Seismic Vulnerability-reduction via Integration of Passive Thermal Technologies

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SUMMARY:
Vulnerability of low-income people to disasters is a worldwide problem. The inability to afford technologies that can provide improved seismic performance results in high casualty rates in seismic events. Struggling to sustain their livelihoods within limited resources, low-income populations often face the question of whether it is worth investing in protection against rare events such as earthquakes. The authors investigate the potential of approaching seismic retrofitting technologies through an alternative outlook; not just as a safety component, but as a feature that can provide multiple benefits. This paper presents the ongoing investigation of low-cost seismic retrofitting technologies that could also enhance the thermal performance of houses. Three separate regions in India with the same level of seismic risk but differing climatic conditions have been selected as the basis for study in order to consider the varying thermal comfort requirements within the same required level of seismic resistance.

Keywords: seismic retrofitting, thermal comfort, developing countries, low-cost technology, India

1. INTRODUCTION

In developing countries, non-engineered construction is common in residential buildings. The simple construction methods, usage of locally available materials, and low construction costs, allow low-income populations to build their own dwellings. In fact, more than 90 percent of the population living in moderate to severe seismic zones of the developing world work and live in such buildings (Arya, 2000). However, while masonry construction can be financially beneficial, it is also seismically hazardous. The maximum number of fatalities in developing countries in earthquakes results from the collapse of these buildings, and historically, the low-income population has been most severely affected (Coburn & Spence, 2002).

Consequently, various low-cost retrofitting techniques have been researched and developed to provide added reinforcement for this type of construction. However, only a very small fraction of the world's developing population has seen their implementation. As Meli & Alcocer (2004) discuss, this is most likely due to the fact that safety is an ethereal concept among the low-income population, not easily understood, and even more difficult to sell to a population with serious unmet needs in their everyday lives.

It is necessary, therefore, to link seismic vulnerability-reduction efforts to other efforts aimed at improving housing habitability, with the hope that it can be better sold if it is accompanied by tangible daily benefits (Meli & Alcocer, 2004). One such possible 'accompanied daily benefit' is thermal comfort. For the majority of the low-income population, the option of using mechanical heating and cooling systems is limited, and their houses are often thermally uncomfortable. Therefore, the central challenge addressed by this study is the potential for integrating retrofitting techniques with passive thermal comfort strategies for low-income housing in developing countries (with a focus on India).

2. PREVIOUS RESEARCH AND GAP

There has been copious research done in the field of seismic retrofitting up to date. Many technologically advanced techniques have been researched and implemented in developed countries. In recent years, after the revelation of a clear difference in earthquake effects among groups of population with distinct income levels (Meli & Alcocer, 2004), research efforts were also directed towards the low-income communities in developing countries, which resulted in the development of low-cost retrofitting techniques applicable to non-engineered housing. Similarly, the issue of thermal comfort in housing has also been widely researched; its effect on human health and performance, methods for evaluating and modelling thermal comfort, and passive and active strategies for improving indoor conditions.

Although, both seismic strengthening and thermal comfort are well-established fields of study, their existence has been distinctively separate as two strands of knowledge; one aims to improve the structural entity while the other aims to improve the enclosed environment. And although researchers like Meli & Alcocer (2004) have recommended linking seismic strengthening efforts to other activities directed towards housing improvement, there has been no previous work known to the authors which concentrates on the integrative potential of seismic retrofitting and thermal comfort.

3. METHODOLOGY

The development of suitable integrative techniques however, is not solely a structural challenge. A thorough understanding of the population and their needs, the climate and geographical landscape, and most importantly, of the previous research regarding thermal comfort and seismic retrofitting for developing countries is essential. This has been achieved through a literature review, which provides the theoretical framework and identifies which seismic and thermal comfort strategies are appropriate for which type of constructions and climates, respectively. Following this, a research-by-design methodology is employed to formulate possible integrative solutions.

This study has four main objectives:

- Identify the challenges, opportunities and theoretical framework for housing the low-income population in India.
- Consider the level of thermal comfort in low-income housing and identify appropriate passive thermal comfort strategies for improvement.
- Consider the level of seismic resistance provided in non-engineered housing and identify appropriate retrofitting techniques for improvement.
- Explore the possibility of developing integrative techniques which combine seismic retrofitting techniques and passive thermal comfort strategies.

In its approach, this research addresses four essential theoretical components of residential building design: safety, comfort, energy efficiency, and affordability. Safety and comfort are considered in terms of seismic provisions and thermal comfort, respectively. The integration of these two with an additional aspect of sustainability, owing to the low-cost and energy-efficient nature of the proposed techniques, produces affordable and durable housing systems which are also safe and comfortable.

4. IDENTIFICATION OF CASE STUDY REGIONS

The regions chosen in India for the study depend on two key features: ‘seismicity’ and ‘climatic condition’. Each location chosen is based in Seismic zone IV (Indian Seismic Code IS 1893-2002) to keep the key requirements for the seismic resisting building structure constant. Zone IV is identified to be a ‘high damage risk zone’ and is equated to VIII of the MSK intensity scale which states that in the case of an earthquake, “most ordinary masonry constructions suffer heavy damage and most rural constructions are destroyed” (Murty, 2005), emphasizing the need for improvement of seismic measures. The variable component is the climate which ranges between the extremes from hot and dry to the cold. This allows for the exploration of a wide range of integrative techniques that would be applicable to different climatic conditions. The common regions for the study (shown in the climatic and seismic zone maps in Figures 1 and 2 respectively) are Palanpur, Jammu and Sikkim.

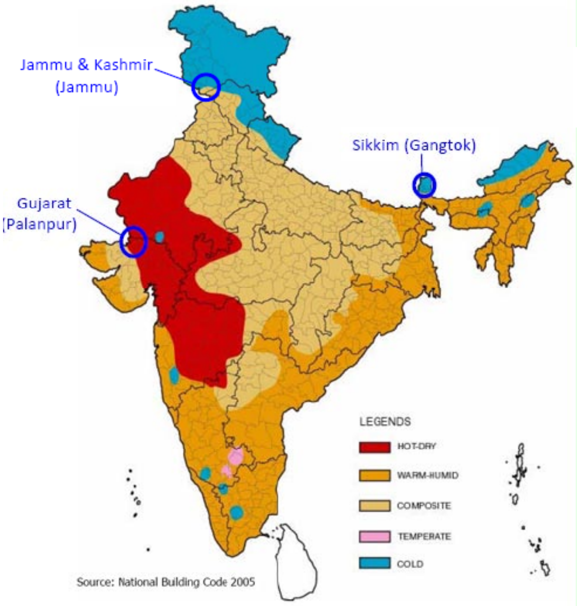

Figure 1 Climatic zone map (HPCB, 2010)

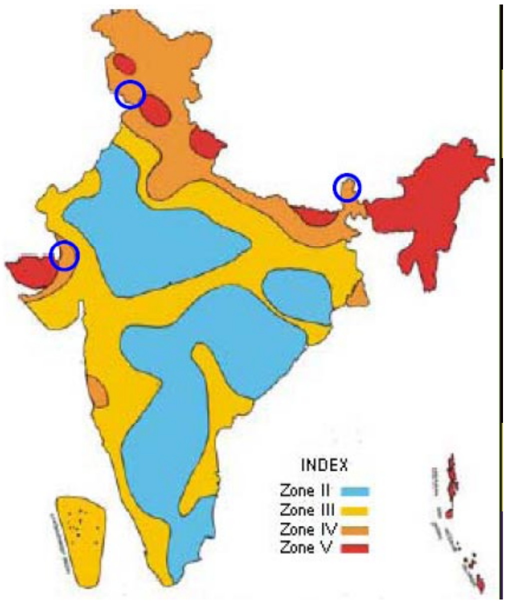

Figure 2 Seismic Zone map (ISR, 2007)

4.1. Climatic profiles of Regions

Climatic data, such as temperature and humidity values, were attained for each region which reiterated the above climatic classifications. Hence, the climatic profiles for each region are mentioned as thus:

- Palanpur (in Gujarat) = Hot-dry (with fluctuating humidity)
- Jammu (in Jammu & Kashmir) = Composite (with fluctuating humidity)
- Gangtok (in Sikkim) = Cold (with high humidity)

4.2. Typical Housing Types

Based on the 2001 Indian Census housing data, this section outlines the typical rural housing types (as these are almost always only inhabited by the low-income population) found in the regions of Gujarat, Jammu & Kashmir and Sikkim. These are non-engineered constructions and therefore have high vulnerability during earthquakes. Based on the analysis of most the commonly used wall materials in the selected regions, the following three main construction types were identified.

4.2.1. Fired/unfired brick

Masonry buildings are brittle and one of the most vulnerable of the entire building stock under strong earthquake shaking. Since usually the walls are not tied together, walls loaded in their weak direction tend to topple. The roofing elements are often not interconnected and the roof structure is not properly anchored to the wall in most cases. In terms of building materials, burnt clay bricks are most commonly used but these bricks are inherently porous and tend to suck water away from the adjoining mortar which results in poor bond between brick and mortar. The mud mortar used also has very low earthquake resistance as it crushes easily when dry. The overall vulnerability of this type of construction is classified to be in a range of *medium to high*; indicating moderate to very poor seismic performance in earthquakes (Kumar, 2002b).

4.2.2. Adobe

During strong earthquakes, due to their large mass, these structures are unable to resist the high levels of seismic forces, and therefore they fail abruptly. Typical modes of failure during earthquakes are the same as other unreinforced masonry buildings and include severe cracking and disintegration of walls, separation of walls at the corners, and separation of roofs from the walls, leading to collapse. In typical adobe construction, there is poor lateral resistance, no lintel bands, improper proportions of openings, poor interconnection of roofing elements and wall-to-wall connection, and lack of sufficient distance between corners and openings. The overall rating of the seismic vulnerability of the housing type is *high to medium-high* which indicates a poor to very poor rate of seismic performance in earthquakes (Kumar, 2002a).

4.2.3. Stone

The thick stone masonry walls built using rounded stones are bound with mud mortar and filled with random rubble in between the wythes. With stones placed in a random manner and an absence of proper connection between the two wythes of the wall, delamination tends to occur and increases the risk of collapse. Other seismic deficiencies include the absence of header stones at corners and junctions, vertical separation joints at wall corners and junctions, inadequate post-to-beam connections, and heavy mud roofs to name a few. The overall seismic vulnerability of common stone masonry construction is *high to medium-high*, (same as adobe construction) and means that the seismic performance of this type of stone construction will be poor to very poor during an earthquake.

5. APPROPRIATE SEISMIC RETROFITTING TECHNIQUES

There are major seismic deficiencies in these houses that require improvement if they are to be made seismically resistant. Although, these may not be sufficient to meet the requirements of the safety levels stated in the seismic code, the improvements will increase the building's collapse time, allowing people the opportunity to escape from the building before it collapses. Seismic retrofitting offers many advantages over reconstruction. Firstly, taking into consideration the economic vulnerability of the low-income population, the cost of demolition and removal of debris from demolition can be eliminated and the total cost of the repairs can also be reduced since there is no need to replace the whole building. Also, retrofitting can be done in a phased manner depending upon the availability of funds and time. So it is not necessary to retrofit the whole structure at once.

The table below (see Table 1) summarizes the existing retrofitting solutions that are appropriate and low cost for non-engineered buildings. The solutions are categorized in terms of the different structural elements and connections that are deficient. These are: roof construction; wall and column reinforcement, wall-to-wall, wall-to-roof, and foundation-to-wall connections; wall openings; and foundation strengthening. For each category, several appropriate retrofitting solutions are presented along with the identification of which retrofitting techniques are applicable to which housing types.

Table 1 Retrofitting Technologies for non-engineered construction

Elements Requiring Retrofit	**Retrofitting Technologies**	**Housing Types**		
		Brick	**Adobe**	**Stone**
Roof construction	• Diagonal struts and braces	✓	✓	✓
	• Tying rafters to the roof truss	✓	✓	✓
	• Anchoring roofing tiles and sheeting to understructure	✓	✓	✓
	• Reduce mud overlay atop the roof (limit to 200mm)	✓	✓	✓
	• Install horizontal collar beams between the opposite rafters	✓	✓	✓
Wall strength	• Installation of seismic belt	✓	✓	✓
	• Strengthening with plastered wire mesh	✓	✓	✓
	• Shotcreting	✓	✓	✓
	• Reinforced tie beams	✓	✓	✓
	• Shear connecters	✓		✓

	• Grouting	✓		✓
	• Masonry buttresses may be added	✓	✓	✓
	• Stitching wall wythes together by installing cast in-situ RC bond elements OR • Installation of through-stones			✓
	• Tyre strap reinforcement		✓	
	• Post-tensioning elastometric tyre straps (Scrap Tyre Rings)	✓		
	• External bamboo reinforcement		✓	
	• Polymer mesh (geomesh)		✓	
	• Polypropylene band mesh	✓	✓	✓
	• Inserting new walls	✓	✓	✓
Wall-to-wall connections	• Previously mentioned wall reinforcement techniques that are effective for wall-to-wall connections also: tie column, horizontal and vertical WWM seismic belts, polymer mesh, and tyre strap reinforcement.	✓	✓	✓
	• Provision of wooden bracing at regular interval in walls	✓	✓	✓
	• Dowels at corners and junctions	✓	✓	✓
	• Tie-beam to tie-column connection	✓	✓	✓
Wall-roof connections	• Bracing of frame (knee-brace/diagonal brace) to strengthen post-to-beam connections using timber or steel elements	✓	✓	✓
	• Anchor roof to walls with brackets	✓		
	• Single vertical reinforcing bar	✓	✓	✓
	• Vertical seismic belt	✓	✓	✓
Wall openings	• Reduce large openings	✓	✓	✓
	• Lintel belts	✓	✓	✓
	• Proper peripheral reinforcement	✓		✓
Foundation-wall connection	• Steel mesh or wooden dowels at corners and junctions	✓	✓	✓
	• Horizontal seismic belt at plinth level	✓		✓
Foundations	• Reinforced concrete strip foundations	✓	✓	✓
Column Reinforcement	• Strengthen masonry column with jacketing	✓		✓

6. THERMAL COMFORT CONDITIONS

The standard definition of thermal comfort is “that conditions of mind which expresses satisfaction with the thermal environment” (ANSI/ASHRAE 11-2004). Alternatively, since our physiological and psychological responses are usually only triggered in cases of ‘discomfort’, comfort can be understood to mean the absence of thermal (heat/cold) discomfort (Givoni, 1998). Comfort, or rather discomfort, can have various effects on a person; it can affect the health as well as performance and productivity. Therefore, it is important to eliminate discomfort in indoor conditions.

Some indigenous construction methods often make the houses well-adhered to the local environment. For example, mud houses are effective for hot and arid climates as they prevent the heat from reaching the interior during the daytime hours due to the mud’s thick layer with insulative properties. Yet sometimes even these passive technologies are not sufficient. In Reddy & Lefebvre’s study (1993), it was noted that though the mud houses provided sufficient thermal insulation against the extremely high daytime temperatures, at night the people moved outdoors to sleep since the outdoor temperature was cooler than the interior. It is thus apparent that discomfort remains an unresolved issue in low-income housing. In general, HVAC systems are not an affordable option for the low-income households. Therefore, with only minimal scope for thermal adjustment (through behavioural adjustments such as opening a window or physiological adjustments such as putting on more clothes), the discomfort can often exceed the manageable limit.

6.1. Models of Thermal Comfort

In order to understand the thermal comfort strategies that can be applied to each of these regions, it is first necessary to understand the climate in terms of the human comfort factor. Psychrometric charts can be utilised for this purpose as they allow the annual graphical representation of climatic factors as well as the thermal performance of buildings through the presentation of a concurrent combination of temperature and humidity at any given time.

Comfort zones can be marked upon this, specifying boundaries within which the majority of persons would not feel thermal discomfort in an indoor environment. In order to determine the comfort zone boundaries, the adaptive model of thermal comfort (instead of the static model based ASHRAE comfort zone developed for mechanically controlled buildings) is recommended for the case of naturally ventilated buildings usually inhabited by the low-income population. This method would consider the wide diurnal climatic range that is experienced by the people in the houses as well as their capacity for acclimatisation.

6.2. Passive Design Strategies and Integration

Once the comfort zone boundaries are attained, a climatic analysis that illuminates the necessary type of passive strategy for each month in each of the regions can be carried out. Currently, work is in progress in this area, and it is hoped that the process will give a clear indication regarding which thermal comfort strategies will have the maximum use and therefore a higher integrative potential.

Basic passive strategies that could be considered are: natural ventilation, thermal mass, radiant systems, evaporative cooling, earth cooling, passive solar heat gain, insulation, shading, and colour. Some of these strategies can have a high integrative potential with the seismic retrofitting technique mentioned above, though some are not directly related to the structural aspect which means that these strategies would only have limited scope for integration. Further research needs to be carried out in order to validate this and propose the possible integrative solutions.

8. CONCLUSIONS

This study looks at the possibilities for integrating passive thermal comfort features with existing seismic retrofitting techniques for non-engineered houses. First, seismic strengthening techniques that are appropriate for non-engineered residential construction are identified in terms of their applicability for each of the typical housing types. Following this, a climatic design process is proposed, in which the appropriate comfort zones for the target population are deduced and the ratio of discomfort for a naturally ventilated house is analysed for each region. This will clarify which thermal comfort strategies are required, and when. Finally, the integration of thermal comfort features with seismic retrofitting techniques can then be investigated. As this work is currently in progress, there is a considerable amount of research that still needs to be done in order to understand the criteria for integration and develop the appropriate systems which shall provide the double benefit of safety and comfort.

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