EARTHQUAKE BUILDING DAMAGE IN DEVELOPING COUNTRIES: A REVIEW OF RECENT RECONNAISSANCE REPORTS

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ABSTRACT

This study reviews twenty-nine earthquake reconnaissance reports from developing countries in the period from 1990–1998. After identifying trends in the different types and causes of damage to buildings reviewed in the reports, the paper suggests areas where earthquake damage mitigation should be focussed; namely architectural and engineering conceptual design, engineering details and construction. An analysis of all causes of seismic damage suggests conceptual design is the most important area to focus on, and that codes or standards must include provisions to prevent poor building configurations. Finally, the paper considers the nature of reconnaissance teams and their reports. It comments on teams' objectives and concludes by suggesting how teams might contribute towards improving the mitigation of earthquake building damage in developing countries more directly.

INTRODUCTION

This research was undertaken under the auspices of the Earthquake Hazard Centre, a non-governmental organisation that disseminates earthquake engineering information to developing countries [1]. Its aim is to reduce the gap between developed and developing countries in terms of knowledge and practice of earthquake hazard reduction. Significant reduction can be achieved by implementing already proven existing seismic design and construction techniques. By providing technologically appropriate information and encouraging local research and other initiatives, skills and standards are improved. Answers to the question that is the basis of this paper, "what are the typical types and causes of earthquake damage to buildings?" will help ensure that the Centre disseminates relevant information and directs its resources where needs are greatest.

For the purposes of the study, a developing country is defined as one that is essentially non-industrialised, where buildings are predominantly non-engineered and building codes are not implemented effectively. A group of such countries exhibits wide variation in geographic location, climate, topography and culture, including construction practices. In the period 1990-1998, one hundred and two earthquakes of approximate Magnitude 6.5 or greater caused fatalities, injuries or substantial damage in developing countries [2]. A combination of literature searches and personal correspondence to earthquake engineering organisations in the affected countries yielded a total of only twenty-nine reconnaissance reports in English for nineteen earthquakes. Even allowing for the fact that some earthquakes are located in remote regions and some reconnaissance reports are published only in local languages, it appears that potentially valuable post-earthquake reporting is not being widely disseminated.

Table 1 summarises the sources of the reconnaissance reports and lists the numbers of individual buildings or groups of buildings whose damage reports are the basis of the study. Most reports mix damage accounts of individual buildings, usually those more prominent or important, with descriptions of damage to groups of buildings, often classified geographically as in the case of villages, or by building type. Low cost housing and non-engineered construction is usually discussed a group. Here are three typical examples of damage accounts to groups of buildings that have been analyzed in the paper:

- "In these villages, an average of 20% of the adobe houses collapsed, 75% were heavily damaged and only 5% received light, if any, damage. The least damaged houses are relatively new constructions with good adobe quality in terms of maintenance and mixture. Three typical failure modes can be detected from severely damaged houses. The first one is the result of inadequate bond in the adobe wall corners, leading to corner cracks and eventually to an outward failure of the walls….."
- "In the epicentral area nearly all the buildings suffered some damage and there was a large number of partial and total collapses. In most cases the absence or inadequacy of lateral ties caused out-of-plane collapse of stone masonry or adobe load bearing walls. Many other stone masonry buildings suffered separation of the inner and outer skins of the wall due to the absence of "through stones" and sufficient bonding."

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- "Damage patterns observed in unreinforced masonry (stone or brick) low-rise construction were (1) serious damage or collapse of parapets; (2) vertical cracks in the walls due to the presence of wide openings (windows and doors); (3) roof and floor partial or full collapse due to inadequate wall support; and (4) separation of complete wedges from the building..."

Engineered buildings tend to be singled out for more detailed description and analysis.

Table 1: Numbers and sources of reconnaissance reports, and numbers of accounts of damaged buildings

Sources of reconnaissance reports	Number of reports	Number of earthquakes	Number of either individual buildings or groups of buildings
Costa Rica	3	1	8
Egypt	2	2	11
Greece	1	1	4
India	2	1	23
Indonesia - Flores Island	1	1	1
Iran	3	2	8
Mexico	3	2	14
Peoples Republic of China	3	2	8
Peru	1	1	3
Philippines	3	2	23
Turkey	6	3	31
Venezuela	1	1	3
Total	**29**	**19**	**139**

Most of the buildings or groups of buildings discussed in these reports comprise one of the following construction types:- unreinforced masonry without reinforced concrete in lateral load resisting elements (URM), reinforced concrete with no structurally significant masonry infills (RC), combinations of reinforced concrete and unreinforced masonry infill walls (URM and RC), and finally, adobe. The frequency with which each construction type is reported upon is listed in Table 2. The relatively low occurrence of reports on adobe damage is due to reports describing damage to *groups* of adobe buildings, often entire villages or even regions. Adobe construction is uncommon in non-residential construction, while RC is generally uncommon in residential situations other than multi-storey apartments. Usually no information on the age of damaged buildings is provided in reconnaissance reports.

Table 2: Percentage of damage reports for different construction materials

Construction material	% total individual building and building group damage reports
URM	6
RC	36
URM and RC	46
Adobe	12

TYPES OF DAMAGE

Many types or descriptions of damage are reported, often in quite general terms. The most significant are classified in Table 3. While some descriptions are not very informative, others point to recurrent themes of damage. For example, unreinforced masonry infills and load bearing walls are vulnerable to both in-plane (shear cracking), and out-of-plane actions. This is hardly surprising given that these two systems represent the most common form of lateral resistance in developing countries. There are virtually no reports of damage to beams, in stark contrast to frequent mention of column damage. Unfortunately, columns are not only more vulnerable to damage, but of all structural elements, most often lead to building collapse when they are damaged. This observation reinforces the importance of the strong column-weak beam concept.

Table 3: Main types of reported damage for buildings that did not collapse

Types of damage	% residential building damage reports	% non-residential building damage reports
Wall out-of-plane damage	24	16
Shear cracks (walls)	19	25
Column damage	16	23
General damage	17	10
Other	24	26

Although the study of types of damage does not identify any unexpected trends, it prepares for a more constructive study of causes of damage, which, when addressed, will lead to more resilient building construction.

CAUSES OF DAMAGE

The reconnaissance reports note a total of approximately thirty different causes of building damage. In some buildings the damage is attributed to more than one cause. An analysis of causes indicates that they can be divided into three groups; conceptual, detailing and construction, as shown in Table 4. Each cause of damage is listed if its occurrence is more than five percent of the total. As mentioned above, due to the fact that residential building damage is usually described in the context of groups of buildings, and non-residential damage to individual buildings, the percentage values are intended only to indicate trends.

Although some reports note poor ground as a cause of damage, due to a general lack of detailed information the study excludes causes of damage resulting from foundations and soil conditions.

Table 4: Categories and causes of damage

Categories of causes of damage	Causes of damage	% of causes in residential buildings		% of causes in non-residential buildings	
Conceptual	Soft-storey	9	44	13	52
	Short column effect	5		9	
	Irregularity of plan stiffness	7		6	
	Other causes	23		24	
Detailing	Poor detailing (unspecified)	9	29	18	30
	Lack of ties	11		4	
	Inadequate ductility	5		5	
	Other	4		3	
Construction	Poor construction (unspecified)	10	27	8	18
	Poor material quality	11		4	
	Other	6		6	

Conceptual

Causes of damage resulting from conceptual architectural, engineering, and traditional building decisions are included in this category. For both residential and non-residential construction, conceptual deficiencies account for about half of all causes of damage. Poor building configuration (structural layout) caused by soft-storeys, short columns, and plan irregularities is a major contributor. Sixteen separate causes of damage are included in the 'other causes' of damage resulting from conceptual deficiencies. They include vertical discontinuity of infills, slender walls, pounding, one-directional structural systems, lack of redundancy, high roof mass, large diaphragm openings, and inadequate roof bracing.

Poor architectural and engineering conceptual design is believed to be an even more significant cause of damage than shown above. A poor building configuration concept increases structural demands on both detailing and construction quality, and, depending on whether the intensity of shaking causes structural damage, these inadequacies may be exposed. However, if a design concept is sound, neither detailing nor construction quality may be tested at all. The importance of sound design concepts in achieving adequate seismic performance is therefore underestimated in this analysis.

In several instances, non-compliance with building codes is noted as a cause of damage in reconnaissance reports. Typical examples include column ties too widely spaced, or ties with ninety degree rather than one hundred and thirty five degree bends. Codes generally provide specific guidelines for detailing and such details are easily checked after a damaging earthquake. Clearly, more emphasis is required on reviewing code compliance with respect to building configuration, which this study shows to be the predominant cause of seismic damage. Where a strong earthquake engineering culture and community exists, and designers are aware of the importance of good configuration, emphasis in codes on detailed rather than conceptual design may not be such a problem. However, building codes in developing countries perhaps need to be more explicit in preventing poorly configured buildings.

Unfortunately, this aspect of code development is difficult. More than detailed structural engineering considerations are at stake. Architectural, building use and other cultural factors can predominate. For example, modern architectural planning with an adherence to open ground floors for shops or parking often leads to numerous soft storeys. In addition, professionals in fields other than structural engineering are often not interested in seismic issues. Not only is a multi-disciplinary approach required where a uniform level of professional commitment is lacking, but the technical basis for inclusion of code configurational constraints may be fuzzy. Engineering judgement honed by exposure to earthquake damage is indispensable for code committee decision making given the levels of structural complexity and uncertainty. For any community to have a satisfactory level of seismic resilience, attention must be paid to conceptual design issues in codes.

Detailing

Depending on the quality of a conceptual design, poor detailing may or may not be another cause of damage. As discussed above, if the design concept is poor, resulting in a soft storey for example, then any poor detailing will be exposed. There are a number of reasons for poor detailing; poor design of details, poor supervision and poor construction. If design details are poor or even non-existent, supervision and construction can not remedy the situation. At best, an enlightened and concerned supervisor or contractor might take remedial action. Structurally adequate details must always be provided in construction documentation. The next method of improving detailing is to provide site supervision. If it is reliable and of sufficient quality it can avoid, or at least reduce instances of poor construction. If supervision is ineffective, and unless there is specific evidence to the contrary, one must assume the quality of construction is suspect.

A review of causes of damage that can be attributed to detailing problems highlights poor detailing of steel reinforcement in reinforced concrete construction, particularly in non-residential buildings. Many reconnaissance teams comment on insufficient amounts of reinforcing steel. While poor performance of reinforced concrete construction is of great concern there is real possibility for improvement. Almost all non-residential buildings and many residential buildings in this study rely upon reinforced concrete. Although it is considered an acceptable, if not indispensable construction material, in many situations it proves inadequate when subject to significant seismic actions. Increased industry education that begins by emphasising the importance of building configuration to designers, and even includes basic lessons for workers on building sites, will improve building standards and reduce vulnerability.

Poor detailing in residential construction is often due to a lack of "through stones" that tie outer wythes of adobe walls together, and an overall general lack of interconnection of building elements. In most cases such buildings are built by owners with minimal financial resources. Again, education should be the focus of any seismic damage mitigation program.

Within reconnaissance reports there are few, if any, causes of damage reported that are believed to be new or not understood. Causes of seismic damage have either been seen before, or at least are expected. This confirms the view that a basic problem of ensuring adequate seismic performance in developing countries may not only be due to a lack of knowledge, but rather a lack of application of techniques that have been proven, at least in structural laboratories in other parts of the world.

Construction

No strong trends emerge from the list of reported construction defects. Construction inadequacy is far more likely to be a cause of damage in residential buildings than in other building types. This is presumably due to the fact that many houses are owner built. In these cases, poor construction and material quality are reported frequently, whereas in non-residential construction these issues represent a surprisingly low contribution to overall causes of damage.

Reasons for poor construction are not usually cited explicitly. Often they are not known with certainty, but one can assume some combination of the following: lack of resources, ignorance and dishonesty. Of these three reasons, the first is the most serious, given its widespread nature, and it challenges those associated with the building industry worldwide to keep developing cheaper and more suitable construction materials, systems and details in order to improve seismic safety. Ignorance can be addressed by improved educational efforts, but dishonesty can be ameliorated only by high quality supervision.

RECONNAISSANCE REPORTS

Two thirds of the reports studied are authored by engineers and researchers from developed countries. In most cases these visitors seek information and lessons that are relevant and transferable to their own situations. Their focus is upon building stock and construction systems similar to their own, increasing the relevance of their reconnaissance to their peers and sponsors back home. Meanwhile host countries may benefit eventually from the considerable expertise of reconnaissance teams via the "trickle down" effect.

The fact that a reconnaissance team's research agenda is orientated towards the needs of its own society rather than those of the local people, is not necessarily bad. However, perhaps this focus should be more openly acknowledged in order to identify more tangible ways of providing local assistance. A voluntary levy, of say ten percent of visiting reconnaissance teams' costs would be very effective in promoting on-going research at a local level. Providing resources for longer term seismic damage evaluation is likely to be particularly valuable, especially considering the lack of detailed study undertaken by reconnaissance teams. Their limited duration of visits does not permit detailed research, or even a more rigorous approach where attention is not inevitably drawn to prominent buildings that have been damaged. Perhaps teams could work specifically with counterparts and report locally as well as to their colleagues back home.

Reports place far greater emphasis on damage to engineered, rather than to non-engineered buildings. Adobe building performance for example, does not receive the attention it deserves, given both its unlimited use and its high vulnerability. Of course, visitors from developed countries may not be conversant with this type of construction.

What is less certain is the extent to which reconnaissance teams understand why some buildings perform better than others. The focus of most reports is on *damage*, even though it is well recognised there is much to learn from less damaged buildings in the same vicinity. There are many accounts of undamaged buildings surrounded by those that have collapsed. Studies of surviving buildings might identify characteristics that contribute to good performance and thereby provide additional evidence for code modifications. For example, correlation of damage with degrees of code compliance might be possible. Due to the limited duration of visits by reconnaissance teams, this work is probably best left to local researchers, where possible, encouraged and aided by personnel of overseas teams.

CONCLUSIONS

The main causes of damage to buildings in developing countries can be classified under the headings of conceptual, detailing and construction.

Flawed design concepts are responsible for over half the damage to both residential and non-residential construction. This area of conceptual design is where education and code development programs should be aimed.

Damage to adobe and other buildings with vernacular construction methods is under-represented in reconnaissance reports.

In recognition of lessons gained by reconnaissance teams from developed countries that are valuable for their own countries, and the fact that much valuable post-earthquake research can be undertaken, visiting teams should consider contributing resources to local researchers. Such a gesture would significantly improve the contribution reconnaissance teams and reports make to developing countries.

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