LONG-TERM CHANGE IN CONSTRUCTION PRACTICE THROUGH POST-EARTHQUAKE RECONSTRUCTIONS

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SUMMARY

Post-disaster housing reconstruction projects present an ideal opportunity to create a lasting change in construction practice, so that houses built during and after technical and financial assistance are disaster-resistant. Recent observations from the 1993 Killari, 1999 Chamoli, and 2001 Bhuj, India earthquake reconstructions indicate that, in the absence of building standard enforcement, a combination of technical, economic, and social criteria must be met in order for new houses to be earthquake-resistant and occupied, and for earthquake-resistant construction technologies to be permanently adopted by individual builders and homeowners. The most sustainable building programs are those that use locally available materials and skills and produce a structure that is both culturally accepted and competitive in cost with common (but vulnerable) building methods. This paper proposes criteria for long-term change in single-family housing construction practice that can be applied to post-disaster reconstruction and new housing construction programs in less developed countries where continued enforcement of building standards is unlikely.

RECENT EARTHQUAKE RECONSTRUCTIONS IN INDIA

1993 Killari, India Earthquake

The September 30, 1993 M_w=6.2 earthquake near Killari in Maharashtra state killed over 8,000 people. Over 1 million were left homeless, and 227,000 housing units were damaged or destroyed. The heavily affected rural farm districts, Latur and Osmanabad, are located in an area of moderate seismicity. The five-year long rehabilitation program (EERI [1]) was primarily donor-driven; 52 villages were relocated and rebuilt by contractors with little input from homeowners. Another 22 villages were rebuilt on the same or nearby sites with nongovernmental organizations (NGOs) or homeowners managing the rebuilding.

1999 Chamoli, India Earthquake

On March 29, 1999, a M_w=6.6 event shook Chamoli and surrounding districts in what is now Uttaranchal state, killing over 100 residents, destroying nearly 14,000 houses and damaging 10,850 others (Pande [2], EERI [3]). This hilly, temperate area of the Central Himalaya is highly prone to earthquakes and landslides. Less devastated than the Killari area, Chamoli received comparatively little funding from international and Indian sources. The donor-driven, contractor-based approach was used to rebuild at least three villages, and demonstration houses were put up throughout the region. Government and NGOs distributed building materials and technical guidelines, but oversight was limited.

2001 Kachchh (Bhuj), India Earthquake

The January 26, 2001 earthquake was centered in a rural area north of Bhachau in the

Kachchh district of Gujarat state, India. The M_w=7.7 event caused at least 13,805 deaths and 167,000 injuries. A total of 215,229 houses were completely destroyed, and 928,369 damaged (GSDMA [4]). Most (89%) deaths took place in the Kachchh district, a hot, arid, predominantly rural environment located in India's highest seismic zone (Zone V). Kachchh is prone to a variety of natural disasters, including repeated strong earthquakes, cyclones, and droughts. Following the earthquake, the Gujarat State Disaster Management Authority (GSDMA) was formed and funded. Approximately 77% of the rural residents whose houses had been destroyed received cash assistance to rebuild themselves (an owner-driven approach) with government oversight. The other 23% partnered with an NGO. This approach varied from donor-driven, in which contractors built the houses with minimal input, to donor-facilitated, in which the NGOs provided varying degrees of engineering advice and materials. In July 2003, the rural reconstruction was nearly complete, and US$268m had been disbursed to homeowners for the reconstruction of 133,493 homes (GSDMA [4]).

Goals and Evaluation of Housing Reconstruction Programs

The overall goals of a post-disaster housing reconstruction program should be to (1) build new houses that are resistant to earthquakes and other disasters and satisfactory to the people, and (2) change the construction practice permanently so that houses built after the technical and financial assistance cease are also earthquake resistant. To evaluate the success of the reconstructions in the context of these goals, the author spent eight months in the Bhuj area in 2003 and 2004, and two months in the Chamoli and Killari areas in 2004. Homeowners, builders, government officials, and NGOs were asked a series of questions related to the construction, training, oversight, and financing processes. A visual inspection was used to document general details and identify earthquake-resisting features, such as seismic bands at appropriate positions. In all, over 100 villages and small towns were visited.

CRITERIA FOR CHANGE IN CONSTRUCTION PRACTICE

A combination of technical, economic, and social criteria must be satisfied during the reconstruction process in order for the new buildings to be earthquake-resistant and occupied, and for the earthquake-resistant construction technologies to be permanently adopted by individual builders and homeowners. The criteria are presented in Table 1.

Table 1. Criteria for Successful Housing Reconstruction Programs

Technical	Economic	Social
• Earthquake resistant design • Earthquake resistant construction • Durable • Easily expanded and maintained • Resistant to other disasters	• Competitive in cost with local, common building methods • Skills and materials widely known and locally available	• Climatically suitable • Appropriate architecture, space and features • Secure • People trust the structure is earthquake- resistant

TECHNICAL CRITERIA

Earthquake Resistant Design

The first of the technical criteria is earthquake-resistant design. In all three reconstructions, rebuilding guidelines were issued by Indian governmental agencies (see e.g., GSDMA [5], HUDCO [6], MEERP [7]). The guidelines, based largely on the Indian Seismic Standards, promote masonry walls (fired brick, stone, concrete block) with horizontal, reinforced concrete (RC) bands at the plinth, lintel, roof and gable levels. A single vertical steel bar at each corner and adjacent to large openings was recommended for the houses rebuilt in Zone V. It has been demonstrated that structures built pursuant to the guidelines are unlikely to collapse in earthquakes, though they may develop cracks (Arya [8], UNCRD [9]).

The guidelines are somewhat limited in their scope in that they do not address the full range of designs commonly used by the homeowners. Following are some examples.

- Although Bhuj guidelines cover a gable roof with tiles on timber rafters and purlins, they are vague in their guidance on the proper connection between the gable band and the roof structure. Most of the pitched-roof, owner-built houses surveyed in the Bhuj area visit had omitted the gable band (Fig. 1).
- In the Chamoli reconstruction guidance, design of an RC slab roof was omitted completely; yet most owners who built new houses opted for an RC slab.
- Masonry confined by RC columns and beams was prevalent in all three affected areas for houses built by wealthier owners.[1] Although the Indian Seismic Standards address reinforced concrete detailing, no guidance was produced for this type of construction. Many design and construction quality issues were observed (e.g., Fig. 2).

Fig. 1. Missing gable band, seismic belt added (Bhuj EQ)

Fig. 2. Confined masonry under construction, note large openings, wide gap between stone and rebar, rebar out of plumb (Bhuj)

Earthquake Resistant Construction

Beyond earthquake-resistant design, the construction process should produce an earthquake-resistant structure. This means that the materials and workmanship are of good quality and the house is built as it was designed. Achieving earthquake-resistant construction is a matter of capacity building (training) and oversight. In all three reconstructions, masons and engineers were trained and homeowners were educated about the importance of earthquake-resistant design and construction. Training efforts were comparatively limited in Chamoli due to lower funds and lesser presence of non-profit organizations. The effort was the greatest following the Bhuj event, in which cement companies, university faculty, engineering consulting firms, and NGOs developed and held training programs reaching over 27,000 masons and over 6,000 engineers and architects. Masons training courses ranged in scope and duration from two-day seminars to two-month long classroom and practical exercises. The basic trainings covered tool identification and usage, site excavation, material usage and preparation, mixing concrete and mortar, foundation and wall masonry construction, reinforced concrete seismic bands, roof construction, flooring, pointing,

[1] The population with potentially vulnerable houses could be generally divided into two economic groups: (1) wealthier residents - village leaders, farmers who own land, small business owners, retired military personnel - who were capable of contributing up to $3000 of their own funds toward housing construction; and (2) poorer residents - agricultural laborers, construction workers, widowed families, members of economically weaker sections - capable of contributing very little cash towards the reconstruction.

plastering. There was a much greater focus on covering the beginner construction skills than advanced topics such as reinforced concrete and earthquake-resistant construction. In one example, only 4 of 40 demonstration hours was spent on elements that contribute to earthquake-resistant construction, such as control on opening size, through stones and corner stones, and reinforced concrete quality (TISS [10]).

Clearly there has been an increased understanding of the prescribed earthquake-resistant design elements among the mason/artisan community, homeowners, and the rural population at large. However, field observations indicate that the skillsets of the masons are not yet complete. In addition, a follow-up study by a cement company with one of the most ambitious and comprehensive post-earthquake masons training programs showed that less than 40% of the structures built by trained masons during the height of reconstruction had any earthquake-resistant features and only 11% of the respondents had retrofit their own homes (TISS [10]).

In the Bhuj and Killari reconstructions, oversight was provided by government-trained engineers, who were also responsible for authorizing the release of cash assistance in installments, assuming the reconstruction guidelines were followed. Also, third party inspectors visited over 200,000 houses in an independent audit. An overall conformance rate of 84% was reported (GSDMA, 2003), which was based on weighting the presence of required elements with overall construction quality. A detailed review of a quarterly audit report indicates that at least 30% of the houses built by owners with government cash assistance were missing at least one earthquake-resistant element.

Durable

The house should be durable, or capable of withstanding earthquakes, heavy rainfall and other natural conditions throughout its useful life. For example, Fig. 3 shows an RC slab roof overhang that partially collapsed shortly after construction. A precast plank and joist system used in the Chamoli reconstruction was widely reported as prone to leakage and cracks (Fig 4).

Fig. 3. Partially collapsed, newly built RC slab roof (Chamoli EQ)

Fig. 4. Precast plank and joist system with crack along joist-wall interface, leakage between planks (Chamoli EQ)

Maintainable and Expandable

The foundation and structure must be capable of supporting extensions, additions, and modifications with inexpensive and locally available skills and materials, while maintaining the integrity and earthquake-resistance of the structure. Maintenance should be possible with locally available skills and materials. Some issues are discussed below.

- If a structure is built with a flat roof, it is likely that a second story will be added as the family expands (Fig. 5). Many foundations for one-story structures with flat roofs were not designed to carry the load imposed by a second story.

- If a structure is built from prefabricated components produced in distant cities, it is difficult for rural residents to obtain additional components for expansion or repair. Similarly, prefabricated structures are typically unable to support the weight of a second story built with locally available, heavy masonry materials.
- Where reinforced concrete columns or bands are used, it is common to extend the steel beyond the existing structure in anticipation of an extension (Fig. 6). The steel rebar was often of insufficient length to provide adequate overlap. Also, the condition of the rebar deteriorates over time as it is exposed to moisture.
- Continuing the masonry beyond a corner so that the proper bond can be taken up when the owner extends (Fig. 6), although somewhat common, was not always done in the preferred location (Fig. 7).

Resistant to Other Disasters

The buildings should be resistant to other common disasters, such as cyclones.

Fig. 5. Preparations for a second story. Toilet on right. (Bhuj EQ)

Fig. 6. Masonry bond for extension; short rebar length (Killari EQ)

Fig. 7. Extension without proper connection (Killari EQ)

ECONOMIC CRITERIA

Cost-Competitive

Foremost among the economic criteria is that the cost of construction must be competitive with common (but vulnerable) building methods. This is especially critical for poorer residents. Table 2 contains cost estimates for a 300 sq ft house built of brick masonry with a pitched roof of Mangalore pattern tiles on timber, typical of Bhuj area. The estimates cover (1) a house built during the reconstruction (cement and steel subsidized), (2) an equivalent house built in Gujarat without any subsidy, and (3) a house built without subsidy and lacking the prescribed earthquake-resistant elements. In comparing the latter two figures, including the earthquake-resistant elements as prescribed can increase the cost by up to 45%.

Table 2. Component and Overall Reconstruction Costs (Materials and Labor)

Component	Subsidized Materials, Guideline-Compliant	Unsubsidized Materials, Guideline-Compliant	Unsubsidized Materials, Traditional
Excavation and Layout	11	11	11
Foundation	196	196	182
Wall Masonry	243 (cement mortar)	294 (cement mortar)	194 (mud mortar)
Seismic Bands	105	246	--
Mangalore Tile Roof	139	139	139
Flooring	64	64	64
Plastering	93	93	93
Windows, Doors, Shelves	124	124	124
Total Cost	$ 974	$1,166	$ 806

Locally Available Skills and Materials

To be permanently adopted and used, materials and technologies and the skills required to implement them must be locally available and widely known about. This criterion clearly overlaps several technical criteria, but because it its importance, additional examples are presented here.

- In Bhuj area villages, several NGOs successfully employed stabilized earth-based technologies. However, due to the high capital cost of the equipment, the entrepreneurial skills required to run a successful construction operation, and economies of scale, this technology has not yet been adopted by independent builders or contractors.
- Any new technology must be flawlessly implemented in order to be accepted by the population and considered for future use. In all three earthquake reconstructions, government and non-governmental organizations alike introduced innovative roofing technologies out of precast components. Many villagers reported leaks, cracks, and safety concerns, and an unwillingness to use the roofing technologies for new houses.

SOCIAL CRITERIA

Suitable to the Climate

The materials and form of the structure should be suitable to the climate. For hot climates, thick (earth, masonry) walls are preferable to thin (prefabricated panels, asbestos or CGI sheets). When air conditioners are beyond the economic reach of the homeowners, pitched or domed roofs provide better air circulation than flat roofs (Fig. 8). Small, covered openings are recommended (Fig. 9). If flat-roofed houses are built in hot climates, the roof should be strong enough to support a ceiling fan. There was a preference in many hot climate villages for a covered verandah for socializing and sleeping on warm nights. In cold climates with heavy rains, lightweight roofing materials were rejected (see discussion under alternative technology).

Fig. 8. Circular, stabilized earth-walled structure with pitched roof, appropriate for hot climate (Bhuj EQ)

Fig. 9. Houses built early in the program without lintels (left), windows with substantial lintels built later (Bhuj EQ)

Architecturally and Spatially Appropriate

The architecture and space should be appropriate to the lifestyle of the homeowners. The input of women is especially critical here; in the villages surveyed for this report, the women typically spend the most time in the house, taking care of the children and preparing meals. Private (shielded from view) but ventilated areas for cooking are essential components for a comfortable life in Bhuj-area villages, yet many organizations omitted these items from the layout. It is also preferential to have doors and windows open to a courtyard, as opposed to a busy street. As a remedy to inappropriate placement of doors and windows, some homeowners blocked in openings and created others in more preferable locations. Not a single homeowner interviewed expressed a preference for locating the toilet and bathing facilities inside the main living area; all residents prefer a separate structure with a separate entrance (Fig. 5). Those toilets that were built inside the structure were used as storage spaces. Provisions for shelves, fan fixtures, and traditional or religions features were also absent in some of the donor-built houses.

In the case of relocated houses and villages, the layout of individual plots and the organization of the village should be appropriate to local culture and lifestyle. If the homeowners keep animals, an enclosed plot is necessary. The character of the place should be preserved or modernized, depending on the preferences of the people. Water and electricity should be available in the village. Relocating a village away from a water source could result in a village that is predominantly unoccupied (Fig. 10).

Fig. 10. Relocated village that is predominantly unoccupied due to lack of water (Killari EQ)

Secure

The walls and roof should be capable of preventing unwanted entry and protect the belongings of the homeowner.

People Trust the Structure is Safe

Finally, people must trust that the structure is earthquake-resistant and safe to live in. In some of the most severely affected villages in the Killari area, residents were not sleeping inside their house, even 10 years after the earthquake. Instead, they had built extensions with corrugated galvanized iron (CGI) sheets (Fig. 11). In some Bhuj-area villages, residents are waiting one year before sleeping inside the house so that the house can be tested by aftershocks. Villagers reported that they had observed poor construction practices, or had not been involved in the construction.

Fig. 11. CGI sheet extension (Killari EQ)

DISCUSSION

That post-disaster reconstruction programs should be leveraged to create permanent changes in building construction practices is a concept that is gaining in acceptance and application. This is especially critical in many developing countries in which hundreds to thousands of residential houses collapse during strong earthquakes, many lives are lost, and the most likely scenario for reconstruction is rebuilding of minimally engineered structures by owners. A set of technical, economic, and social criteria has been proposed. If the criteria are met, it is likely that new houses built during the reconstruction process will be earthquake-resistant and occupied, and the earthquake-resistant construction technologies will be permanently adopted by individual builders and homeowners in future constructions.

The ability to satisfy the entire set of criteria presented herein is dependent upon the approach used in the reconstruction. Although there are exceptions, the social criteria are more commonly satisfied when the owners manage their construction, while the technical criteria are more easily satisfied in a donor-driven approach. There is some overlap and contradiction among the criteria. Lightweight materials, especially for the roof, are preferable for earthquake-resistance; however, these types of materials typically do not possess the desired waterproof and thermally insulating properties.

Finally, the discussion of social preferences and amenities is not meant to imply that all amenities and fixtures should be donor-provided; it is widely accepted that such an approach can create a dependency situation. In many cases, homeowners have taken it upon themselves to build perimeter walls, add fixtures and shelves, and build their own toilets and cooking areas. Failing to satisfy social preferences in the reconstruction process, however, can lead to the occupancy of a structure that is not earthquake-resistant. Owners may move back into their damaged house, take it upon themselves to do structural modifications that may compromise the integrity of the structure, or build an extension or addition that is not earthquake-resistant.

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