Background

The Earthquake

A strong earthquake of magnitude 6.4 on the Richter scale struck the Marathwada region in the state of Maharashtra on September 30, 1993. The earthquake took a tremendous toll in human life—over 8,000 people were killed, another 16,000 were injured, and over one million local residents were rendered homeless. (For details about the earthquake and its immediate aftermath, see Browitt, 1993; GSI, 1996; Gupta, 1993; Jain et al., 1994; Kagami et al., 1994.)

Approximately 67 villages were completely destroyed, and extensive damage was reported in over 700 villages in the Latur district and in over 600 villages in the Osmanabad district (Figure 1). Eleven other districts in Maharashtra suffered heavy damage to private and public property. The total property loss was approximately $333 million (Rs. 11.8 billion). A series of earthquake aftershocks was recorded in October and November of 1993; the largest shocks occurred on October 9 (M 5.2), November 12 (M 5.0), and November 24 (M 4.4). The September 30, 1993 main shock was preceded by numerous foreshocks from August 1992 to September 1993. The strongest foreshock was recorded on October 18, 1992 (M 4.5), causing damage in Killari village. From 1993 to 1995 numerous earthquake tremors were also recorded in the

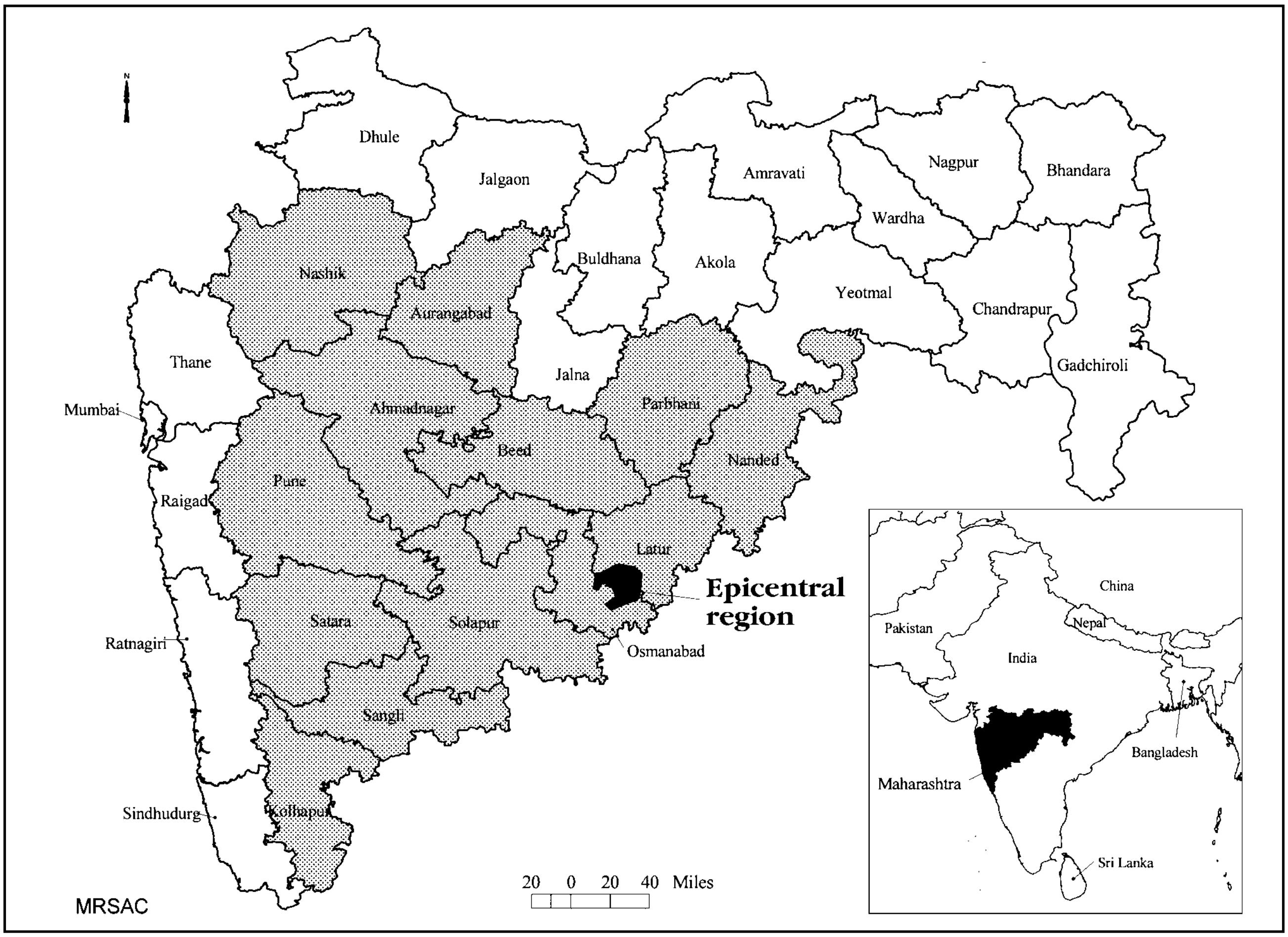

Figure 1 *Maharashtra state earthquake rehabilitation project area.*

Figure 2 *A typical stone masonry and mud mortar building in complete ruins after the earthquake.*

Satara district, including 34 tremors over magnitude 4 and two over magnitude 5 on the Richter scale; over 100,000 tremors have been recorded in that district since 1963. The Marathwada area also continues to experience tremors. The strongest tremor following the September 1993 earthquake was recorded in December 1997 (M 3.5).

The devastating effects of the earthquake were largely due to:

- Vulnerable housing stock.
- Shallow focus of the earthquake, which caused widespread damage.
- Time of the event—(early morning when many people were asleep in vulnerable structures).
- Density of the population in the area.

Based on historical records, Marathwada was considered an area of low seismicity; therefore no special seismic design provisions were required for residential buildings. Moreover, the earthquake affected primarily rural settlements, where building construction is entirely in the hands of local artisans with limited technical skills. No form of development control existed in rural areas of the state before the earthquake. The majority of earthquake-damaged dwellings were nonengineered, stone masonry structures (Figure 2).

The inferior quality of construction and the degradation in stone masonry construction practices were among the underlying reasons for the vulnerable housing stock and the resulting extensive damage (Momin, Nikolić-Brzev, and Bajoria, 1996). Results of the damage assessment revealed that most of the fatalities reported were due to the failure of stone masonry walls and/or the collapse of heavy earthen roofs supported by the stone walls. It is worth noting that the presence of timber frames (“khands”) saved many lives. After the earthquake, in many of the devastated villages it was common to find an intact pavilion of timber frames with roofs standing in a mass of rubble (Figure 3).

Some of the most critical construction faults observed in the earthquake-affected area were:

- Absence of through-stones for tying the exterior and interior wall wythes, resulting in delamination.
- Extremely large wall thickness (up to 2 m [6.5 ft.]).
- Excessive weight of a mud overlay atop the roof, varying from 500 to 800 mm (1 ft. 8 in. to 2 ft. 8 in.).
- Use of unshaped/improperly shaped/round stone boulders in thick walls with mud as a binder.

Figure 3 *A typical timber frame with mud overlay in Killari village. The frame withstood the earthquake, but the walls collapsed.*

- Absence of header stones at wall corners and junctions.
- Vertical separation joints at wall corners and junctions.

The state of Maharashtra is the third largest state in India in terms of land area (308,000 sq. km. (118,920 sq. mi.), has an estimated population of 78.7 million, and is the country's most heavily industrialized state (Figure 1). It is one of the most developed states in India, with a per capita income over 48 percent higher than the national average. Mumbai (formerly called Bombay) is Maharashtra's largest city, with a population of over 12 million people, and is India's financial center. Marathwada, the area of the state of Maharashtra affected by the earthquake, is an underdeveloped area compared to the other regions of Maharashtra. Since 1984 the GOM has been allocating development funds (about Rs. 3 billion or U.S. $91 million annually) as a part of its state development plan to reduce the disparities between the Marathwada region and the more developed parts of the state.

The state consists of 31 districts (similar to U.S. counties). Latur and Osmanabad were the two districts that suffered the most from the earthquake, with over 40 percent of the population affected in each. A large majority of the population in those two districts (over 82 percent in Latur and 64 percent in Osmanabad) live in villages where agriculture is the predominant occupation. Grapes grown for wine production and sugar mills are the primary industries in the area. About 50 percent of all agricultural workers in the two districts are landless, indicating the poor economic status of the rural population. The average size of a land holding owned by the cultivators is 5.4 hectares (13.3 acres); only 8 to 10 percent of the cultivated land was irrigated before the earthquake. The literacy rate is 58 percent in the Latur district and 44 percent in the Osmanabad district. The female literacy rate is considerably less than the average (35 percent).

Infrastructure services in the rural areas of Marathwada were underdeveloped prior to the earthquake (GOM, 1993). Larger villages had a rudimentary but intermittent water supply. A significant number of villages had a limited water supply: 36 percent of the villages in the Latur district and 53 percent of Osmanabad district had neither independent nor common water supplies. Hence, a considerable portion of the population had to rely on wells and rivers to provide for this basic need. Access to private or public toilets was also limited; only 35 percent of population in Latur district and 51 percent in Osmanabad district had access to toilets before the earthquake.

The area is characterized by an extremely hot climate (average temperatures range from 9 to 43°C or 48 to 110°F) and low precipitation (average annual precipitation of 790 mm [2 ft. 7 in.], with the lows of 500 mm [1 ft. 8 in.] and less). The rainy (monsoon) season is from June to October. Due to the hot climate and the moderate rainfall, the area is prone to droughts, especially from February to June.

Apart from the Marathwada area, some of western Maharashtra, including the districts of Satara (epicenter of the 1967 Koyna earthquake), Sangli, and Kohlapur, was also affected by the 1993 earthquake. The extent of housing damage in those districts was considerably less than the damage reported in the Latur and Osmanabad districts. Western Maharashtra has very high precipitation (annual rainfall up to 2,200 mm [7 ft. 4 in.]) and the majority of the rural settlements are located in hilly areas.

Rural Housing Stock and Traditional Architecture of the Area

The condition of housing in the area prior to the earthquake was poor. According to the Census of India, 48 percent of the rural dwellers in the Latur district and 65 percent in the Osmanabad district were residing in temporary or semi-permanent shelters before the earthquake. The annual growth rate of the housing stock in the two districts was small (about 3 percent), and as a result, only 3 to 4 percent of the total population was employed in the construction industry.

According to a 1993 study carried out in villages of the Osmanabad district (Umarga tahsil) and Latur district (Ausa tahsil) by the Building Materials and Technology Promotion Council (BMTPC) of the Indian Ministry of Urban Development (GOI, 1993a), approximately 90 percent of the buildings in the earthquake-affected area were constructed with uncoursed random rubble (UCR) stone masonry. Unburned mud (adobe) bricks were used for wall construction in only 4 percent of the houses. The predominant type of roof construction was a timber plank and joist roof with mud overlay (84 percent), whereas corrugated galvanized iron (CGI) sheets were used in only 6 percent of houses. However, according to information obtained from the Census of India (1981), CGI sheets were used for roof construction in over 39 percent of rural houses in the Latur and Osmanabad districts.

It is important to note that, according to the statistical data, clay brick masonry was not used at all for wall construction in rural Marathwada prior to the earthquake. However, in the urban areas of the Latur and Osmanabad districts burnt clay masonry was used for the wall construction in over 22 percent of the houses, and it was the second most popular wall material after stone masonry, which was used for construction in 39 percent of houses. Adobe masonry was the third most popular wall material, which was used in 21 percent of houses (Census of India, 1981). CGI sheets were the predominant roofing material in urban construction (63 percent of

Figure 4 *The typical densely built village, consisting of clusters of houses, provided very limited opportunity for horizontal extensions.*

houses); thatch/timber and mud were used in another 12 percent of houses, and concrete slab was used as a roof structure in 11 percent of urban houses. It should be noted that the term “urban” here denotes smaller townships (as per Indian standards), such as Latur city (population approx. 80,000).

The typical villages of the affected area were generally old and had an almost medieval urban form: the so-called gaothans (village residential sections) were compact and densely built (Figure 4), and they frequently featured monumental, arched gateways. The abutting stone masonry walls of houses delineated narrow, winding streets, rarely wider than 3 m (10 ft.), just enough to allow for the passage of bullock carts. House fronts had very few openings, since for security reasons the houses were inward-oriented. A high plinth was used on almost all the houses, giving them a monumental appearance (World Bank, 1993).

The majority of traditional dwellings in low rainfall areas (Marathwada and Solapur districts) are single-story buildings consisting of several small rooms with small door openings and no window openings. Stone, a durable and abundantly available material, has been used for wall construction in the Marathwada region for centuries. For the sake of thermal comfort during the hot summer months (when peak temperatures exceed 40° C [104° F]), extremely thick stone walls (ranging from 500 mm to 2 m [1 ft. 8 in. to 6 ft. 7 in.] thick) are common (Figure 5).

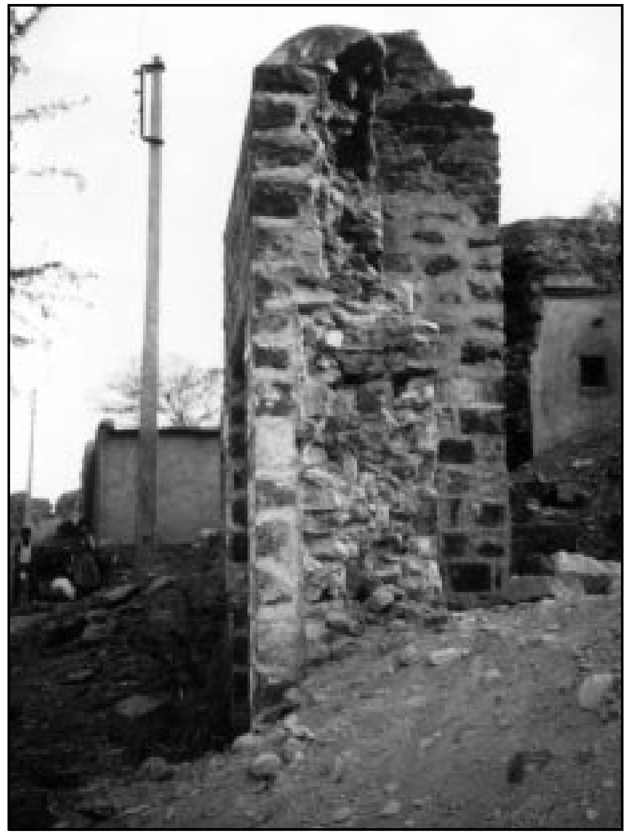

Figure 5 *A typical stone wall with two exterior wythes and interior filled with rubble and mud (wall thickness over one meter).*

Traditional rural houses in the high rainfall areas of Maharashtra (Satara, Sangli, Pune, Kohlapur districts) are characterized by sloped timber roofs covered with clay tiles (Figure 6). The core area of such a house typically consists of two rooms, enclosed by a verandah on all four sides.

Figure 6 *A typical house with a sloped timber roof covered in clay tile in the high rainfall area of Maharashtra.*

The Marathwada villages are usually located in river valleys where water availability is ensured and the agricultural land is fertile. The settlement structure is typically semicompact or compact, with distances of up to 5 km (3.1 mi.) between adjacent settlements. The average settlement size in the rural areas of the Latur and Osmanabad districts is about 250 houses (GOI, 1993a). However at the time of the earthquake, some villages were very large and densely populated. Killari, for example, the village most affected by the earthquake with a death toll of over 2,000, was a township of over 10,000 residents and 2,800 houses. The average land area of villages is reported to range from 2,000 to 5,000 hectares (5,000 to 12,350 acres). The dense populations in some of the villages contributed to the heavy earthquake impact and death toll (GOI, 1993a; World Bank, 1993).

An extensive discussion of traditional building practices in the earthquake affected area is contained in the *Manual for Earthquake-Resistant Construction and Seismic Strengthening of Non-Engineered Buildings in Rural Areas of Maharashtra*, published by the Project Management Unit, MEERP, in July 1998 (GOM, 1998a). The level of precipitation was a major factor affecting the type of construction in these rural areas. The type of construction was also affected by socioeconomic conditions and the availability of building materials.

The Context in Which Rebuilding Took Place

The GOM developed a massive rebuilding program in response to the enormous devastation of the earthquake. This section briefly highlights some of the important conditions that determined the context for rebuilding. These conditions influenced rebuilding choices, in some cases acting as constraints and in other cases providing opportunities.

Improving the Living Standard of Those Affected

Prior to the earthquake, the GOM had been working to improve the standard of living in this underdeveloped area of the state. Rather than only replacing what existed at the time of the earthquake (substandard housing with little or no infrastructure), the government announced a policy to improve the quality of life for the affected communities by providing better housing and developing an infrastructure in the earthquake-affected area. They viewed this as one of the critical factors of sustainable development (GOM, 1993). In particular, the resettlement objective as spelled out by the GOM (1994a) was to "ensure socially, culturally and economically self-sustaining communities in an environment that includes appropriate housing and civic amenities and addresses issues in relation to social infrastructure." The GOM designated those who were affected by the earthquake and who were participating in the rebuilding program as "beneficiaries" rather than "victims," which reflected this policy to improve the standard of living.

Scale and Magnitude of the Required Rebuilding

The size of the tragedy and the resulting scale of the required rebuilding dictated the use of certain strategies and limited the use of others. The enormous number of deaths as well as the large number of housing units (over 227,000) spread out over a large geographic area (40,000 sq. km [15,440 sq. mi.]) required either relocation or in-situ rehabilitation and contributed to difficulties in implementation.

Differences in how severely villages were affected also contributed to the development of different options for rebuilding. In the villages that bore the brunt of the devastation, the GOM felt that villagers were too traumatized to undertake rebuilding themselves. The GOM took responsibility to relocate these villages and to accomplish this relocation in a very limited time frame. Contractors were used to build the new houses in the relocation villages for consistency and better quality control, but also because it was easier for the government to manage the construction process with a small number of contractors than for thousands of individual homeowners to assume that task. Some nongovernmental organizations (NGOs), working in relocation villages, were able to successfully rebuild villages with certain designs or amenities that the GOM-managed projects were unable to consider, in part because the GOM was rebuilding many villages simultaneously.

In the less severely damaged villages the GOM did not take direct responsibility for rebuilding and/or strengthening. In the repair and strengthening program, which was the largest component of the rebuilding effort, an owner-driven program was the preferred strategy; people were in a far better position to reconstruct their houses themselves, physically and psychologically.

Since large-scale rebuilding added a dimension of complexity, strategies that were successful at a smaller scale (the village level, a compact region, a small number of housing units, etc.) needed to be evaluated carefully for their potential effectiveness on a larger scale.

A Short Time Frame for Rebuilding

The time frame for the implementation of the program was proposed by the lead lending agency, the World Bank. The rebuilding program was conceived as an emergency program that, according to the World Bank's procedures, needed to be implemented within a three-year period (it is typically not considered an emergency program if it takes longer). It should be noted that most of the important decisions were made at the beginning of the program because of the short implementation period of three years. Considerable time was consumed in the initial phase of the project, setting up all the processes required to implement such a large project. Progress was very slow in the initial two years of project implementation. Ultimately, the World Bank agreed to extend the program implementation period to four and a half years, ". . .understanding that projects with hazard mitigation and loss reduction components take longer than three years to develop and execute."

Significant Resources Available

A Memorandum of Understanding was signed with the World Bank within a week of the earthquake, so the GOM knew very early in the rebuilding phase that resources would be available. This allowed consideration of large-scale rebuilding strategies, such as the use of contractors to rebuild entire villages and the creation of a separate project management structure. In addition to resources available from the World Bank, other international donor agencies offered assistance, as did many NGOs and the GOI. All these outside resources helped shape the structure and focus of the rebuilding project in a different way than if the area had to be rebuilt entirely using its own resources.

It is also important to keep in mind that the GOM structured this program essentially as a grant program. Therefore, individual villagers did not have to take much initiative in rebuilding their homes, particularly in the relocation villages, since the GOM initiated and managed the program. The presence of such significant resources may have contributed to a greater sense of dependency on the part of the villagers whose homes were being relocated. In the villages rehabilitated in-situ (as part of the repair and strengthening program), the program was owner-driven, and the beneficiaries had to take a more active role in managing the available outside resources.

Widespread Support for Mitigation

In the design and implementation of this rebuilding project, all the various agencies and individuals involved placed significant emphasis on mitigation, or reducing the risks associated with future disasters. This interest affected the scope and direction of the overall project. The World Bank stressed the importance of mitigation both in the documents associated with the project and in its allocation of resources. The GOM emphasized mitigation in its objectives for the overall rebuilding project. Specifically, two of the three project objectives focused on mitigation: to enhance the earthquake resistance of buildings through improved standards of design and construction, and to reinforce the capability of the GOM to respond more efficiently to possible future disasters, including earthquakes. This intense emphasis on mitigation spurred the creation of a number of innovative educational and demonstration strategies to educate artisans and villagers about earthquake resistant technology. It also resulted in the creation of an elaborate disaster management initiative, described in more detail in later sections of this report. Villagers themselves demonstrated a commitment to mitigation by investing their own funds as well as materials and labor in improving their homes.

The World Bank's role in promoting mitigation in disaster recovery is noteworthy. Over time, the Bank has recognized the special conditions related to disaster recovery and has created a category of lending, the Emergency Recovery Loan (ERL), to provide expedited consideration for "emergency recovery projects." During the period 1988-1998, it is estimated that the World Bank provided approximately $9 billion in ERL assistance. (This can be compared to the Bank's new loan portfolio of approximately $20 billion per year.)

The MEERP coincided with the significant expansion of World Bank emergency recovery lending. Of particular importance for earthquake hazard mitigation is language in the loan guidelines that authorizes lending for purposes related to disaster mitigation. Requiring mitigation in recovery lending and general development lending introduces effective mitigation practices in disaster-affected areas. Certainly in Maharashtra, such support for mitigation was an important factor in setting the direction for the rebuilding project.

Problems with Data Available from the Damage Assessment Process

Problems arose in the initial design of the rehabilitation project because of confusion resulting from damage assessment. Three damage assessments were ultimately conducted, but continuing confusion resulted in many claims petitions later in the process. A preliminary damage assessment in the affected area was carried out immediately after the earthquake, in October 1993, by GOM revenue officers (nontechnical staff). Following the suggestions of the World Bank Pre-Appraisal Mission and the Advisory Committee Report (GOI, 1993a), two further damage assessments were conducted by a team of over 900 GOM technicians. Initially, damage categorization proposed by the International Association of Earthquake Engineering (IAEE) was considered an adequate basis for damage assessment. The IAEE damage classification (IAEE, 1986) includes five distinct categories corresponding to the following damage intensity levels:

- Slight nonstructural damage
- Slight structural damage
- Moderate structural damage
- Severe structural damage
- Collapse

Damage to the buildings classified under Categories 1 to 3 is generally repairable, whereas the buildings classified under Categories 4 and 5 need to be rebuilt. However, an analysis of the results of the damage survey of stone masonry buildings in mud mortar, the prevalent type of construction in the area, indicated that the technicians who had performed the damage survey had problems differentiating between buildings falling into Damage Categories 1, 2, and 3. In some cases, stone masonry buildings with only a few cracks in mud bedding joints were classified as Category 3. As the stone masonry walls were typically over 600 mm (2 ft.) thick, even a 15 mm-wide (5/8 in.) gaping crack in stone and mud construction could generally be repaired in order to restore the structure to the pre-earthquake condition without demolishing the wall.

The IAEE damage categorization offered general guidance regarding the structural damage patterns but very few quantitative indicators. This problem was recognized by the GOM and was an underlying reason for ultimately offering a uniform package of financial assistance to all beneficiaries in the villages rehabilitated in-situ whose houses were classified under the IAEE Damage Categories 1 through 3.

Although the second and third rounds of damage assessment were carried out by GOM technical staff (mainly the engineering staff of the Maharashtra Public Works and Irrigation Departments), most staff members did not have any previous exposure to earthquake engineering (World Bank, 1994a).

Before the second damage survey, the GOM organized a one-day training workshop in the districts most affected by the earthquake. During the second assessment, the teams of engineers did not have a uniform damage assessment form developed specifically for this exercise. Based on this evidence, World Bank officials believed that the second damage survey was not rigorous enough to serve as a basis for the post-earthquake rehabilitation (World Bank, 1994a). However, the GOM believed that two damage assessment exercises were adequate and that, instead of doing another reassessment, it was of paramount importance to launch the rehabilitation program as soon as possible.

The importance of a rigorous and objective damage assessment was underscored by the difficulties later in the program. After the MEERP was launched, a large number of court appeals were filed by citizens from the affected villages who claimed that their houses should have been included in the post-earthquake rehabilitation program. While few of these petitions were ultimately granted, the required court hearings for each took an inordinate amount of staff time for senior government officials in the PMU. In fact, the third round of damage assessment was made as a result of these petitions after the MEERP had been launched and the first installment of financial assistance had been given to a majority of the beneficiaries. The purpose of the third assessment, made by the PMU engineering field staff, was to investigate whether some houses that were not included in the program were in fact damaged in the earthquake. However, as this assessment was carried out almost two years after the earthquake, it was very difficult to determine whether damage to stone masonry construction in mud mortar was caused by the earthquake or poor maintenance.

Some of the problems outlined above could have been avoided by providing uniform damage assessment forms, training, and exercises; publicizing clearly the results of the damage assessments, both by marking damaged buildings in different colors and by announcing the results in public places at each village; and by modifying the IAEE damage classification for stone masonry buildings. For low-strength stone masonry buildings in mud mortar, it would have been more appropriate to simplify damage classification into two major categories—repairable damages and those beyond repair.