Housing Reconstruction

The rebuilding project represented a complex effort on many fronts. Not only did the GOM create a separate management structure for the project, but it also developed three alternative approaches for rebuilding.

1. Relocation was selected as most appropriate for the most severely damaged villages. Construction was managed by contractors under the supervision of the PMU or by NGOs and donor agencies that adopted certain villages.
2. Twenty-two other villages ultimately fell into the hybrid approach-–a new village, usually built on a new site, with construction managed by the PMU or supervised by owners and NGOs.
3. The reconstruction, repair and strengthening program was developed to rehabilitate moderately damaged houses in-situ. Under this program, beneficiaries were given the options of building a new safe room onto their houses or of strengthening the existing house with earthquake-resistant technology. Owners managed the repairs with technical support from the government.

Immediately after the earthquake, the GOM began considering options for rebuilding on the massive scale that was required. The GOM developed its housing rebuilding policy based on the extent of damage and the earthquake fatalities. Political, psychological, religious, technical, and pragmatic reasons all played a role in the government's decisions concerning available options.

There were three general categories of damage: housing in completely destroyed villages, severely damaged housing to be replaced in-situ, and moderately damaged housing to be repaired or rebuilt in-situ. Packages of financial assistance were developed according to these three general damage categories. These categories also corresponded to the three alternative approaches for rebuilding.

Relocation Villages

Observations

- *To handle rebuilding of entire villages at new sites, the government needed to use contractors. Local artisans were not available in the numbers required. Scale of the work was too large to be managed by the beneficiaries themselves in the initially-assumed implementation period of three years, particularly given the traumatized psychological state the GOM perceived in the villagers.*
- *While some evaluation studies suggest that the program design for the relocation villages dampened the initiative of the beneficiaries, in contrast to the repair and strengthening program where beneficiaries were actively involved in the rebuilding decisions, a comprehensive survey of every beneficiary in the relocation villages found a high level of satisfaction with the new houses.*
- *Extensive use of concrete technology in the rebuilding presented problems related to the quality of construction. It would have been better to use alternative technologies, even at the cost of prolonging construction and extending the implementation period.*

Discussion

The most affected villages, practically reduced to rubble in the earthquake, were considered for reconstruction at new sites (relocation). Relocation villages were those in which more than 70 percent of the houses were either destroyed or substantially damaged according to the IAEE Damage Categories 4 and 5 (IAEE, 1986), and those villages located on soft soil (so-called “black cotton soil”) of more than 2 m (6.5 ft.) depth. Villagers believed that since most of the earthquake fatalities occurred in these villages, they had become cremation sites and burial grounds and thus were uninhabitable for psychological and religious reasons. Arguments for relocation also included the fact that because there was so much debris in the totally destroyed villages, it was not economically feasible to clear it out and rebuild at the same sites. There was also a fear that black cotton (expansive) soils would make villages vulnerable in future earthquakes. The expansive nature of black cotton soil not only necessitated the construction of deep foundations (i.e., either deep strip foundations or piles), it also had substantial cost implications. In addition, popular sentiment considered relocation an opportunity to provide earthquake victims with “well-planned and neatly laid out new villages at new sites without any segregated compartments for different castes and communities” (GOM, 1993). Villagers, reinforced by prominent social science institutions, pleaded for relocation. The government responded politically to such strong sentiment by agreeing to the relocation. More than 27,000 houses were ultimately relocated in over 52 villages.

From the first days after the earthquake, government officials recognized the dilemma inherent in the decision to relocate entire villages, acknowledging that it was not feasible to abandon the area where people had lived for generations, had established social relationships, and were close to their agricultural lands. The scientific basis for relocation was also not strong, since the sites were only to be moved a few kilometers at most. On the other hand, the villagers were not psychologically prepared to stay in their destroyed villages, and consequently they put enormous pressure on the GOM to move them. Some of the villages absolutely refused to consider rebuilding in-situ, and although the GOM attempted to convince villagers that rebuilding in-situ would be safe, they were ultimately unsuccessful. The GOM felt obliged to be responsive to the demands of the villagers. It is important to emphasize that the demand for relocation was very pronounced, and the GOM did not believe it had the time or resources necessary to mount a major education campaign to convince villagers otherwise.

As the GOM evaluated the option of a more tailor-made approach to rebuilding houses in the severely damaged villages, they decided that given the scale of rebuilding required, it would be impossible to rebuild in a timely fashion if each house were treated as a separate project (find the space within the house, clear debris, modify each design, find individual builders, etc.). There were significant administrative issues in thinking through costs associated with a less standardized package. (Could existing foundations be used? If not, how would new foundation costs be factored in in a uniform manner? How would debris removal costs be handled in a uniform fashion? Etc.) These significant administrative issues were important to the GOM in designing a program that would have a high probability of success in terms of the number of units rebuilt in a timely fashion, improvements in the standard of living, and enhancements in earthquake-resistant construction (Vatsa, 1999) (Figure 8).

The new villages were located close to the old. There were three house types available under this program, which varied in size. Type A was 250 sq. ft. (this was the core house that most people received as grant assistance), Type B was 450 sq. ft., and Type C was 750 sq. ft. The size of the house the beneficiaries had before the earthquake determined which size they received. (Details are available in the “Earthquake Rehabilitation Policy of the Government of Maharashtra,” GOM, 1994a.) The sites selected for resettlement were acquired either through voluntary transfer to the GOM by the landowners or land acquisition was carried out under relevant law. Ownership rights to the house plots in the original villages were surrendered to the GOM upon acceptance of the new houses. While some of the NGOs involved in various relocation villages later reported that the resettlement away from the original land was inevitable and unavoidable, others thought that the siting of new settlements at original places would have made better use of the old plots and materials (CSSS, 1998).

Immediately after the earthquake there was an outpouring of help from various NGOs and charities. Since the World Bank-assisted program was not officially launched until June 1994, when credit from the World Bank was received, many organizations began rebuilding villages at new sites before this program was in place. The donor agencies made decisions regarding construction materials and technologies that did not necessarily conform with the guidelines later developed by the GOM. Other NGOs committed to rebuilding housing, but waited until the GOM program was in place to make their units conform to those that were built under the government program.

Although an initial principle of the program was to involve the beneficiaries directly in the rebuilding, the GOM decided to let contracts for the construction of entire villages because of the scale of the

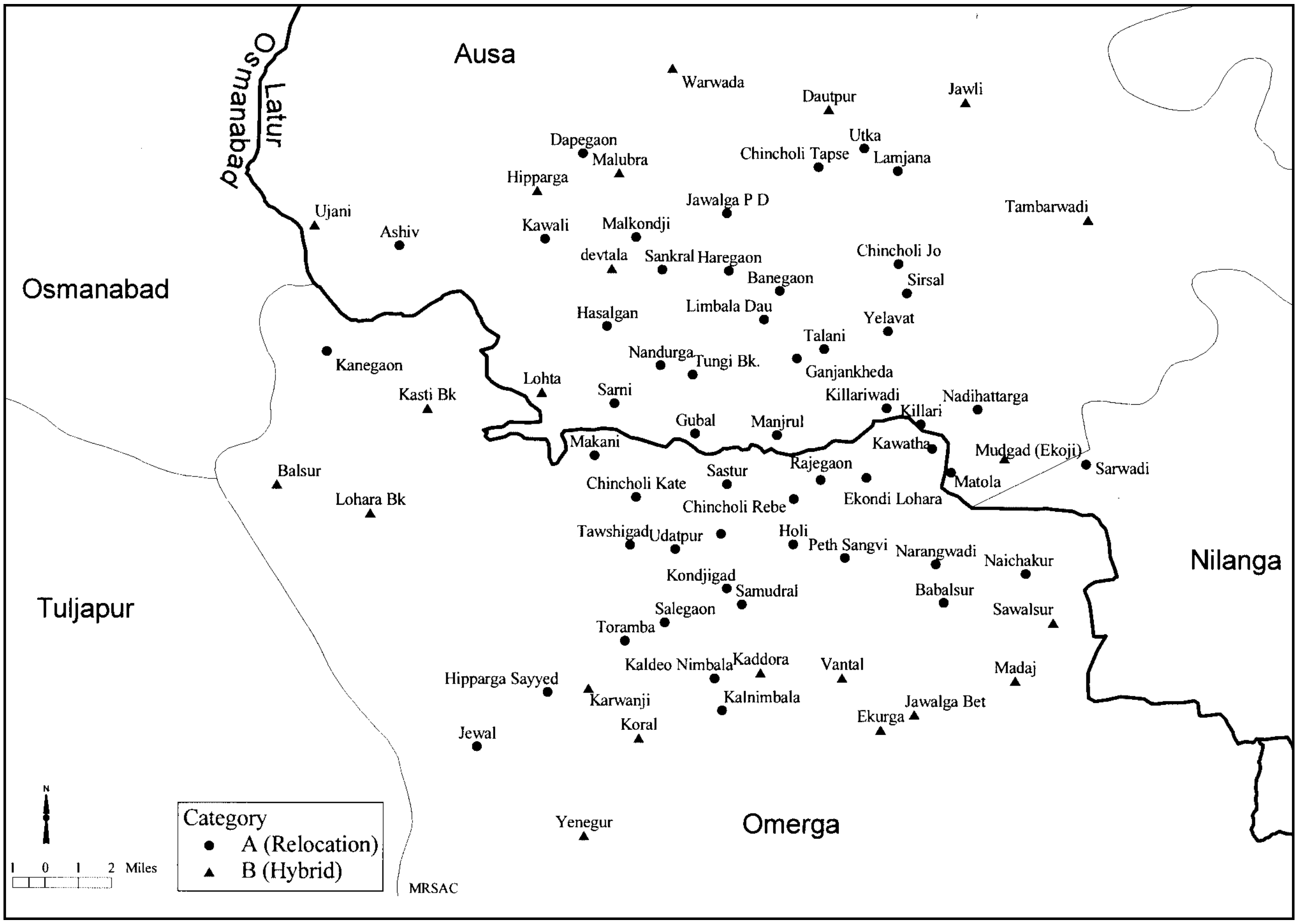

Figure 8 *Category A (relocation) and Category B (hybrid) villages in the Latur and Osmanabad districts.*

relocation and the limited number of local artisans available for construction. Different contractors were selected for each of the relocation villages and were then responsible for all the construction in the village. These contracts were managed by the Project Management Unit (PMU) created for this project. Engineering consultants and rural resettlement planners carried out village planning and design and supervised the contractors who did the construction (Figure 9).

A total of 27,919 houses were constructed in the relocation villages. Construction of the majority of houses (19,513) was managed by the GOM. Donor agencies and NGOs constructed the remaining 8,406 houses. The NGOs and donor agencies managed construction in the smaller villages, and because they were not waiting for financing from the World Bank they were able to proceed more quickly. Once they finished their own programs, the GOM asked them to continue construction at government cost. The GOM gave the NGOs certain concessions to encourage their participation, including exemptions from sales and excise taxes, free water and electricity during construction, and the land.

One unforeseen consequence of relocation was an aggravation of the problem of the drinking water supply. According to some of the NGOs working in the relocation villages, water supply in this drought-prone region has always been problematic. However, moving the villages 2 to 4 km (1.2 to 2.5 mi.) increased the problem for several reasons: the village was resettled away from the existing water source, the inferior construction quality of the drinking water pipeline, and construction of the drinking water systems was delayed (CSSS, 1998).

Figure 9 *Manufacturing of concrete blocks by a contractor using a block-making machine in a relocation village.*

Construction Process

Given the issues of land ownership, home ownership, beneficiary preferences, and contractor management, the construction process for houses in the relocation villages was complex. The key steps are outlined below. The MEERP was launched on June 30, 1994, nine months after the earthquake, and as noted above, although the government-sponsored rebuilding did not begin until then, some donor agencies had begun construction earlier.

- First, the GOM had to acquire land for the plots in all 52 villages. As an example, the total area acquired for the construction of 2,551 houses in the Killari village, the largest village and the one most affected by the earthquake, was over 203 hectares (502 acres) (GOM, 1998c). It took the GOM over a year to complete the land acquisition process. By June 1995, in the Latur and Osmanabad districts 94 percent and 87 percent of land was acquired.
- Secondly, the GOM had to appoint the design consultants, who were responsible for preparing the designs and the tender documents for 52 villages. Local competitive bidding was used for this purpose and the World Bank procurement procedures, new to the PMU officials, had to be followed. As of June 1995, 62 percent of the contracts had been awarded and another 17 percent were in the tendering stage.
- To plan the villages (village layouts) and to allot plots to individual beneficiaries, the PMU hired community participation consultants to work with the villagers, the design consultants, and the district administration.
- After the contracts were awarded, the design consultants prepared the house designs (generally three typical designs for each village), which had to be approved by the project's chief engineer. Most consultants hired rural architects and/or rural resettlement planners to assist them in the design.

In general, the design consultants appointed were from the largest and most reputable engineering consulting firms in Maharashtra and India.

- The final step in the process was the construction of the houses. The design consultants hired the contractors to carry out the construction. Due to a lack of interest by local contractors from the affected area and even from Mumbai, the large majority of the contractors came from the neighboring state of Andhra Pradesh. The construction was supervised by the consultants and the PMU engineering staff.

Some of the reasons for the slow initial progress of the PMU-constructed housing are documented in progress reports from the first two years of the MEERP implementation. These reasons include an acute shortage of water in the general drought-prone area and erratic power supply; shortage of good quality construction materials like sand/brick/hollow blocks; revisions in the beneficiary lists due to increases in the number of claimants; inability of the contractors to provide adequate manpower and machinery; delay in land acquisition due to bifurcation problems (some castes and communities wanted to be separate) and demand for undue compensation; an acute shortage of skilled construction workers; work stoppage by villagers for undue demands; and delays by donors in turning over sites in villages constructed jointly by the PMU and donor agencies.

New Village Design

From the earliest days immediately after the earthquake "modern and neat settlements" were called for by village leaders, prospective beneficiaries and the GOM's own policy document (GOM, 1993). Through the community participation process, villages were designed to meet the wishes of the beneficiaries. Later, there was criticism of the "grid" layout (Figure 10). However, it did expedite construction, improve circulation patterns, and reduce congestion. In fact, most of the donor agencies also used grid layouts in the villages they constructed. Better infrastructure facilities were provided. In some villages, attempts were made to maintain traditional character and linkages. In addition, the land area in the new villages was significantly larger, allowing space for further extensions to individual homes. The majority of the traditional rural houses in the area are one story and hence only a horizontal building extension is possible. In a large survey in which 23,498 beneficiaries were interviewed, and which was conducted as one of the evaluation components of the rebuilding project by the Center of Studies in Social Science (CSSS), 77 percent of the respondents were of the opinion that the design of the new village was better than the old. Only 10 percent believed that the overall design of the old village was more convenient than the new. This same study surveyed 13 NGOs that had been involved in the relocation villages. Many of these NGOs argued that the basic design for

Figure 10 *A grid-like layout of a relocation village, Latur district*

the new houses was not suitable for agricultural communities.

The community participation consultants hired by the PMU developed campaigns to disseminate information and elicit peoples' views on the MEERP. This was the first time that the GOM had used community participation consultants in a program, and they were given varying degrees of support. In some instances their role was welcomed, while in others it was viewed as "unnecessarily interfering" (TISS, 1997). They were brought in late, after a number of critical policy decisions had been made. In general their role included familiarizing government officials with the process of community participation, forming the village-level committees (VLCs), capacity building through various training programs, and information dissemination and documentation (TISS, 1997).

To help with information dissemination, the community participation consultants along with three local NGOs and community-based organizations organized a program called Jagar in each of the 52 relocation villages. The troupe prepared a package consisting of a "Prabhat Pheri" exhibition, songs, group discussions, and popular theater. Each of these contained messages related to the earthquake rehabilitation program and invited people to share their views, suggestions, doubts, or problems with the team (TISS, 1997), but it did not include any training or beneficiary education in earthquake-resistant construction, since all the construction was managed by contractors. This is in contrast to the reconstruction, repair, and strengthening program, which was an owner-managed program that developed a number of strategies to educate villagers about earthquake-resistant construction technology.

In retrospect, this lack of community education in the relocation villages was probably a weakness of the program. As villagers in the relocation villages construct additions to their homes or new villagers add homes, it is less likely that the owner-builders will be familiar with earthquake-resistant technology.

In the CSSS study referred to above, only 15 percent of the relocation beneficiaries reported participating in the community participation component of the rebuilding program. The major areas of participation for those who did participate included deciding the location of villages, planning the layout of villages, and planning the allocation of houses (Figure 11).

Figure 11
Interior of a new house in Killari village in the Latur district.

Figure 12 *Vertical reinforcement bars were provided in concrete block wall construction (Killari village, Latur district).*

Building Technologies Used in the New Villages

In developing the technologies for the relocation villages, the GOM's prime concern was "to ensure that housing provided in the area be earthquake-resistant to prevent any life loss due to possible future earthquakes" (GOM, 1993). The following factors were considered:

1. Use of locally available materials (e.g., stone and sand) as much as possible.
2. Provision of permanent shelter to the affected communities.
3. Functionality of the new houses and easy maintenance in the long run.
4. Thermal comfort.
5. Possibilities for replication of the proposed technologies in future construction.

Load-bearing masonry construction was considered the most feasible technology for the resettlement villages in light of traditional construction, the level of artisan skills, and various socioeconomic factors. The main objective of the housing design was to introduce improvements in traditional construction practices, mainly by incorporating the provisions of Indian seismic standards (such as IS 1893-1984, IS 4326-1993, IS 13827-1993, and IS 13828-1993) related to Seismic Zone IV of India. The key seismic provisions used in the project were seismic concrete bands (bond beams) introduced at the plinth, lintel, and/or roof levels (as per IS 4326-1993). In some villages (e.g., Killari), vertical reinforcement bars were provided at the wall corners in the pockets of the hollow concrete blocks (Figure 12).

Certain improvements and innovations were also introduced in construction materials. Several types of masonry products were offered for wall construction, such as hollow/solid concrete blocks, stone-crete blocks (concrete blocks cast with larger pieces of stone rubble), and burnt clay bricks. Ultimately, the majority of houses in the relocation villages were constructed using solid concrete blocks

Figure 13 *Construction of building foundations in Killari village. Stone masonry was used up to the plinth level.*

(200 mm [8 in.] thick) that appeared to be acceptable to the affected communities. Due to the villagers' immense fear of stone construction in the aftermath of the earthquake, stone boulders were used only for the construction of strip foundations (up to the plinth level) (Figure 13).

Crushed stone rubble from the abandoned village sites was also used for the production of concrete blocks. Also, because of the time constraint for the project, mass use of stone masonry did not appear to be feasible, as building earthquake-resistant stone masonry construction for 27,000 houses would compel the shaping of hundreds of thousands of stone boulders. On the other hand, the use of brick masonry was discarded due to the limited availability of bricks (brick kilns) in the area; the bricks needed to be transported from faraway locations. In fact, use of concrete blocks appeared to be the most feasible technology from the project management viewpoint, as these units could be manufactured directly at the construction sites.

Reinforced concrete slabs were selected as feasible roofing structures, replacing the traditional timber plank roofs. Mud mortar, frequently used as a binder in masonry construction prior to the 1993 earthquake, was replaced with a cement-based mortar (1:6 cement/sand ratio), as recommended by the GOM technical guidelines (1994b, 1994c), and by the GOI reports (GOI, 1993a, 1993b). It has been reported that, in an area with extremely hot weather and acute water scarcity such as Marathwada, extensive use of concrete technology in the rebuilding presented problems related to construction quality (see LASA, 1998; see also the section "Evaluation of Construction Quality and Program Outputs" in this report). Detailed coverage of construction technologies used in the relocation villages, including the house and village plans, is provided in the monograph *Maharashtra Emergency Earthquake Rehabilitation Programme–Housing Project* (GOM, 1998b).

The CSSS study found that the vast majority of relocation village households responding (80 percent, or 14,543 households) believed the new houses to be safer. Of these, 88 percent said it was because of the use of cement and sand, and 64 percent said it was because of the use of earthquake-resistant technology (multiple answers were allowed). Of the 20 percent (3,472) of households that did not believe the house to be safer, 79 percent said it was because of the fear of additional earthquakes and 70 percent had doubts about the quality of construction. It is interesting to note, however, that even though the vast majority of households believe the houses to be safer, most were sleeping outdoors even as recently as 1997, in part because of their fear of future earthquakes.

Special Case of Hybrid (Category B) Villages

Observation

- *There were 22 villages in the GOM's Category B villages, which were not quite as severely damaged as the relocation villages discussed above, but which required complete rebuilding. These villages were ultimately rebuilt in-situ, or in some cases, relocated nearby but with more beneficiary participation in the construction process. This modification in strategy appears to have increased satisfaction among the beneficiaries with their new housing and resulted in actual increase in floor area. Beneficiaries were able to construct larger houses by managing the construction process themselves.*

Discussion

Sixteen villages that were originally scheduled for relocation because of severe damage were eventually rebuilt in-situ. In these villages over 70 percent of the houses classified under Categories 4 and 5 per the IAEE damage categorization (IAEE, 1986) suffered extensive damage. In subsequent consultations with World Bank officials, and because of some of the negative consequences of moving villages, it was decided to carry out the in-situ rehabilitation of these villages.

The GOM decided to manage the rehabilitation of Category B villages through the Maharashtra Housing Development Authority (MHADA), which was in charge of obtaining the consent for house reconstruction from the beneficiaries, preparing house designs, and managing the construction carried out by the contractors. As the plan was to carry out the rebuilding in-situ, debris had to be removed prior to construction. However, the beneficiaries in these villages were not willing to give consent for the in-situ rebuilding; instead, they desired to move to new sites like the beneficiaries of the relocation villages. In October 1995, 17 months after the MEERP was launched, virtually no progress had been made in the rehabilitation of these Category B villages (Nikolić-Brzev, 1995b). Due to the extensive damage in these villages and the fear of possible earthquake tremors, villagers stayed in temporary shelters (huts) located away from the villages. The temporary shelters, put up by the beneficiaries themselves, had no water or power. The villages appeared to be practically uninhabitable because of a lack of maintenance. In spite of the difficult living conditions, the beneficiaries were persistent in their decision *not* to have their houses rebuilt in-situ.

Based on interviews with the villagers, MHADA field staff, and the PMU officials, the key reasons for the prolonged standstill in the Category B villages were:

- Changes in the rehabilitation policy. Initially the GOM planned to relocate these villages and the beneficiaries were aware of that decision.
- Proximity to the relocation villages so it was easy to see the new houses and amenities constructed to better standards.
- Post-earthquake rebuilding was perceived as an opportunity to move away from a village. The traditional cluster architecture of the villages made it very difficult to carry out horizontal extensions of the existing houses. As a result, even before the earthquake many people constructed their houses away from the villages on their own plots.
- In the majority of the Category B villages there were at least two distinct groups: one group desired to stay in the old village and have their houses rehabilitated in-situ, while the other group desired to move out of the village.
- A considerable amount of debris in the villages.

In 1996, two years after the MEERP was launched, the GOM ultimately decided to have the Category B villages resettled at the new locations. However, it was the responsibility of the beneficiaries to acquire the plots for the new construction and only some civic amenities were to be provided by the GOM—thus the "hybrid approach." (The GOM agreed to provide schools, electricity, and water supply, but not roads and drainage systems.) In three or four villages with strong leadership, the owners took responsibility for managing their own construction. In other villages the beneficiaries came to the GOM and asked them to find NGOs for them. The GOM invited NGOs to manage the construction in these hybrid villages. In total, 14 NGOs signed a Memorandum of Understanding with the GOM. They were responsible for managing the construction of 8,916 houses, and the full financial assistance package was provided by the GOM. Construction of the remaining 1,712 houses was managed by the owners, with assistance from the PMU, following the same guidelines and procedures as in the villages rehabilitated in-situ (GOM, 1998c). There were also villages where the NGOs managed half the rebuilding and the owners managed the other half. During the last year of the project another six villages were added to this category, bringing the total of hybrid villages (relocated but managed by beneficiaries and NGOs) to 22.

These villages are examples of a hybrid housing rebuilding effort, both in terms of the management strategy and the construction standards. The villages were rebuilt as a result of the mixed community-led effort and mass construction. In some cases the NGOs managed the construction carried out by the contractors, with all the house plans predefined and the same building materials used in all the houses. In other cases the beneficiaries managed the construction of the houses themselves, with the financial and technical assistance provided by the government in exactly the same fashion as in the villages rehabilitated in-situ.

During a July 1998 field trip, the authors visited several of these hybrid villages (Krimgold and Nikolić-Brzev, 1998). The case of Jawli village in the Latur district appeared to be a particularly interesting one (Figures 16 through 19). Out of the 561 (100 percent) houses in total, 215 (38 percent) houses were constructed by an NGO (CARITAS), whereas the remaining 356 houses (62 percent) were constructed by the beneficiaries themselves (GOM, 1998c). The entire village was resettled at a new location approximately 3 km away from the original one. All the houses constructed by the NGO looked alike; a single-house plan with two rooms and approximately 250 sq. ft. of carpet area was used for the entire village. Solid concrete blocks were used in the wall construction, and a concrete slab was used in the roof construction. Strip foundations were constructed in stone masonry. Cement-based mortar was used in the construction of the foundations and the superstructure.

The beneficiaries themselves constructed the remaining houses in the village (Figures 14 through 17). Each house was of a unique design, created by the beneficiary and his family. In most cases, the walls were constructed using brick masonry or, less often, stone masonry. Either concrete slab or corrugated galvanized iron (CGI) sheets were used in the roof construction. According to the rapid survey made by the authors, a considerably larger built-in house area was obtained in the case of owner-managed construction. In some cases, the beneficiaries were able to construct four rooms with approximately 450 sq. ft. of carpet area using the same financial package. In this example, community-managed construction appears to have been more cost-effective (by approximately 33 percent) than mass construction.

Reconstruction, Repair, and Strengthening Program (RRSP)

Observation

- *The Reconstruction, Repair and Strengthening Program (RRSP) was one of the most innovative aspects of this project for two reasons. First, owners were directly involved in the construction process. They were managing the process and deciding whether to repair and strengthen or rebuild their houses and selecting which masonry materials were going to be used in construction (e.g., stone, clay bricks, or concrete blocks). In some cases, beneficiaries and their families also provided the labor or assistance in post-construction activities (e.g., curing of concrete and masonry construction). This resulted in a high level of satisfaction in these villages. Second, the project incorporated knowledge about earthquake-resistant technology and developed a comprehensive program to educate owners, artisans, and engineers through training, hands-on experience, demonstration projects, and model buildings.*

Figure 14 A house in the new Jawli village constructed by the beneficiaries. A larger built-in area was obtained within the same financial package for this owner-managed project. Huts similar to that shown in the foreground were made by beneficiaries who were afraid to stay in their houses, even though many houses were only moderately damaged.

Figure 15 (Left) Houses in the new Jawli village constructed by Caritas.

Figure 16 A beneficiary standing in front of his old house in the Jawli village (Latur district).

Figure 17 The same beneficiary standing in front of his new house, constructed by Caritas (Jawli village, Latur district).

Discussion

The RRSP sought to reconstruct, repair, and strengthen approximately 212,000 moderately damaged houses scattered over 2,400 villages, in 13 districts and covering 40,000 sq. km (15,440 sq. mi.) using earthquake-resistant technology appropriate for the unreinforced masonry construction of the area. Ultimately, 189,000 houses were completed under this program, since a number of beneficiaries failed to complete the construction according to the government specifications. This undertaking was one of the most complex and challenging components of this massive rebuilding project. The beneficiaries took the initiative to repair, strengthen, and reconstruct the damaged houses with financial grants and technical support from the government.

There were three categories of financial assistance provided to the beneficiaries in the RRSP. Owners were given the choice: if their homes were severely damaged, they could completely reconstruct them using earthquake-resistant technology; if moderately damaged, they could repair and strengthen their home, or they could build one new room attached to the existing structure, using earthquake-resistant technology for the new room. The GOM financial assistance was limited to a fixed amount, given in the form of cash and kind. Using materials from old damaged houses wherever feasible, the beneficiaries supervised construction work and, in some cases, provided family labor.

One of the major challenges of the rebuilding program was to introduce basic earthquake-resistant construction technology and know-how into nonengineered rural construction practices. To achieve this, the GOM provided hands-on training to all those involved in the RRSP implementation, particularly the beneficiaries, local artisans (especially masons), and engineers who were providing technical assistance to the beneficiaries.

According to Nikolić-Brzev and Anicic (1994), it was proposed that the houses that suffered varying degrees of damage in Maharashtra be either reconstructed or repaired and rehabilitated in-situ. Out of those, the majority of houses (approximately 85 percent) were slightly to moderately damaged (IAEE Damage Categories 1 to 3), while the remaining 15 percent were severely damaged or had collapsed in the earthquake (IAEE Damage Categories 4 and 5). Two different packages of financial grant assistance were offered for these houses, depending on the level of damage. Due to a number of defaulters (beneficiaries who had initially been included in the program and failed to comply with the government policy and complete the construction per the GOM specifications) the total number of beneficiaries in the program was approximately 185,000.

An inherent complexity of the RRSP was the fact that it was a government-sponsored but community-managed program. The program was developed as a community-based construction process, controlled by the owners. A number of important decisions related to the RRSP implementation were made by the beneficiaries, their families, and entire village communities.

Since damage to these houses was generally repairable, the GOM's initial approach was that the houses could have been rehabilitated or strengthened in order to mitigate the losses due to future earthquakes. However, the local population had a pronounced fear of stone masonry and even a year after the earthquake perceived stone as a culprit in the collapse of or damage to their homes. Consequently, the GOM decided to offer an alternative for seismic strengthening of the existing houses by granting financial assistance to the beneficiaries for partially reconstructing their houses on the existing plinth (e.g., building a new room with earthquake resistant technology). The identical package of financial assistance was provided in both cases. **The selection of a preferred technology package was a voluntary decision made by the beneficiaries**.

Proposed Technology Packages

Building technologies proposed for the reconstruction, repair, and strengthening of buildings in the RRSP were developed based on the lessons learned from the earthquake, as well as from previous post-earthquake reconnaissance studies in developing countries with similar construction practices. Construction techniques (not just the building materials) present one of the key factors determining the performance of structures during an earthquake. In the area affected by the September 30, 1993 earthquake, there were many traditional stone or brick masonry buildings constructed to higher standards. While those buildings experienced

Figure 18 *An unreinforced masonry building constructed to the higher standards and with a concrete lintel band survived the 1993 earthquake without any damage (Killari village, Latur district).*

damage to the structural and nonstructural elements, they did not collapse and thus fatalities were avoided. The lessons learned in this earthquake indicate that the required level of seismic safety can be achieved by using local construction materials and skills in an adequate manner and by following the minimum seismic requirements recommended by Indian seismic codes and standards (Figure 18).

Viable technology packages were offered within the two overall alternatives of the RRSP: 1.) Reconstruction of the existing houses or portions thereof, and 2.) Repair and strengthening of the existing damaged vulnerable houses. *The Guidelines for Repair, Strengthening and Reconstruction of Houses Damaged in the September 30, 1993 Earthquake in Maharashtra, India* (GOM, 1994b) and the *Manual on Earthquake-Resistant Construction and Seismic Strengthening of Non-Engineered Buildings in Rural Areas of Maharashtra* (GOM, 1998a) provided recommended technologies for the RRSP implementation. A summary of the salient features of the recommendations is presented below.

Reconstruction. In general, construction technologies recommended for the in-situ rebuilding were similar to those adopted in the relocation villages. The following technologies were recommended for the wall construction: UCR stone masonry, burnt clay brick masonry, solid/hollow concrete blocks, stone-crete blocks (i.e., concrete blocks cast with large pieces of stone rubble), and stabilized soil blocks. Cement mortar was used as a binder in masonry construction. The two recommended roofing solutions were: corrugated galvanized iron (CGI) sheets, or reinforced concrete slab. The recommended building technologies were already in use in the area before the 1993 earthquake (to a limited extent in the villages and mainly in the townships, e.g., district centers). The key features of the proposed rebuilding technologies were:

- Reinforced concrete bands (bond beams) at the plinth, lintel, and/or roof levels were recommended as one of the most important seismic provisions per the requirements of pertinent Indian standards related to seismic-resistant design of low strength masonry (IS 4326-1993, IS 13828-1993).
- Replacement of mud mortar (which was frequently used in construction before the earthquake) with a lean (1:6) cement/sand mortar was recommended to ensure improved seismic performance of new houses. Cement mortar also improves the health standard of rural construction by providing protection from water penetration during monsoons (heavy

rains); hence the chance of dampness in the interior of the house is minimized, a condition which reportedly was a serious health hazard of stone and mud construction.

- Construction using the same foundations and plinth, starting with the plinth band construction was recommended (Figure 19).
- In case of UCR stone masonry construction, recycling of the stones dismantled from the existing house was recommended. Beneficiaries were given guidance regarding the selection and cleaning of adequately shaped stones (Figure 20).
- Maximum utilization of the existing construction elements, such as door and window frames, was recommended.
- Mandatory use of UCR stone masonry in an improved manner, with wall thickness restricted to 450 mm (1 ft. 6 in.), through-stones, corner stones, and shaped stone boulders. This was of utmost importance to ensure considerable improvement of the seismic safety of stone buildings in future earthquakes.

Figure 19 *The GOM recommended reconstruction on the same plinth. The existing timber structure was preserved, and the walls were reconstructed in the improved manner.*

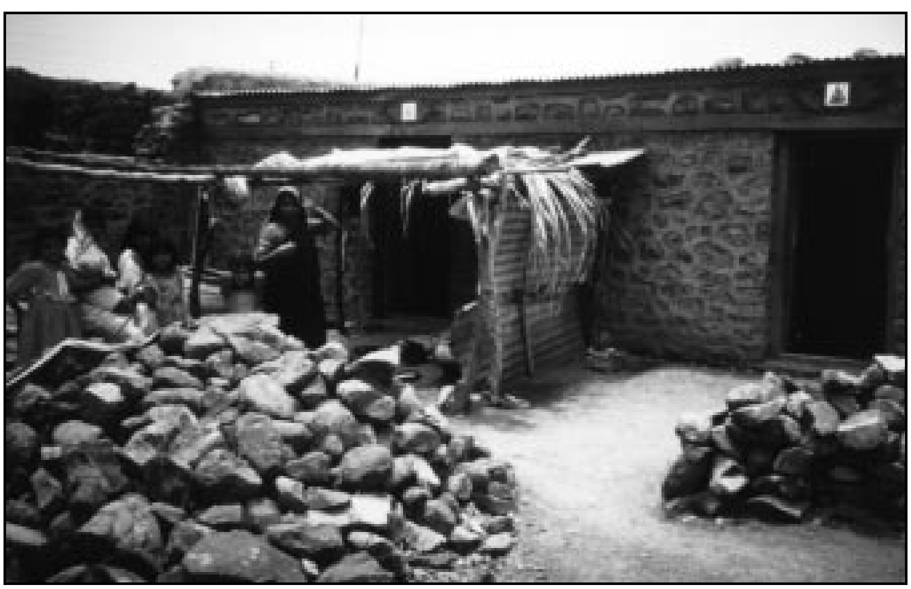

Figure 20 *A stone masonry house reconstructed in an improved manner. The round stone boulders dismantled from the original house were not used for the construction.*

Figure 21 *An example of concrete band installation at the eaves level of a stone masonry wall.*

Repair and Strengthening. A considerable number of houses in the RRSP suffered only moderate damage. Hence, in the rehabilitation policy the GOM offered a package of financial and technical assistance to beneficiaries whose houses were considered feasible for repair and strengthening. Apart from offering solutions for repair of earthquake-induced damage, the package also included technologies to mitigate seismic hazards posed by the existing vulnerable masonry structures. Since the Marathwada region was previously not considered earthquake-prone, a large majority of houses were constructed without any seismic provisions and were vulnerable, as demonstrated in the 1993 earthquake. The most important elements of the rehabilitation technologies used in the RRSP were:

- The existing heavy roofs were either removed and replaced with lighter structures or, alternatively, roof weight was considerably reduced by removing some of the heavy mud.
- Reinforced concrete bands (ring beams) were installed at the lintel and/or roof levels in order to preserve the integrity of the building in an earthquake and to minimize chances of an out-of-plane wall failure (Figure 21).
- Stone masonry walls were strengthened by providing through-wall anchors (through-stones) at certain predefined locations.
- Knee-braces were provided at the beam-to-post junctions to prevent the swaying of timber frames (Figure 22).

Beneficiary-Managed Selection of Construction Technologies

The RRSP was designed to be managed by the homeowners themselves. They were expected to decide whether to strengthen or to construct a new “safe” room in their house. They were encouraged to

__Figure 22__ A beneficiary of a rebuilt strengthened house where a timber frame was retrofitted with knee braces (steel angles).

participate in the construction themselves, and they received training in the principles of earthquake resistant construction from the GOM Junior Engineers (JEs), community participation consultants, and some of the local village leaders (Figure 23).

More than one million people (including the beneficiaries and their families) participated in the RRSP. While the large majority of the beneficiaries were of a similar rural background, there was a broad range of economic and social statuses. The two most important decisions made by the beneficiaries/owners of moderately damaged houses (IAEE damage categories 1 to 3) in the RRSP were to choose a construction technology package (i.e., reconstruction or strengthening), and to choose the wall/roofing material to be used in the reconstruction. The rationales for the beneficiaries' choices and preferences are discussed in the following sections.

Selection of Masonry Technologies in Rebuilding

In the initial phase of rehabilitation, the large majority of beneficiaries refused to use stone in the construction. Instead, they showed a strong preference for alternative, "modern" masonry technologies, like burnt clay bricks or solid concrete blocks. According to a field survey (Nikolić-Brzev, 1995),

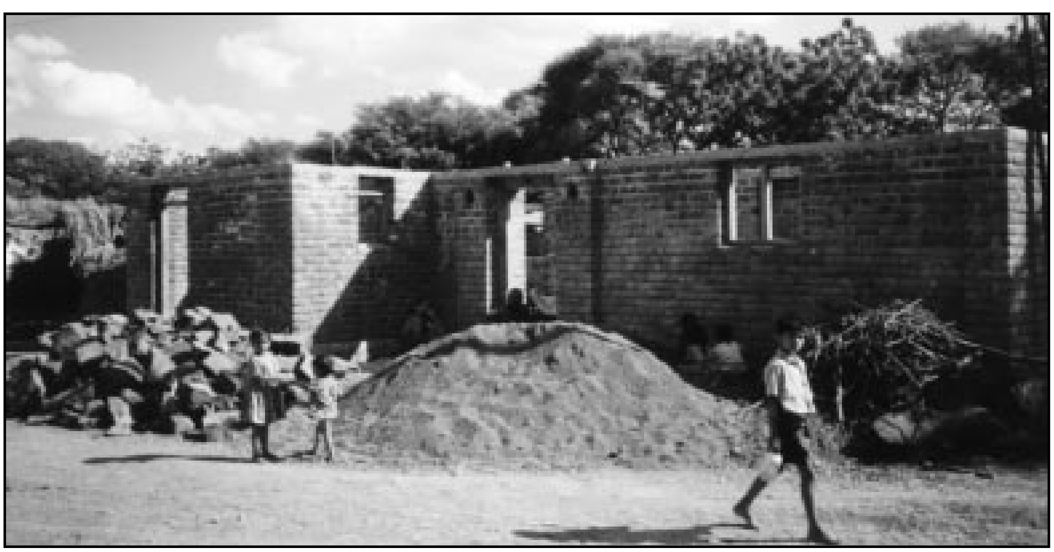

__Figure 23__ A large majority of beneficiaries decided to dismantle their stone houses and carry out new construction in brick masonry.

the majority of beneficiaries in the RRSP villages who chose the reconstruction option selected burnt clay bricks for the wall construction instead of stone, although in most cases they had owned stone masonry houses before the earthquake. The survey (based on approximately 200 villages) revealed that over 75 percent of the beneficiaries in the Latur district and 60 percent in the Osmanabad district chose clay bricks for the wall construction (Figure 23); the second most popular masonry material was stone (Figure 24). Other types of masonry units (such as solid concrete blocks, stone-crete blocks, or soil cement blocks) appeared to be less popular.

The beneficiary preference appears to be mainly of a psychological nature. The beneficiaries thought that in case of a wall collapse during an earthquake, the chances of a serious injury (or even fatality) in a stone masonry house would be greater than in a similar house made of clay brick or concrete block wall construction. Interestingly, the beneficiaries believed that stone boulders were more hazardous than clay bricks or concrete blocks because stone boulders are larger than the other two types of masonry units. This belief was widespread among the beneficiaries (Nikolić-Brzev, 1996; Krimgold and Nikolić-Brzev, 1998).

In fact, however, the progressive collapse of a masonry wall usually happens suddenly because masonry has a brittle nature. Since the weight of masonry rubble from a collapsed wall would be similar no matter what masonry materials were used (it would mainly be a function of the wall thickness), the complete collapse of any masonry wall would likely result in a similar kind of casualty. In many cases, the beneficiaries decided to use stone masonry up to the sill level, and then burnt clay brick masonry for the upper wall portion. In most cases, however, stones were used for the construction of strip foundations up to the plinth level.

According to the GOM policy for the RRSP villages, the selection of building construction materials was to be made at the discretion of the beneficiaries themselves (from technology options offered in the GOM Guidelines – GOM, 1994a, 1994b). It was initially anticipated that a majority of the beneficiaries would select stone masonry as a preferred choice. As suggested in the GOM Guidelines (GOM, 1994b), the beneficiaries could recycle the stone boulders from their original houses. On the other hand, in order to carry out brick masonry construction, the beneficiaries had to procure bricks at the market rate, which doubled in the four years of project implementation.

There were also cost considerations to rebuilding using stone masonry construction and upgrading to the level specified in Indian seismic standards. The

Figure 24 *In some villages, stone masonry remained the most popular building material after the earthquake. Here a Junior Engineer is inspecting several new stone masonry houses.*

Figure 25 *New stone walls were constructed using shaped stones cut by stonecutter artisans.*

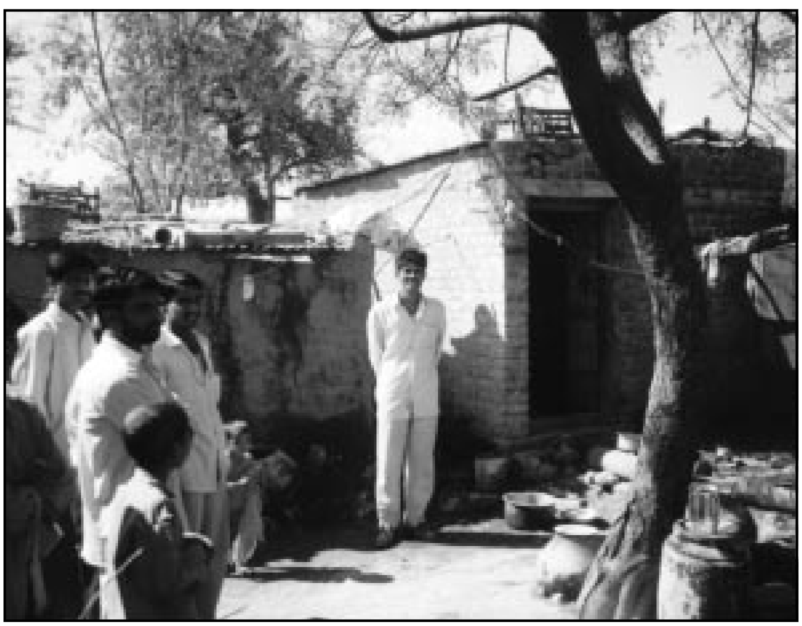

Figure 26 *New houses were constructed to much higher standards than the houses that were built before the earthquake. An old house (left) and a new house (right)are shown here, with the beneficiary standing in front of the new one.*

stones had to be cut and shaped, and the stone masonry used a higher volume of cement because of the larger spaces between stones (Figure 25). As a result, stone masonry appeared to be the most expensive construction technology of all the packages offered in the MEERP. This cost, therefore, was another important factor that led the majority of beneficiaries to select brick masonry construction, even though it also had increased in cost.

Finally, it appears that social factors also played an important role in the selection of masonry material. The majority of the population in the earthquake-affected Marathwada region was poor. A brick masonry house was something most had aspired to but had never been able to afford. Brick masonry construction in cement mortar is locally known as “pukka” construction and is found mainly in the townships (such as in the Latur or Osmanabad district centers). Prior to the earthquake, pukka houses were generally owned by the wealthier members of the village (landowners or tradesmen). Many beneficiaries used this program as a unique opportunity to develop and construct “dream” houses (Figure 26). As the financial grants offered by the GOM were of a set amount, many beneficiaries contributed their own funds in order to expand the size of their new houses. The typical beneficiary contribution was 10 to 20 percent of the GOM grant assistance.

Figure 27 *An example of a situation where retrofitting was not a feasible option due to excessive wall thickness and poor quality of construction. Masons are shown constructing a new plinth band.*

Strengthening of Moderately Damaged Houses vs. New Construction of a "Safe" Room

From the inception of the RRSP, it was apparent that strengthening was not a preferred technology package for the beneficiaries. Only a very limited number voluntarily selected strengthening over new construction of an additional room. The official figure is not known; however, according to the Quality Assurance and Technical Audit consultants (LASA, 1998), only 0.1 percent of the beneficiaries decided to repair and strengthen their houses. Based on numerous field visits and interviews with hundreds of beneficiaries, field engineers, PMU officials, and community participation consultants held from 1994 to 1998 (Nikolić-Brzev, 1999; Krimgold and Nikolić-Brzev, 1998), the authors believe that the most important factors influencing a beneficiary's choice of construction technology package (construction of a new room versus strengthening of the entire existing house) were:

- **House condition and/or age.** At the time of the earthquake, many houses in the affected villages were in a deteriorated condition due to aging, adverse weather conditions, and lack of maintenance. In many cases, for example, for houses constructed in sun-dried mud/adobe blocks, strengthening was not considered a feasible rehabilitation option (Figure 27).
- **Level of beneficiary income.** A large majority of low-income beneficiaries selected reconstruction as the preferred option. Before the 1993 earthquake, a large majority of low-income beneficiaries owned hut-like ("kutcha") houses, for which strengthening was not a feasible rehabilitation option in any case. On the other hand, middle- and upper-class beneficiaries owned houses that were only 15 to 20 years old

and were better constructed. They were built with cut stones instead of round field stone boulders, lime or cement mortar instead of clay mud mortar, and quality timber in the frame construction. For these reasons, upper-income beneficiaries owned a majority of the houses strengthened in the RRSP.

- **Need for an expansion of built-in house area.** The area affected by the earthquake consisted of old rural settlements inhabited for several centuries. Many houses in the villages were constructed hundreds of years ago (Nikolić-Brzev, 1999). At the time of their original construction, those dwellings had been designed to shelter smaller families. Due to the specific architectural and structural features of traditional houses and the limited plot area available in the congested village environment, it was virtually impossible to make either horizontal or vertical building extensions. The need to extend the existing built-in house area was certainly one of the underlying reasons for many beneficiaries to select reconstruction instead of strengthening as an option. This was particularly common for beneficiaries whose houses had only been moderately damaged (Figure 16).
- **Extent of the earthquake damage/proximity to the epicenter.** For the beneficiaries whose houses suffered more extensive damage in the earthquake (e.g., collapse of a portion of a stone masonry wall or large gaping cracks in a wall), strengthening was an unacceptable option. Due to factors such as relative proximity to the relocation villages where mass construction of brand new houses was in progress and memories of the earthquake that had caused a large number of fatalities because of the poor quality of stone masonry construction, it was very difficult for the GOM field staff to persuade the beneficiaries to re-inhabit their houses. In the year following the earthquake, fear of a recurrence was so strong that the majority of beneficiaries, especially the ones whose villages were located close to the epicenter, stayed in self-made bamboo and thatch huts at night (Figure 14), even though they occupied their houses during the day. In spite of all the GOM education and information dissemination campaigns and the special incentive schemes developed to promote the strengthening option, the majority of beneficiaries in the villages located closest to the epicenter ultimately decided to reconstruct rather than to strengthen their houses.
- **Time constraint for the recovery.** According to the conditions of the World Bank credit, MEERP was developed as a 3-year emergency program. Therefore, the GOM officers who were taking part in the RRSP were pressed to meet deadlines to complete housing construction on time. Moreover, a majority of the JEs who were providing technical guidance and overseeing the program implementation at the “grassroots” village level had been hired on a contract basis, with a 6-month contract extension period. They were given a certain target number of houses to rehabilitate in 6 months, or else their contract would be terminated. Besides the penalty clause, the JEs were also given financial incentives if they completed more than the target number of houses. Under such circumstances, it was much easier and more time-effective for them to oversee reconstruction rather than the strengthening of a house. Strengthening is clearly a more complex option, both in terms of technical solutions (each house was a unique case study) and physical implementation. A considerably larger effort was required by a JE to provide frequent site instructions to the artisans who were generally not familiar with the strengthening technology.
- **Implementation experience.** The RRSP was officially launched in June 1994. The PMU Technical Guidelines (GOM, 1994b, 1994c) were published that month, and subsequently several orientation training sessions for the PMU engineering staff took place. In September 1994, over 400 JEs were mobilized and started field activities in the villages. The RRSP strategy document (Nikolić-Brzev and Anicic, 1994) proposed phasing the program into four stages and the construction target numbers were subsequently modified in the MEERP Implementation Plan (GOM, 1995b). Per the initial agreement of the World Bank credit (World Bank, 1994), the RRSP (and MEERP in general) was scheduled for completion in June 1997. However, due to various problems, the program implementation progressed slowly in the first

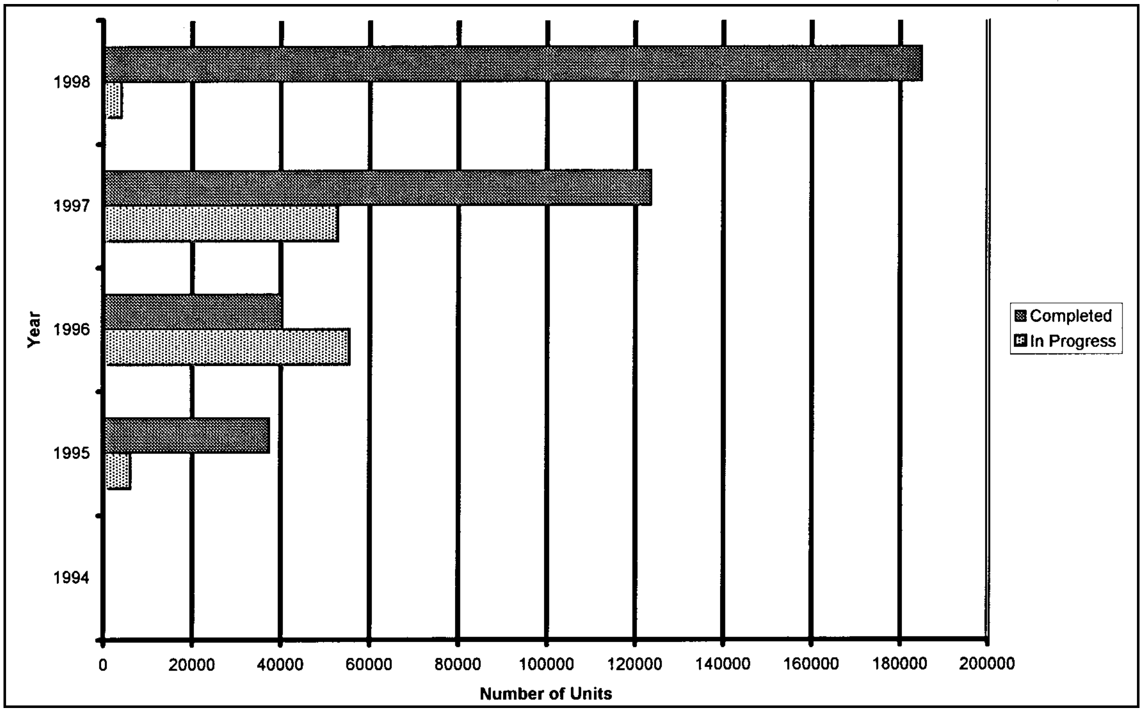

Figure 28 *Construction progress in the repair and strengthening villages.*

two years (from June 1994 to 1996) and thus it was not possible for the GOM to complete this component within the initially agreed upon time frame. Consequently, the World Bank agreed to extend the entire MEERP duration by 18 months, until December 1998.

Figure 28 summarizes the physical progress of the RRSP implementation (expressed in terms of the number of completed houses) in the last four years. It is very interesting to compare the actual pace of progress with the original implementation plan developed by the PMU. According to the field reports (LASA, 1998), it took beneficiaries between 3 and 24 months (per house) to complete the post-earthquake rehabilitation sponsored by the GOM. At the end of the RSSP implementation, approximately 10 to 15 percent of the total number of beneficiaries were designated as "defaulters." The defaulters were those who had consented to carry out the construction under RRSP according to the GOM policy and had received at least one (or more) installments of the financial assistance but had failed to complete the construction during the RRSP implementation period. Interestingly, the defaulters were mostly beneficiaries from the higher economic status whose houses had not been severely damaged (Nikolić-Brzev, 1999).

Figure 28 shows that the pace of progress was very slow in the initial two years of the program implementation and the problems were numerous, in part because of the community-managed strategy for the program implementation. These problems included:

1. Lack of beneficiary motivation to participate. Initially the beneficiaries were also hoping to get a "better" package of financial assistance, i.e., to resettle at the new locations like the beneficiaries in the relocation villages.
2. Beneficiaries' lack of awareness of the deadline for the rehabilitation effort.
3. Administrative problems related to the disbursement of cash installments.
4. Beneficiaries' reluctance to carry out construction on the existing plinth (they wanted to rebuild on their own plots away from the village).
5. Increased foundation costs in the expansive soil areas (black cotton soil).

6. Water scarcity (an acute problem).
7. A shortage of local construction labor available for the RRSP.
8. Management problems such as inadequate coordination between the PMU and the engineering and administrative field staff.

The PMU and its consultants undertook a series of actions to deal with the problems that hampered the progress of the RRSP implementation. These included:

1. Development of the implementation work plan at the micro (village) level (developed by the PMU and the project management consultants). The plan was displayed in each village with the time frame and deadline for the beneficiaries in a particular village.
2. Development of an improved strategy for monitoring progress, including use of the computerized PMIS by the project management consultants.
3. Decision by the GOM to allow new construction on the land acquired by the beneficiaries themselves and away from their original houses.
4. Improved monitoring strategy for material disbursement by distributing material coupons with an expiration date (45 days from the release).
5. Improved strategy for community participation and information dissemination, including the appointment and training by the community participation consultants of community-based organizations (Mahila Mandals) who were responsible for information dissemination at the village level.
6. Improved management strategy for the JEs appointed on a contract basis, including a performance-oriented incentive/penalty scheme.
7. Improved accounting procedures and recruitment of additional accounting staff at the field level.
8. Improved troubleshooting procedures, which included formation of special PMU teams to appraise villages where implementation problems were reported.

Training Initiatives

A number of important innovations were necessary to successfully implement this complex rebuilding program, including various types of training and education initiatives. This section discusses the training initiatives developed as part of this project, with the major observations connected to each initiative highlighted in italics at the beginning of the discussion.

Engineers as Technical Advisors to the Beneficiaries

Observation

- *The technical support and guidance provided to the beneficiaries and local artisans by the PMU engineering staff were of great importance to ensure the successful transfer of building technology know-how to rural residents who had no previous background in earthquake-resistant technology.*

Discussion

The RRSP program used Junior Engineers (JEs), primarily from the earthquake-affected area, to work with individual beneficiaries to provide technical assistance in the reconstruction or repair and strengthening of their homes (Figure 29). These engineers were each assigned to one or more villages and were expected to help beneficiaries work out the design for repair and strengthening or for new construction. They also acted as intermediaries between the GOM and the local villages. Activities of the JEs in the Latur and Osmanabad districts were supervised by the PMU senior engineering staff, including deputy engineers, executive engineers, and superintending engineers, who visited the villages regularly and communicated with the beneficiaries and village leaders.

As mentioned earlier, in the RRSP the engineers were given the unique role of technical advisors to the beneficiaries, who then actually managed the rebuilding of their own houses. JEs were hired by the GOM on a contract basis to ensure an adequate level of technical support and supervision in the villages where rebuilding in-situ was in progress. JEs either resided in the villages allotted to them or commuted daily by bus, motorcycle, or bicycle. The main scope of their work was to:

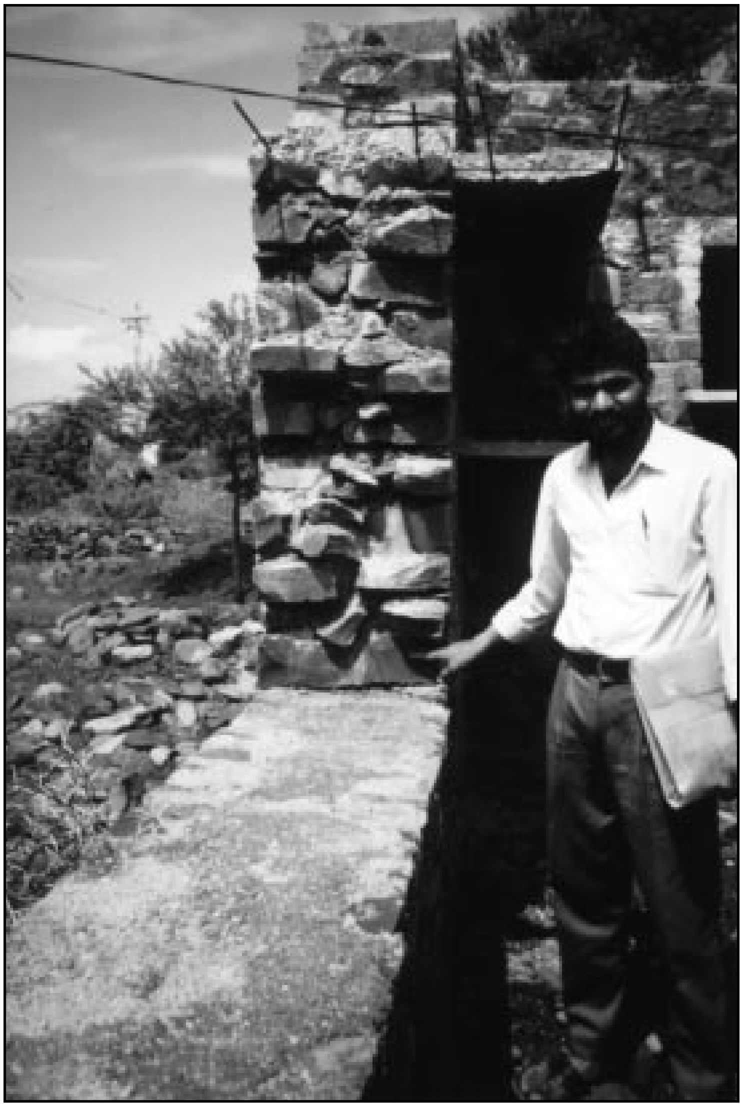

Figure 29 *A GOM Junior Engineer inspecting a newly built stone wall and pointing out a through-stone.*

1. Prepare construction cost estimates for each house, including any estimates of additional funds required by a beneficiary.
2. Process the building materials entitlement and certify their use.
3. Ensure that construction was carried out in conformance with the GOM Technical Guidelines (GOM, 1994b, 1994c).
4. Oversee progress in the construction and certify that a beneficiary was qualified for the next installment of financial assistance.

As the work began in each village, JEs organized a village gathering to explain the project and the technology packages offered to the beneficiaries. Later, JEs visited each beneficiary and discussed the program according to the predefined implementation procedures (GOM, 1994e, Nikolić-Brzev and Anicic, 1994).

Since the traditional masons did not have any background in earthquake-resistant construction technology and since some of them had very limited construction skills in general, JEs also had to hold training sessions for the local masons. The JEs demonstrated excellent social skills, partly because their backgrounds were similar to the beneficiaries.

There were 60 female JEs out of a total of 790, considered a positive feature of the program, given the feudal nature of the area. The female JEs had an advantage over the males in being able to communicate with the female beneficiaries (because of specific social norms in the rural areas of India). Hence, progress in the villages supervised by the female JEs was either equal to or better than the pace in the majority of villages supervised by male JEs. Due to a special incentive scheme developed by the PMU, JEs were financially motivated to accomplish more work than their target quota within a six-month contract period. It is noteworthy that six-month renewable contracts for JEs were used as a strategy to avoid their demands for permanent positions with the GOM (at the time of the earthquake, there was a high unemployment rate among civil engineers in Maharashtra). In spite of that, JEs went on three one-month strikes during the program implementation, thereby causing disruption and delays in the project. At the end of the project, the majority of PMU engineers were pleased that they had had an opportunity to provide a social service to their communities, especially since a considerable number of them were originally from the earthquake-affected area (Nikolić-Brzev, 1999, Krimgold and Nikolić-Brzev, 1998) (Figures 30 and 31).

Figure 30 *Junior Engineers inspecting a retrofitted stone house that has through-stones and a roof band.*

Training of Junior Engineers

Observation

- *Through a comprehensive training program developed as part of the RRSP component of the rebuilding project, engineers working in the field were given an opportunity to improve their knowledge of earthquake-resistant technology for this and future projects.*

Discussion

The key technicians in the RRSP implementation were JEs hired by the GOM to oversee the project field implementation and provide technical guidance to the affected village communities. Most of the JEs were recent graduates of the local engineering colleges with limited backgrounds in the area of earthquake engineering. Due to a rather high rate of unemployment among civil engineers, they were happy to have the opportunity to work. Training of this engineering field staff was mainly a responsibility of the national seismic consultants. The training curriculum was primarily based on the material covered in the *Guidelines for Repair, Strengthening and Reconstruction of Houses Damaged in the September 30, 1993 Earthquake in Maharashtra, India* (GOM, 1994b, 1994c). The guidelines were the first technical publication issued by the PMU in the project implementation phase. A major part of the guidelines concentrated on the technologies and technical specifications for the repair and strengthening of moderately damaged buildings that were within the scope of the RRSP. The document included typical damage patterns reported in the 1993 earthquake (illustrated with photographs), the associated seismic risk, and the methodology for repair and retrofitting. Since approximately 80 percent of the damaged houses were of stone masonry construction and the remaining portion were mainly unreinforced brick masonry, the guidelines concentrated on those two types. Along with the remediation measures, the construction technology packages that were to be used in the reconstruction were also included.

The guidelines were issued in English and several thousand copies were printed. They were distributed to PMU engineering personnel and to the Public Works Department engineering staff working in other rural areas of Maharashtra. An abridged

Figure 31 *A Junior Engineer (in black trousers) with a beneficiary standing in front of a completed house in the repair and strengthening program.*

version of this material was translated into the local Marathi language, printed in August 1994 and distributed to most beneficiaries and village leaders. In order to facilitate field implementation of the technologies recommended in the guidelines, the PMU engineering staff prepared a booklet that included unit cost estimates for the key strengthening and reconstruction features (GOM, 1994f).

In addition to the guidelines, the training material included information on basic concepts of earthquake engineering and the design of timber structures. The consultants used printed materials and video presentations in the training sessions. On several occasions consultants prepared technical notes on mistakes observed in the construction carried out in the RRSP. Apart from the seismic engineering consultants, quality assurance and technical audit consultants also conducted several technical workshops for the PMU field engineers. Curriculum for those workshops included topics related to the quality of cement-based construction technologies, as well as common mistakes reported in the field implementation.

In the initial phase of the program implementation, the consultants organized short-term (one to two days) training courses for the PMU engineering staff. The courses were conducted once a month in the districts of Latur and Osmanabad. Occasionally, training courses were also organized in other earthquake-affected districts, especially Solapur and Satara. A special series of training courses was organized in the 13 districts of Maharashtra that were not damaged in the 1993 earthquake, where implementation of the Pilot Strengthening Program (PSP) was occurring (see discussion on page 49).

Training of Artisans

Observation

- *This program was structured to ensure the improvement of existing construction by providing training to the technicians involved in program implementation, including the construction labor and engineering staffs. The training program in the MEERP was customized. This training initiative contributed to the success of the project, particularly the in-situ rebuilding component.*

Discussion

In order to ensure the successful transfer of knowledge regarding earthquake-resistant construction technology to the rural communities, the GOM developed training programs for artisans in the earthquake-affected area. Early in the project preparation phase (Nikolić-Brzev and Anicic, 1994), the GOM realized that the number of traditional artisans (especially masons) working in the area before the earthquake (approximately 2 percent of the population) was not adequate to meet the demands of the in-situ rehabilitation of 185,000 damaged houses. In addition, the program was to be managed by the local communities and the construction carried out in large part by local artisans (Figure 32). Hence, the GOM launched the following three training initiatives for masons:

- **Training of unskilled labor.** In June 1994 the Directorate of Vocational Education and Training launched training programs for unskilled labor in the earthquake-affected area; the programs were sponsored by MEERP. An existing network of 32 vocational training centers in the most affected districts of Latur, Osmanabad, Satara, and Solapur was used for this purpose.

  The training lasted two months and covered four trades: masonry, carpentry, electric works, and welding. The training curriculum covered

Figure 32 *A village artisan preparing to install a through-stone. Here, he is removing a stone with a crowbar.*

masonry skills for basic elements of stone and brick masonry construction, as well as elements of earthquake-resistant masonry construction. Training for each trade was two weeks. Trainers were the instructors of the Industrial Training Institutes, a chain of government centers in charge of providing education to unskilled laborers. Prior to the training, the trainers themselves were given training in earthquake-resistant construction.

The multitrade training course was organized because even though MEERP only required training for the masonry trade, interest in masonry training was very poor. Of 3,500 candidates interviewed, less than 10 percent showed interest in being trained in masonry skills. Another problem was that the GOM was not in a position to bind the trainees to take part in the RRSP because it was a community-managed effort, and it was up to the individual beneficiaries to contract for the construction labor. Nevertheless, from May 1994 to May 1995 over 6,800 individuals were trained under this program (Nikolic´-Brzev and Anicic, 1994).

- **Training of traditional masons in the Latur and Osmanabad districts.** The PMU made an effort to improve the skills of the traditional masons by imparting practical, hands-on training in earthquake-resistant construction technology for masonry buildings. The idea for this training emerged during the RRSP implementation. The community participation consultants proposed the program in May 1995 and it started in November 1995. A team of one deputy engineer and two JEs was assigned to this training full-time; the training was managed by a PMU executive engineer (Deshmukh, 1998). The training curriculum was developed by the community participation consultants and reviewed by the chief engineer, PMU, and the foreign seismic consultant.

  The two-day training covered basic principles of stone masonry construction, use of cement-based mortar, and the construction of key seismic features for masonry buildings.

  The first part of the training was conducted in the classroom; the second part was hands-on practical training conducted in the villages where construction under the RRSP was in progress, so the trainees got an opportunity to carry out actual construction during the training. During the classroom training, the trainees were shown patterns of damage to masonry construction reported in the 1993 earthquake; common drawbacks in traditional masonry construction found in the earthquake-affected area were highlighted during the training. Each trainee received a mason tool kit and a stipend equal to two days at market wages for a skilled mason.

  At the end of the training, each trainee received a certificate and took an oath vowing that he would follow the principles of earthquake-resistant construction that he had been taught. In the period from November 1995 to February 1997, approximately 4,000 traditional masons were trained in the Latur and Osmanabad districts under this program. Most of them participated in the RRSP implementation. There was an obvious improvement in the quality of masonry construction in the villages where trained masons were doing construction. The masons were very proud of the training and liked to show their certificates to visitors (Nikolic´-Brzev, 1999).

- **Hands-on mason training in the villages by the PMU engineering field staff.** One of the most important training initiatives was undoubtedly the training provided to traditional artisans by the PMU engineering staff working in the villages. Most important, JEs of the PMU played a very important role in educating the local artisans regarding the improved construction practices.

  The JEs taught local artisans how to construct a seismic band, an important seismic feature very rarely found in the area before the earthquake. Thanks to the JEs, local artisans learned to bend steel reinforcement bars and manufacture kneebraces for the strengthening work (Figure 33). In addition to the JEs, their peers in the PMU, deputy engineers, executive engineers, superintending engineers, and chief engineers also visited the villages and provided guidance to the traditional artisans on a regular basis. Figure 34 shows a PMU deputy engineer (with a

scarf) explaining the concept of a seismic band to a homeowner and the masons. “If four persons are braced together (like a house with a seismic band), they become more resilient to the effect of a push than each of the four persons individually.”

Figure 33 *A village artisan working on fabrication of steel hoops for seismic bands and knee-bracings (rolled steel angles at the right).*

Figure 34 *A PMU Deputy Engineer (left, wearing a scarf) explains the concept of seismic band to traditional artisans (masons).*

Technical Assistance

Observation

- *Since the implementing agency (GOM) did not have any previous experience in managing a post-earthquake rehabilitation project on such a scale, technical assistance played an important role in project implementation. An important innovation that the GOM intends to use in other government projects is the program management consultant.*

Discussion

Considering the complexity and scale of the project, at the time of negotiations with the GOM, the World Bank required that a number of external consultants and agencies be appointed in the MEERP preparation and implementation. The World Bank outlined a number of consulting assignments considered important for the design, supervision, and monitoring of project components (World Bank, 1994a):

1. Project management experts.
2. International earthquake engineering experts to design the strategy for the reconstruction in-situ and propose building technologies for reconstruction, repair, and strengthening of existing buildings.
3. Local earthquake engineering experts to provide the PMU technicians with training related to earthquake-resistant construction technology.
4. Consultants experienced in earthquake engineering to investigate and test, both in the laboratory and in the field, stone masonry strengthening solutions to be adopted in the affected areas.
5. Architectural, engineering, and planning consultants to prepare detailed architectural and engineering designs and contract documentation for the relocation villages.
6. Consultants for community participation.
7. Consultants for quality assurance and technical audit functions.
8. Consultants (national and foreign) for developing the State of Maharashtra disaster management plan.
9. Experts to train village artisans, builders, and NGOs.
10. Experts to prepare educational video films for confidence building and public awareness.

Except for two foreign seismic engineering consultants (sponsored by the World Bank credit), three disaster management consultants (sponsored by the DFID), and a project management advisor (sponsored by the ADB), all of the remaining consulting services were provided by Indian consulting firms, government agencies, or individuals. Technical assistance was also provided by consultants in the preparation of rehabilitation action plans for those whose lands were acquired and thus became landless, the documentation of the entire project experience, and the development of databases of beneficiaries and disaster management information.

Of particular importance was the technical assistance provided by the program management consultants, who set up a management information system, the monitoring of performance indicators, and a monthly and yearly reporting mechanism. In addition, valuable technical assistance was provided by the quality assurance team. This was the first time that the state used an external mechanism for project management and quality supervision on a regular basis. The GOM hopes to incorporate such assistance in future project management activities.

In total, approximately $21 million (10 percent of the total World Bank credit) was allocated for technical assistance (GOM, 1998b). This represents a very high percentage of the total project cost for a typical World Bank project and indicates the high level of importance placed on technical assistance in this project. In addition, a number of technical support and training activities in MEERP were sponsored by grants provided by the Department for International Development (approximately U.S. $3.8 million), the United Nations Development Program ($0.6 million), and the Asian Development Bank ($0.6 million).

Innovative Strategies to Demonstrate Earthquake-Resistant Construction

A major strength of this rebuilding project was that it emphasized the introduction of earthquake-resistant technology and mitigation or reduction of future losses through the strengthening of both damaged and undamaged structures. In order to introduce the new technology and demonstrate the efficacy of mitigation, a number of innovative demonstration strategies were adopted:

- Confidence-building project
- Model buildings
- Pilot demonstrations
- Base isolation demonstration project

Each of these strategies is discussed briefly below.

Confidence-Building Project

Observation

■ *Since the population of the affected area lost confidence in stone as a building material, the GOM supported an innovative project. Tests were conducted in the field on a rudimentary shake table to demonstrate to beneficiaries and technical professionals the reliability of strengthening technologies for stone masonry construction.*

Discussion

Due to the poor performance of stone masonry buildings in the 1993 earthquake, the population of the affected area lost confidence in stone as a building material. They considered it the primary culprit responsible for the loss of life and destruction of their houses. Similarly, in the initial phase of the post-earthquake rebuilding, they were generally suspicious of the effectiveness of seismic strengthening technologies proposed for the mitigation of seismic hazards attributed to stone masonry buildings. In spite of all their efforts, the GOM field staff found it difficult to convince the beneficiaries that there was nothing wrong with stone as a building material if it was used in a proper fashion. However, the fear was so pronounced that many people were sleeping in thatch huts outside their houses for almost a year after the earthquake. Some of the houses that were retrofitted in the initial phase of MEERP were either completely deserted (used as storage) or inhabited only in the daytime.

In order to build confidence among the local population and the GOM technicians concerned about the seismic safety of retrofitted stone masonry buildings, the GOM launched the Experimental Verification and Confidence Building Project, carried out under the leadership of Professor A.S. Arya of the Earthquake Engineering Department, University of Roorkee. The program was sponsored by the ADB and the World Bank. The most important tests conducted under the project were impact shake-table tests on stone masonry building models (ADB, 1995, Arya, 1996). Two one-room house models were constructed to a reduced scale (approximately half of the real size) using local building materials and following the construction practices typical for the Marathwada area. Defects in traditional construction practices, such as using round stone boulders in the walls, the absence of stone interlocking and through-stones, very thick walls, unbraced timber frames, and a thick mud overlay atop a roof were replicated in both of the models. For testing purposes, however, one model was retrofitted using the seismic strengthening methodology recommended in MEERP (GOM, 1994b, 1998a) and the other was tested in its unstrengthened condition (Figure 35).

The tests were carried out using a custom-made mechanical shaking table facility in the city of Omerga, in the Osmanabad district. Both models were tested simultaneously using tractors that created repeated shocks to the shaking table. The specimens were subjected to 12 shocks in total. The intensity of shocks varied from 0.06g to 1.6g in terms of acceleration level (g denotes the acceleration due to gravity). Major findings of the testing program are summarized below (ADB, 1995).

- The strengthened specimen sustained the effects of all 12 shocks without collapse. The last shock was extremely severe, characterized by peak base (table) acceleration of 1.6g. The model developed only minor cracks in the shock characterized by a peak base acceleration of 0.47g. The extent of cracking increased in proportion to the intensity of impact loading, although collapse did not occur during the tests.

Figure 35
Experimental verification of the retrofitting technology at Umarga, Osmanabad district. A retrofitted model is shown at the right and the unstrengthened model (damaged) is shown on the left.

- The unstrengthened specimen developed severe cracks. Walls delaminated during the shock—characterized by a base acceleration of 0.47*g*; masonry fell off the walls and wooden frame tilted in the subsequent shocks. The damage pattern observed in the tests resembled that observed in the 1993 earthquake.

It is very difficult to draw general conclusions on the performance of an entire building category based on a single experiment, especially where nonengineered masonry buildings are concerned. Masonry construction in general, but especially stone masonry, is characterized by broad variations in construction quality.

Consequently, the seismic performance of masonry is affected by the mechanical characteristics of this material (with significant implications as to its capacity to sustain lateral loads) as well as how it is used in construction. In addition, it is very difficult to scale the properties of stone masonry because of the unique composition and geometry of each stone wall. Finally, impact-type shake table tests represent only crude simulations of real earthquake motions; the frequency content and the duration of an earthquake are equally important factors in building response to the maximum intensity, expressed through the value of peak base acceleration. It is difficult, if not impossible, to account for frequency and duration using tractor-induced (impact) dynamic motions.

The confidence building program undoubtedly served its purpose—it demonstrated the effectiveness and the benefits of strengthening technologies proposed in MEERP. The tests were carried out publicly and were attended by more than 300 GOM engineers, district administrators, and beneficiaries of the MEERP. The tests were also recorded on video and were used by the community participation consultants working in the RRSP villages. According to interviews with the PMU field engineers (Krimgold and Nikolić-Brzev, 1998; Momin, 1998), the tests convinced the GOM technicians of the effectiveness of the proposed strengthening technologies. Based on the information provided by the PMU engineers, the beneficiaries who attended the tests were also convinced of the effectiveness of stone masonry strengthening technologies. However, very few beneficiaries (including those who attended the tests) reversed their original decisions to build a new room rather than strengthen the existing house.

Model Buildings

Observation

- *To demonstrate earthquake-resistant building construction technology in the earthquake-affected area, the GOM built model buildings throughout the region as part of the rebuilding program. They were built within the first year of the project implementation and featured earthquake-resistant technology and the changes in construction practices.*

Discussion

In the initial year of the post-earthquake housing rebuilding, over 500 model houses were constructed all over the affected area to demonstrate cost-effective building techniques, use of local materials, and earthquake-resistant construction features. The objective was not only to demonstrate the improvements in traditional building practices, but also to generate confidence among the residents about the use of stone and its by-products for housing construction. Out of 528 buildings, 400 were constructed in the two most affected districts, Latur and Osmanabad. The remaining model buildings were constructed in the districts of Solapur, Satara, and Sangli. The model houses had different types of plans and material options, e.g., stone masonry, stone-crete block masonry, hollow block masonry, and clay brick masonry (World Bank, 1994a).

Contractors under the supervision of PMU engineers constructed most of the model buildings. The program was completed in the initial year of the program implementation. During the MEERP implementation, model buildings were used as offices for the PMU engineering staff, or as part of civic amenities and other public buildings planned under MEERP. In fact, some of the highest ranking PMU field engineers made the model houses their official residences during the MEERP implementation since Indian government agencies provide official accommodations for their employees. In the Latur district, for example, the superintending engineer (the topmost GOM engineering position at a district level), and his subordinates (five executive engineers and over 20 deputy engineers) all resided in the stone masonry model houses (Figure 36). This gesture was an effective "confidence-building" tool for the many beneficiaries who feared stone construction. The model houses incorporated seismic features and were highlighted by bond beams that were painted in bright colors. Most model buildings were constructed at exposed locations. In front of some buildings there was a sign, written in the local Marathi language, which described the salient seismic features of that particular building.

Figure 36 *A model house used as a residence of a PMU Deputy Engineer in Latur.*

Pilot Demonstration Strategy

Observation

- *In order to get the Reconstruction, Repair and Strengthening Program (RRSP) under way, the GOM supported the construction of demonstration houses in some of the villages. This was intended to help motivate other beneficiaries to participate.*

Discussion

In the first year of the post-earthquake rebuilding project, the PMU field staff found it very hard to launch the RRSP. The relevant GOM policy decisions regarding the RRSP and the key features of the technology packages offered in the program were summarized in a brochure that was printed in a local language in August 1994 and circulated to the majority of beneficiaries. Senior GOM administrative officers at the district level toured the villages and conducted meetings to familiarize the beneficiaries with the RRSP.

In spite of all those efforts, the GOM field engineers found it difficult to get the rebuilding under way. The beneficiaries did not understand the time frame of the rehabilitation nor the need to mobilize the materials and labor required for the construction. In some villages, none of the beneficiaries initially agreed to sign the consent for the RRSP, which was an essential initial step in the RRSP implementation procedure.

In an effort to facilitate implementation of the RRSP, the PMU decided to launch the Pilot Demonstration Project in October 1994. The project was intended to assist the beneficiaries in the construction or strengthening of at least one house in each village. The PMU engineering staff, particularly the JEs, assisted the beneficiaries in their efforts to procure the materials and artisans for the construction. Some JEs even accompanied beneficiaries to the material markets and assisted them in the selection of building materials, e.g., cement, steel, sand, and bricks. Later, the JEs mobilized the construction labor (masons) and oriented them regarding earthquake-resistant stone and brick masonry construction. The project proved to be very successful, and according to the project chief engineer, it represented a major breakthrough in the RRSP implementation (Momin, 1998).

Pilot Strengthening Program (PSP)

Observations

- *The GOM used the rebuilding effort as an opportunity to provide information on improved construction practices, including the seismic strengthening of undamaged structures in parts of the state not affected by the 1993 earthquake, by launching the Pilot Strengthening Program (PSP) and providing financial and technical assistance to 5,000 owners of undamaged vulnerable houses in 13 districts of Maharashtra. Although the underlying idea behind this pilot program—to demonstrate seismic strengthening technology using traditional rural houses—was very innovative and positive, the program was difficult for the GOM to manage simultaneously with the post-earthquake rebuilding effort. The key lesson learned in this pilot program is that the implementing agency needs to plan the program very carefully and ensure maximum technical assistance and supervision in the implementation phase. In a first-time application of such a program, with a population that did not have any previous exposure to earthquake-resistant construction practices, a single poorly retrofitted house might set a wrong example to others.*
- *Strengthening of 46 undamaged public buildings (mainly schools) managed by the PMU was included in the program at a later stage. This program was more successful in terms of quality of technical solutions and construction, and it was easier to implement than the strengthening program for private buildings.*

Discussion

There are more than 2.5 million traditionally built stone masonry buildings in the high-risk seismic zones in Maharashtra. In view of the complete destruction of or damage to more than 230,000 houses in the 1993 earthquake, and the documented vulnerability of this type of construction in earthquakes elsewhere in the world, the GOM and the World Bank agreed to launch the PSP for 5,000 private buildings scattered throughout 13 districts in the state.

The GOM prepared the strategy document on the PSP (GOM, 1996a), which contained the policy for the program implementation, including the criteria for the selection of beneficiaries. According to the strategy document, the houses that were supposed to be selected for the PSP were similar to those affected by the 1993 earthquake (mainly unreinforced stone masonry dwellings with interior timber frames and heavy earthen overlays atop the roofs), with similar seismic strengthening features required. In order to ensure the demonstration effect, the GOM policy required that the houses included in the PSP be located in the central village of each district. Implementation of the program was partially sponsored by the GOM grant assistance, and partially self-supported by the homeowners.

According to the strategy document (GOM, 1996a), information dissemination was considered to be a critical aspect of the PSP. Information about program policy and the implementation methodology was to be made available to the target communities via various media, including newspapers, radio, TV, mobile video units, street plays, and government publications. The GOM prepared illustrative pamphlets and posters on seismic strengthening technologies in the local Marathi language and circulated them in the villages included in the PSP (Figure 37). In order to highlight the seismic features, special plaques describing the strengthening work that had been done were to be custom made for each house.

The initial plan was to implement this program through the PMU. However, due to the large area covered by the PSP (13 districts totaling approximately 146,000 sq. km [56,370 sq. mi.]) and the fact that this program was scheduled for implementation simultaneously with the rebuilding of 230,000 earthquake-damaged houses, the GOM believed that it would be very difficult to stretch the PMU workload any farther. (The PMU engineering cell had a staff of over 900.) Therefore, the GOM decided to implement this program through the local district governments—Zilla Parishads (ZPs) and their engineering units. However, it seems that the choice of implementing agency in this case was not ideal. ZP engineering units had several other simultaneous assignments related to rural development programs in the districts. As a result, ZP engineers assigned to this program were not able to provide adequate guidance and supervision to the PSP beneficiaries. By and large, the ZP engineers did not have any previous exposure to earthquake-resistant construction technology. They were offered training by the national seismic consultants to the PMU. The foreign seismic consultant to the PMU prepared technical guidelines for the PSP (GOM, 1995a) that were circulated to the ZP engineers that outlined the vulnerable types of traditional houses and the corresponding seismic strengthening provisions (Figure 38).

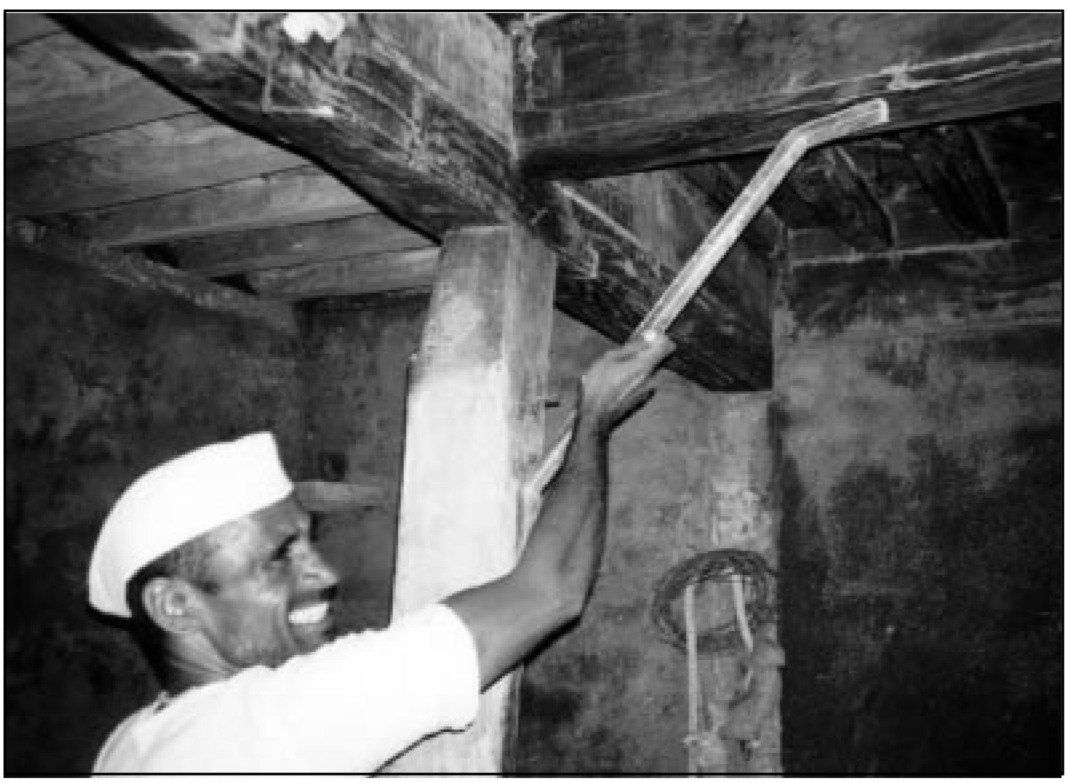

Figure 37
A beneficiary of the PSP showing a knee-brace used to retrofit a timber frame structure.

Figure 38 *The buildings selected for the PSP were located at the central locations in a village (building at the back, left). This village was a "market place" in the Ahmadnagar district, and a weekly market was taking place.*

The program was implemented in the period from May 1996 to June 1998. It may be concluded that the implementation of this program was not very successful, especially compared to the in-situ rebuilding program. With few exceptions, a majority of the PSP beneficiaries carried out the construction. However, in many cases new construction, either extending the existing house area or rebuilding on the existing plinth, was carried out instead of strengthening. Unfortunately, very few cases of houses strengthened in accordance with the GOM technical guidelines were observed during the authors' field visits. The main causes for inadequate quality of program implementation appear to be the inadequate technical assistance offered by the ZP engineers to the beneficiaries and artisans, and the failure of the ZP as the program implementing agency to launch an effective information dissemination campaign. Due to the lack of information provided in the early stages of the program, the beneficiaries had no faith in traditional construction methods and did not want to invest funds in such buildings.

It is noteworthy that in 1997 the GOM and the World Bank decided to expand the PSP to include the strengthening of undamaged public buildings in six districts of Maharashtra (the same districts included in the PSP of private buildings). This program was implemented by the PMU. In total, 46 public buildings (mainly school buildings) were strengthened. The buildings selected were of typical rural construction, mainly unreinforced brick or stone masonry buildings, 10 to 40 years old without any seismic features. Strengthening of these buildings was done using the same technology as for the PSP involving private buildings (Figure 39). The program was implemented in 10 months by a team consisting of an executive engineer, three deputy engineers and

Figure 39 *Students and teachers in front of a retrofitted elementary school building in the Latur district. The concrete bands are dark stripes near the top of the buildings.*

several JEs of the PMU (in Latur). The program was successful primarily for two reasons: 1.) the engineering team was enthusiastic and had four years of similar experience working in MEERP (i.e. in-situ rehabilitation of earthquake-damaged buildings), and 2.) the engineers were in control of the program implementation, since the construction carried out by the contractors was based on documents prepared by the engineers. As this program was launched in the fourth year of the MEERP implementation, most of the other project components were almost completed, enabling the PMU engineers to provide adequate field supervision in the construction phase.

Base Isolation Demonstration Project

Observation

- *To demonstrate effective strategies for earthquake mitigation that could be used in future construction of important facilities in Maharashtra, the GOM decided to construct two base-isolated demonstration buildings close to the epicenter of the 1993 earthquake. Public buildings of masonry construction typical for the rural area were selected. Although rubber bearings had to be imported for this application, the entire construction was carried out using local artisan skills and tools and was supervised by the PMU engineers. This was the first reported application of base isolation technology in India and one of the very few applications in rural areas worldwide.*

Discussion

Base isolation is an advanced technology for seismic protection of building structures and their contents. The concept is that base isolation provides flexibility in building structures by means of rubber bearings installed underneath the superstructure at the plinth level, thereby “isolating” the structure from damaging ground shaking effects. This technology is especially effective in providing seismic protection to rigid building structures (e.g., load-bearing masonry and concrete buildings). It is noteworthy that, by and large, fatalities in major earthquakes (especially in developing countries) have occurred due to the collapse of rigid low- and medium-rise low-strength masonry buildings.

Even though the concept of base isolation is simple, several decades of development and sporadic applications were required for it to gain wider acceptance in the worldwide engineering community. Effectiveness of this technology was confirmed in the 1994 Northridge and 1995 Kobe (Japan) earthquakes.

Most of the applications of base isolation technology to date have occurred in industrialized countries, like Japan, the U.S., and New Zealand. Among developing countries, China appears to be at the forefront in the number of design applications (following a United Nations Industrial Development Organization (UNIDO)-sponsored project completed in 1994); some design applications have also occurred in Armenia (sponsored by a World Bank project after the 1988 earthquake), Indonesia (a UNIDO-sponsored project), Chile, Mexico, and Russia. A major research effort in the area of base isolation has taken place in India in the last 20 years, especially at the Department of Earthquake Engineering, University of Roorkee, with the first Ph.D. thesis on the subject completed in 1978 (Qamaruddin, 1978). The research has mainly concentrated on seismic protection of masonry buildings using simple and low-cost base isolation systems based on the friction concept (Figure 40).

Advanced analytical studies related to the mechanics of base isolation and the seismic response of isolated systems were also carried out in several academic centers in India, especially at the Indian Institute of Technology, Delhi and Powai (Mumbai), and the University of Roorkee. Unfortunately, no practical construction application of this technology in India has been reported to date.

In November 1997, the World Bank and the GOM decided to use the post-earthquake rebuilding project as an opportunity to demonstrate the practical application of base isolation technology for the first time in

Figure 40 *A half portion of the Killari school building was constructed as a base-isolated structure (under construction in foreground), and the twin building (brick masonry building in the background) was constructed in a conventional manner.*

Figure 41 *Installation of isolation bearings carried out manually using local artisans under the supervision of PMU engineers.*

India. Two base isolation demonstration buildings were constructed at the new (relocated) Killari village, very close to the 1993 earthquake epicenter (approximately 10 km [6.2 mi.] away). Two public buildings were selected for this project—one a school building and the other a part of the shopping complex. The buildings selected were single-story with rectangular plans, made of brick masonry wall construction and concrete roof slab and constructed with the seismic features recommended by Indian seismic standards. Cement mortar was used in construction, and reinforced concrete ring beams were constructed at the lintel level of the buildings. Vertical reinforcement was not provided. In general, the same technical specifications and design features that were used in other public buildings constructed in the relocation villages under MEERP were used here.

The only additional construction features specific to the isolated structures were concrete ring beams installed below and above the isolation bearings (Figures 41 and 42). The isolation bearings were made of natural rubber reinforced with steel shims. A bolted connection was used to attach the bearings to the adjoining structures. Installation of the bearings was completed in February 1999. The installation was carried out manually, and the construction was done by the local construction work force (masons) with experience in masonry construction and without any previous exposure to complex engineering projects. The supervision during the construction was provided by the PMU engineers assisted by the foreign seismic consultant to the PMU.

Figure 42 *Construction of an upper concrete ring beam above the isolators for a school building in Killari village.*

Because the seismic provisions for base isolated structures are not included in the current seismic code in India, design of the structures followed the seismic provisions for base isolated buildings of the 1994 Uniform Building Code (UBC, 1994). Seismicity of the site was found to correspond to the UBC 1994 Seismic Zones 2B or 3. Since this was the first application of base isolation technology in India, the bearings were imported from the United States. Rubber bearings with mechanical characteristics suitable for base isolation applications are not presently available on the Indian market. However, since India is a producer of natural rubber, the required facilities might be developed in the future, once this technology gains wider acceptance by government agencies and the private sector.

To demonstrate to the general population the effectiveness of base isolation technology in the absence of seismic instrumentation, both demonstration buildings were split into two identical portions (in terms of design and dimensions). One was constructed in a conventional manner, while the other was equipped with isolation bearings. It is expected that the isolated buildings will remain undamaged even in a major earthquake that might affect the area in the future (the 1993 earthquake was an intraplate earthquake characterized by an unpredictable recurrence pattern), whereas the conventional half of the buildings are expected to experience structural and nonstructural damage. However, collapse is not expected to occur (compatible with the performance objectives of the current Indian seismic code).