**Ninth Canadian Conference on**
**Earthquake Engineering**
**Ottawa, Ontario, Canada**
**26-29 June 2007**

# EARTHQUAKE DESIGN CODES FOR PAKISTAN: AN OPTION OR A NECESSITY?

A. Masud[1] and A.S. Elnashai[2]

## ABSTRACT

The Kashmir earthquake of October 8, 2005 which had a magnitude of 7.6 inflicted a heavy toll on lives and livelihoods in a large region in northern Pakistan, Kashmir and even parts of northern India. This geographical location is an active tectonic region where the Indian plate subducts under the Asian plate, creating an arc of high seismicity that has been responsible for major earthquakes in the past. The damaged observed in the region affected by the October 2005 earthquake clearly demonstrates the urgent need for a comprehensive reassessment of hazard, micro-zonation and detailed seismic code development in Pakistan. The urgency of the above efforts is underlined by the fact that slip rate measurements in the Himalayan Arc confirm the likelihood of further earthquakes [1] that can be much larger than the October event, i.e., in excess of magnitude 8. The objective of this paper is to provide global recommendations and a course of action that Pakistan will need to adopt to develop a National Seismic Mitigation, Response and Recovery Plan including design codes that are most suited to local needs while taking advantage of the construction materials available in the country.

### Overview of the Earthquake

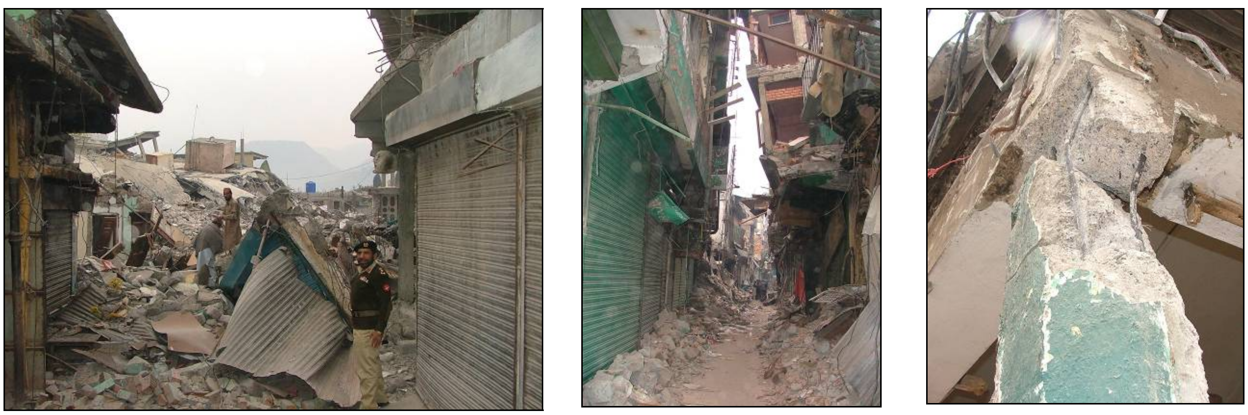
At 8:50 am Pakistan Standard Time on October 8, 2005, an earthquake of magnitude Mw 7.6 hit northern Pakistan, the Kashmir region and parts of India. With almost 80,000 dead, more than 70,000 injured, and in excess of two million homeless, the earthquake ranks amongst the worst natural disasters in the history of Pakistan and the Indian subcontinent. The total cost of reconstruction is in excess of five billion dollars. The indirect losses may be 2-3 times the direct loss estimates.

A review of the earthquake history of the area confirms that the Kashmir earthquake, though large by normal standards, is considered ‘moderate’ when viewed in the context of earthquake generation potential of the India-Tibet subduction region. Moreover, theoretical studies indicate that the energy stored along the Himalayan arc suggests a high probability of several massive earthquakes of magnitude greater than 8.0 in the future. Based on the limited amount of available strong-motion data, contour maps for peak ground acceleration in the horizontal and vertical directions were derived [2]. Estimates indicate that it is likely that average peak ground acceleration in the epicentral region was 0.7g-1.0g in the horizontal direction and 0.6g-0.9g in the vertical direction. The duration of shaking was exceptionally long even for an earthquake of this magnitude.

---

[1] Associate Professor, Civil & Environmental Engineering, University of Illinois at Urbana-Champaign (UIUC), USA.
[2] Bill and Elaine Hall Endowed Professor, Director of Mid-America Earthquake Center, UIUC, USA.

The widespread structural damage that was observed on ground was not unexpected. Two dominant factors for this widespread destruction were (i) the poor quality of construction of traditional housing units that can also be categorized as non-engineered buildings, and (ii) non-existent seismic design to resist earthquake action on modern RC structures. It should also be noted that preliminary analysis of a set of strong-motion records from Abbottabad indicated that shaking in the epicentral region was severe; comparable to shaking in previous major damaging earthquakes in Turkey, the USA and Japan. Since design wind loads are rather modest in the northern regions hit by the October 8 earthquake and are therefore rarely taken into account, even engineered structures were not expected to resist significant lateral loads since they were not designed to resist significant wind loads. Site investigations concluded that for the class of engineered structures that were fairly well constructed, and causes of failure were due mainly to layout defects, such as soft ground storey, short columns, irregular plans and elevations, as well as lack of maintenance in a few cases. Bridge structures on the whole responded well to the earthquake with only very few cases of heavy damage, and fewer cases of collapse. Figures 1 through 8 give some indication of the widespread damage to engineered and non-engineered buildings. The collapsed engineered buildings had significant engineering design flaws, and point towards the critical importance of new code provisions.



(a) Overview of Madina market (b) Interior street (c) Failure of beam-column joint

Figure 1. Damage in Madina market, Muzaffarabad. Poor construction materials, lack of seismic detailing, poor layout, and pounding between adjacent buildings are all evident.

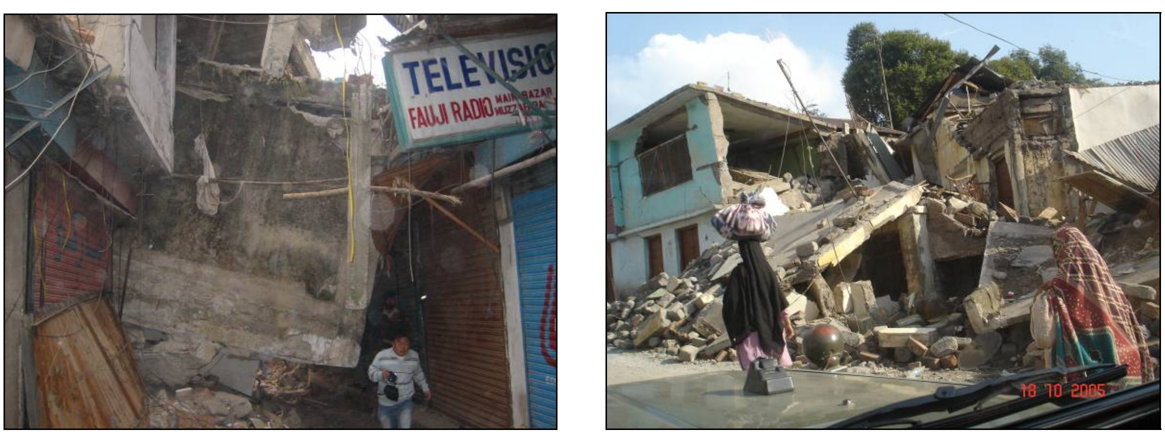
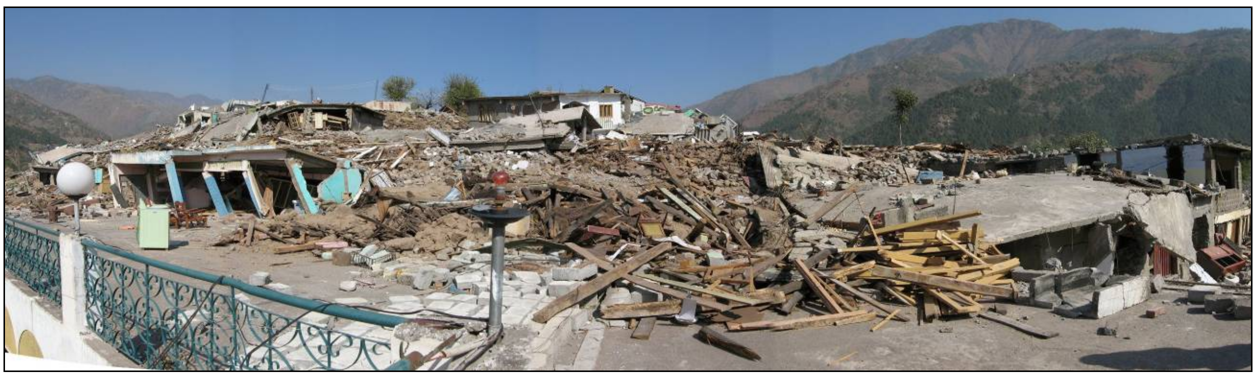


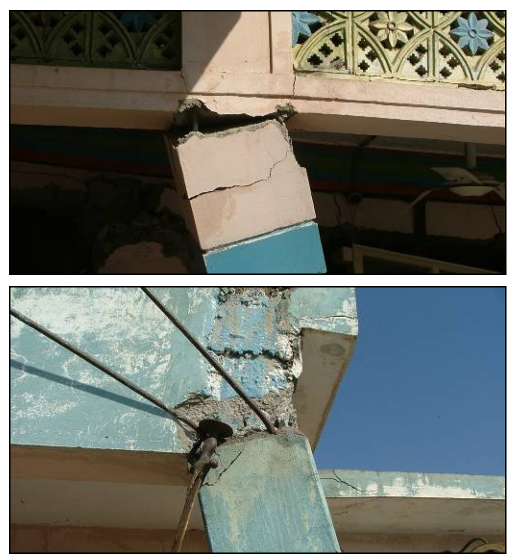

Figure 2. Typical old urban and rural housing units made of brick walls and concrete slabs, Muzaffarabad.

Figure 3. Structural failures due to soft story along main street in Balakot.



(a) Pictorial view of ridge effect on collapse on a hill in Balakot.

(b) Balakot hill



(c) Cold joint and use of unreformed bars

Figure 4. Collapse of an entire community on a hill in Balakot indicting ridge effect and emphasizing the need for micro-zontation and cautious siting of developments.

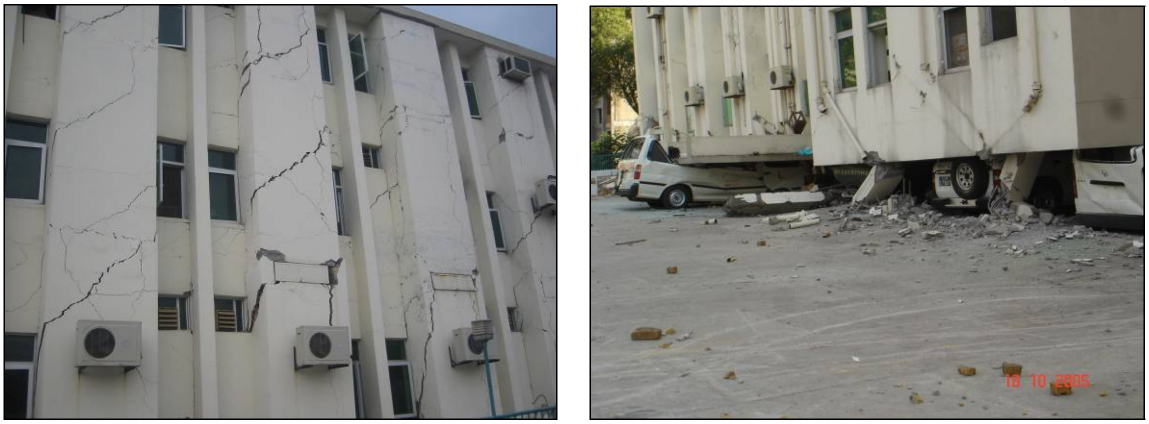


Figure 5. (a,b) Front and back views of the Combined Military Hospital (CMH) in Muzaffarabad. Poor layout leading to soft storey collapse has lead to total lack of function and condemnation.

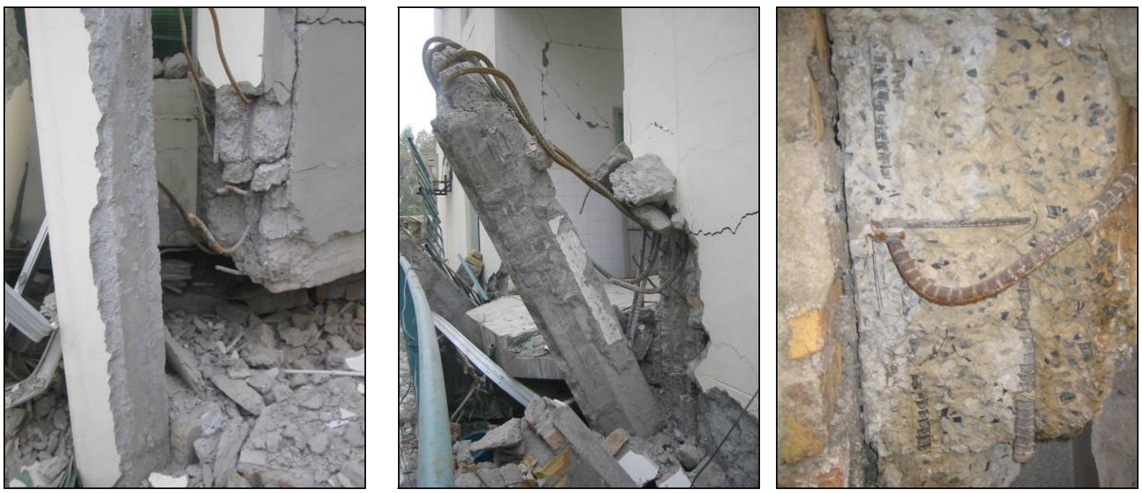


Figure 6. (a) Failure of a beam-column connection, (b) failure of a ground floor columns, and (c) details of the transverse reinforcement, CMH Muzaffarabad. All confirm very poor design and construction practices in the earthquake-affected area even for an engineered critical facility.

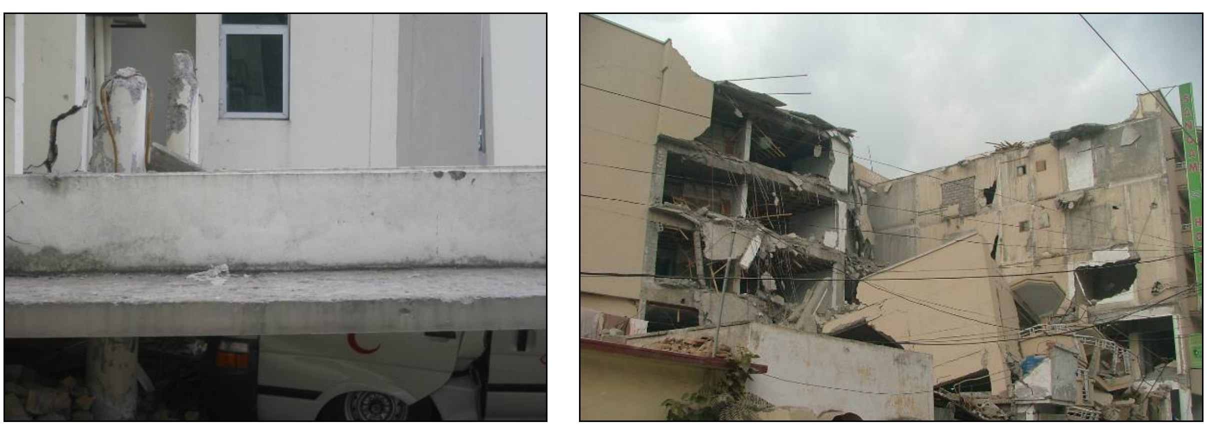


Figure 7. (a) Punching failure of the slab in CMH Hospital. (b) Failure of a hotel building in Muzaffarabad. Poor layout and materials are evident.

Figure 8. (a) Ground floor of Margala Towers (Islamabad) indicating stronger axis of all the columns aligned in one direction, leaving the system weaker in the lateral direction, (b) Amount of reinforcement and approximate sizes of reinforcing bars at the base of one of the interior columns.

The October 8 earthquake also emphasized the impact of slope failures, site response and the effect of topography. Tens of miles of slope failures were observed, and many other slopes remained precariously unstable awaiting a triggering event, several weeks and months after the earthquake. With regard to site response features, in at least two cases, in Balakot and Muzaffarabad, significant ridge effects were observed, leading to totally disproportionate levels of damage, relative to other regions (Figures 3 and 4).

Lifelines behaved reasonably well, with pockets of severe damage that had a significant short-term effect on search and rescue operations in the region. The impact on healthcare and education was severe. The response of Government organizations, the Pakistani Army and private companies was impressive, as evidenced by the rapid return to a manageable situation and effective distribution of national and international aid. The rapid move from search and rescue to emergency management and to planning for the reconstruction phase was admirable.

**Recommendations for Priorities and Actions**

It is clear that Pakistan needs to set priorities rather cautiously in order to use the devastating impact of the Kashmir earthquake in as positive a framework as possible. Technical expertise needs to be developed to renovate the built environment based on rigorous redesign and reconstruction criteria, benefiting from available technologies, whilst adapting them to Pakistani circumstances. At the same time great caution should be exercised in selecting guidelines, materials, systems and experts to aid in the reconstruction efforts. A multifaceted global approach balancing short- and long-term needs recovery and planning for future earthquakes, especially for critical facilities (e.g. hospitals, schools, power plants) and densely populated structures (e.g. sports and recreational facilities, convention centers) is essential. It is critical to develop design and construction guidance that is based on rigorous and confirmed engineering knowledge, while maintaining simplicity and ease of application. Finally, filtering of overseas knowledge and experience is another critical issue so that homogeneous and nationally-applicable retrofitting and design approaches and emergency planning measures are adopted and applied uniformly in Pakistan. The foundation of all aspects of re-engineering of the built environment should also be based on comprehensive, modern, useable and regionally applicable codes of practice. A framework for code development in Pakistan is outlined below.

***Code Development***

There is a pressing need to develop material and loading codes for Pakistan to support the large reconstruction effort that is starting now and will intensify in the coming years. Comprehensive code development will also be a necessary pre-requisite to further economic development and prosperity of the country. The current situation is that a mixture of informal guidance notes, and hastily-prepared regulations and foreign codes are being used. There is great danger attached to the current situation and practice. Reason is that informal guidance notes are not legal documents and hence are neither enforceable nor do they lead to clear accountability. Hastily-prepared regulations are the same, i.e., they are uncalibrated, untried, unsupported by scientific data and are therefore extremely dangerous. Foreign codes on the other hand are calibrated and tested. But they are pertinent to fundamentally different design, construction and supervision practices. Mixing different codes from leading industrialized countries is also fraught with danger. In mixing various codes, it is not even possible to rationally design for high levels of conservatism since the required level of safety in unknown, and therefore there is no datum to measure conservatism or otherwise from.

The framework for code development for Pakistan can follow other international models for code development. For example, over a period of 12-14 years, the European Community has established a complete set of codes for all products, not just buildings and bridges. A framework similar to that of the Eurocode can be followed in Pakistan. The development of complete structural codes for Pakistan can be accomplished in 2-3 years, provided adequate resources and decisive leadership is combined with technical personnel that have a proven track record in code making. There is an urgent requirement for the following codes;

- Philosophy of Design and Actions on Structures
- Reinforced Concrete Design and Retrofitting
- Steel and Composite Design and Retrofitting
- Masonry Design and Retrofitting
- Timber Design and Retrofitting
- Earthquake Design and Retrofitting
- Foundation Design and Geotechnical Aspects

To underpin code developments, important facets of research and investigation under the categories of hazard identification, and mitigation, urban and rural planning, design and practice, and social aspects of the earthquake disaster are listed below.

***Hazard***

- Development of a national instrumentation program to deploy, operate and maintain a dense network of digital acceleration recording stations that covers not only the northern regions but the entire Pakistani territory, as well as a mandatory requirement for instrumenting all new projects with a minimum of sensing stations for the collection of vital response data.
- Development of a micro-zonation program for areas of (i) special soil conditions, (ii) in the vicinity of large steep slopes, and (iii) on significant ridges.
- Undertaking of comprehensive seismic risk assessment studies using probabilistic hazard analysis (PSHA), deterministic studies for critical sites (DSHA), and time-dependent seismic hazard assessment, leading to nationally accepted hazard maps.

***Urban and Rural Planning***

- Development of a comprehensive multi-scale land use management policy and grand plan to gradually move population, business and infrastructure systems away from regions of the highest exposure to natural disasters such as earthquakes and floods.
- Clearing congested old town centers gradually to widen streets and provide access to emergency services, and to construct using modern techniques, materials and codes of practice.
- Implementation of planning permit guidelines to influence characteristics of buildings and bridges to reduce amplification effects taking into account site conditions and topography.
- Development or adoption of a loss assessment software tool that is used in regional and national scenario loss assessments for the purposes of planning of response, stockpiling of required equipment and recruitment of necessary personnel.

***Design and Construction***

- Development of two levels of codes for design, one for detailed design of important facilities and large civil infrastructure projects, based on the latest technologies and international experience adapted to Pakistan (as outlined above), and the second as a set of 'deemed-to-satisfy' codes using local practice, regional languages, pictorial-visual presentations and no calculation requirements, for small family residences and similar structures, using indigenous materials.
- Implementation of hierarchical, self-monitored, strict construction authorization procedures. This should include continuous control of all construction and concurrent penalties on defaulting, non-conforming and random housing.
- Mandating earthquake resistant design according to the published codes.
- Development of codes for seismic resistance of infrastructure and lifeline systems.
- Increasing the use of tunnels to reduce the impact of earthquakes on the transportation network in the mountainous regions.
- Use of the most advanced tunnel design and construction practice to increase the reliability of tunnels as vital components of the transportation systems.

***Social Impact Reduction***

- Development of special policies for design and construction for critical facilities, primarily schools, hospitals, emergency response centers, power generation, water supply, gas supply and similar facilities critical to the operation of a complex societal system.
- Mandating of disabled access provisions in all civil infrastructure works.
- Planning of disabled support and rehabilitation centers taking into account the current distribution of residences of the large population of disabled citizens from the Kashmir earthquake.
- Development of medium and long-term plan for widowed women and orphaned children in terms of a continuous and accessible support structure for rehabilitation, education and integration in other families.

***Legislation***

- Backing up all the above by rigorous legislative structures and clear frameworks for adherence.
- Legislating for a complete and comprehensive framework of emergency management professionals at the local, regional and national levels, and a clear reporting mechanism, alongside a tiered emergency preparedness plan.
- Establishing a 'Disaster Fund' that is used to provide emergency relief, and that is funded by a modest tax on new projects. Such funds have precedence, and experience should be gained from other countries on this issue.

The above list is not comprehensive and is subject to further refinement and articulation as more information becomes available and the needs are better defined in Pakistan. It is therefore concluded that the need for new seismic and even general design codes in pressing. Codes in general, and seismic design codes in particular, are an absolute necessity, not an option, for Pakistan if the authorities want to avoid a repeat of the Kashmir disaster or even much worse. This is underpinned by the fact that the next earthquake will be larger than the Kashmir event and it will most probably occur further south, hence closer to Islamabad.

## References

Bilham, R. and N. Ambraseys, May 2005. "Apparent Himalayan slip deficit from the summation of seismic moments for Himalayan earthquakes, 1500-2000", *Current Science*, VOL. 88, NO 10, 1658-1663.

Durrani, A., E.L. Elnashai, Y. Hashash, S.J. Kim, and A. Masud, December 2005. "The Kashmir Earthquake of October 8, 2005: A Quick Look Report", Mid-America Earthquake Center, University of Illinois at Urbana-Champaign, USA.