17 Codes, Licensing, and Education

INTRODUCTION

The earthquake of January 26, 2001 occurred in a known seismic region. The development of earthquake engineering started rather early in India. And yet, about 13,800 persons died due to building collapses; about 130 multistory buildings collapsed in Ahmedabad alone, at a distance of 200 km from the epicenter. It is therefore important to review the historical developments of earthquake engineering in India, the status of Indian seismic codes, status of code compliance, and professional and academic environment for seismic engineering. These could provide important lessons not just for Gujarat and for rest of India, but also for many other developing countries.

HISTORICAL PERSPECTIVE ON EARTHQUAKE ENGINEERING IN INDIA

Dr. Thomas Oldham, the first Director of the Geological Survey of India (GSI), is credited with laying the foundation of the scientific studies of earthquakes in India (West, 1937). He compiled the well-known catalog of Indian earthquakes and carried out investigations of the Cachar earthquake of 1869. His son, R.D. Oldham, also went on to become Director of the GSI and contributed substantially to earthquake studies. His memoir (Oldham, 1899) of the 1897 Assam earthquake was considered by Richter (1958) as one of the most valuable source books in seismology. In this volume, R.D. Oldham for the first time scientifically interpreted a seismogram and laid the foundation of modern seismology. The descriptions of the 1897 Assam earthquake provided the principal model for the highest grade, XII, of the MMI Scale (Richter, 1958).

Since the days of Oldham, the GSI officers have carried out extensive field studies of important Indian earthquakes and published their findings, e.g., the 1905 Kangra (Middlemiss, 1910) and the 1934 Bihar-Nepal (GSI, 1939) earthquakes.

The first major initiatives for earthquake-resistant construction emerged after the Baluchistan (now in Pakistan) earthquakes of the 1930s. After the Mach earthquake of 1931 (M7.4; intensity VIII on Rossi-Forel Intensity scale of I to X), about 60 km from Quetta in Baluchistan (now in Pakistan), formal earthquake-resistant houses were constructed in the region by the railways. The railways used a seismic coefficient of 0.10 g. S.L. Kumar, the young railway engineer who designed these houses, documented this work (Kumar, 1933). This paper provided the first seismic zone map of the country (Figure 17-1) and suggested seismic design coefficients (Table 17-1). In the 1935 Quetta earthquake (M7.6; intensity up to X on the I to X Rossi-Forel scale; about 20,000 dead), the earthquake-resistant railway quarters, located in the area of maximum damage were the only houses that remained undamaged.

Table 17-1. Seismic factors for different seismic zones, as suggested by Kumar (1933)

Class of building	Values of the seismic factor			
	Areas of violent earthquakes	Areas of strong earthquakes	Areas of weak earthquakes	Areas of rare earthquakes
A	0.15g	0.10g	0.05g	Nil
B	0.10g	0.075g	Nil	Nil

Type A: Monumental buildings and those more than 50 ft. high

Type B: All others

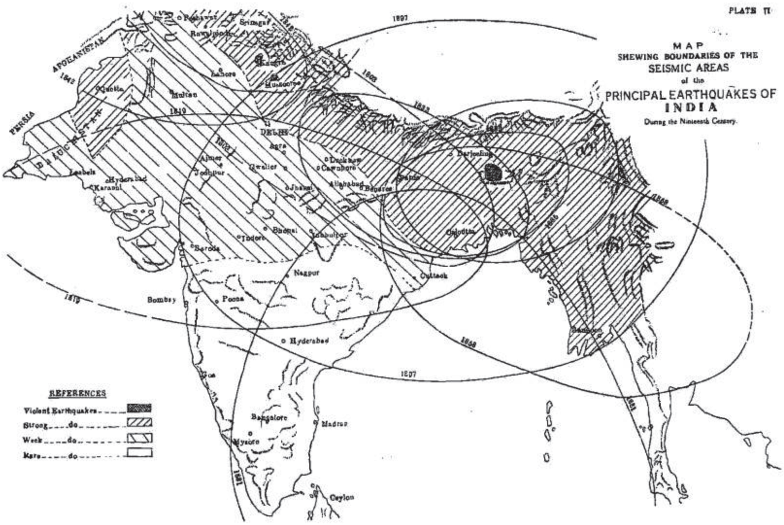

Figure 17-1. First seismic zone map of India (Kumar, 1933)

The 1935 Quetta earthquake led to massive reconstruction programs by the railways, the military, and the civil administration (Thomson, 1940; GOI, 1940; Robertson 1948). A seismic coefficient of 0.125 g was adopted and comprehensive guidelines developed for earthquake-resistant features. A code was also proposed along with an excellent commentary (GOI, 1940). This new construction was put to test in 1941 when an earthquake caused shaking of intensity VIII to IX on the Rossi-Forel scale, and they performed extremely well (Mair, 1942).

The 1935 Quetta earthquake was interesting from several viewpoints. For the first time, serious and systematic efforts were undertaken to promote earthquake-resistant construction and develop earthquake codes. More important, in terms of this earthquake, is that for the first time in India, the effectiveness of earthquake-resistant construction was tested during a severe earthquake. The evolution toward using reinforced concrete bands at plinth, lintel, and roof levels in masonry buildings took place after this earthquake. In fact, the actions taken subsequent to the 1935 Quetta earthquake provided the model to be recommended for other earthquake-prone regions of the country (Geological Survey of India, 1939):

> *In the Quetta area an excellent building code has recently been drawn up, and reconstruction has been rigidly enforced in terms of that code. Such enforcement is, perhaps, easier in such a military area, but at least Quetta provides an example of the practicability of a building code and of its usefulness. It is, perhaps, not too much to hope that the rest of Northern India will some day follow Quetta's lead.*

The concrete industry developed an early interest in earthquake engineering. The *Indian Concrete Journal* published a special issue (ICJ, 1934) on the 1934 Bihar-Nepal earthquake that featured excellent well-captioned photographs. After the Anjar (Kachchh) earthquake of 1956, two articles (ICJ, 1956a; ICJ, 1956b) were published in the same journal outlining the design principles of earthquake-resistant buildings. A monograph on earthquake-resistant buildings was published in 1954, and revised in 1958 and 1965 (CAI, 1965).

An institutional base for earthquake engineering was established around 1958, when Professor Jai Krishna started teaching and research in earthquake engineering at the University of Roorkee (now Indian Institute of Technology Roorkee) following his visit to the California Institute of Technology (Caltech). First of the symposia (symposia are now held every four years) on earthquake engineering was organized at Roorkee in 1959. Professors D.E. Hudson and G.W. Housner of Caltech stayed at Roorkee for several months to help Professor Krishna and others set up the academic engineering program and organize the first symposium. The School of Research and Training in Earthquake Engineering (now the Department of Earthquake Engineering) was set up at Roorkee in 1960. The Indian Society of Earthquake Technology (ISET) was established in 1962; it now has about 1,000 members. The first Indian seismic code was published in 1962, and a comprehensive earthquake catalog was published in 1983 (ISET, 1983).

INDIAN SEISMIC CODES

After the Quetta earthquake in 1935, a building code was developed, but its application was perhaps limited to the reconstruction project in Baluchistan and there is no evidence that it was seriously applied elsewhere in the country. The first formal seismic code in India was published in 1962 (IS:1893-1962). In the intervening period, there were some efforts to develop earthquake-resistant construction monographs, and a number of seismic zone maps were developed (e.g., West, 1937; Krishna, 1958; Mithal and Srivastava, 1959).

Currently, the following Indian codes published by the Bureau of Indian Standards (BIS) cover seismic design:

- IS:1893-1984. *Indian Standard Criteria for Earthquake Resistant Design of Structures* (4^{th} Revision). First published in 1962, revised 1966, 1970, 1975 and 1984
- IS:4326-1993. *Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings* (2^{nd} Revision). First published in 1967, revised 1976 and 1993
- IS:13827-1993. *Indian Standard Guidelines for Improving Earthquake Resistance of Earthen Buildings.* First published in 1993.
- IS:13828-1993. *Indian Standard Guidelines for Improving Earthquake Resistance of Low Strength Masonry Buildings.* First published in 1993.
- IS:13920-1993. *Indian Standard Code of Practice for Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces.* First published in 1993.
- IS:13935-1993. *Indian Standard Guidelines for Repair and Seismic Strengthening of Buildings.* First published in 1993.

IS:1893-1984 is the main code that provides the seismic zone map and specifies seismic design force for different structures: buildings, overhead water tanks, stacks, bridges, dams and retaining walls. Provisions of this code that apply to buildings are discussed in detail by Jain et al. (1994). Revision of IS:1893 is in the process—it is being split into several parts. The first part containing general provisions and provisions for buildings is in the printing stage. Other parts will contain provisions on liquid retaining tanks, bridges, industrial structures, dams, etc. After the Bhuj earthquake, it has been decided that a new code will be developed on damage assessment, repair, restoration, and seismic strengthening of buildings. Prior to 1993, the provisions on masonry buildings and ductile detailing of reinforced concrete frame buildings were covered in IS:4326. A brief discussion of IS:13827 and IS:13828 and part of IS:4326 can be found in Chapter 11, Masonry Buildings.

SEISMIC ZONE MAP

The seismic zone map (Figure 17-2) in the 1962 edition was developed based on the epicentral distribution of past earthquakes (M > 5) and the isoseismals of such events. The enveloping lines marking areas that have sustained shaking of different intensity were then plotted. The map demarcated areas of potential ground shaking with intensity (Modified Mercalli scale) of: less than V, V, VI, VII, VIII, IX, and X (and above) and termed these as Seismic Zones 0, I, II, III, IV, V and VI, respectively. Based on geological and geophysical data obtained from tectonic maps and aeromagnetic and gravity surveys, the zonation map was revised in the 1966 and 1970 (Figures 17-3 and 17-4) editions of the Indian seismic code.

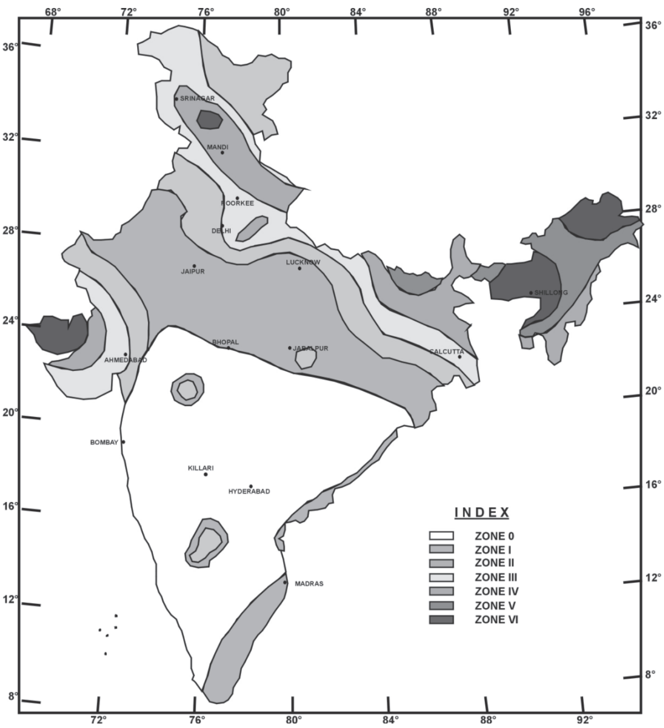

Figure 17-2. Seismic zone map of India (1962).

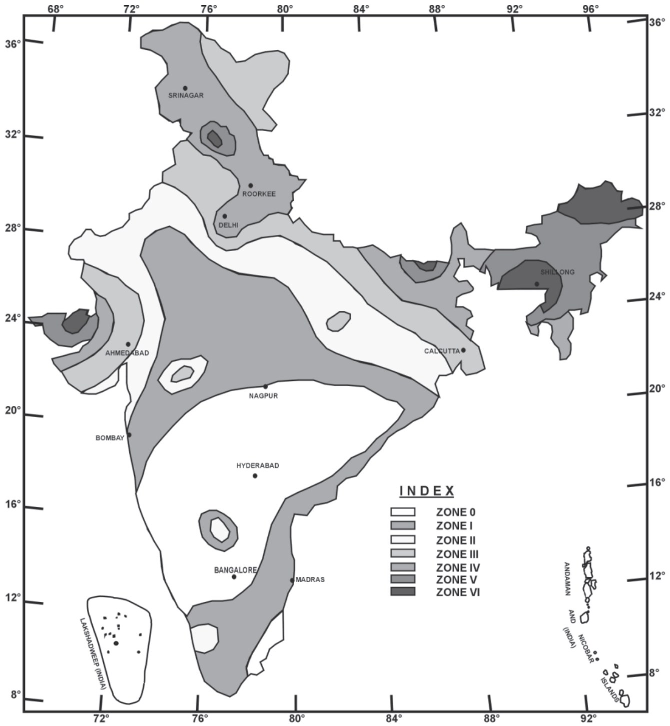

Figure 17-3. Seismic zone map of India (1966).

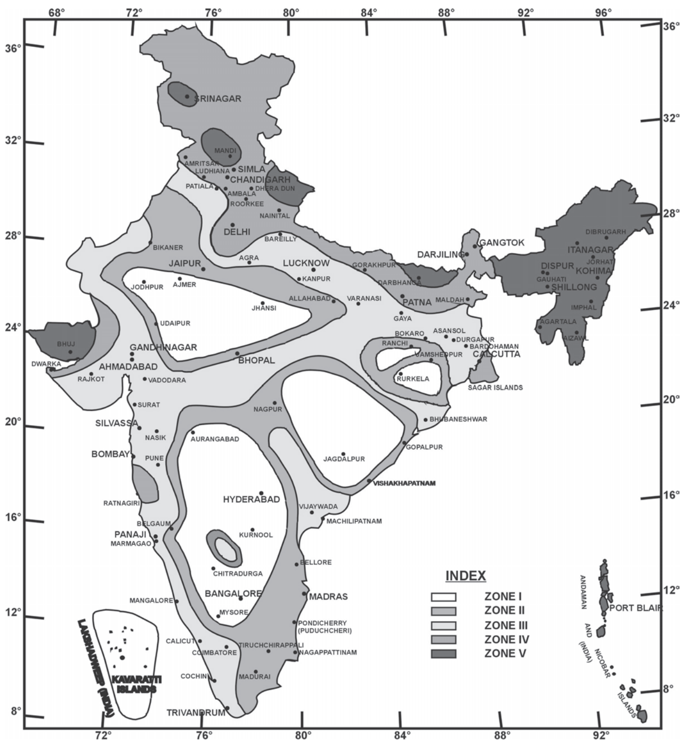

Figure 17-4. Seismic zone map of India (1970).

The 1966 version of the code also provided seven seismic zones. The Koyna earthquake of 1967 (M6.5, maximum intensity of shaking VIII, about 200 dead) occurred within Seismic Zone I and caused major revision of the seismic zone map in the 1970 edition. The number of zones was reduced from seven to five by dropping the Zones 0 and VI. Zone 0 was merged into Zone I and Zone VI was merged with Zone V. The five seismic zones of the 1970 edition correspond to areas liable to shaking intensity of V (or less), VI, VII, VIII, and IX (and above), respectively. This zone map has remained unchanged ever since.

The Latur earthquake of 1993 (M 6.4; about 8,000 dead; maximum intensity of shaking VIII-IX on MM scale) occurred in Seismic Zone I and again underlined the need to review and revise the seismic zone map. A revision of the seismic zone map was undertaken and the new zone map (Figure 17-5) has been included in the latest version of IS:1893 (at press). Seismic Zone I has been dropped by merging it with Zone II; and, some parts of the peninsular India have now been brought into Zone III. Postearthquake reconstruction in the Latur region was undertaken corresponding to Zone IV provisions of Indian codes. The Latur area is now classified in Zone III.

The Basic Seismic Coefficient (α_o) used in the seismic coefficient method is 0.01, 0.02, 0.04, 0.05, and 0.08, respectively, for the five zones (Table 17-2). The Seismic Zone Factor (F_o) used in the response spectrum method is simply five times α_o.

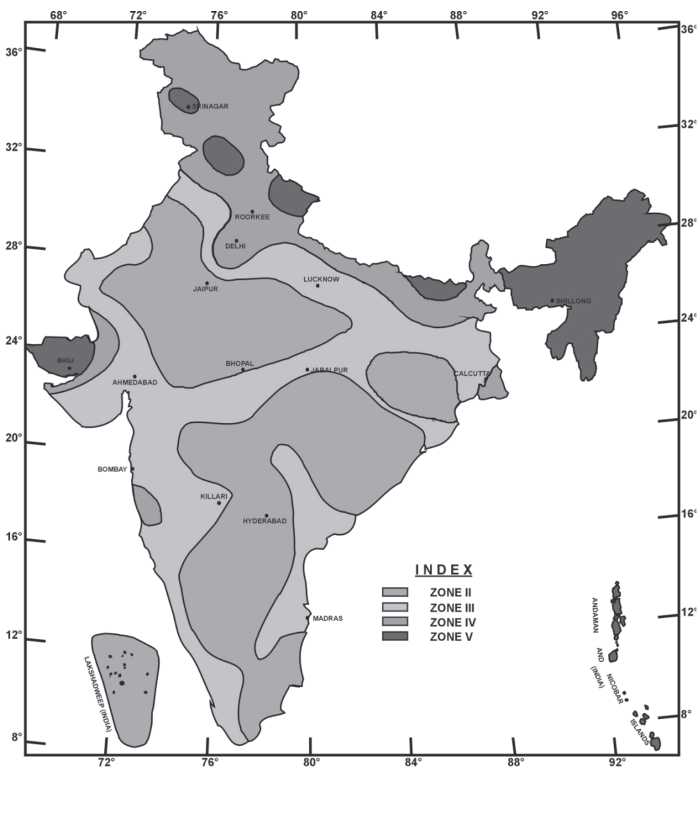

Figure 17-5. Seismic zone map of India (draft code).

Table 17-2. Values of basic seismic coefficient and seismic zone factor

Serial No.	Seismic Zone	Basic Horizontal Seismic Coefficient[1] α_o	Seismic Zone F_o Factor[2]	Zone Factor[3] Z
1	V	0.08	0.40	0.36
2	IV	0.05	0.25	0.24
3	III	0.04	0.20	0.16
4	II	0.02	0.10	0.10
5	I	0.01	0.05	-

1. For seismic coefficient method as per IS:1893-1984
2. For response spectrum method as per IS:1893-1984
3. As per IS:1893 revision (at press)

IS:1893 PROVISIONS ON BUILDINGS

The code provides two methods for calculation of seismic design force: the seismic coefficient method and the response spectrum method. In the seismic coefficient method, the design base shear V_B is obtained as:

$$V_B = K\,C\,\beta I\,\alpha_O\,W$$

where W is the total dead load plus appropriate amount (25 or 50 percent depending on load class) of live load, K is the performance factor (1.0 for ductile building system, 1.6 for buildings not detailed for ductility, and 1.3 for an intermediate case), C is the flexibility factor (Figure 17-6), T is the fundamental natural period, β is the soil-foundation system factor that takes values of 1.0, 1.2 and 1.5 depending on type of foundation and type of soil (higher value for situations more vulnerable to differential settlements), and I is the importance factor which assumes a value of 1.5 for important buildings and 1.0 for regular buildings.

The fundamental natural period can be obtained by dynamic analysis or by using the following empirical equations:

$$T = \begin{cases} 0.1n & \text{for moment resisting frames without shear walls or bracings} \\ \dfrac{0.09H}{\sqrt{d}} & \text{for other buildings} \end{cases}$$

where n is the number of stories including basement stories; H is the total building height in meters; and d is the maximum base dimension of building (in meters) in the direction parallel to the applied seismic force.

Thus, in Seismic Zone V (α_o=0.08) an ordinary (I=1.0) reinforced concrete frame building detailed for ductility (K=1.0), supported on raft foundation (β=1.0), having fundamental natural period of 0.5 sec (C=0.82) may be designed for a seismic coefficient of about 0.066 g. However, since the code allows the designer to obtain fundamental period by dynamic analysis, many engineers use this option. While carrying out the dynamic analysis, the stiffness contribution of infill walls is often ignored, leading to much larger value of fundamental period, and hence seismic design force is further reduced considerably. A critical review of the building provisions of this code is available elsewhere (Murty and Jain, 1994).

The code specifies a parabolic distribution of seismic force with respect to height, given by:

$$Q_i = V_B \frac{W_i \, h_i^2}{\sum_{j=1}^{j=n} W_j \, h_j^2}$$

where Q_i is the lateral force at floor i (or roof); W_i it the gravity load (dead load + appropriate amount of live load) of floor i, h_i is the height measured from the base of the building to floor i; and n is the number of stories. The gravity load, W_i, at floor i is to be obtained by equally distributing the weight of walls and columns in any story to the floor above and the floor below the story.

The response spectrum method is required for irregular buildings and those with building height exceeding 40 m or 90 m, depending on the seismic zone. In this method, the design spectrum is given by:

$$\text{Design Spectrum} = K \, \beta \, I \, F_O \, \frac{S_a}{g}$$

where S_a/g is given by Figure 17-7. Since the value of F_o is five times that of α_o and the response spectrum for 5 percent damping is about one-fifth the curve for C versus T, the two methods give about the same design base shear if the value of natural period used is the same. However, most of the time in professional practice, the dynamic analysis in the response spectrum method ignores stiffness contribution of infill walls, leading to reduction in design seismic force in this method.

The code requires that the interstory drift in the building under design seismic force should not exceed 0.004 times the story height. It requires that all vertical cantilever projections attached to a building be designed for five times the horizontal seismic coefficient. Similarly, the horizontal projections are to be designed for a vertical coefficient equal to five times the vertical seismic coefficient.

REVISION OF IS:1893, PROVISIONS ON BUILDINGS

A revision of the building provisions of this code has been in progress for many years now, and is currently in the printing stage. There are major modifications in this revision. The soil-foundation factor (β) has been dropped, and different design spectrum curves are specified for three soil types. The design horizontal seismic coefficient A_h is given by:

$$A_h = \frac{Z}{2} \frac{I}{R} \frac{S_a}{g}$$

where Z is the Zone factor (0.10, 0.16, 0.24 and 0.36 for Seismic Zones II, III, IV and V, respectively (Table 17-2), R is the response reduction factor as per Table 17-3, and S_a/g is as per Figure 17-8.

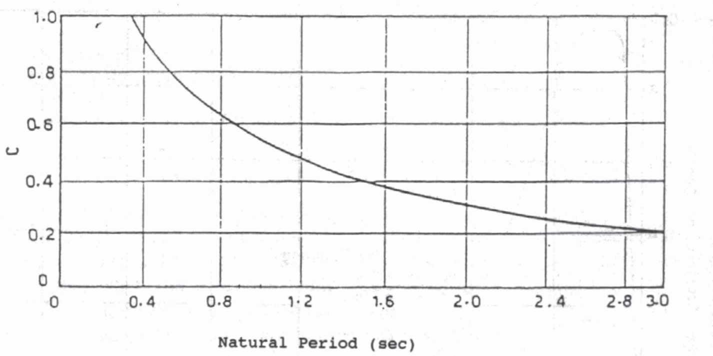

Figure 17-6. Seismic coefficient *C* versus *T*.

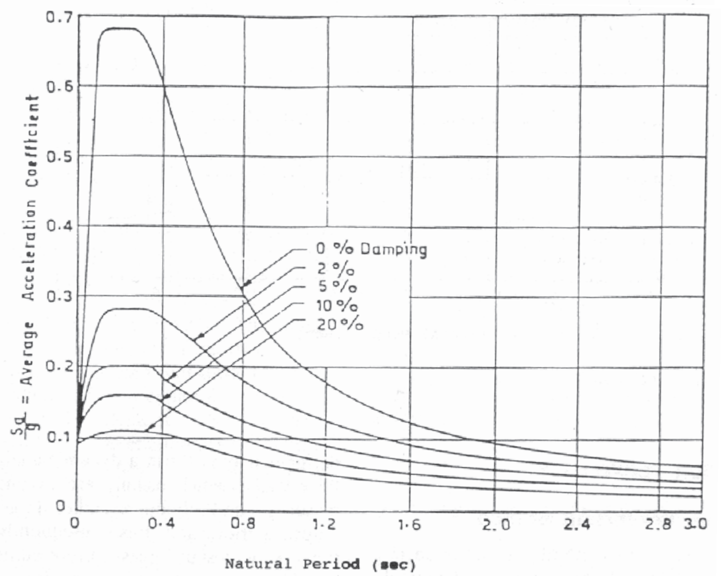

Figure 17-7. Average acceleration spectra S_a/g versus *T*.

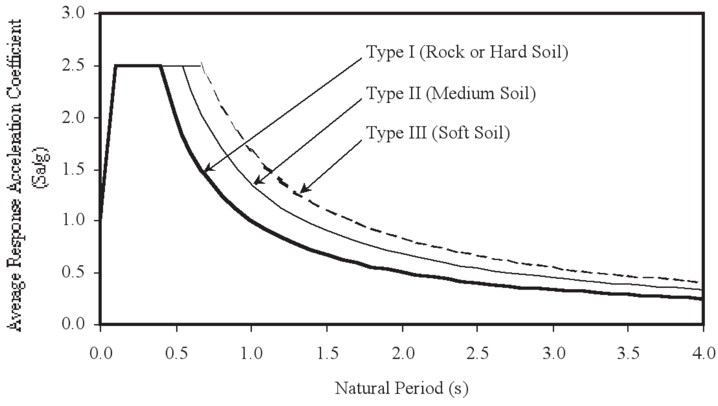

Figure 17-8. Average response acceleration spectra for 5 percent damping.

Table 17-3. Response reduction factor, *R,* for building systems as per revised IS:1893 (at press)*

Serial #	Lateral Load Resisting System	R[1]
Building frame systems		
1.	Ordinary RC moment-resisting frame (OMRF)[2]	3.0
2.	Special RC moment-resisting frame (SMRF)[3]	5.0
3.	Steel frame with:	
	• Concentric braces	4.0
	• Eccentric braces	5.0
4.	Steel moment resisting frame design as per SP: 6(6)	5.0
Buildings with shear walls[4]		
5.	Load-bearing masonry wall buildings[5]	
	• Unreinforced	1.5
	• Reinforced with horizontal RC Bands	2.5
	• Reinforced with horizontal RC bands and vertical bars at corners of rooms and jambs of openings	3.0
6.	Ordinary reinforced concrete shear walls[6]	3.0
7.	Ductile Shear Walls[7]	4.0
Buildings with dual systems[8]		
8.	Ordinary shear wall with OMRF	3.0
9.	Ordinary shear wall with SMRF	4.0
10.	Ductile shear wall with OMRF	4.5
11.	Ductile shear wall with SMRF	5.0

* The value of response reduction factor cannot be directly compared with that in codes such as the International Building Code. In this code, the value of zone factor has been divided by a factor of 2 before applying these values of R. Thus, for comparison with values in the IBC, the values shown here should be multiplied by a factor of 2.

1. The above values of response reduction factors are to be used for buildings with lateral load resisting elements, and not just for the lateral load resisting elements built in isolation.
2. OMRF are those designed and detailed as per IS 456 or IS 800 but not meeting ductile detailing requirement as per IS 13920, or SP6(6), respectively
3. SMRF defined in clause 4.15.2 of IS:1893 Draft Code (in press)
4. Buildings with shear walls also include buildings having shear walls and frames, but where:
   a) frames are not designed to carry lateral loads, or
   b) frames are designed to carry lateral loads but do not fulfill the requirements of 'dual systems'
5. Reinforcement should be as per IS 4326.
6. Prohibited in Zones IV and V.
7. Ductile shear walls are those designed and detailed as per IS:13920.
8. Buildings with dual systems consist of shear walls (or braced frames) and moment resisting frames such that the two systems are designed to resist the total design force in proportion to their lateral stiffness considering the interaction of the dual system at all floor levels; and the moment resisting frames are designed to independently resist at least 25 percent of the design seismic base shear

The empirical expression for fundamental period have been changed somewhat. Further, it is now specified that in case dynamic analysis is carried out, the overall seismic design force for a building should not be lower than what is obtained by using an empirical value of fundamental period.

After the 2001 Bhuj earthquake, empirical clauses on soft story buildings were added to this revision. There is now a provision requiring that the columns and beams of the soft story be designed for 2.5 times the story shear and moments calculated under design seismic loads. Alternatively, the columns of soft story may be designed as per calculated design seismic loads, and shear walls may be provided in both the directions such that the walls take 1.5 times the calculated design seismic forces.

PROVISIONS FOR BRIDGES

In India, seismic design force provisions for bridges are covered in three codes: IS:1893-1984 from the Bureau of Indian Standards, IRC 6-2000 from the Indian Roads Congress, and Bridge Rules (1964) from the Ministry of Railways. While all highway bridges must follow IRC 6, railway bridges must follow the Bridge Rules. In that sense, IS:1893 provisions on bridges are hardly used in practice. Conceptually, the three documents give the same equation and factors for seismic design force, even though there are some differences in the implementation of seismic provisions. The IRC still requires that bridges be designed as per the working stress design procedure. However, Indian Railways now allow use of the limit state design method.

All three codes on bridges provide seismic coefficient method for most of the bridges, and require that dynamic analysis be carried out for large or irregular bridges in high seismic regions; the criteria as to when dynamic analysis is required varies among these codes. As per the seismic coefficient method, the seismic design force F is given by

$$F = \begin{cases} \beta I \alpha_0 W_m & \text{for horizontal force} \\ 0.5\beta I \alpha_0 W_m & \text{for vertical force} \end{cases}$$

where β, I, and α_o are as defined earlier for buildings, and W_m is the seismic weight (dead weight plus part of superimposed weight) considered, excluding buoyancy or uplift. The code does not incorporate the effect of bridge flexibility (natural period) in computation of seismic design force. Also, the concept of performance factor (response reduction factor) is not included for bridges, even though the same is included for buildings. In practical terms, the seismic provisions in the Indian Roads Congress have not been revised in about the last 30 years.

IS:1893-1984 provides for consideration of hydrodynamic forces, while the same is not included in the IRC code. As per IS code: (a) for parts of structure or foundation at 30 m depth or below, the seismic coefficient is to be taken as one half of that for the aboveground structure, and (b) linear interpolation may be used for parts between ground and 30 m below ground. However, IRC code provides that parts of structures embedded in soil shall not be considered to produce any seismic forces.

Clearly, the seismic force provisions in Indian codes for bridges are much lower than those in other countries for areas of comparable seismicity. For instance, an ordinary bridge (I=1.0) located in Seismic Zone V (α_o=0.08) supported on piles resting on hard soil or rock (β=1.0) will be simply designed for a horizontal seismic coefficient of 0.08 g: a rather low value considering that Zone V corresponds to shaking intensity of IX (and above) where the peak ground acceleration itself can be about 0.6 g. This low value of design coefficient is particularly detrimental to bearings in simply supported spans.

Currently, a committee of the Indian Roads Congress is working on the revision to IRC 6 provisions. Since the comprehensive revision of the seismic provisions being currently discussed will take time to be finalized and approved, it has been suggested that an interim revision to the seismic force provision be implemented immediately wherein the design horizontal force would be given by:

$$F = \frac{\left(\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)}{\left(\frac{R}{I}\right)} \text{ (dead load + appropriate live load)}$$

where the terms are the same as in the revised IS:1893 (at press) and the value of R is suggested as 2.5 for bridges. Thus, if this interim revision is approved, the design seismic force will also depend on the natural period of the bridge. As per this proposal, an ordinary bridge (I=1.0) with fundamental natural period of 0.3 sec (S_a/g = 2.5) located in Seismic Zone V (Z=0.36) with rock site will be designed for a seismic coefficient of 0.18 g, which is significantly higher than the current provision of about 0.08 g. On the other hand, if the bridge is more flexible, with a fundamental period of 1.0 sec (S_a/g = 1.0), it will be designed for a seismic coefficient of 0.072 g. Thus, as compared to the present provisions, the interim provisions will increase the design seismic force for stiff structures and reduce that for flexible structures.

The detailed revision being discussed by the Indian Roads Congress incorporates the concept that different parts of the same bridge (superstructure, connections between superstructure and the substructure, and the substructure, etc.) may have different values of response reduction factor and hence may be designed for different levels of seismic coefficient.

PROVISIONS FOR ELEVATED WATER TANKS

The provisions for seismic design of elevated water tanks are reviewed elsewhere (Jain and Sameer, 1993). The design seismic force is given by $\beta I F_o (S_a/g) W$. The tank is to be checked for both tank-full and tank-empty condition. In case of tank-full condition, the entire mass of the water is to be added to the mass of the container; thus the concept of impulsive and convective mass is not considered in evaluating seismic design force. The water tanks are to be designed for importance factor (I) of 1.5. For an elevated reinforced concrete tank (5 percent damping for S_a/g curve) located in Seismic Zone V (F_o=0.40), supported on raft foundation (β=1.0) having fundamental period (T) of 1.0 sec (S_a/g=0.11), the tank will be designed for a seismic coefficient of about 0.066 g—again too low. Performance of elevated tanks in the Jabalpur earthquake (Rai, 1998) and in the Bhuj earthquake (Chapter 15, Elevated Water Tanks) also indicates need for upward revision of design seismic force for tanks.

The code provides expressions for impulsive hydrodynamic pressure and allows one to ignore the convective hydrodynamic pressure.

PROVISIONS FOR EARTH AND ROCKFILL DAMS AND EMBANKMENTS

The code specifies a simple check on slope stability for earth dams under seismic condition. The procedure consists of first finding the fundamental period (T) as follows:

$$T = 2.9 H_t \sqrt{\rho / G}$$

where H_t is the height of the dam above toe of the slopes, ρ is the mass density of the shell material, and G is the modulus of rigidity of the shell material. Slope failure, with the lowest point of the rupture surface at any depth y below top of dam, is to be checked with the following value of equivalent uniform seismic coefficient:

$$\alpha_y = (2.5 - 1.5\frac{y}{H})\beta I F_o \frac{S_a}{g}$$

where H is the total height of the dam and (S_a/g) is to be obtained for the fundamental period and 10 percent damping. The code states that dynamic analysis is desirable for final design of important dams to estimate the deformations.

IS:13920, PROVISIONS FOR DUCTILE DETAILING OF REINFORCED CONCRETE STRUCTURES

Prior to publication of this code in 1993, the seismic detailing requirements on reinforced concrete frame buildings were covered in IS:4326-1976. However, those provisions were considered inadequate and hence led to this code. This code provides fairly detailed provisions on ductile detailing of reinforced concrete frame and shear wall structures in line with the international practices. Originally, this code was meant to be mandatory for (a) all structures in Seismic Zones IV and V, (b) structures located in Zone III but with importance factor greater than 1.0, (c) industrial structures in Zone III, and (d) structures more than 5 stories high in Zone III. However, after the Bhuj earthquake of 2001, it has been decided to make this code mandatory for all structures in Zones III, IV and V.

The code restricts the reinforcement grade to Fe415, that is, it does not permit use of reinforcement with yield stress (0.2 percent proof stress) exceeding 415 MPa. However, a recent amendment to the code permits high strength deformed steel bars, produced by the thermomechanical treatment process, of grade Fe500 and Fe550, having elongation more than 14.5 percent.

Most residential multistory buildings in India tend to have thin columns. Usually one of the column dimensions is 230 mm to match the thickness of brick masonry infill walls. It was felt that very drastic changes in one revision of the code may not be conducive to ensure better compliance of the code. Hence, even though a minimum width of column was specified (300 mm, except when beam spans are up to 5 m and the column height is up to 4m the column width can be as low as 200mm), the code refrained from providing two requirements on column sizes that are prevalent in international practices: (a) column width be at least 20 times the largest beam bar diameter passing through the joint, and (b) strong column-weak beam requirement, wherein at the beam-column joint, the sum of moment capacity of the two columns meeting at the joint is at least 20 percent higher than that of the beams. Similarly, for the exterior beam - column joints, the code does not require the minimum column width to depend on the beam bars to be anchored into the joint. Further, the code does not require explicit calculation of joint shear stress and design for the same.

This code was published in 1993 and based on experience gained on its use, it now requires revision and upgrade. For instance, while seismic codes of developed countries allow all the column bars to be spliced at the same location (even though with a penalty on the lap length), IS:13920 insists that not more than 50 percent of the bars be lapped at one location. This makes the Indian provision somewhat impractical for tall buildings using mechanical construction methods.

Table 17-4. Gap width for adjoining structures as per IS:4326-1993

Serial #	Type of Construction	Gap Width/Story[1] in mm for Design Seismic Coefficient $\beta I \alpha_o = 0.12$
1.	Box system or frames with shear walls	15.0
2.	Moment resistant reinforced concrete frame	20.0
3.	Moment resistant steel frame	30.0

1. Minimum total gap is 25 mm. For any other value of $\beta I \alpha_o$, the gap width shall be determined proportionately.

IS:4326-1993, DESIGN AND CONSTRUCTION OF BUILDINGS

This code provides general principles for earthquake resistant buildings. For instance, it provides that (a) the buildings should have a simple rectangular plan that is symmetrical, (b) buildings with plans like *L, V*, *T* shapes, be separated into rectangular parts by providing separation sections, (c) bracing effect of stairs be eliminated by providing sliding joints between the stairs and the floors, and in case of large stair halls, those should be separated from the rest of the building by separation joints, and (d) isolated footings or pile caps in soft soils be provided with reinforced concrete ties. It requires that adjoining structures, or parts of the same structure, be separated by a minimum distance specified in Table 17-4 to prevent pounding damage. Further, for buildings of height exceeding 40 m, it suggests that the separation be not less than the sum of the deflections of two adjacent buildings as per dynamic analysis. However, the draft revision of IS:1893 requires that the separation gap should be at least *R* times the sum of calculated story displacements, where *R* is the response reduction factor as per Table 17-3.

Other than the general specifications for buildings, a few of which have been discussed above, the code gives empirical specifications for masonry buildings. These are briefly discussed in Chapter 11, Masonry Buildings.

IS:13935-1993, PROVISIONS ON REPAIR AND SEISMIC STRENGTHENING OF BUILDINGS

These guidelines cover selection of materials and techniques for repair and seismic strengthening of masonry and wooden buildings. The code also provides very brief coverage for reinforced concrete members in such buildings. Thus, the code does not cover the reinforced concrete frame or shear wall buildings. Most of the material in this standard has been drawn from Chapter 9 on *Repair, Restoration and Strengthening of Buildings* of the IAEE Guidelines (IAEE, 1986).

CODES NEED UPDATING

It is clear that the development of seismic codes in India started rather early. However, with time, progress became quite sluggish. The main code (IS:1893) was first published in 1962, and revised in 1966, 1970, 1975, and 1984. The next revision is still in process: while Part I of the next revision is now at press, revision of the other parts is not yet complete. Moreover, even in the earlier revisions, the focus tended to be on buildings and the provisions for other structures did not always receive the due attention. As a result, for instance, the provisions on bridges are very much obsolete and do not yet require the seismic design force to be a function of the bridge flexibility. The seismic zone map was last revised in the 1970 edition, and the next revision of the zone map was initiated after the 1993 Latur earthquake and is to come out only now in the IS:1893 Part I.

The codes in India are developed by the Bureau of Indian Standards (BIS). BIS is responsible for developing standards not just for the civil engineering industry, but also for a very wide range of other products and processes. The Civil Engineering Division at BIS acts as secretariat, and the actual work is carried out by committees consisting of professionals who serve on a voluntary basis: they are neither compensated for their time nor provided support for travel expenses in connection with the committee meetings. The professional societies such as the Indian Concrete Institute, Indian Society of Earthquake Technology, Association of Consulting Civil Engineers (India), Indian Buildings Congress, and Indian Society of Structural Engineers have not yet developed strong interest in developing their own codes or pre-code documents. Development of pre-code or model-code documents by the professional societies can go a long way in expediting the revisions and incorporation of the latest developments into the Indian codes.

Since the codes are not being revised in a timely manner, the gap in state-of-the-practice in India versus that in other countries has been increasing with time. For instance, the Indian seismic design provisions for highway bridges (IRC 6) have remained the same for more than 30 years, despite the fact that in other earthquake-prone countries, state-of-the-practice on bridges has advanced considerably. Bridge provisions are barely four pages long (IRC 6-2000). By comparison, the seismic provisions and commentary of Caltrans (ATC-32, 1996) and Japan (PWRI, 1998) run to more than 200 pages.

The question then is—what is the appropriate level of sophistication to be brought into Indian practice? On one hand, it will be reasonable to upgrade codes to an intermediate level of sophistication in the immediate future. In about 8 or 10 years, another major upgrade can be attempted. On the other hand, there is an argument that in order to ensure better compliance, very simplistic solutions should be adhered to and that even an intermediate level of sophistication at this stage will only discourage professionals. The choices to be made here are indeed very difficult.

What is being said about seismic code provisions on bridges is true for many other structures. To date, no code provisions are in place in India for ductile detailing of steel structures in high seismic regions or for nonstructural elements of a building.

CODE COMPLIANCE

Before the Bhuj earthquake, in most parts of the country, seismic codes were not mandatory. Sometimes design or construction documents would require compliance with all relevant codes and in that sense there was an indirect requirement. Further, most of the government departments handling building construction would tend to follow the codes. Otherwise, it was generally the discretion of the owner, builder, or engineer whether or not to apply the seismic code provisions in design and construction. The results are obvious in the Bhuj earthquake, where most of the multistory collapses occurred in the construction financed by the private sector, particularly where the building was built by a developer and individual flats sold immediately thereafter to the users.

India has a very complex socio-cultural environment and its built environment encompasses the widest possible range: from nonengineered dwellings built without any technical skills to the most modern buildings. Because all the earthquakes in recent years occurred in rural or semi-urban environments and because most of the deaths were caused by collapse of nonengineered structures, the attention of decisionmakers and leaders was diverted by the nonengineered construction. In the process, there was a sense of trivialization of the earthquake engineering issues. For the first time in India, the Bhuj earthquake has caused a large number of collapses of multistory modern buildings, whose collapse resulted in a significant number of deaths; in fact, most of the multistory buildings that collapsed were built in the last ten years. This forced attention to the issue of earthquake safety of engineered construction.

Before this earthquake, the Ahmedabad Municipal Corporation required the structural engineer to give a certificate regarding the building wherein one was required to specify the live load, wind load, and the earthquake load considered in the design. Thus, there was an indirect requirement that the buildings should be designed for seismic loads. Unfortunately, most often the structural engineers put a cross in front of earthquake loads and the building permits were still issued routinely. However, in general, bylaws in most cities did not require compliance with seismic codes anyway. Several states have now made compliance with the seismic codes mandatory, and several local authorities now insist on an explicit undertaking by the structural engineer that the building complies with seismic codes.

CONFUSION OVER SEISMIC REQUIREMENTS

Since the January 2001 Bhuj earthquake, India is going through a transition phase in seismic issues and there is bound to be confusion in the short term. For instance, after the earthquake, bylaws of a city have the following provision on soft-story buildings:

> *In case the building is constructed on stilt, it shall have enough shear walls of required dimensions and strength in the stilted story so as to ensure almost equal (with variation between ±10 percent) lateral stiffness along both axes to that of the upper floor (including the stiffness contributed by in-fill walls).*

Clearly, the above requirement is too stringent. Even the stiffness calculations for RC frame building with masonry infills cannot be accurate within 10 percent, and to expect that all buildings will have uniform stiffness to that extent is unrealistic. Further, the same byelaws also require compliance with the Indian seismic code IS:1893. The revision of this code (at press) includes altogether different empirical provisions for treating the soft-story buildings. It requires that (a) columns and beams of the soft story be designed for 2.5 times the seismic design forces, or (b) columns be designed for design forces and that shear walls also be provided in the soft story with design strength of 1.5 times the design story shear and design story moment. In many cases, the above requirement on stiffness uniformity will conflict with the code requirement.

Following the earthquake, many state governments issued requirements on buildings to comply with seismic codes. Some of these were hastily drawn orders, knee-jerk reactions to the event. For instance:

- 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 programs in the country do not teach earthquake-resistant design and construction. This requirement was later dropped and the requirement for structural engineer was defined based on minimum experience depending on: (a) building height, (b) seismic zone, (c) undergraduate versus postgraduate qualifications.
- It seems that in some areas, buildings are now required to be designed for one zone higher than that specified in the seismic code.
- Building officials of the local government of a city located in Seismic Zone III required the structural engineer to 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. Moreover, this undertaking is required on a legal stamp paper.
- Yet another state government required that all seismic codes be complied with along with the Building Materials and Technology Promotion Council (BMTPC) Guidelines (1998). The BMTPC guidelines essentially discuss the provisions of Indian 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.

- In a town located in Seismic Zone III, local administrators became quite concerned about seismic safety. Based on technical advice, they implemented certain requirements for building construction, but many of these had no bearing on seismic safety. Moreover, they made geotechnical investigations for every building mandatory and there were inadequate facilities for such investigations. The result was a major setback to the buildings industry in that town.

Despite the above shortcomings—which are understandable in view of the lack of earthquake engineering expertise available 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. Moreover, the increased concern about earthquake issues among the decisionmakers and administrators will contribute enormously to earthquake risk reduction in India.

LICENSING OF STRUCTURAL ENGINEERS

In India, the situation of engineers is different from that of other professionals. The professions of medicine, law, chartered accountancy, and architecture are governed by legislation that provides legal status and regulates these professions. There is no such legislation for civil engineers, and the entire profession is quite disorganized. For instance, Raj (2001) quotes a recent judgment by one of the high courts on a petition filed by the Institute of Architects against allotment of a project to an engineering firm:

> *Architects are professionals and their qualifications are enumerated in the Schedule to the Architects Act. So far as the Civil Engineers are concerned, nothing has been placed before us indicating that they are required to be enrolled with the statutory body recognized under the Act empowering the statutory body to exercise powers over the members or to take action such as disciplinary action. An Engineer cannot be equated with an Architect.*

There is no licensing system in the country for structural engineers and any person with a degree in Civil Engineering can generally practice as one. In a few cities, the structural engineers' licenses are issued by local authorities based on qualifications and number of years of experience. Thus, as such there are no mechanisms for a client to ensure that the engineer involved in the project is indeed competent in general, and in seismic engineering in particular.

In the absence of proper legal standing of the structural engineering profession, most often the entire building project is undertaken by the architect and the structural engineer works as a sub-consultant to the architect. Many good structural engineers avoid such projects and focus on specialized projects such as the industrial buildings where they can have a more serious role.

The professional associations of civil engineers in the country have long demanded a formal regulation of their profession through an Engineers Bill in the Indian Parliament. Even before the earthquake, developments on the General Agreement on Trade in Services (GATS) under the World Trade Organization (WTO) had been causing concern that in the absence of such a regulation, India will be at a significant disadvantage. To ensure free flow of services across their boundaries, different countries need to examine each others licensing processes and enter into bilateral or multilateral agreements to recognize registration and licenses of engineers of other countries. In the absence of a proper licensing system for engineers in India, it is not possible for the country to enter into such agreements with other countries. Thus, any engineer from any other country could practice in India while Indian engineers will not be able to practice in other countries.

However, the earthquake in Gujarat pressed the urgency of the problem, and the Government of India agreed to proceed with the formation of the Engineering Council of India, followed by an Engineers Bill in the Parliament. The profession is keenly awaiting these developments.

The concept of professional liability has not yet been developed fully in India. In the absence of proper regulation, the concept is practically nonexistent in the structural engineering profession. Most structural engineers do not carry any liability insurance. However, the prosecution of engineers and builders associated with the collapsed buildings in Ahmedabad has clearly outlined the associated risks for the engineers. The engineers remain fearful that they could be charged with serious criminal offenses if buildings designed by them in good faith do not perform well during future earthquakes. They see themselves carrying unlimited liability for the professional services provided and it adversely affects their morale. A robust framework of professional liability and insurance is a must for ensuring safety of the built environment.

TRAINING AND EDUCATION

Unfortunately, the issue of training structural engineers in earthquake design and construction has still not received adequate attention, and there seems to be an impression that making the seismic codes mandatory will solve the earthquake problem. There is still a notion among decisionmakers and administrators that an average engineer should be able to follow the seismic code and comply with it.

The fact that the earthquake codes have substantial sophistication and engineers require significant training and supporting resource materials before they can correctly implement the same is still not recognized. This is particularly so, since engineers have not come forward to express their difficulties in seismic engineering.

Professionals need to emphasize to decisionmakers that compliance of seismic codes requires fairly good earthquake engineering expertise on the part of an engineer and for this substantial training and resource materials are imperative. Massive human resource development efforts—in the form of substantial training and resource materials—are necessary to correct this situation. The efforts need to be directed at institutional development, teaching of earthquake engineering in the engineering and architecture curricula, and continuing education activities for the professional engineers.

FUTURE NEEDS FOR TRAINING AND EDUCATION

Earthquake engineering is not taught at the undergraduate level in Indian technical institutions. Even in the Masters' program in structural engineering, very few institutions in India give any exposure to earthquake engineering. Further, there are inadequate opportunities for continuing education in general, and in earthquake engineering in particular. Hence, with rapid developments in earthquake engineering, the gap between the knowledge of an average engineer in India and state-of-the-practice in earthquake-resistant construction has been increasing at an alarming rate. Infrequent revisions of the seismic codes have further compounded this problem. The Bhuj earthquake has clearly brought out the training and education needs in the area of earthquake engineering. For instance:

1. A sound strategy must be evolved for training of engineers in the State of Gujarat. This is essential so that short-term reconstruction, repairs, and retrofitting projects can proceed satisfactorily and so that the State can gain long-term, sustainable expertise in earthquake engineering. The State cannot depend on outside expertise for routine earthquake engineering matters in the long run. Similarly, other states also need to develop and maintain adequate expertise in earthquake-resistant construction.

2. To have structural engineering manpower working for the local and the state governments, and who will be experts in earthquake engineering, a suitable cadre management and incentive system needs to be developed. Otherwise, most engineers may be reluctant to become specialists for fear of blocking their career prospects.
3. There is an urgent need to develop strong teaching and research programs 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, and for institutional development.
4. Currently, no system exists in the country to ensure that the structural engineer providing technical services is competent to the job. This is a particularly serious problem in the area of seismic engineering. Hence, as a pilot project, a voluntary licensing test for seismic engineering could be developed, and the consultants for major reconstruction/rehabilitation projects could be asked to qualify the same. As more experience is gained on such tests, its scope can be widened before making it mandatory for obtaining a structural engineering license.
5. At present the municipal engineers are not required to review the structural drawings or design. Hence, most municipalities do not have in-house expertise for the same. The municipal engineers need to be trained so that they are able to carry out a general review of structural drawings.

CONCLUSIONS

The Bhuj earthquake of January 26, 2001 was the first major earthquake in India to hit an urban area, and the destruction it caused was widely telecast. While many developed countries have been able to considerably reduce the earthquake risk, the Bhuj earthquake is a grim reminder of the vulnerability of Indian construction to damaging earthquakes. This earthquake has done more to sensitize the country to its earthquake problem than any other action or event in the last 50 years. It has led to many long-term programs to improve earthquake safety. For instance, numerous conferences and seminars in earthquake-resistant construction were organized all over the country by the professional societies.

India has a fairly good range of seismic codes covering a variety of structures, ranging from mud or low-strength masonry houses to modern buildings. Development of building codes in India started rather early. However, in recent years there have been rather infrequent revisions of the codes. As a result, some of the code provisions are obsolete and require major upgrading. There has not been enough attention paid to development of quality manpower in earthquake engineering. Because there are not enough professionals with state-of-the-art background, development of codes is sluggish. Since the codes are not revised as earthquake engineering knowledge advances, professionals do not get a chance to upgrade themselves in the subject. The recent e-conference on Indian seismic codes (NICEE 2002) hosted by the National Information Centre of Earthquake Engineering at Indian Institute of Technology Kanpur has brought out many interesting issues on code compliance.

Code development and compliance, and licensing and training for structural engineers are key to achieving an earthquake resilient society. A suitable infrastructure is needed wherein only competent structural engineers can practice the profession and the local municipal authorities are able to ensure compliance. Alarmed by the damages caused by this earthquake, the seismic codes have now been made mandatory in several states; however, that is only one part of the solution. There still is a long way to go in terms of code development, training of professionals, inclusion of seismic engineering in the technical education system, development of commentaries and other resource materials, and code compliance.

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
- A healthy professional environment
- A vibrant academic system, covering education and research that supports the above.

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 the 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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