Historical Developments And Current Status of Earthquake Engineering in India

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SUMMARY

Some of the largest earthquakes of the world have occurred in India and the earthquake engineering developments in the country started rather early. After the 1897 Assam earthquake a new earthquake resistant type of housing was developed which is still prevalent in the north-east India. The Baluchistan earthquakes of 1930's led to innovative earthquake resistant constructions and to the development of first seismic zone map. The institutional development started in the late 1950's and earthquake engineering concepts have been applied to numerous major projects in high seismic regions in the country. Extensive damage during several moderate earthquakes in recent years indicate that despite such early gains, earthquake risk in the country has been increasing alarmingly. Most buildings even in high seismic regions of the country continue to be built without appropriate earthquake resistant features. At the higher end of earthquake technology, the gap between state-of-the-practice of earthquake engineering and research in India, bench-marked against the advanced countries, has been widening. The paper explores these issues in detail.

1. INTRODUCTION

Indian earthquake problem cannot be overemphasised. More than about 60% of the land area is considered prone to shaking of intensity VII and above (MMI scale). In fact, the entire Himalayan belt is considered prone to great earthquakes of magnitude exceeding 8.0, and in a short span of about 50 years, four such earthquakes have occurred: 1897 Assam (M8.7), 1905 Kangra (M8.6), 1934 Bihar-Nepal (M8.4), and 1950 Assam-Tibet (M8.7).

Earthquake engineering developments started rather early in India. For instance, development of the first seismic zone map and of the earthquake resistant features for masonry buildings took place in 1930's, and formal teaching and research in earthquake engineering started in late 1950's. Despite an early start, the seismic risk in the country has been increasing rapidly in the recent years. Five moderate earthquakes in the last eleven years

(1988 Bihar-Nepal: M6.6, about 1,004 dead; 1991 Uttarkashi: M6.6, about 768 dead; 1993 Latur: M6.4, about 8,000 dead; 1997 Jabalpur: M6.0, about 38 dead; and 1999 Chamoli: M6.5, about 100 dead) have clearly underlined the inadequate preparedness of the country to face damaging earthquakes. The paper discusses the developments of earthquake engineering in India during the last one hundred years, the current status of earthquake risk reduction in India, strengths and weaknesses of Indian model of earthquake engineering developments, and the future challenges.

2. HISTORICAL DEVELOPMENTS

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 catalogue 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 very substantially to the 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*. 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.

Some of the early Indian earthquakes also led to interesting insights into the subject. For instance, the 1819 Runn of Cutch earthquake (Oldham 1898) of M8.3 created a fault scarp about 100 km long and 3 m high (named *Allah Bund*: embankment created by the God); it provided the *earliest clear and circumstantially described occurrence of faulting during earthquakes* (Richter 1958). The descriptions of 1897 Assam earthquake provided the *principal model for the highest grade, XII, of the MMI Scale* (Richter 1958). Referring to Oldham's 1899 volume on Assam earthquake, Tandon (1959) states: *It was in this study that Oldham, for the first time recognized the existence of longitudinal (P), transverse (S) and surface (L) waves on records of seismographs, and thereby laid the foundations of modern seismology.* The devastation of the 1897 earthquake led to the development of the *Assam-type house*, which later became popular in the entire north-eastern India. The first seismograph in India was installed in 1898 at the Colaba Observatory in Bombay.

The first major initiatives for earthquake resistant constructions emerged after the Baluchistan (now in Pakistan) earthquakes of the 1930's. After the Mach earthquake of 1931 (M7.4; intensity VIII on RF scale), about 60 km from Quetta, formal earthquake resistant construction was carried out in the region for the railways using a seismic coefficient of 0.10g. S.L. Kumar, the young railway engineer who designed these constructions, documented this work (Kumar 1933), provided the first seismic zone map of the country and suggested seismic design coefficients (Table 1). In the 1935 Quetta earthquake (M7.6; intensity upto X on RF 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 1: Seismic factors for different seismic zones 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.

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

Clearly, the 1935 Quetta earthquake was interesting from several view points. For the first time, serious and systematic efforts were made in the country at earthquake resistant constructions and for developing earthquake codes. More importantly, for the first time in India, efficacy of earthquake resistant constructions was tested during a severe earthquake. The evolution of the provision of 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: *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* (GSI, 1939).

The concrete industry developed an early interest in earthquake engineering. The *Indian Concrete Journal* brought out a special issue (ICJ, 1934) on the 1934 Bihar-Nepal earthquake with excellent well-captioned photographs. After the Anjar (Cutch) 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 which was revised in 1958 and 1965 (CAI, 1965).

Institutional base for earthquake engineering was established around 1958, when after a visit to the California Institute of Technology (Caltech), Professor Jai Krishna started teaching and research in earthquake engineering at the University of Roorkee. First of the four-yearly symposium on earthquake engineering was organised at Roorkee in 1959. Professors D.E. Hudson and G.W.Housner of Caltech stayed at Roorkee for a few months to help in setting up the academic programme and in organising the first symposium. School of Research and Training in Earthquake Engineering (now Department of Earthquake Engineering, DEQ) was set up at Roorkee in 1960. The Indian Society of Earthquake Technology (ISET) was established in 1962 which now has about 1,000 members. The first Indian seismic code was published in 1962 (IS:1893-1962) and a comprehensive earthquake catalogue was published in 1983 (ISET, 1983).

Several academics from India have also played major roles in the international activities. For instance, Professor Jai Krishna and a few others helped Yugoslavia establish earthquake engineering activities at Skopje. India hosted the 6th World Conference and Professor Jai Krishna served as President of the International Association of Earthquake Engineering (IAEE). Professor A. S. Arya chaired the IAEE group to develop the seismic guidelines for non-engineered constructions (IAEE 1986), and recently received the prestigious Sasakawa Award.

The important research projects undertaken at Roorkee in the early years include: lateral resistance of masonry walls and enclosures, development of indigenous strong motion instruments, and studies on liquefaction. Research on base isolation of masonry buildings was conducted at DEQ as early as 1970's. Several innovative experimental set ups were developed at Roorkee to conduct research, including a two-dimensional shake table. DEQ provided earthquake engineering consultancy for major dams and nuclear power plants; for instance, the Narora atomic power plant located on a site with deep alluvium (zone IV) and the rock-fill dam at Tehri in the Himalaya (zone V). State-of-the-art non-linear dynamic analysis has been performed by DEQ for the seismic safety evaluation of Tehri dam.

The M6.5 Koyna earthquake of 1967 (Berg et al., 1969) yielded the first strong motion record in India. Koyna is the most damaging (about 200 dead) of the reservoir-induced earthquakes in the world. The Koyna dam (103 metre high concrete gravity), designed for 5%g static horizontal force coefficient, sustained a much stronger shaking; at mid-height of the dam, peak ground acceleration of 0.45g and 0.39g in horizontal and 0.36g in vertical direction were recorded. The dam performed quite well with only nominal damage and could be repaired and retrofitted. This earthquake, being the first damaging earthquake to occur in India after the setting up of the earthquake school at Roorkee, helped create awareness about the earthquake problem and justified the investments in the institutional development.

3. CURRENT STATUS AND MAJOR CONCERNS

3.1 Development of Seismic Codes:

The main seismic code (IS:1893-1962) has been revised in 1967, 1970, 1975, and 1984; its next revision is now in progress. It provides seismic design criteria for buildings, bridges, liquid retaining tanks, stacks, gravity dams, earth dams, and retaining walls. Another code (IS:4326) was published in 1967 (revised in 1976 and 1993): it outlines the aseismic design and construction requirements for buildings. In 1993, with publication of four new seismic codes (IS:13827, IS:13828, IS:13920, and IS:13935), India became perhaps the first country to have developed codes on low-strength non-engineered masonry constructions. The early seismic zone maps of the country (e.g., Kumar, 1933; West, 1937; Auden, 1942; Krishna, 1959) divided the country into three or four seismic zones which were described in qualitative terms (e.g., areas liable to severe damage, moderate damage, etc.). The first formal zone map (IS:1893-1962) divided the country into seven seismic zones (0 to VI) corresponding to areas liable to MM intensity of: less than V, V, VI, VII, VIII, IX, X and above, respectively. The zone map was revised somewhat in the 1966 version. After the 1967 Koyna earthquake, the zone map went through a major revision (IS:1893-1970). It reduced the number of zones from seven to five (I to V). Next revision of the zone map has been taken up after the Latur (1993) earthquake and the number of zones will now be further reduced to four (II to V).

A major concern today remains the development of Indian seismic codes. Over the years, the dynamism to update our seismic codes seems to have been lost as seen by the frequency of the revision of the main code (IS:1893). The code committee decided to revise the seismic zone map in 1976 (Krishnaswamy, 1977); however, this could not be done. Map revision initiated after the 1993 Killari earthquake is yet to be formalised. Sluggish development of codes has led to some aspects of Indian codes being very obsolete. For example, the seismic design force prescribed by the Indian code for bridges is too low by the international bench marks, and these provisions are so obsolete that the design force on the bridge does not depend on its flexibility (e.g., Jain and Murty, 1998). This has resulted in the bridges of recently started Delhi Metro project being designed for a constant coefficient without consideration of the structure's natural period. Another concern is the lack of integration of seismic codes with other construction codes. For instance, the main concrete design code (IS:456-1978) does not give cross reference to the seismic detailing code (IS:13920-1993 now, and IS:4326-1976 earlier) and often the professional engineers are unaware of the additional detailing requirements for high seismic regions. Indian seismic codes are yet to incorporate some of the modern concepts such as the probabilistic features. There is no effort to develop code commentaries and the seismic codes are yet to be translated into the regional languages.

3.2 Code Compliance and Earthquake Resistant Constructions:

Indian codes, developed by the Bureau of Indian Standards (BIS), are not mandatory and are only in the nature of guidelines. The construction as such is governed by the municipal bye-laws which is within the jurisdiction of the state governments. Unfortunately, the seismic provisions have not yet been incorporated into the building bye-laws. Since majority of the building construction activity in the country is carried out in an informal manner with no involvement of engineers, most of it is done with no regard to seismic safety. The government departments and public sector organisations manage a large fraction of the formal sector constructions and are formally committed to follow the codes. However, even in such organisations, the seismic aspects do not get due attention. The situation is similar even when professional consultants are involved in a project. One needs to keep in view that the concept of liability of the professional for poor services has not yet developed in the country. Even when an engineer wants to ensure aseismic construction, he is often unable to do so due to lack of training, sometimes vaguely worded and obsolete codal provisions, and the absence of codal commentaries. Some government construction agencies and private sector consultants, however, do tend to fulfill the codal requirements rigorously.

On the one hand, the country has failed miserably in ensuring earthquake-resistant constructions in high seismic regions. On the other hand, numerous major projects such as large dams and nuclear power plants have been built in high seismic regions with due regard to earthquake safety and for which seismic analysis and design have been handled within the country. Also, considerable experience has been gained in the country in seismic repair and strengthening of masonry buildings following a number of moderate earthquakes in the recent years. Yet, at the higher end of the earthquake technology, the gap in our state-of-the-practice with the developed countries has been widening. Till date, no structure in India has utilised base isolation or other seismic control devices; the only exception is the construction in progress of two base-isolated one-storey demonstration buildings in Killari village in the 1993 Latur earthquake affected region (EERI, 1999).

3.3 Institutional Development:

The establishment of a separate Department at Roorkee proved instrumental in rapid early growth of earthquake engineering in India. The DEQ provides under one roof all disciplines associated with earthquake engineering and currently has about 25 faculty members. It was developed unlike other typical academic departments in the sense that providing consultancy and testing services was one of its major aims and this enabled the incorporation of earthquake engineering inputs into major projects. However, the presence of such a department also had a somewhat negative fall-out as it was felt that the DEQ can provide whatever earthquake solutions the country needs, and no efforts were made towards further institutional development. For instance, the five prestigious Indian Institutes of Technology (IIT's) and concerned laboratories of the Council of Scientific and Industrial Research (CSIR) did not take up earthquake engineering in a significant manner until very recently. This meant that the number of highly-trained manpower got highly restricted. More importantly, the DEQ was in a peculiar situation of having to meet two often conflicting objectives: on one hand to promote earthquake engineering education and carry out research and development, and on the other hand, carry out enough industrial consultancy to meet bulk of its expenditures. This also blurred the difference between the Department encouraging and supporting the professional engineers versus it competing with the professional firms. And finally, it did not challenge the Department to have a healthy competition from groups in other institutions.

The institutional development with regard to the earth science groups working on earthquake problem has been somewhat better. A number of universities have fairly strong earth science groups, many of them carry out earthquake related research. Two major organisations, Geological Survey of India and Seismology Division of the India Meteorological Department, have had a long history of working on earthquakes. Besides, a number of research institutions in earth sciences were set up after independence which have considerable interest in earthquakes.

3.4 Involvement of Professionals and Professional Societies:

The earthquake engineering developments in the 1930's were spearheaded by the professional engineers from railways and military. However, after the setting up of DEQ at Roorkee the discipline came to be regarded as some sort of a super-specialty and the professionals tended to leave the subject for the academics. The ISET has over the years been run primarily by academics without much involvement of the professionals. Other professional associations, such as the Indian Concrete Institute or the Indian Institute of Bridge Engineers, are run by professionals and are far more active; they have not developed much interest in the aseismic constructions, leaving it perhaps to ISET.
Lack of involvement of professional engineers in seismic agenda of the country has been extremely detrimental to the cause of seismic risk reduction. It shows up in numerous manifestations, and poor state of our seismic codes is only one such example. With no pressure from the users, that is the professional engineers, the codes cannot be expected to remain in a healthy dynamic state of development.

3.5 Education, Training and Manpower Development:

Undergraduate civil engineering education in India, as in other countries, does not expose the students to the issues of seismic risk. In the post-graduate programmes in structural engineering, some students may get exposed to dynamic analysis and a still fewer numbers to aseismic design (Murty et al., 1998). The total number of Master's graduate from DEQ, IIT's and other premier institutions with specialisation in earthquake engineering will perhaps be less than 40 per year and many of them choose a non-civil engineering career. Thus, a huge engineering work force, having no formal exposure to seismic design in college, requires training through continuing education programmes. Short courses for professionals have been conducted at Roorkee for a long time now. Since 1992, IIT Kanpur has conducted numerous short courses on seismic design of reinforced concrete buildings, the most common type of multi-storey buildings in urban areas.

For a large country like India, the number of agencies, organisations and competent individuals involved in earthquake engineering is totally inadequate to fulfil its needs. The shortage of highly-trained personnel is particularly severe in certain specialisations, e.g., engineering seismology, and geotechnical earthquake engineering. The situation needs to be overcome by training of young faculty members and researchers in appropriate international environment.

3.6 Research Facilities:

A 3.5m x 3.5m biaxial shake table was installed at Roorkee in 1986 with a 20 tonne payload capacity. This is the only large shake table available in the country for earthquake engineering work, and hence, has been used primarily for testing rather than research. Clearly, more such facilities are needed; moreover, even this facility now needs major upgradation. Modest facilities for conducting cyclic tests on structural components using state-of-the-art actuators are now available at several of the Institutions: IIT's at Kanpur, Bombay, Delhi and Madras, Roorkee University and some of the CSIR laboratories. The country is yet to develop or acquire a large eccentric mass shaker for carrying out forced vibration tests on proto-type structures. A state-of-the-art centrifuge facility for geotechnical earthquake engineering is currently being developed at IIT Bombay.

The India Meteorological Department maintains the national seismological network. Many other institutions and organisations operate local microseismic and strong motion networks. The University of Roorkee maintains three major strong motion arrays: in the north-east India, Garhwal Himalaya, and Kangra region. These have given many high quality accelerograms in the recent moderate earthquakes. The instrumentation network in the peninsular India has been strengthened after the 1993 Latur earthquake with the assistance of a World Bank loan. Unfortunately, no strong motion records were obtained during the Latur (1993) and the Jabalpur (1997) earthquakes in the peninsular India. Ground motion characteristics of the peninsular India may be quite unusual, with a very large high frequency content, as seen by a small event recorded by IIT Kanpur in the Latur area recently.

3.7 Some Other Concerns:

A number of groups in the country have carried out post-earthquake reconnaissance studies of the recent damaging earthquakes. However, we are yet to develop a formal *learning from earthquakes* programme which will ensure that reconnaissance of all damaging earthquakes are carried out in a systematic manner and the findings disseminated expeditiously. The country is yet to formally take up activities in seismic microzonation. There is not much activity in the area of earthquake prediction. Data sharing remains a major handicap; we have yet to develop mechanisms for open data sharing.

There are not much inter-institutional or inter-disciplinary collaboration activities in the country. Except the DEQ, none of the institutions in the country have strong groups of engineers and earth scientists working together on earthquakes. The result is that both groups, engineers and scientists, often tend to have a rather narrow view of the earthquake problem. Similarly, architects, town planners, and social scientists have no involvement in earthquake issues. The Himalayan Seismicity programme of the Department of Science and Technology has enabled nurturing of a reasonable level of activity in the area of seismology. A similar programme on earthquake disaster mitigation needs to be operated by a major nodal agency in the country to nurture the research, development and extensional activities. A vibrant *earthquake industry* wherein earthquake-related services and products can be conveniently made available within the country on a commercial basis is yet to develop (Murty et al., 1999).

Even though some academics maintain good international linkages, the country has not yet developed any significant official collaborative programmes with other earthquake countries. In recent years, there have been no worthwhile collaborative workshops with researchers from outside the country. Even the four-yearly symposium at Roorkee, which used to attract a sizable number of participation from abroad, has ceased to do so. On the other hand, participation of Indians in the international conferences outside has been coming down due to weak Indian currency. The country which hosted the 6WCEE in 1977 at N. Delhi was represented by just six persons in the 10WCEE and by thirteen persons in the 11WCEE.

4. FUTURE OUTLOOK

Two important elements emerge which need urgent attention to improve the earthquake safety scenario in the country: the institutional development whereby the discipline of earthquake engineering is nurtured and developed at a much larger number of locations, and involvement of professional engineers and architects into the seismic agenda. Quality manpower in earthquake engineering is clearly in short supply and a major effort needs to be made to strengthen the same. With the above background, it may be pertinent to discuss some recent positive developments:

1. In recent years, earthquake engineering activities have spread to other institutions in the country and active earthquake engineering groups now exist at IIT Kanpur and Mumbai. Also, some of the CSIR laboratories are now engaged in earthquake engineering research and consultancy. In addition, Nuclear Power Corporation and other organisations dealing with nuclear power plants now have considerable capabilities in earthquake engineering as is the case with some of the top consulting firms.

1. A few individual enthusiasts are now spearheading the efforts towards earthquake safety in their own region. For instance, a few engineers and architects in Darjeeling (zone IV) have been instrumental in incorporation of nominal aseismic provisions in the building bye-laws for that region. Another local group has been pushing the agenda of earthquake safety in Imphal (zone V) in north-east India.
2. The highly successful continuing education programmes conducted by IIT Kanpur at different locations in the country, at times with class size of about 100 persons, have created considerable interest amongst professional engineers, and clearly demonstrated that the professional engineers are willing to join the seismic safety agenda if given the right tools.
3. The Indian Concrete Journal, a very old and respected journal with wide-spread readership amongst the professional engineers, has brought out two exclusive issues related to earthquake engineering (ICJ 1994, 1998). The recently published Vulnerability Atlas of India (BMTPC, 1997) is expected to help contribute significantly in sensitising the administrators and engineers to the earthquake problem.
4. Five damaging earthquakes in the last eleven years have made it easier to initiate discussions in the country on earthquake issues. The enormous tragedy of the Latur earthquake and the massive earthquake rehabilitation programme thereafter have contributed significantly to capacity building and awareness at least in and around Maharashtra. After the recent Chamoli earthquake, there is now a discussion on setting up of a Earthquake Risk Evaluation Centre for north India.
5. A National Information Centre for Earthquake Engineering is in the process of being set up at IIT Kanpur with the objective to acquire and disseminate the earthquake engineering materials.

In a developing country such as India, basic poverty issues like food, shelter, health, and education remain the highest priority and natural disaster mitigation does not get the priority that it should. Amongst the major challenges ahead is to sensitise the policy makers, the politicians and the administrators to the issues of earthquake safety. With five damaging earthquakes in the last eleven years, this is the right time to initiate a sustained and proactive effort in this direction.

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