POST-EARTHQUAKE HANDLING OF BUILDINGS AND RECONSTRUCTION ISSUES EMERGING FROM THE 2001 BHUJ EARTHQUAKE

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ABSTRACT

The January 2001 Bhuj earthquake in Gujarat state in India caused the largest earthquake disaster in the country in last 50 years. About 20,000 persons lost life and about 300,000 houses collapsed while another 700,000 houses damaged. Numerous multistorey buildings collapsed. Handling of the building stock immediately after the earthquake posed a serious challenge to an administration that was not prepared for earthquake emergencies. Reconstruction of this scale poses serious challenges. The paper discusses these issues alongwith the professional background of the building industry in the country in general and in Gujarat in particular. Also discussed are the long term actions towards better earthquake safety that have emerged as a result of this great human tragedy.

Introduction

India and its neighboring region has experienced many large earthquakes, *e.g.*, 1819 Kachchh earthquake (~M8.3; ~1,500 deaths), 1897 Assam earthquake (M8.7; ~1,500 deaths), 1905 Kangra earthquake (M8.6; ~19,000 deaths), 1934 Bihar-Nepal earthquake (M8.4; ~11,000 deaths), 1935 Quetta earthquake (M7.6; ~30,000 deaths), and 1950 Assam-Tibet earthquake (M8.7; ~4,000 deaths). However, in recent years, the country experienced only moderate earthquakes (e.g., 1988 Bihar-Nepal: M6.6, ~1,004 deaths; 1991 Uttarkashi: M6.6, ~768 deaths; 1993 Latur: M6.4, ~8,000 deaths; 1997 Jabalpur: M6.0, ~38 deaths; and 1999 Chamoli: M6.5, ~100 deaths). With the exception of 1997 Jabalpur earthquake, these earthquakes were centred around rural areas or semi urban areas. While these events caused concerns in the country about earthquake safety, such concerns were short lived.

The 26 January 2001, M7.7 Bhuj earthquake in Kachchh district (Gujarat state) on the west coast of India is somewhat of a wake up call. With about 20,000 persons dead, about 167,000 injured, it became the largest natural disaster since Indian independence. The earthquake destroyed about 300,000 houses and damaged another 700,000 houses. Moreover, numerous modern multistorey RC frame buildings in urban areas collapsed killing large number of people. With the television and newspapers showing graphic pictures of the death and destruction for several weeks, this earthquake for the first time has shaken the confidence of the general public on the adequacy of modern Indian constructions to withstand strong earthquake shaking.

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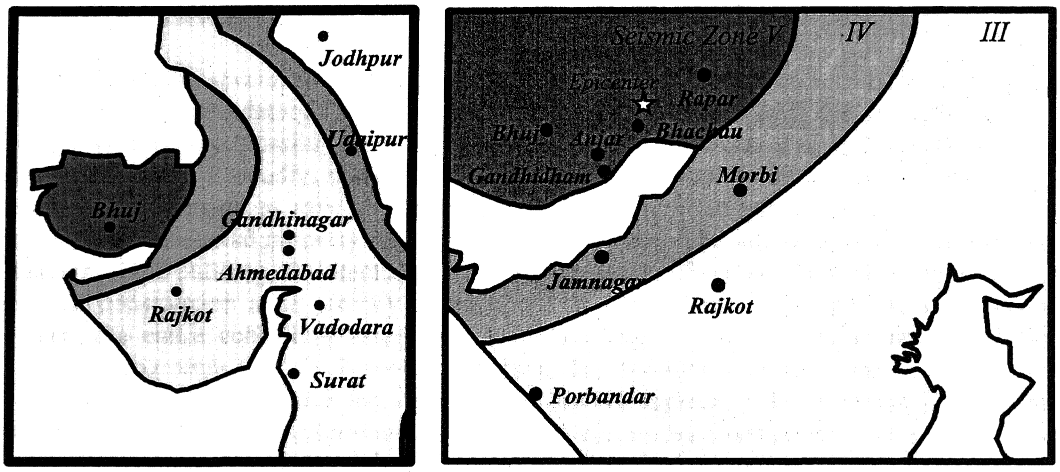
The area affected by this earthquake has experienced strong shaking in the past and has been placed in the highest seismic zone (Figure 1). The earthquake of 1819 in this area caused a fault scarp of about 3m height and about 100km length and it provided the *earliest well-documented instance of faulting during an earthquake* (Richter, 1958). More recently, on July 21, 1956, a M7.0 earthquake caused severe damage to Anjar town in the Kachchh district with about 115 lives lost. Thus, the earthquake hazard of the area is well recognized not just through the Indian seismic zone map, but also because many people of Anjar have experienced a damaging earthquake in their own life-time. Despite this, the entire region was totally unprepared for the earthquake of January 26, 2001 as illustrated by numerous collapsed buildings in the entire region, including about 130 buildings that collapsed at Ahmedabad (200 km from epicenter) and one building collapse at Surat (340km from epicenter). This paper discusses the professional setting of the building industry of the area and the post earthquake handling of buildings with particular emphasis on Ahmedabad. Also, some of the repercussions of this earthquake in the entire country are discussed.



(a) **(b)**

Figure 1: (a) Seismic zone map of Gujarat; and (b) Close-up of important towns in Kachchh district.

Professional Setting of the Building Industry

After the Anjar earthquake (1956) in the region, articles were published in the *Indian Concrete Journal* on how to build earthquake resistant buildings (Annon., 1956). The first formal Indian code for aseismic constructions was published in 1962 (Jain and Nigam, 2000). Yet, most constructions in India do not tend to follow the seismic code provisions and the affected area is no exception. The code compliance is better in constructions by the government agencies as compared to that in the private sector. The local city authorities issue building permits primarily based on whether these satisfy the requirements on floor area constructions, building height, offsets from the road, etc, and do not require submission of structural drawings or calculations. Moreover, most local authorities do not have structural engineering manpower to look at structural safety.

In India, the situation of engineers is different from that of other professionals. The doctors, lawyers, chartered accountants, and the architects have formal structure of licensing. They are regulated and can be penalized for deficient professional services by the respective professional councils. As against this, there is no licensing system for the structural engineers and any person with a degree in Civil Engineering can generally practice as one. In a few cities, the structural engineering licenses are issued by local authorities based on qualifications and number of years of experience. The engineers have long demanded a formal regulation of their profession through an Engineers' Bill by the Indian Parliament. Generally, there is no system of professional liability insurance in the engineering profession. In other words, the entire profession of structural engineering is fairly disorganized.

At the time of the Bhuj earthquake, most towns in India did not explicitly require compliance with seismic codes. Only a structural stability certificate was required, this too was often given by the architect rather than by a structural engineer. The bye-laws of Ahmedabad Municipal Corporation (AMC) were more advanced vis-à-vis seismic safety; these required a report by the structural engineer wherein among other things the engineer was to specify the live loads, wind loads, and the earthquake loads considered in design of the building. However, in many cases, the section on wind and earthquake loads was not filled and it did not cause concern to the local authorities while issuing the building permit.

There are several reasons for non-compliance of the seismic code. Firstly, the seismic codes were not mandatory. Further, both public and the professionals did not view seismic design as important possibly because there were not many earthquakes in the recent past in the urban India. Secondly, there is considerable competition in the building industry and every effort is made to save the costs. This is particularly so when a *developer* builds a multistorey residential property for sale of individual flats. The sale price is governed by the location of the building, architectural configuration, and the finishes. Thus, any savings in the cost of construction adds directly to the profit of the property developer. Also, in many places, the entire consulting assignment for a building is given to the architects and the structural engineers act as sub-consultants: here, the structural engineers may have to work under pressure from the architects who do not always appreciate the structural issues. And finally, even when the structural engineer wants to ensure codal compliance, he may not have the required expertise. With no formal education in earthquake resistant constructions in the curricula of most universities, no licensing, and no enforcement, it is hardly surprising that very few engineers in the country have acquired competence in earthquake resistant design and construction.

In Ahmedabad, as in many other towns in India, there is intense competition amongst the structural engineers and their consulting fees for design of a multistorey building tends to be rather low. This at times could be a paltry Rs 1.0 per square foot of built up area. This cannot be conducive to quality in structural design and drawings. Moreover, there is a pressure on the engineer to minimize the quantity of materials consumed in the building; for instance, it is not unusual to hear one say that the reinforcement and cement consumption per square yard of the built up area should remain within a certain range, which is very low. Moreover, the architects tend to make additional demands on member sizes to be within certain limits. Indian bricks usually are of size 9″×4.5″×3″, and the architects often insist that the column and beam widths be kept 9″ so that the brick partition walls could be flush with the beams and columns. In recent years, there have also been instances of column widths being restricted to just 4.5″. With the above scenario, it is not unusual to see many structural engineers making very simplistic assumptions even in the gravity design. For instance, in many cases, RC frame building is designed assuming that (a) all beams are simply supported on columns, and (b) columns carry only axial loads.

The cost cutting in building construction also affects the geotechnical investigations. For instance, for most of the four or five storey buildings, no geotechnical investigations are performed, and even for a ten-storey building, only one bore hole upto a depth of say 10m may be performed. There are also serious deficiencies in the quality control during constructions. Often, the materials do not meet the specifications and there is hardly any competent supervision at site. Thus, many of the buildings that collapsed may have been deficient not just from seismic considerations, but also for gravity loads. Moreover, even the buildings that did not collapse may be deficient both for seismic and gravity loads.

Immediate Aftermath of the Earthquake

The earthquake caused maximum shaking intensity of X on the MSK scale while Ahmedabad (about 200km from the epicenter) experienced shaking intensity VII. Even though there were far more collapses and deaths in the Kachchh district, the initial focus after the earthquake was on Ahmedabad: it being a major business center and adjacent to the state capital.

In Ahmedabad, with numerous building collapses and loss of life, initial few days were spent on rescue and relief on one hand. On the other hand, there was total confusion regarding buildings that were still standing. The residents were scared and did not want to stay inside the buildings. The city as such had hardly any expertise on earthquake issues locally. On the morning of 31st January, five days after the earthquake, the second author along with another structural engineer from Hyderabad reached Ahmedabad and started providing informal advice to local administrators. They also provided the published guidelines, booklets and codes to the authorities.

Soon after the earthquake, anger turned to the builders and structural engineers, which lead to filing of criminal cases and arrest of many of them. Builders and structural engineers involved in buildings that caused deaths were charged with serious non-bailable criminal charges, and remained in jail without bail for about six months. Many builders and engineers connected with the collapsed buildings went underground for fear of arrests. Moreover, structural drawings of the buildings, much needed at that stage, became unavailable; the residents having bought individual flats did not have the structural drawings, the local authorities did not require submission of the same, and the engineers and builders were not willing to part with these for fear of persecution.

An unfortunate situation arose when an astrologer with some credibility predicted an earthquake on February 3, and this was well publicized by the print and television media. This caused panic and most people closed shops, offices and vacated their houses on that day. The astrologer was quietly arrested for rumour mongering.

Considering the panic and fear of falling buildings, the local engineers and builders started strengthening the buildings in their own way. This is a peculiar aspect of the Civil Engineering profession. The local engineers and builders could not have simply waited for the outside experts to come and advise them on methods of seismic retrofitting. They had to do something to save the buildings from collapse during the aftershocks and to restore the confidence of residents. Since the region had no serious compliance with the seismic codes, the local engineering community was oriented towards gravity loads. In most cases, strengthening meant jacketing of the ground storey columns in open ground storey buildings, and this too left much to be desired in many cases. There were instances such as: (a) columns

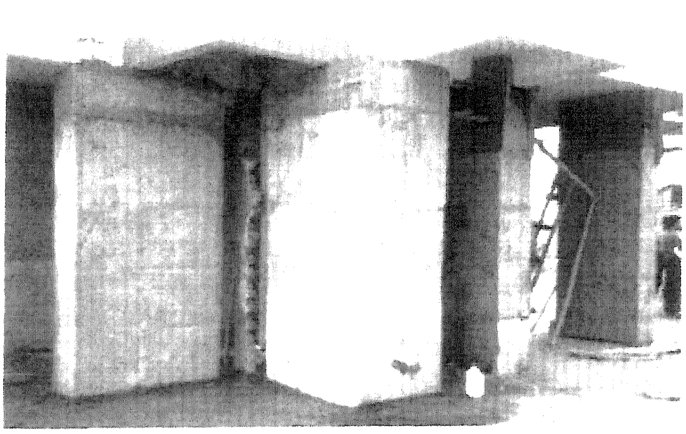


Figure 2: Unusually large sizes of jacketed ground storey columns.

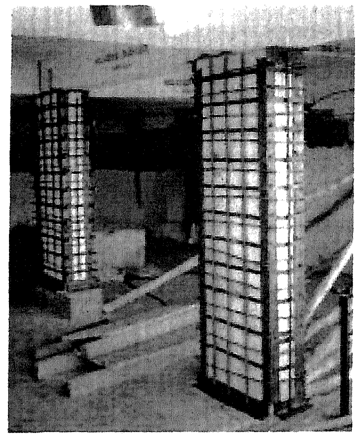


Figure 3: Columns being jacketed without removing the plaster.

were jacketed to an unusually large size (Figure 2), (b) the strengthening started from the finished ground floor and not from the foundation, (c) the new RC jacketing was not properly integrated with the floor beams or the upper storey columns, and (d) the jacketing was done without preparing the surface of the existing columns. Figure 3 shows a column being jacketed without removing plaster around it. The association of architects and engineers in Ahmedabad immediately issued a guide on repair and strengthening. Again, this was concerned more about giving vertical support to the building, and not about lateral strengthening against future earthquakes.

About a week after the earthquakes, it was a confusing time for the residents. People wanted some solution for the safety of their building, and lacked confidence in local builders and engineers. Numerous visitors and *experts* were visiting the buildings and taking pictures. Some visitors gave conflicting oral advice, while many others resisted from giving any advice; this sometimes made residents feel frustrated with the visitors.

Damage Assessments

Immediately after the earthquake, the local officials started a quick survey of a large number of buildings but without uniform criteria for damage classification. It is only on reaching Ahmedabad on February 3, the first author emphasized to the local authorities the need for objective damage assessment criteria. The following day, many other experts from the country reached Ahmedabad, and the criteria were evolved for building damage classification. In the Latur earthquake of 1993, most of the damaged buildings consisted of stone masonry and the damage classification criteria as per MSK intensity scale was adopted (G0 to G5, with G0 means no damage and G5 means collapse). The same was modified for Ahmedabad to also cover the RC frame buildings. Together with these, damage assessment proforma were also evolved.

It was also realized by the local authorities in Ahmedabad that the damage classification should be done by a fairly independent agency. Therefore, Centre of Environmental Planning and Technology (CEPT) at Ahmedabad was entrusted the job to carry out damage assessment survey for multistorey residential buildings in Ahmedabad. CEPT is an institute for education in architecture, town-planning and building science. Even though they had no prior experience in earthquake issues, and had very low manpower considering the job requirements, in the spirit of public service, CEPT leadership agreed to take up the assignment on the basis of direct cost reimbursements. The cooperative societies of the multistorey residential buildings were to apply within a certain cut-off date to seek a survey of their building; there were no charges levied on the owners for the survey. CEPT conducted damage survey of about 7,200 buildings. An appeal was issued by CEPT to structural engineers across the country to come forward and volunteer their services for damage assessment. The engineering community responded well and about 160 senior engineers from different parts of the country (e.g., Delhi, Calcutta, Indore, Bombay, Pune, Bangalore, Chennai, Kochi, Vishakhapatnam, in addition to different towns of Gujarat) participated in the damage surveys. Typically, out-station engineers spent about a week for this work, and in the process had a lifetime experience of learning from real earthquake damages. These engineers were reimbursed their travel expenses, provided local hospitality, and a notional honorarium. It is a question that needs to be debated if it would have been better to have the damage survey done through professionally-paid structural engineers. In addition, about 80 senior students (post graduate or undergraduate final year) of several engineering colleges in Gujarat and another 30 junior engineers contributed towards the damage assessment by CEPT in Ahmedabad.

The damage survey team consisted of (a) a senior structural engineer, (b) a junior engineer who could also be a senior student of civil engineering, (c) one cameraman to take pictures, and (d) one representative of the local authorities for liaison. This team was given a vehicle and a driver. On the first day, the team was given a one-and-a-half hour orientation on use of the damage survey forms. On a typical day, about 20 - 25 such teams were out surveying, with each team completing about 10 buildings in one day. At the end of the day, the senior engineer will submit the damage assessment forms alongwith his recommendation on the damage grade to the central unit at CEPT. A smaller group of six or seven persons at CEPT then carefully scrutinized the forms before finally awarding the damage grade.

The damage assessment survey started at Ahmedabad on February 5 and continued for almost three months. The first one and a half month took the field visits and filling up of the forms, and the remaining time in finalizing the recommendations and gradings. Since the financial aid for repair and rehabilitation of buildings was linked with the damage category, the buildings in Ahmedabad not covered by CEPT were surveyed by other agencies. In view of the financial aid, there were instances of the beneficiaries putting pressure to have their property classified in a higher damage category.

Reconstruction and Retrofitting

The entire rehabilitation project in Gujarat is owned-driven wherein the residents are themselves responsible for repairs, strengthening or rebuilding of their own houses. The Government of Gujarat (GoG) is providing cash relief and some technical assistance. Several aid packages have been implemented by the GoG for building activities: different for rural and urban areas, different for urban areas of Kachchh district versus other districts. For instance, the assistance for repair/strengthening of RC frame residential buildings in towns of Bhuj, Anjar, Bhachau and Rapar (all in Kachchh district) ranges from Rs 50,000 to Rs 800,000 per building depending on the category of damage. In case of reconstruction, the assistance is at the rate of Rs 3,000 per sq.m subject to a maximum of Rs 150,000 per flat.

Several thousand civil engineers have been recruited by the GoG as an immediate measure to help with the reconstruction project. Most have little or no professional experience. It is expected that with some training, these engineers will assist the owners to build or repair their homes to be earthquake resistant. Technical Assistance Cells have been set up in the towns of Bhuj, Anjar, Bhachau and Rapar (Kachchh district) to assist the private owners with structural issues and to advise the local government officials. Structural engineering manpower for these Cells has been drawn from professional consulting firms through competition.

About six weeks after the earthquake, the Ahmedabad Municipal Corporation held a meeting of about 40 structural engineers from Ahmedabad and outside and developed some seismic strengthening guidelines. The focus of recommendation on the five storey RC frame buildings was to provide brick masonry infills in the open ground stories. Thereafter, many buildings have adopted this as the strengthening technique. However, the entire exercise of retrofitting of multistorey buildings in Ahmedabad remains quite empirical without proper structural calculations. This is possibly due to inadequate structural expertise in the area and the limited financial means of the residents to hire good consulting firms.

Situation In Kachchh District

As compared to the situation in Ahmedabad, the building industry in Kachchh district was even less professional. For instance, there were no formal building bye-laws for towns of Kachchh and no restrictions on floor area that can be built on a given plot size. Permissions were routinely given for construction of ground plus seven storey buildings. It seems that after the earthquake, during one of the legal proceedings, the Bhuj municipality pleaded that they were not aware that the town is in seismic zone V and that they never received any circular from the state government regarding matters of earthquake safety.

Ahmedabad being 200km from the epicenter had a relatively smaller ratio of building stock that collapsed or was severely damaged. By a crude estimate, Ahmedabad may have about 1,500 RC frame buildings of around 10 storeys, and more than 25,000 RC frame buildings of five stories; of these, 2 and ~130 buildings, respectively, collapsed during the earthquake. As against that, there were far more percentage of collapses of buildings in Bhuj and other towns of Kachchh district (Table 1). Ahmedabad had relatively better availability of structural engineering expertise locally, as well as in terms of outside experts after the earthquake (e.g., Mankad, 2001). Moreover, Ahmedabad, being a more prominent town and just adjacent to the capital Gandhinagar, attracted more urgent attention of the administration. As a result, even though the damage survey criteria and the survey forms were developed for Ahmedabad and used starting February 5, it was almost another month before the damage survey was started at Bhuj.

Table 1 : Damage statistics in towns of Kachchh district.

Town	**Intensity**	**Epicentral Distance**	**Damage Grade**				
			G1	**G2**	**G3**	**G4**	**G5**
Bhachau	X	13 km	0.0	0.0	0.9	0.7	98.4
Raper	IX	33 km	3.1	11.2	21.0	31.9	32.7
Anjar	IX	41 km	35.5	12.7	12.7	6.7	32.4
Gandhidham	IX	44 km	47.4	22.6	12.9	8.5	8.5
Bhuj	IX	63 km	16.0	19.2	18.3	20.5	25.7
Mandvi	VIII	109 km	58.5	21.5	8.5	8.4	3.2
Total			***29.2***	***17.4***	***14.1***	***13.1***	***26.2***

Like in Ahmedabad, in Bhuj too criminal cases were filed against structural engineers and builders, and some were arrested. One of the engineers remained in jail without bail for about 4 months, while many others were arrested much later and allowed bail within a few days of arrest.

Bye-laws for building construction in the four towns of Kachchh district have now been issued, and these restrict the buildings to be not more than ground plus two storeys as against ground plus seven storeys that were routinely permitted before the earthquake.

Long Term Actions

Since this was the first major earthquake in India to have hit the urban area and its destruction was widely telecast, it lead to numerous long-term actions in the country towards better earthquake safety. Numerous conferences and seminars in earthquake resistant constructions were organized all over the country by the professional societies. The Government of India decided to move forward with the process of setting up the *Engineers Bill* to regulate the engineering profession. Many state governments issued requirements on buildings to comply with seismic codes. Some of these were hastily drawn orders; for instance:

a) One state government required that the structural design be done by an engineer with postgraduate diploma or degree in structural engineering. This ignored the fact that most engineers already practicing for many years do not have postgraduate qualifications and that most postgraduate programmes in the country do not teach earthquake resistant design and construction.

b) Another state now requires that buildings in that state be designed for one zone higher than that specified in the seismic code.

c) The local government of a city in seismic zone III required that the structural engineer should certify that the building meets the requirements of zone III/IV and is safe for Richter magnitude 7.5. Engineers seem to be giving such a certificate without understanding the implications of Richter magnitude 7.5.

d) Yet another state government required that all seismic codes be complied with along with the BMTPC Guidelines (1998). The BMTPC guidelines essentially discuss the seismic codes. Hence, as the codes get modified, unless the Government order is revised continuously, there will be conflicting requirements on the engineer to follow the new code as well as the BMTPC guidelines based on the old code.

Despite the above shortcomings, which are understandable in view of the lack of earthquake engineering expertise with the state governments and local bodies, the fact that seismic codes have been made mandatory will go a long way towards better earthquake safety. The increased concern about earthquake issues amongst the decision makers is also evident from the fact that currently local authorities in many cities have become very reluctant to give permissions for construction of multistorey buildings.

Unfortunately, the issue of training structural engineers in earthquake design and constructions has not received adequate attention, and there seems to be an impression that making the seismic codes mandatory will solve the earthquake problem. This is partly because the engineers have not emphasized the sophistication of the structural engineering, and in particular of the seismic design, to the decision-making administrators and politicians. Mechanisms are not yet developed to ensure that only a competent engineer, proved by some sort of examination, will sign a structural design. Also, mechanisms of professional liability have not been developed, and the engineers remain under the fear that they could be charged with serious criminal offences if buildings designed by them in good faith do not perform well during future earthquakes.

Concluding Remarks

The earthquake of January 26 was unprecedented in the last fifty years, and the system was least prepared for it. Considering this, the entire system has responded quite satisfactorily. However, as is the case with all major disasters, there remain areas for further actions:

a) A sound strategy needs to be evolved for training of engineers in Gujarat state both for short term to undertake reconstruction, repairs and retrofitting projects, and for long term to provide the State with sustained expertise in earthquake engineering. The State cannot depend on outside expertise for routine earthquake engineering matters in the long run.

b) To have engineering manpower working for the local and the state governments who will be experts in earthquake engineering, a suitable cadre management and incentive system needs to be developed. Else, most engineers may be reluctant to become specialists for fear of blocking their promotion prospects.

c) There is an urgent need to develop strong teaching and research programmes in Earthquake Engineering in the universities in Gujarat (and elsewhere in India). Hence, concurrent with the training of professional engineers, there is need for training of faculty members of the colleges of engineering and architecture.

d) Since the training of engineers in Gujarat will take considerable time and the development activities cannot wait for the same, there is need to induct a large number of professional engineers from outside. Moreover, it is important to ensure that the structural engineers providing services to the State indeed have adequate competence in earthquake resistant constructions. Since there is no licensing system in India, this assumes additional importance. Hence, some sort of a test in seismic design aspects may be conducted periodically, and engineers providing structural services to the state should have to qualify this test.

e) The GoG (and the Governments of other states and the Central Government) should try to resolve the issue of professional liability of structural engineers. With criminal cases filed against the structural engineers in the state, the engineers see themselves carrying unlimited liability for the professional services provided and it adversely affects their morale.

The chain for earthquake safety consists of several critical links: sensitization of the public and the decision makers to earthquake safety, mandatory nature of earthquake codes, technical competence for design and construction, enforcement mechanisms, and healthy professional environment. The January 2001 Bhuj earthquake has already provided the first two links. A vigorous capacity building effort remains to be carried out wherein a large body of professional engineers in India will have the required expertise, and there will be required enforcement together with right professional environment. A fair system of insurance for professional services and liability will go a long way to ensure better seismic safety. A demoralized structural engineering community cannot be expected to deliver outstanding services.

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