Some Observations on Engineering Aspects of the Jabalpur Earthquake of 22 May 1997

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Introduction

The Jabalpur earthquake of May 22, 1997, in the state of Madhya Pradesh in central India, is an important event for India from the point of view of seismic preparedness and expertise in repair of seismically damaged structures. This is the first time that an M6 earthquake has occurred this close to a major city in India, Jabalpur having a population of about 1.2 million people. This means that for the first time, it was possible to observe the seismic response of modern Indian building types which are prevalent all over the country and are unique to India.

Fortunately, the earthquake magnitude was only about 6.0. Another fortunate aspect was that it occurred in the early hours of the morning during the summer season when most people sleep outdoors, leading to a very low number of fatalities. Therefore, even though tragic, this earthquake provided an opportunity to learn about the earthquake response of modern Indian construction at a relatively low human cost.

Two separate groups carried out the post-earthquake investigation. A four-member group conducted an eight-day survey of the worst-affected areas a week after the quake. This team consisted of Sudhir K. Jain (EERI 1987), C.V.R. Murty (EERI 1995) and Jaswant N. Arlekar (all three of the Department of Civil Engineering at the Indian Institute of Technology Kanpur), and Chandrasekhar K. Jain (a consulting structural engineer at Pune). A second group consisting of Ravi Sinha (EERI 1996) and Alok Goyal (both of the Department of Civil Engineering at the Indian Institute of Technology Bombay) surveyed the meizoseismal area for six days a fortnight after the event. EERI sponsored the visits of these two groups as part of the *Learning From Earthquakes* project funded by the US National Science Foundation.

The purpose of this report is to give a summary of the observations made by the team in the meizoseismal area of the earthquake, covering damage to engineered and traditional structures, post-earthquake management and related socio-economic aspects.

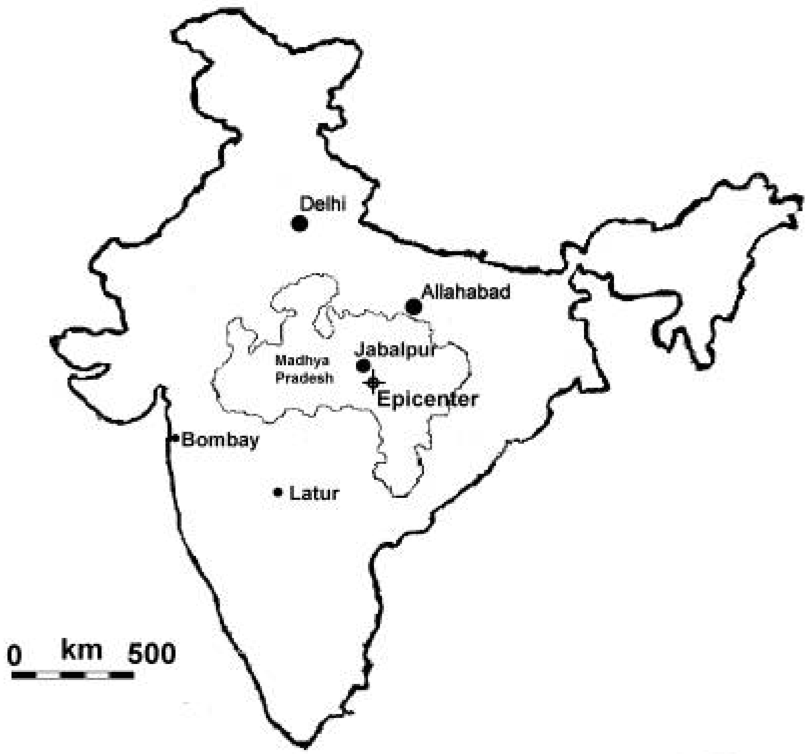

Figure 1 - Map of India showing the epicenter southeast of Jabalpur.

General Aspects of the Earthquake

The earthquake occurred on May 22, 1997 at 04:22 am (local time) centered about 8 km southeast of the city of Jabalpur (epicenter 23.18·N 80.02·E) in the state of Madhya Pradesh in central India *(Figure 1)*. USGS estimates the depth of focus at a default 33 km. It caused significant damage to structures in the districts of Jabalpur, Mandla, Sivni and Chhindwada in the state of Madhya Pradesh. The maximum damage was in the districts of Jabalpur and Mandla. About 8546 houses collapsed and about 52,690 houses were badly damaged. In all, 887 villages (or equivalent) were affected. More than 90% of houses collapsed or were badly damaged in at least two of these villages with a population of about 500. During this earthquake, about 38 persons died and about 350 were injured.

The affected area lies in peninsular India and is along the Precambrian Narmada rift zone. There are several faults in this region. The area is covered by a layer of basalt flows (about 4 m thick at Jabalpur) with basal contact of the Lameta rock at ground surface at many locations. The soil in the area is known as "black cotton soil"; it is black or dark gray and contains a high percentage of montmorillonite. This soil has very high compressibility and shrinkage, and very high swelling characteristics.

There was very little foreshock activity in the area, even though there have been many moderate size earthquakes up to about 35 years ago. On 2 May 1995, a magnitude 4.4 earthquake (epicenter 22·42'N, 78·18'E) was experienced; however, no damage was reported. The earthquake of 22 May 1997 was followed by relatively little aftershock activity; fortunately, none of the aftershocks was damaging.

The maximum intensity of shaking experienced during the earthquake was VIII on the MSK scale at the villages of Kosamghat and Kudaria. However, the intensity of shaking showed significant variation from location to location. For example, some areas of Jabalpur town had intensities of VII while in other areas it was as low as V.

No strong motion instruments were present in the affected area. The nearest strong motion records obtained came from Bhopal, a distance of about 275 km, which is inadequate for characterizing the ground motion experienced in the meizoseismal area. The Indian seismic code classifies this area in seismic zone III *(Figure 2),* implying that the area is likely to sustain a maximum shaking intensity of VII on the MSK scale. This is consistent with the shaking intensity experienced in the area; unlike the Latur earthquake of 1993, the earthquake in Jabalpur was not a surprise from a scientific view-point.

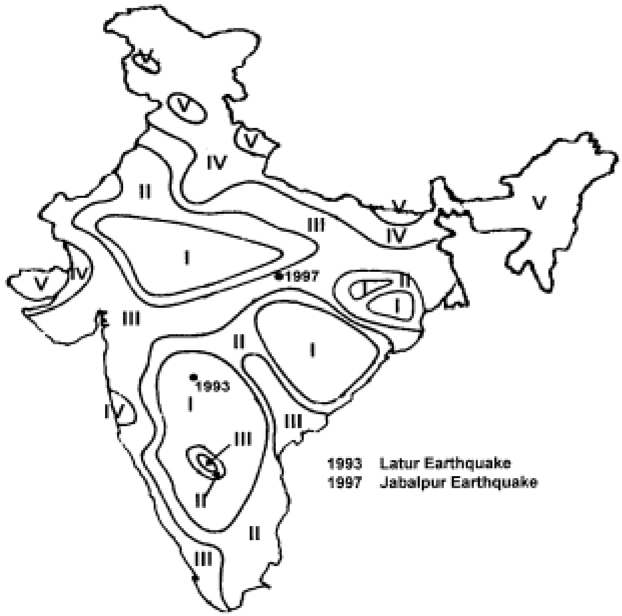

Figure 2 - Seismic zones used by the Indian seismic code.

The earthquake did not manifest itself in visible deformation features of the ground. No surface trace of rupture was noticed. There were no instances of liquefaction during the earthquake. Longitudinal cracks in the ground were seen in some locations in the affected area. White fumes resembling steam were reported to have escaped from the ground in the village Ghana, near Khamaria, situated about 12 km northeast of Jabalpur. A very large number of persons reported earthquake sound, with occasional "blastlike" noise. A few persons also reported "earthquake lights" during the shaking.

Behavior of Buildings

The affected area consists of both rural and urban environments. The predominant type of construction in the rural areas is earthen, while that in the urban areas is load-bearing brick masonry with mud or cement mortar. In Jabalpur, there are a good number of reinforced concrete (RC) moment resisting frame multi-story buildings with infill walls consisting of unreinforced brick masonry in cement mortar.

The rural dwellings are usually a single story with earthen walls (usually 10 to 12 feet high; about 30 inches wide at the base and about 12 inches at the top) supporting a pitched tile roof having wooden rafters and purlins. The rafters and purlins are circular posts up to 15 feet long made from locally available trees. In general, rafters and purlins are tied together with coir rope. In some dwellings, the pitched roof is extended outward to form an open veranda supported by wooden posts rising from the ground.

The thick earthen walls are not well connected to each other at the corners, resulting in the out-of-plane collapse of walls as individual segments. In some cases with low wall heights, the walls were found to be reasonably integral, but the roof had collapsed.

Some houses in rural as well as urban areas are built with burnt brick masonry in mud mortar. Unlike the traditional construction practice, the mud mortar is not reinforced with straw in this type of construction. Most structures of this type are one or two-story buildings whose walls are a single brick thick (230 mm). These structures sustained significant cracking *(Figure 3).*

Figure 3 - In rural and urban areas, houses are built using a single wythe of burnt brick with mud mortar. Buildings of this type suffered significant cracking.

In Jabalpur, there are a number of examples of load-bearing masonry houses built of brick with cement mortar and having a reinforced concrete roof slab, with good quality of construction. Many of these houses performed extremely well during the earthquake, even though they had no special earthquake-resistant features such as a "lintel band."

In the urban area, the maximum damage was experienced at the Jawaharlal Nehru Agricultural University campus in the Adhartal area of Jabalpur. The laboratory buildings and residential quarters were load-bearing brick masonry structures. The damage varied from traditional diagonal cracks in walls to partial collapse of buildings. The failures are attributed to the weak cement masonry walls and poor connection between the walls. The severe damage to the post-graduate students' hostel building is shown in *Figure 4.*

Figure 4 - Load-bearing brick masonry structures on the campus of Jawaharlal Nehru Agricultural University in Jabalpur were badly damaged.

The Ordnance Factory and the Gun Carriage Factory in the affected area have housing colonies of about 400-600 houses each. These houses are typically two-story load-bearing brick masonry structures with RC roof and floor slabs. Housing in these colonies suffered extensive damage. Similarly, the residential colony of the Department of Telecom in Jabalpur, consisting of up to three-story load-bearing masonry construction, had very significant damage. The damage in these and other such houses in the area consisted primarily of collapse of the staircase tower portions (called *mumty*) *(Figure 5)* and traditional crack patterns in walls. The mumty, consisting of brick masonry walls and concrete roof slab, acts as a vertical projection of about 2 m above the roof slab. The two walls in the mumty portion are usually connected to each other only through the slab above it. Vertical projections in houses (for example, chimneys) are known to be particularly prone to damage during earthquakes, and extensive damage to mumty is a clear indication of this behavior.

Figure 5 - Many staircase towers, called "mumty," which project about 2 m above the surrounding construction in masonry houses, collapsed.

Fortunately, no lives were lost in the numerous government-owned housing colonies, even though a large number of such houses were irreparably damaged. For instance, about 1500 houses owned by the Indian Railways were damaged by the earthquake; of these, about 300 are likely to be demolished and about 500 will require major repairs. None of these housing colonies had adopted earthquake resistant features such as the lintel band.

Jabalpur has a number of multi-story RC frame buildings with brick infill walls; most of these did not comply with Indian seismic codes for earthquake forces or for seismic detailing. Despite this, most such buildings performed well with only nominal damage, usually cracking of brick infill walls. The brick infills apparently played a role in the seismic response of such buildings. For buildings that are reasonably symmetric in geometry and do not have significant variation in stiffness and strength in plan and in elevation, brick infill, if intact, acts as a source of strength and stiffness, and leads to improvements in seismic performance. This is in line with the observations made after the Uttarkashi earthquake of 1991 where a number of four-story RC frame hotels with stone masonry infill sustained no damage, despite the fact that these buildings were not formally designed by engineers and certainly not designed for earthquakes.

A number of RC frame buildings with brick infill did sustain severe structural damage; however, this was only in buildings having abrupt changes in stiffness, e.g., open ground story, and torsion due to more infill panels on one side of the building than on the other. All metropolitan towns in India have a large inventory of multi-story housing colonies with these very features; the experience of the Jabalpur earthquake clearly illustrates the potential for disaster for such towns. These case histories are discussed in more detail in the following:

1. Himgiri Apartment in Jabalpur. This is a five-story RC frame building with brick infill located in the "Wright Town" area of Jabalpur. There are shops on two adjacent faces of the building at the ground story with brick masonry partition walls *(Figure 6).* The remaining corner of the building on the ground story is meant for parking and hence is "open," i.e., with no walls. The columns in the ground story in the parking area were badly damaged; shear failure of columns, opening of transverse ties, and buckling of longitudinal reinforcement bars occurred. There was only nominal damage in the upper stories consisting of cracks in the filler walls. This is a clear case where the columns were damaged as a result of the "soft first-story" effect. Moreover, loading on these columns may have increased through the torsion effect caused by higher lateral stiffness on the other side due to filler walls in the shops.

Figure 6 - The columns in the ground story parking area of the Himgiri Apartment Buildings, a five-story reinforced concrete building with brick infill, suffered shear failure.

2. Ajanta Apartments in Jabalpur. Located in the Snehnagar area of Jabalpur are two almost identical four-story RC frame (with brick masonry infills) apartment buildings located side-by-side. These buildings, named "Ajanta Apartments" and "Nalanda Apartments," were built by the same builder at the same time. In the Nalanda Apartments, there are two apartments on each story, including the ground story. Ajanta Apartments has two apartments each on the upper stories, but only one apartment on the ground story; space for the other apartment at ground story in this building is meant for parking, and hence has no filler walls. Only very nominal damage occurred in the Nalanda Apartments, but the ground-story columns of the Ajanta Apartments were very badly damaged. The damage consists of buckling of longitudinal bars, shear damage to columns, etc.

3. Youth Hostel Building in Jabalpur. This is a C-shaped RC frame building built by the Central Public Works Department but not then occupied. It is located in the Ranital area of Jabalpur. The building is located where there originally was a pond. It is supported on piles, pile caps, and stilt columns. Above the stilt columns are two stories with brick masonry infill. The damage is concentrated only in the stilt columns; severe cyclic shear cracking in many columns was observed *(Figure 7)*. The soft story at the stilt level is clearly the primary reason for such severe damage.

Figure 7 - Built on piles and stilt columns on the site of a previous pond, the new, still unoccupied Youth Hostel in Jabalpur suffered serious damage to its stilt columns.

4. Survey of India Colony. The residential colony of the Survey of India is located in the Vijaynagar area of Jabalpur. Here, there are a large number of three-story RC frame apartment blocks with brick masonry infills. In many such blocks, an apartment at the ground story has been replaced by a parking garage; i.e., there are fewer filler walls on the parking garage side in the ground story. In many such cases, it was observed that the filler walls of the garage side were cracked but those on the apartment side were not. This is clearly due to torsion effect.

Industrial Facilities and Special Structures

There are several major industries in the area, including three ordnance factories and two Telecom factories. Of the three ordnance factories, the Ammunition Factory had the most damage, the Gun-Carriage Factory less damage, and the Vehicle Factory quite nominal damage. The team visited the Ammunition Factory and the Gun-Carriage Factory. Amongst the Telecom factories, the team visited the pole-making factory located at Richhai near Jabalpur.

The damage to industrial facilities was rather low or moderate. At the Ammunition Factory, a number of single-story barrack-type sheds of brick masonry were built with pitched roofs of corrugated asbestos sheets. These buildings suffered diagonal cracks in the walls and damage to the gable end walls. In the Gun-Carriage Factory, a number of large industrial sheds (approximately 15m x 100m in plan) had damage to the gable ends. In one instance, concrete-encased steel columns supporting an overhead crane started undergoing significant vibrations during operation of the crane.

The Telecom Factory in Richhai consists of regular industrial-type sheds with north-light roofs supported on steel trusses. The trusses are supported on concrete columns which also support a traveling gantry girder at an intermediate level. These structures performed very well.

The 33kVA electric substation in the Telecom factory premises at Richhai is a single-story RC frame building with masonry brick infills. The story height is about 5 m; the partition walls inside this building were made only up to 2.4 m from the ground. Several interior columns above the infill sustained damage, perhaps due to "short column effect."

A 225m high TV tower (lower 175m RC shaft; upper 50m steel truss) located in the Katanga area of Jabalpur was built during 1989-1992 *(Figure 8).* Careful observation did not reveal any earthquake-induced distress. Minor cracks were seen at the junction of the concrete balcony and the concrete shaft, which may have been construction-related and therefore existed prior to the earthquake.

Figure 8 - No damage was observed to the 225 m high RC and steel TV tower in Katanga.

A 175m high radio transmission guyed mast is located in the Karmeta area of Jabalpur. After the earthquake, small amounts of kinking (about 0·02') in the steel frame were observed at the higher connections of the guys.

Elevated Water Tanks

There are a number of elevated water tanks in the area for storage and distribution of drinking water. The majority of the elevated water tank structures are supported on reinforced concrete frame stagings, which did not suffer any damage. However, a 500,000 gallon-capacity shaft-supported tank *(Figure 9),* located in the Gadha area of Jabalpur, sustained horizontal cracking at the ground level and diagonal cracking in two directions at about every 15· angle subtended at the center. The horizontal cracking was restricted to two circumferentially equal segments. The tank is supported on piles in black cotton soil.

Figure 9 - Horizontal and diagonal cracking occurred at the base of the 500,000 gallon shaft-supported water tank.

Bridges

There are a good number of highway and railway bridges in the area. All the bridges except one major railway bridge performed very well.

The two-lane road bridge across the Narmada River at Mandla, 95 km southeast of Jabalpur, consists of a two-span prestressed concrete superstructure supported on non-prismatic RC piers founded on base rock. The bridge has RC restrainers to prevent the super-structure from dislodging from the elastomeric bearings and from the pier top. This bridge performed very well. The damage sustained by the buildings in the neighbor-hood suggests an intensity of shaking of around VI. Another nine-span bridge across the river Gaur near Kosamghat sustained no damage.

The damaged bridge was a six-span steel through-bridge across the river Narmada between Tilwara and Gwarighat in the Nagpur Division of the South Eastern Railway. In the roller and rocker bearings of this bridge, one 32mm diameter pin connects the knuckle pin to the saddle cover plate. These pins were fractured at several of the supports, and the spans were displaced transversely by about 100 mm. Fortunately, none of the spans was dislodged from the piers. The fractured pins were replaced, and the bridge was restored to working condition in about two days.

The weight of the superstructure span is about 200 tons. The tensile strength of each of the 32 mm diameter mild-steel pins is about 20 tons. The transverse load of one span is resisted by four such pins. Hence, the total transverse load carrying capacity is around 80 tons. The pin failures indicate that, at the top of the piers, the peak acceleration may have exceeded 0.4g.

Irrigation Structures

There are quite a few irrigation structures in the area. The concrete gravity dam at Burgi did not show any damage. However, a number of earthen dams located in the districts of Jabalpur and Mandla were reported to have developed longitudinal cracks. The team visited two such dams: the 16.9-m-high earth dam at Mahgaon (30 km east from Jabalpur), and the 29-m-high Matiyari dam (95 km southeast of Jabalpur). Both suffered longitudinal cracks along the crest and the down-stream face *(Figure 10).* These dams are made of the locally available black cotton soil, which is known for its high shrinkage characteristics in dry conditions. The intensity of shaking at village Mahgaon was about VII on the MSK scale, while that at Matiyari dam was about VI.

Figure 10 - Longitudinal cracks appeared along the crest and downstream face of several earthen dams.

Other Lifelines

Lifeline facilities remained in service after the earthquake. With the exception of the bridge discussed earlier, railway bridges were undamaged. The station buildings and signaling cabins at a few stations on the broad gauge rail line were seriously damaged; however, this did not stop the movement of trains. (Speed restrictions were imposed.) None of the road bridges incurred damage.

A three-story telephone exchange building at Miloniganj in Jabalpur had damage in the filler walls; however, this did not affect the functioning of the exchange. The volume of telephone communication traffic increased after the quake by a factor of three. Additional staff was needed to constantly flush open the jammed gates in the telephone exchanges.

The power supply was interrupted immediately after the earthquake, but was restored after about 15 minutes.

Socio-Economic Aspects

The task of search and rescue was fortunately small. The number of fatalities in the earthquake was only 38, compared to about 9000 in the Latur earthquake of 1993. Due to summer heat, only raw food materials were supplied to the victims immediately after the earthquake, rather than cooked food. The Army was called out to help the day after the quake. Many people were provided cloth tents as temporary shelters.

The monsoons were expected to arrive in Jabalpur about three weeks after the earthquake. The impending rainy season was an immediate concern. Many of the cracked houses might collapse during the rains. Hence, there was a lot of urgency regarding repair of damaged houses. The state government provided cash assistance of Rs.3000/- per housing unit to enable the people to repair their houses. Distribution of this money led to numerous difficulties, as there was a lot of pressure on the concerned officials to give this money to undeserving persons as well as the afflicted. There were numerous road blockades in Jabalpur to put pressure on the administration. Perhaps a better strategy would have been to provide the assistance in-kind rather than cash.

In rural areas persons whose houses had collapsed were given 18 wooden posts and 50 wooden purlins for reconstruction, in addition to cash of Rs.3000/-. The army personnel called in for relief operations were helping the villagers reconstruct wood frame houses with pitched thatch roof and mud walls when the reconnaissance teams were in the area.

Most of the injured suffered only minor injuries and were treated as outpatients. Within two days, the number of new cases reporting earthquake-related injuries fell, and hospitals returned their priority to the inpatients. However, the in-patients refused to go into the hospital building, because the walls had sustained cracks. The patients moved their hospital beds outdoors (under trees) due to fear of another earthquake, and continued to accept treatment outdoors, including administration of intravenous fluids.

Some Important Issues and Recommendations

The earthquake caused moderate shaking of intensity up to VII-VIII on the MSK scale in an area that lies in seismic zone III of the country. This shaking intensity is in conformity with the expected level of shaking in such a seismic zone. For the first time in recent years, we in India had a damaging earthquake near a large town. Hence, the earthquake revealed some important and interesting issues. Some of these issues are:

a) The performance of RC frame buildings with brick infills having no abrupt changes in stiffness or mass has been very satisfactory. In this earthquake, there has been a positive contribution from unreinforced masonry to the behavior of these buildings. Current design practices treat the masonry infill as non-structural and ignore its contributions to strength and stiffness.

b) RC frame buildings with an open ground story for parking have shown very poor performance. This has serious implications for a very large stock of such buildings in modern India.

c) None of the overhead water tanks supported on RC moment resisting frames was damaged, even though most may not have been designed for seismic forces. This is in line with what was seen in the Latur (1993) earthquake. Such structures are quite flexible and have long fundamental periods. It indicates that the ground motion in the peninsular shield may be rich in high frequency waves and poor in low frequencies.

d) The Indian Standard code has specific provisions regarding seismic design, detailing and construction in seismic zone III. Despite this, hardly any concern existed in the area for seismic safety of construction, and the seismic codes were simply not being followed in most of the construction in that area. This includes construction of many multi-story RC frame buildings. It is expected that the situation is similar in most other towns in the country. The questions that arise are: Is this situation acceptable to society? If not, how can it be tackled?

e) A huge inventory of government-owned housing was severely damaged in the earthquake. The concerned engineers had no prior experience in handling post-earthquake safety evaluation. For most of them, it became very difficult to address issues such as: (i) distinguishing houses which people can continue to occupy from those which residents should evacuate immediately; (ii) deciding between those houses that can be economically repaired and those that need to be demolished; and (iii) appropriate repairs and strengthening methodologies. The visiting team from IIT Kanpur held two separate training sessions (one for state government engineers and one for railway engineers, the former in collaboration with Mr. S. S. Momin, Chief Engineer of the 1993 Latur Earthquake Rehabilitation Project) for this purpose; however, this was hardly sufficient. A massive training program is needed to train local engineers (as well as non-engineers such as administrators, politicians, opinion makers, and interested residents) on the issues of post-earthquake safety evaluation of buildings.

f) There is a clear need to develop resource material on post-earthquake safety evaluation of buildings in the form of manuals, brochures, video cassettes, and posters in English as well as in local languages that can be effectively used after future earthquakes.

g) Considerable expertise on post-earthquake safety evaluation of buildings now exists in the neighboring state of Maharashtra after the massive rehabilitation project following the 1993 Latur earthquake. However, that expertise apparently has not been effectively utilized in handling this earthquake. There is a clear need to develop mechanisms whereby the state governments can collaborate more effectively after an earthquake emergency.

h) In India, the subject of earthquake engineering is viewed as a super-specialty to be handled by "professors" and not by structural engineers. A time has come when we need to have a pool of structural engineers who are specialized in earthquake engineering. We need to establish an "earthquake engineering industry" so that expertise of various kinds is available on commercial terms, in case of an earthquake emergency.

i) Post-earthquake repairs need to include strengthening against future earthquakes, and this takes time. These time issues are not well understood, leading to unusually high expectations among many administrators regarding the time frame needed for reconstruction.

j) For government engineering departments, it is very difficult to handle a huge emergency project of seismic repair and strengthening using only the existing work force in the concerned town. The only example of dealing with this issue witnessed by the team was a department that had arranged to bring some junior engineers from neighboring districts on temporary duty for assisting with this work.

k) Many engineers and administrators were cautious in making decisions regarding the safety of structures; this caused additional hardship to the affected people.

l) An interesting factor emerging from this earthquake was that some organizations decided to demolish many houses that could have been economically repaired. Reasons included: (i) the existing accommodation was too congested and very unpopular with the employees; hence, the earthquake provided a good opportunity to replace these houses with better housing; and (ii) the space to be vacated by such houses could be used more effectively for other purposes. Therefore, the post-earthquake handling of large building stocks involved management as well as technical issues. The available literature in India on post-earthquake handling of buildings is primarily concerned with technical aspects.

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