Engineering design for dwellings and small housing in seismically active regions of Pakistan : towards a more holistic approach

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A background paper jointly prepared by NED University of Engineering and Technology, Pakistan and Loughborough University , UK

Introduction

This paper is an outcome of a 3 year research link programme. Over a period of time several people have contributed towards the development of the ideas. It is difficult to acknowledge all. For the production of this paper Dr Lee Bosher, Dr M.Sohail, Professor Lodi and Professor Rafeeqi have contributed.

"Earthquakes don't kill people: buildings do"[1]. The earthquake in October 2005 in Kashmir and northern parts of Pakistan once again highlighted the unresolved issue of poor design and quality of buildings, especially non-engineered buildings and infrastructure[2]. This paper introduces the 'Holistic Engineering Design' (HED) project that aims to ensure that best practice in the design and construction of resilient informal (non-engineered) buildings in seismically active areas can be more widely achieved. In doing so, the proposed project will address key questions about the technical, financial and social feasibility of current practice and possible seismic hazard engineering measures; including the potential to learn lessons from traditional construction techniques and 'professional wisdom'; this is what the authors have referred to as a '*holistic approach*' to engineering design. This paper highlights the main issues globally regarding the engineering design of dwellings and small housing in seismic zones before defining and considering the case for a more holistic approach in Pakistan.

The main issues

Earthquakes

While earthquake fatalities in the developed world have become a rarity, seismic activity in developing countries can be catastrophic. The Indian tectonic plate is moving at a very rapid pace - approximately 44 mm per year (Bilham *et al.* 1996). The rapid movement of the Indian plate into the Eurasian plate is the cause of innumerable earthquakes causing an enormous loss of precious human life and huge loss to property as well as leaving millions homeless. Since 1998 there have been about 12 major earthquakes within and around the Indian plate. In October 2005 the massive earthquake of Kashmir was responsible for about 73,000 lives lost, nearly 70,000 injured and about 2.5 million rendered homeless. In 2003, an earthquake in Bam, Iran killed more than 26,000 people. Over 13,000 were killed near Bhuj, India in 2001. Although the force of nature cannot be completely controlled or predicted it is now well established that with strategic planning, and appropriate engineering solutions non-engineered construction (such as housing units) can be made more resilient to earthquake shaking; it is through these endeavours that the loss of human life and suffering can be minimised.

The technological fix approach – globally

Most of the deaths associated with earthquakes in developing countries are caused by the collapse of un-reinforced masonry and adobe structures – these are typically the materials that the poor use to build their homes. Recent earthquakes in rural and small town settings the world over have revealed the high seismic vulnerability of adobe, stone, and rammed earth dwellings in countries such as Turkey, Iran, Peru, and Pakistan (Green 2007). Yet, many traditional forms of construction do have effective disaster-resistant construction techniques such as seismic belts, lintel bands,

[1] As stated by Susan Hough and Lucile Jones of the U.S. Geological Survey, Pasadena in the San Francisco Chronicle Op-Ed Commentary, 12/4/2002
[2] Non-engineered construction refers to informal construction that normally relies on local skill.

thru stones, cross beams, and timber bracing (Green 2007). The un-engineered structures of the Americas and Asia that rigorously incorporate aseismic components have consistently fared well in seismic events, often even better than more recent construction of masonry, steel and concrete (Tolles *et al.* 2000; Kaushik 2006; Langenbach 2005, 2000).

In many wealthier nations buildings are designed using certain standards that are effectively enforced and are thus less vulnerable to major structural damage. The starkest failure of many structures can be traced in countries with well-educated engineering elites who have promulgated universal standards, yet where most of the construction is semi-engineered or not engineered (Petal *et al.* 2007). For example, *"nations such as India, Pakistan Mexico, Iran and Turkey have suffered heavy loss of life from earthquakes, and large vulnerabilities remain, despite their adoption of building codes suited to modern construction techniques.….. Modern forms of construction, perceived as 'development' and 'progress', have undercut the value of traditional apprenticeships, degraded traditional construction and demanded technical knowledge and skills that builders have not yet acquired. The lack of formal educational opportunities combined with high illiteracy make it challenging to communicate knowledge and techniques"* (Petal *et al.* 2007). Nations such as Peru, Turkey and to a certain extent India have developed guidelines for earthquake resistant design of adobe or non-engineered construction. The Earthquake Engineering Research Institute (EERI) in Oakland, California, has developed guidelines for adobe construction in Peru (Blondet *et al.* 2003). Similarly the University of Kassel (Minke 2001) has developed guidelines to introduce seismic resistance in non-engineered adobe dwellings. The Earthquake Engineering Research Centre at Middle East Technical University, Turkey has been actively involved in this area for the last several years and has produced some interesting and valuable reports on Turkish earthquake experience (www.eerc.metu.tr). Cowasjee Earthquake Study Centre at NED University of Engineering and Technology in Pakistan is one the active places producing some useful information about seismicity and the state of affairs of earthquake resistant construction in Pakistan (www.neduet.edu.pk). These initiatives are fine but it should be noted that in studies of risk perception, Asgary and Willis have found that "*safety measures enforced without considering people's preferences fail to be adequately adopted in practice*" (Asgary and Willis, 1997:613). In the same way, a close examination of economic and social realities in less economically developed countries is critical to understanding the continued construction of highly vulnerable housing in the face of natural hazards (Green 2007; Bosher (ed.) 2007).

The situation in Pakistan

The recent Pakistan and Kashmir earthquake has demonstrated the major deficiencies of non-engineered buildings to resist the force of an earthquake. This mainly arises from three main reasons; 1) poor quality of materials (e.g. poor quality of mortar, excessively thick bedding joints) and construction (poor quality of construction per requirements of national codes and standards, poor quality of construction and workmanship), 2) poorly planned and designed construction (the lack of building Permits and Development Control Rules is a key problem for example in Islamabad where Capital Development Authority does not have any legislated document (such as a code) or any design guide or else the non-existence of data on design forces or basic engineering properties of the indigenous material used in construction is another major hindrance) and/or 3) poor building maintenance and monitoring. It has even been argued by some that the construction methods prevalent in Pakistan are partially to blame for the high number of fatalities that resulted from the October 2005 earthquake (Kaushik 2006; Langenbach 2005).

Un-reinforced brick masonry construction in Pakistan may constitute more than 50% of all buildings. In rural areas, un-reinforced buildings in clay mortar and adobe construction were very common in the past and still exist in some areas, but now are being replaced by un-reinforced brick masonry with cement sand mortar. In hilly areas, un-reinforced stone masonry without mortar or with cement sand mortar is widely used. The poor tend to live in these types of 'non-engineered' small units which are not typically designed by engineers or architects and are built from substandard construction material such as random rubble stone masonry in mud mortar or un-reinforced brick masonry. Those with financial resources opt for reinforced concrete frame structures with stone infill or concrete block walls. For instance, Karachi, the largest city of Pakistan, has an estimated population of 15 million. A majority of these people live in dwellings and housing units built from un-reinforced masonry with some reinforced concrete elements; this makes them highly vulnerable to ground shaking. Problems also can occur during an earthquake if a building is made of a combination of rigid and flexible materials. This happens because earthquake forces focus on the stiffer elements of a building and cause them to fail abruptly and shatter. For example, a Mw=7.5 earthquake near or beneath Karachi could kill *more than 1 million people* (Bilham and Hough, 2006, Bilham 2006), and be potentially destabilising politically, with reconstruction costs of $10-$100 billion. The vulnerability of families to an earthquake is also increased with the number of inhabitants in a house. In urban areas one family normally occupies the buildings, but in some cases there may be two or even three families residing in one building. In rural areas the house is typically occupied by one family, with the number of inhabitants frequently exceeding six. In addition to the risk of direct harm to people and the built environment, several secondary hazards from earthquakes exist. The secondary effects of earthquake-induced fires, hazardous material spills, and breakdowns in utility lifelines can cause extensive damage and loss of life.

So what can be done?

Severely damaging earthquakes have repeatedly demonstrated the importance of improving the quality of both earthquake design and construction. Knowledge of earthquakes, earthquake forces, and improved building techniques has expanded rapidly. Many techniques have been developed that mean buildings are less likely to collapse and kill or injure people during an earthquake. In recent years research on earthquakes has focused on: Design and construction methods for earthquake resistant structures; to strengthen the building (e.g. with shear walls, braced frames, moment resisting frames, horizontal trusses), and to reduce the earthquake-generated forces acting upon it e.g. energy dissipation devices**;** Earthquake prediction; Model building codes; Education of the public, public officials, and private sector; and Research in earthquake hazard mitigation and earthquake insurance.

However, to date, there has been a lack of earthquake-resistant building design aimed to benefit the poor with real, accountable stakeholder participation in the design and construction process rather than by top-down blueprint planning (Petal *et al.* 2007; Jigyasu 2004; Lewis 2003). Jigyasu (2002) states that five main issues and challenges are evident in the context of rural communities of South Asia for reducing their disaster vulnerability through building local knowledge and capacities. These are: (1) Loss of material and land resources (from rural communities), (2) Loss of Traditional Skills, (3) Cultural Incompatibility of external interventions, (4) Increasing Social and Economic inequity, and (5) Weakening of Local Governance (Jigyasu 2002). Therefore, where building standards are not enforced, earthquake-resistant construction will become common only if earthquake-resistant technology is locally available, widely known, easy to adopt with limited training and education, competitively to a low cost and culturally accepted.

Towards holistic engineering design in seismic zones

There is a growing appreciation among academics and aid agencies of the need for methods of building earthquake-resistant houses that are safe and affordable (Hansen 2005; Jang *et al.* 2002; Elingwood 2001; Hurol and Wilkinson 2005; Charleson 2001; Carreno *et al*. 2004; Novokschenov 2006; Davis and Miller 1984; Coburn *et al.* 1984; Saito *et al.* 2004; Carreno *et al.* 2003). Whilst, the principles of earthquake resistance are well-understood when dealing with semi-engineered and engineered buildings, there is a lack of understanding of how non-engineered buildings can be made capable of withstanding an earthquake. If non-engineered buildings can be improved by earthquake-resistant construction methods this will not only reduce the number of deaths and injuries during a future earthquake, but also reduce the amount of foreign and domestic aid spent on disaster relief and reconstruction.

For example, the UK's Department for International Development (DFID) committed £53.3 million out of a total £58 million pledged to the 2005 Pakistan earthquake (which killed 73,000 people). £70 million has also been pledged for reconstruction over three years. In a DFID press release, Britain's International Development Secretary Hilary Benn, said "*The biggest challenge still lies ahead. Helping to rebuild the physical infrastructure, schools, hospitals, water and electricity supplies is the next step*" (DFID 2006). Reconstruction efforts following disasters often give opportunities to reduce vulnerability to future disasters[3]. Buildings constructed according to estimates of how fast, how long, and how much the ground moves during an earthquake will sustain far less damage. However, after earthquakes, residents often rebuild with un-reinforced methods, leaving the new houses just as vulnerable as those that collapsed during the earthquake. Petal *et al.* (2007) have noted that this might be because earthquake-resistant designs are too expensive, rely on materials that are not available through the local market, or demand a level of construction skill that has not been developed within the local population. Thus, construction based on earthquake-resistant building design should be aimed to benefit the poor. For example, Jigyasu (2004) describes an increase in the vulnerability of local communities after the Latur 1993 earthquake in India, where sustainable recovery interventions were poorly planned and implemented. Therefore, a 'community-based imperative' is needed in which construction and design professionals learn to share their knowledge with, and at the same time learn from, the users of the structures. These users include owners, renters, teachers, school children, activists, and government workers. This knowledge exchange would yield a bottom-up demand for safe construction, voluntary compliance with standards, and public, government, and private sector expectation and support for enforcement (Petal *et al.* 2007).

It might be thought that communities would give careful consideration to location before starting to build, particularly avoiding known faults or sites that are subject to or can be affected by a landslide. However, for many people in developing countries: There is no choice about where they live; The benefits of a location outweigh the costs; People grow accustomed to a low-probability risk and they accept it; The hazard is perceived as being unavoidable or an act of "God", and Natural hazards are familiar. People have different capacities to avoid or cope with disasters, in other words, differing *vulnerability.* Vulnerability is '*the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with and recover from the impact of a natural disaster'* (Wisner *et al*., 2003:11). People's vulnerability is generated by social, economic, and political processes that influence how hazards affect people in varying ways and different intensities (Wisner *et al.* 2003). Therefore, the outcome of a disaster is shaped both by the physical nature of the hazard and the vulnerability of people who are involved (e.g. why people live in dangerous locations, unprotected buildings, and the lack of disaster preparedness at particular places at particular times).

Therefore, while many efforts to deal with earthquake hazards have focused on changing the structures, less attention has been paid to effecting needed change within specific social, political, cultural and economic environments (Petal *et al.* 2007). The consequence is that the people who are the intended beneficiaries of these advances in both technical knowledge and policies have sometimes become steadily more vulnerable. For example, poverty is often suggested as breeding fatalism with regards to disasters. However, in reality, when informed choices are permitted with regards to building, most people tend to incorporate affordable safety concerns (Maskrey 1989). In contrast, people who have homes built for them—without consultation, without information and without choice—are likely to adopt a fatalistic view of the product, including with regards to safety. This tragic irony suggests the necessity for a community-based approach to construction for disaster risk reduction (Petal *et al.* 2007). It is in view of these concerns that a more 'holistic approach' to engineering design is required. The authors propose that a 'holistic approach' is an approach that utilises, in a socially, culturally, financially, and technically appropriate manner, the 'middle ground' between the top down technological approaches and the 'bottom up' or traditional approaches to the construction of buildings (see figure 1).

[3] There are also socio-economic and political pressures for swift reconstruction after a disaster has occurred which tends to impinge on the ability to learn lessons from previous events and enforce the types of seismic guidance and legislation that is required (see Menoni 2001).

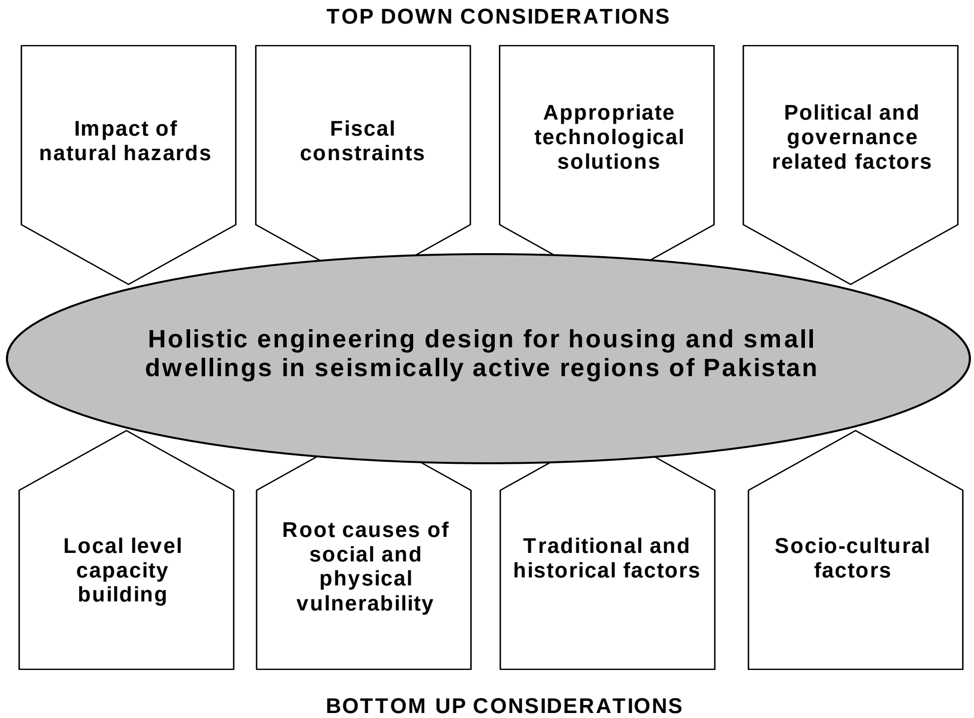

Figure 1: The holistic focus of the project

THE PROPOSED RESEARCH

Research aim and objectives

The ‘Holistic Engineering Design’ (HED) project seeks to ensure that best practice in the design and construction of resilient informal (non-engineered) buildings in seismically active areas can be more widely achieved through a more holistic engineering design process. In doing so, it will address key questions about the technical, financial and social feasibility of current practice and possible seismic hazard engineering measures, and the potential to learn lessons from traditional construction techniques and ‘professional wisdom’. The HED project will focus on case studies located in regions of Pakistan that were affected by the 2005 earthquake. The specific objectives are to:

1. Review literature, guidance and legislation to help understand accepted seismic engineering solutions globally;
2. Identify and assess methods of traditional (non-engineered) construction; this will consider design issues, and the range of materials and construction methods that are utilised in seismically active regions of Pakistan;
3. Investigate appropriate (culturally, socially, financially, technically) ways to incorporate ‘tried and tested’ and traditional seismic engineering solutions for dwellings and small housing units;
4. Develop models for the technical and financial evaluation of the ‘optimum’ solutions for earthquake resistant dwellings and small housing units; maximise the benefits from the ‘tried and tested’ and ‘traditional’ approaches.
5. Assess the cultural and social appropriateness of the earthquake resistant dwellings and small housing units;
6. Develop guidelines (for practitioners and trainers) for holistic engineering design of earthquake resistant dwellings and small housing units;
7. Establish a research ‘road map’ for exploring emerging issues and any identified gaps in knowledge.

EXPECTED RELEVANCE TO BENEFICIARIES

There are four clear categories of beneficiary (or customer) for the HED Project's outputs: (1) UK government, through DFID, who have formal responsibility for sustainable developmental initiatives in less developed nations and as financial contributors to post-disaster relief and reconstruction programmes in Pakistan; (2) The Government of Pakistan and associated national and regional developmental departments and infrastructure related departments (3) Non-governmental organisations involved with disaster reduction and international development, such as '*Karavan*'[4], and (4) a range of construction, engineering and design organisations that plan, design, and build housing and of course the public themselves. The timescales over which exploitation of the research can take place are short. Design guidelines and other publications will be available for immediate use at the end of the project. These publications will also be a foundation for the establishment of training (formal and informal) programmes targeted at and designed in liaison with local engineers and builders of traditional dwellings. The beneficiaries will gain advantage in the design and engineering of non-engineered dwellings and small housing units through an improved understanding of what is both acceptable and effective in resilient seismic design.

SUMMARY

The proposed research is particularly timely given the impact of the 2005 earthquake in Pakistan and the enormous costs to the Pakistan and UK Governments in relief and reconstruction aid. This project fits into the disaster risk management framework that is advocated by the United Nations. In this sense, resilience against seismic hazards needs to be systematically built-in to the planning and design processes of public buildings, not simply added on as an afterthought (Bosher *et al.* 2007). The novelty of the project lies in its exploration of the construction of traditional and non-engineered housing in a holistic and multidisciplinary manner. The HED project will take best practice from national and international systems, and develop a framework for its application in seismically active regions of Pakistan. It is also intended that the project will contribute towards the integration of processes that are typically fragmented across disciplines (both formally educated and informally trained). This will be achieved through the exchange of ideas from the multiple perspectives of key stakeholders (such as architects, planners, engineers, traditional builders, material suppliers and end users) and through involvement with relevant government agencies, international non-governmental organisations and a range of international academics.

The research outcomes will provide new approaches to ways that people's (particularly low-income) homes are designed, in a form suitable for organisations with or without the resources for dedicated staff with seismic design experience. This will improve the quality and long-term resilience (and therefore sustainability) of homes in seismically active regions of Pakistan. The HED project will also encourage informed decision making for key stakeholders with responsibility for designing resilient and acceptable resilient public housing.

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[4] For instance, the Karavan Self-built Vernacular Housing unit is seeking to maximise the use of local workforce, locally available materials and time-tested traditional methods that are cost-effective, speedy and a safer option in the seismic context. It is intended that the proposed project will collaborate with the Karavan team. For details of the work of Karavan refer to http://www.karavanpakistan.com/index.asp

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