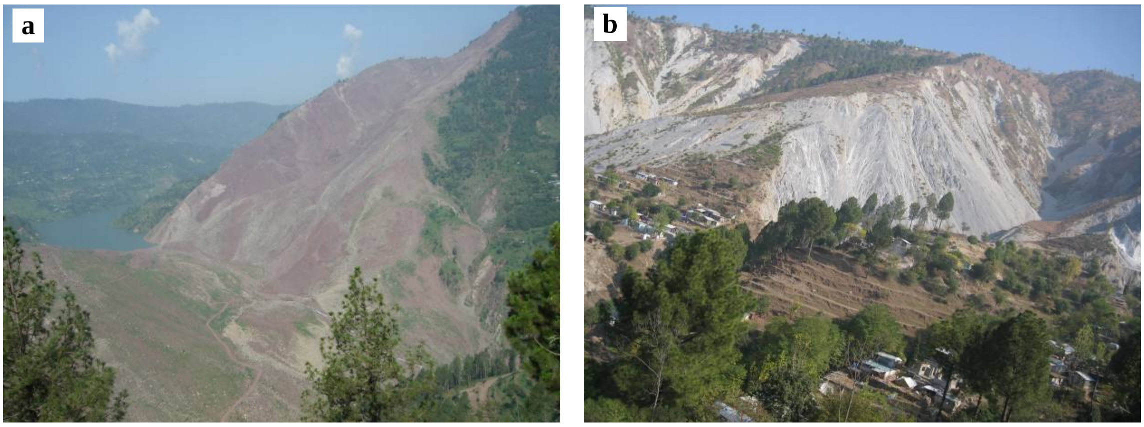

Fig. 6 Landslides and slope failures caused by Kashmir Earthquake a) Hattain Bala landslide b) surficial slope failure along Balakot-Bagh fault (Photos by Kazmi, 2008)

STAGE-2 TWO YEARS AFTER THE EARTHQUAKE

Construction, rehabilitation, strengthening and retrofitting of the infrastructure in the devastated areas of Kashmir Earthquake were prominent research topics during the two year (approximately) from the date of earthquake (Kumahara and Nakata 2006, Peiris, 2005, Sato et al. 2006 etc). Particularly, for seismic resistant house, a good number of procedures are proposed in the literature (Dowling et al., 2005 and Sathiparan et al., 2008). In that time, public sector was also interested to develop the guidelines for seismic resistant construction. Methods and efforts to incorporate the seismic safety in new construction and improve the seismic performance of existing houses are summarized in the following sub-sections.

Establishment of disaster mitigation organizations and interest of public sector to develop guidelines for seismically safe construction

To cope with the tragic devastation, Earthquake Reconstruction and Rehabilitation Authority (ERRA hereafter) was established soon after the earthquake. Later in 2006, National Disaster Mitigation Authority (NDMA hereafter) came into existence. They had a vision to achieve sustainable development by reducing risk and to recover from disasters. Along with achieving mile stones in rehabilitation and reconstruction work, these organizations played an important role in developing the basics for safer construction by revising the seismic zoning of the country, establishing/revising the design codes, developing the skilled manpower etc. The distinguished contributions by these organizations are in followings

Revision of seismic zoning of country and setting seismic provisions in building codes:
Following the earthquake, the major discussion at the national level was to revise the seismic zoning of the country. According to the seismic risk map of Pakistan, 2005 (available from Pakistan Meteorological department), the whole country was divided into four zones (Zone-1 to Zone-4, representing low to high seismicity). However, most of the areas devastated by Kashmir Earthquake lied in Zone-3 (NED, 2007). This indexes the necessity of revision of seismic zoning of the country. Revised seismic zoning was completed by ERRA in accordance with modified seismicity, and was critically discussed by few other researchers (Rossetto and Peiris, 2009) as well. Formulation/Revision of Pakistan Building Code (PBC, 2007) was made possible by the continuous effort of ERRA and may other organizations/individuals. Revision of seismic zoning and formulation of building codes is discussed in step by step process by Shabbir and Ilyas (Shabbir and Ilyas, 2007).

Training the worker for seismically safe construction:
Training of workers to modify the traditional construction style was an important work accomplished by disaster mitigation authorities. Common construction mistakes/flaws which lead to failure during the seismic activities were conveyed to the workers by model explanation and other means. For example, importance of proper joints at wall corners, vertically staggered joints in brick or concrete block walls, concept of monolithic construction etc.

Public awareness for safe construction:
Disaster mitigation authorities and NGOs invested in the projects of public awareness for safe construction, because seismic safety was not a major concern during the constructions of houses before the earthquake (Haseeb et al., 2011). Explanations from model tests and technical brochures, written in local language, were used as tool to invoke the awareness of seismic safety to general public. Site selection, type of construction, method of construction, and sizes of openings were the main focus of the model test and technical brochures (Stephenson, 2008).

In essence, the approach of disaster mitigation authorities and NGOs was to educate the people to consider the seismic safety in new construction and also to introduce simple techniques/approaches which would be helpful to enhance the seismic safety both in the new construction and existing dwelling.

Seismic safety of adobe houses and non engineered dwellings

State-of –the-art residential buildings in Pakistan are un-reinforced brick masonry buildings (Ali, 2006), stone masonry buildings (Ali and Muhammad, 2007) and reinforced concrete buildings (Badrashi, 2010). Majority of the residential buildings in earthquake affected areas were adobe houses; constructed by sun-dried mud bricks with mud mortar or burnt bricks with mud or cement sand mortar. Such dwellings have no resistance to seismic excitation. A good number of procedures are proposed to reduce the vulnerability of adobe houses against seismic activity (Smith and Redman, 2009). Conclusively, increase in tensile strength in horizontal and vertical directions is the prime objective of such procedures. To meet that objective, use of PP-band is suggested by many researchers (Sathiparan at el., 2010, Macabuag and Bhattacharya, 2009). Effectiveness of the PP retrofitted panels against out of plane loading is also claimed (Sathiparan at el., 2008).

Other methods, proposed to reduce the vulnerability of adobe houses against seismic activity, use a verity of materials to improve the tensile strength in horizontal and vertical direction. Such as, first; reinforcement with wire mesh covered with lime or cement mortar (Yamin et al., 2004, Bartolome et al., 2004) second; circumferentially cut straps from used car tyres (Charleson and French, 2008, Turer et al., 2007), third; by using bamboo's strips on both faces for horizontal and vertical directions (Dowling et al., 2005). The availability of material, workmanship to accomplish the proposed methods, acceptance and affordability of such methods by local community are more important questions than the evaluation of effectiveness of the procedures by laboratory tests or by model tests in the field.

Construction of buildings with 150 mm wide concert blocks or fired bricks supporting heavy concrete slab, non-engineered concrete frames with in-filled brick/stone masonry are common in the semi urban areas. For safety of non engineered houses, ERRA proposed general guidelines for opening sizes and locations, reinforcement details, joint details, x-sections of beams and columns etc. Many foreign and local NGOs have also been contributing to accomplish this purpose. Some NGOs and other organizations claim that they have introduced some effective concepts for seismic retrofitting of houses in devastated areas of Kashmir Earthquake like, seismic strips, techniques to effectively join the timber post to make rafters of trusses (Stephenson 2008).

Seismic safety of engineered-buildings

Methods and Procedures for seismic design of structures are evolving day by day. Sophisticated finite element based model to contribute the details of beam column joints (Elmorsi et al., 2000), structure specific ground motion (Honda and Ahmed, 2011, Ahmed and Honda 2010), and nonlinear response based design ground motion selection methods (Ahmed and Honda 2011 a, b) are few examples. Code based design approach is proffered by the design engineers due to issues of time, cost, responsibilities and reliabilities.

Seismic detailing of structural members, loadings according to nature and use of the buildings, shear and flexural capacity of members etc. are discussed in revised building code of Pakistan 2007. To consider seismic forces, equivalent static lateral load procedure is proposed for certain height of the buildings while a time history analysis for complicated structures.

Site selection

The earthquake devastated area is one of the most landslide prone areas of the country due to its rugged mountainous terrain. The earthquake resulted in building up large strains in soils and rocks along the dislocated fault which can trigger post-earthquake disasters such as landslides and debris flows. Another major concern was that the disturbed soil masses will move again during the heavy rains and snow melt seasons. Therefore, flat and stable terraces were recommended for the satellite towns and new constructions.

In hilly areas, back wall of house is mostly adjacent to the slope of mountain. By Earthquake rehabilitations authorities, it was particularly emphasized through the technical broachers and other mediums to avoid construction against the slope if back wall is not designed as a retaining wall.

Authors appreciate the efforts by public sector organizations and researchers to promote the seismic resistant construction. In true sense, such efforts are reflected in projects funded by reputable organizations such as UNISCO etc. In particular, these projects were supervised by ERRA and good quality of work was maintained. But in general, the proposed methods were not accepted by the community due to economic and other constraints.

STAGE-3 TWO YEARS AFTER THE EARTHQUKE TO DATE

As discussed in the previous stage, a lot of work has been done by disaster prevention authorities and individual researchers by revising the building code (Pakistan Building Code, PBC, 2007), defining new seismic zones, and proposing new methods for rehabilitation and/or reconstruction of the damaged buildings/houses. However, all the attempts for their practical implication were frustrated by socio-economic constraints, lack of awareness and availability of the budget for any individual project. Despite of experiencing such a tragic devastation and losing many lives, people could not learn enough from the Earthquake and have been building new structures/houses on the old patterns. Economical conditions of most of the devastated areas made any expensive methodology to be divorced from the ground reality. Furthermore, there was no law, enforcing individuals to follow the recommendations proposed by the experts. With this type of reconstruction, any future seismic activity could be as catastrophic as the Kashmir Earthquake of 2005. The authors have been surveying the areas which were seriously devastated (Muzaffarabad, Bagh, Rawalakot and Hajirah), to evaluate new construction strategies, and have concluded some of their observations in the following sections.

Site Selection

When a disaster strikes our fragile world and causes some serious devastation, it interrupts our senses for some period of time. But as the time passes by, we easily forget all that. Similarly, forgetting all what happened during Kashmir Earthquake, people are still constructing their houses against the hill slopes (Figure 7) by cutting the toes of natural slopes.

Fig. 7 Construction of the new house with their back wall facing the natural slope (Photo by Kazmi, 2008)

Flaws in Concrete Construction

Figure 8 shows construction of government hospital at Hajira, a typical example of post earthquake construction. Both the photos in Figure 8 witness poor quality of design and construction. According to the revised seismic zoning, the building is located in zone-4 but the reinforcement detailing and structural members are not concordant with that. Spacing for the shear ties was larger than the maximum limit specified by the revised design code even at the locations of concentrated loads from the bracing beams. Sizes of many of the beams and columns were also violating the code specifications. Roof slab was not monolithically cast with the supporting beams and shear ties and negative reinforcement of the beams was exposed to the atmosphere. In addition to the inappropriate design/detailing, poor quality of construction was also observed. As can be seen from Figure 8, the whole construction was presenting concrete segregation and honeycombing while the reinforcement was exposed to the surfaces. While surveying the devastated area to evaluate the reconstruction, a large number of similar cases were observed. Any future seismic activity may repeat the history with such a poor quality of design and construction. Although there are many socio-economic issues, people might have learnt from this recent incident to ensure safety for their lives.

Fig. 8 A typical example of reconstruction for concrete frame structure (Photos by Kazmi, 2007).

Flaws in Masonry Construction

Despite of the effort made by ERRA and other authorities to communicate the recommendations for adobe houses to local society, local houses have been constructed on the older fashion with slight modification. Figure 9 shows a typical example of reconstruction for masonry houses. Very thin columns (equal to the width of concrete block, 150mm) were provided on corners and a single bar around the wall openings. 150mm wide hollow blocks were used for the in filled masonry. The adopted construction methodology can neither be cauterized as frame structure nor a masonry structure and are vulnerable to any extreme condition. Recommendations made to make the masonry houses seismic resistant (application of PP band etc.) were not observed in practical.

Fig. 9 A typical example of reconstruction for masonry houses (Photo by Kazmi, 2007)

CHALLENGES IN APPLICATION OF PROPOSED GUIDELINES FOR SEISMIC-RESISTANT CONSTRUCTION

Methods and guidelines for seismic resistant construction proposed by researchers, disaster mitigation authorities and NGOs are proved to be effective in seismic resistant construction by laboratory test (Sathiparan at el., 2010, Macabuag and Bhattacharya, 2009). In laboratory tests, the field conditions are artificially reproduced to verify the effectiveness of the methods (Dowling et al., 2005). However, the adoptability by the local community is an important issue. By analyzing the survey results and based on ground facts, following challenges in application of proposed guidelines for seismic resistant construction are noticeable, specifically for Kashmir Earthquake affected areas.

- Financial Aspects: Finance is major challenge to successfully implement the new seismic resistant construction techniques. The average income of the earthquake affected areas was very low, which can be imagined from type and size of dwellings and their living styles. Additionally, people lost their business, jobs and savings due to the earthquake and fell to miserable financial conditions. Due to lack of financial assistance, people were forced to build houses on traditional construction style, reusing debris of their collapsed houses.

- Lack of availability of material, workmanship and machinery: To imply the earthquake resistant construction, special materials, skilled workers and machineries were required. These were neither locally available nor in the financial approach of local people. Therefore, the community imagined the proposed techniques to be divorced from the ground reality and adopted the traditional construction with locally available material. The inconsistency between the resources required for seismic resistant construction and locally available resources was another hindrance in the application of proposed guidelines.

- Proposed methods are sophisticated: Methods proposed by researchers were very sophisticated. For example, orientation and anchorage of the PP-bands (Macabuag and Bhattacharya, 2009), proper fixing of the wire mesh to the wall etc. Sophisticated methods are good for test conditions. Simplicity and flexibility in application to a variety of conditions are prerequisites for a method to be followed by local masons and builders.

- Accessibility: The area devastated by earthquake was more than 26,000 square kilometers. Limited communicating structures connecting the sparse settlements were destroyed by the earthquake, hindering the quick access of responsible authorities to the far settlements.

- Lack of access to information: Social-net-works, the only reliable and effective source of communication in the target area, were also severely joggled by the earthquake. Therefore, the staggered community of the area has the least access to information about seismic resistant construction techniques and methods.

CONCLUSIONS AND RECOMMENDATIONS

Massive earthquakes often leave their fringe patterns behind. Whenever a strong earthquake hits our fragile world, it interrupts our senses for some period of time. However, time is best healer and we forget the things as the time passes by.

The Kashmir Earthquake of 2005 stuck northern areas of Pakistan and the state of Kashmir. This is a remote area and there was no concept of seismic safety for the construction of buildings/houses. Therefore, the earthquake caused a widespread destruction with a tragic loss of lives and property. Soon after the earthquake, many disaster mitigation authorities, local organization and local and foreign NGOs came into play for technical assistance. A lot of effort has been put by these organizations to improve/revise the design codes, to literate the local community about the seismically safe reconstruction and to train the technical staff. Many individual researchers were also attracted and they have put a remarkable input at their capacity. Authors highly appreciate the efforts made by these organizations and researchers to promote the seismic resistant construction.

However, all the attempts for the implication of these techniques have been frustrated by the social, socio-economic, topographical and geophysical constraints. Despite of experiencing a massive destruction in the very recent history, people have been reconstructing their dwellings on the older patterns (with the exception of some public sector buildings which were funded by reputed organizations and supervised by ERRA) with locally available materials and limited resources. Although all the sympathies of the authors are with the inhabitants, most of the reconstructed buildings/houses are not capable of sustaining any serious seismic event and the history can be repeated.

The authors strongly recommend that along with technical development, there should be some incentive and law, enforcing the inhabitants to comply with the updated guidelines. As has been repeatedly discussed that financial constraints are the most critical, no technical or administrative development can be of use as long as there is no financial assistance.

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