# Earthquake safety of houses in India : Understanding the bottlenecks in implementation

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in

*The Indian Concrete Journal*

Report No: IIIT/TR/2014/-1

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August 2014

# Earthquake safety of houses in India : Understanding the bottlenecks in implementation

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According to current seismic zone map around 60% of India's land area is prone to moderate to severe earthquakes. And earthquake losses, in terms of life and property in last 2 decades have been high, with housing contributing to over 95% of life loss; this failure attributed to improper design and construction practices of housing. Thus, all the three factors influencing earthquake risk of houses in India are above danger levels in many districts of India – hazard, exposure and vulnerability. This paper classifies housing risk in the entire country into four groups; about 47% of population is living in the highest risk. Gigantic effort is required to mitigate the risk. The paper also suggests some steps to move forward to reduce earthquake risk to housing in India.

## 1. EARTHQUAKE RISK OF HOUSING

Earthquake Risk is the projected aggregated effect of the expected number of lives lost, persons injured, property damaged and economic activity disrupted due to an expected strong earthquake in an area. Usually, it is represented as the product of the prevalent earthquake hazard (H) of the area, the number of persons exposed to the earthquake hazard (E), and the known vulnerability (V) of the houses in that area, as:

$$Risk = H \times E \times V \quad ...(1)$$

Each of these components of risk has its own characteristics, which can be spatial (e.g., hazard) temporal (e.g., exposure) and thematic (e.g., vulnerability of houses).

### 1.1 Seismic Hazard (H)

Earthquake Hazard is defined as the potential threat of occurrence of a damaging earthquake, within the design life of the house in a given area. The hazard due to an earthquake can be reflected by expected intensity of ground shaking (quantified by PGA, PGV and PGD), soil liquefaction, surface fault rupture and slope instability. India has experienced several major earthquakes in the past few decades and according to IS 1893 (Part I):2007 around 60% (12% in Zone V, 18% in Zone IV, 26% in Zone III and 44% in Zone II) of its landmass is prone to moderate to severe earthquake shaking intensity. Especially, in the last 23 years, the country has witnessed several moderate earthquakes (Table 1) (Bihar-Nepal border (M6.4) in 1988, Uttarkashi (M6.6) in 1991, Killari (M6.3) in 1993,

**Table 1. Human fatalities during past earthquake events**

| Year | Location | Casualties | Buildings Collapsed |
|---|---|---|---|
| 1988 | Bihar | 1,004 | 2,50,000 |
| 1991 | Uttarkashi | 768 | 42,400 |
| 1993 | Killari | 8,000 | 30,000 |
| 1997 | Jabalpur | 38 | 8,546 |
| 1999 | Chamoli | 100 | 2,595 |
| 2001 | Bhuj | 13,805 | 2,31,000 |
| 2004 | Sumatra | 10,805 | Not available |
| 2005 | Kashmir | ~1,500 | 4,50,000 |
| 2006 | Sikkim | 2 | Not available |

[Murty, 2007; Sebeer et al, 1993; Jain et al, 1994; Jain et al, 1997; Jain et al, 1999; Jain et al, 2001; Jain et al, 2005; Murty and Rai, 2005; Murty et al, 2011; Murty et al, 2012]

Jabalpur (M6.0) in 1997, Chamoli (M6.8) in 1999, Bhuj (M6.9) in 2001, Sumatra (M8.9) and Kashmir (M7.6) in 2005) caused around 40,000 fatalities due to collapse of buildings. Seismic Hazard Assessment quantifies the physical expression of the hazard, in the form of intensity of earthquake shaking. Rational understanding of the seismic hazard of the different areas is critical to a meaningful risk assessment exercise.

Figure 1 shows the seismic activity in India from 1819 to 2009. There is a noticeable increment in the number of earthquakes especially after 1950. Also, the fault map of India (Figure 2) suggests the landmass is highly fragmented by faults and the likelihood of damaging earthquakes taking place at different areas. A seismic zone map is expected to provide the levels of earthquake shaking expected in different areas.

The Bureau of Indian Standards (BIS) has been publishing seismic hazard maps since 1962. The first map of 1962 identified seven zones (Figure 3a). The division of seismic zones was based upon the Maximum Mercalli Intensities (MMI) of earthquakes experienced in the past in each area. These were named Zone 0, I, II, III, IV, V and VI. The Peninsular India was said to be stable and aseismic region. The second map was published in 1966 (Figure 3b). This map also is based on intensities experienced during past earthquakes. Some portion of peninsular India was upgraded from zone 0 to zone I. The third revision of the seismic hazard map was in 1970 after 1969 Koyna earthquake (M6.5). This map divided India into five seismic zones from zone I to zone V based upon MSK Intensity Scale, again based on historically observed intensities in these areas. Concept of seismic zone 0 was abolished in support to the fact that there is no region in India with probability of an earthquake equal to zero (Figure 3c).

After the 1993 Killari earthquake and 1997 Jabalpur earthquake, the researchers showed interest to develop a comprehensive seismic hazard map of the country. But the fifth revision of IS 1893:2002 that took place immediately after the devastating 2001 Bhuj earthquake did not bring new rationale. In this revision four zones

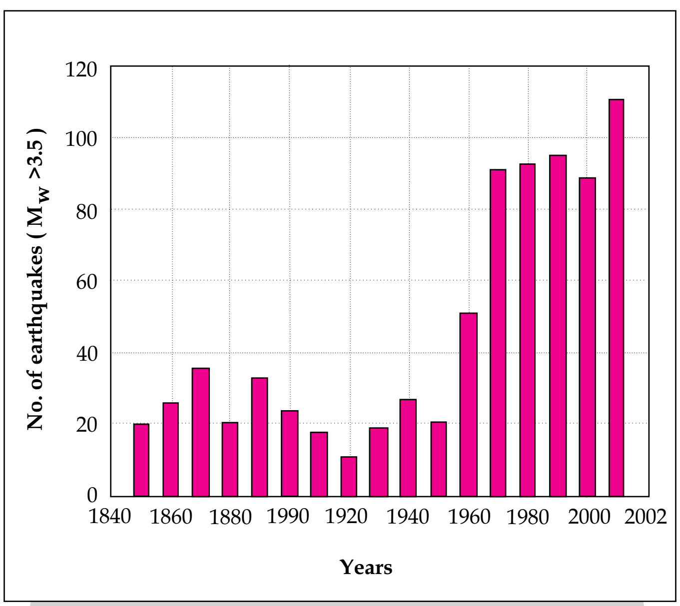


*Figure 1. Past earthquake events in India in last 160 years*

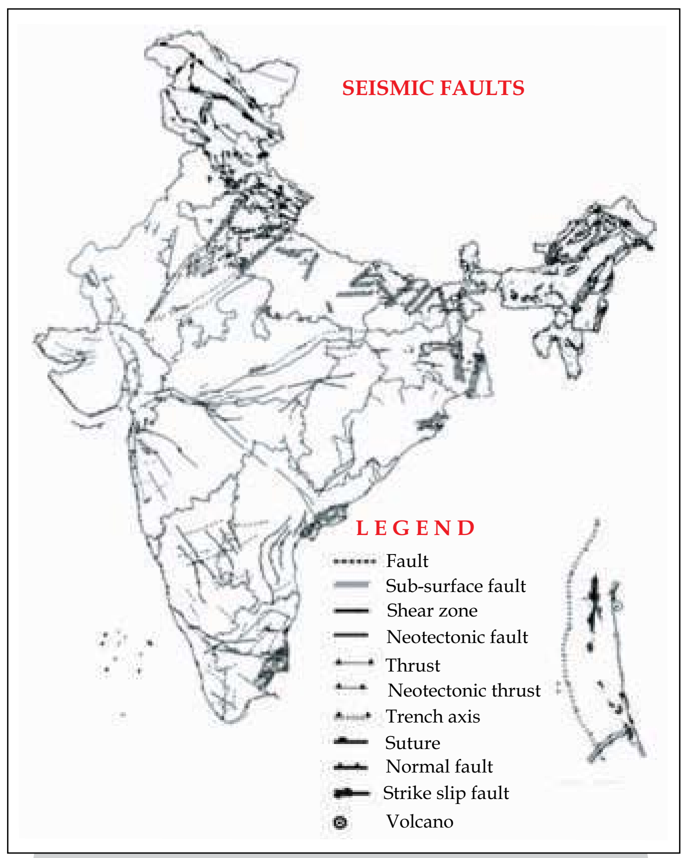


*Figure 2. Map showing major faults in India ( Based on GSI, 2003)*

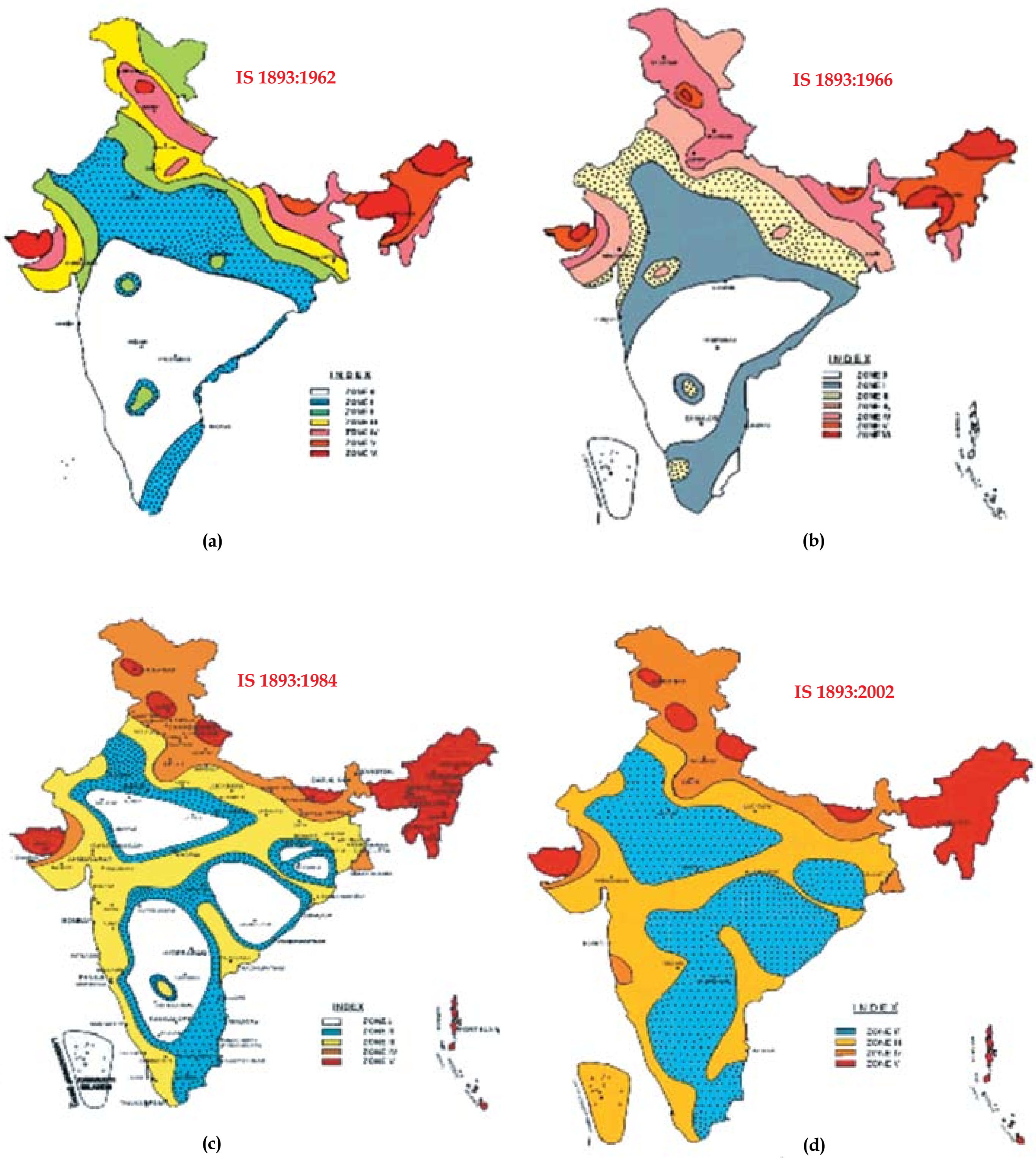


*Figure 3. Sketches of seismic zone maps of India (Based on IS 1893-1962, 1966,1984 and 2007)*

were adopted namely zones II, III, IV and V (Figure 3d). The erstwhile areas under zone I were merged with areas in Zone II. Zone II is said to experience low intensities of shaking and zone V high. Most of peninsular region is shown under zone II and III. Zone I was completely discarded in this revision. This map only tells about the intensity experienced in the past, but not the intensity of shaking expected in the future. It does not address another concern, namely what is the maximum shaking intensity that is likely to occur during the life of a house in a certain area of the country. But, for a common man the value of probability is not important. It is necessary to know the worst intensity of shaking that his house should be designed for so that he is safe during that expected design event. Table 2 gives the projected intensities of shaking in different seismic zones in India.

## 1.2 Exposure (E)

Presently, India is home for about 1.2 billion people. Over the last six decades, there has been a great shift of population from rural to urban areas, thus increasing the densities of population in urban areas. This suggests that about 300 million houses are necessary to house them. According to National Housing Policy 2007 [MoHUAPA, 2007], the housing shortage is estimated to be about 25 million. And according to 2011 Census [MHA, 2011], Indian urban population constitutes 32.25%. However, it is increasing at an alarming rate of 4% per year. The number and proportion of cities with a population of one million or more has grown significantly in recent decades. From 12 in 1981 with 26.8% share of the total population, the number of million-plus cities has increased to 35 in 2001 with 37% share of the total urban population. In addition housing shortage is already higher in urban areas, notwithstanding the ever increasing population densities. Figure 4 shows the district-wise spatial distribution of population density in India. Population in India is distributed unevenly with minimum of 50 persons per km$^2$ in some districts and up to 14000 persons per km$^2$ in some other districts.

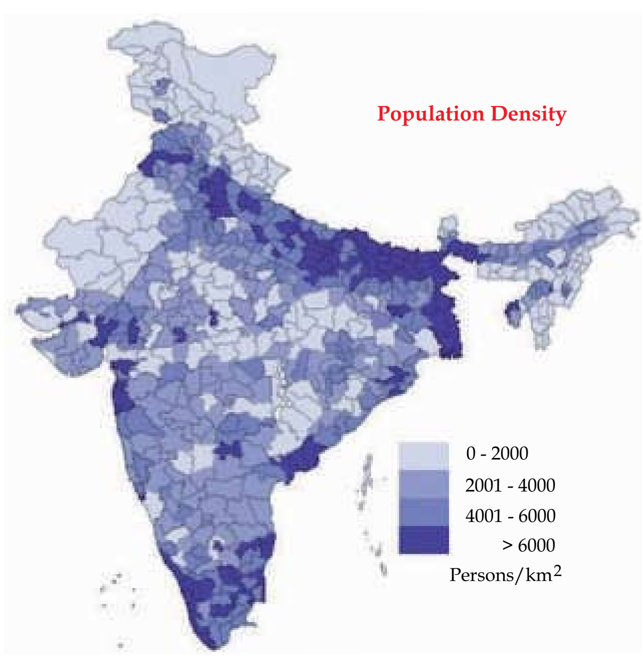


*Figure 4. Population density in districts of India (Based on census of India, 2011)*

Currently, there are over 300 million census houses as per Census 2011 of India [MHA, 2011]. The increase with respect to previous decade is around 18-25%; it is showing a decreasing trend (Table 3). But, the absolute number of houses is rising; the decadal increment of the houses added with respect to the building stock in 1961 has been increasing since independence. The last decade of 2001-2011 shows an increase of about 43.8%. This has

**Table 2. Intensity corresponding to different zones as per IS 1893 (Part I)-2007 and number of houses in each zone**

| Zone | Seismic Zone Factor (Z) | Shaking Intensity | Houses | |
|---|---|---|---|---|
| | | | Number | % of total |
| II | 0.10 | VI (or lower) | 4,39,86,517 | 17.78% |
| III | 0.16 | VII | 11,58,68,042 | 46.86 |
| IV | 0.24 | VIII | 6,32,83,128 | 25.60 |
| V | 0.36 | IX (or higher) | 2,41,44,350 | 9.76 |

**Table 3. Housing stock in India [source: census of India, 2001]**

| Year of Census | Number of Houses | Increase (%) | | |
|---|---|---|---|---|
| | | From previous decade | Cumulative since 1961 | Decadal Increment since 1961 |
| 1961 | 10,98,00,000 | - | - | - |
| 1971 | 13,70,00,000 | 24.80 | 24.77 | 24.77 |
| 1981 | 17,08,00,000 | 24.67 | 55.56 | 30.79 |
| 1991 | 21,16,00,000 | 23.85 | 92.71 | 37.15 |
| 2001 | 25,68,00,000 | 21.35 | 133.88 | 41.17 |
| 2011 | 30,48,82,448 | 18.69 | 177.67 | 43.79 |

led to shortage of technical manpower to undertake the construction work, in addition to shortage of construction materials. Figure 5 shows district-wise spatial distribution of housing densities. Rural districts have up to 100 houses per $km^2$, towns 1000-1500 $km^2$, cities 1500-2500 houses per $km^2$ and urban centers and metro go as high as 7000 houses per $km^2$. As per 2011 census, district-wise density of housing is higher near urban areas. Many of these high density areas also lie in moderate to high seismic zones.

## 1.3 Vulnerability (V)

Earthquake vulnerability of a house is the amount of expected damage induced to it by a certain level of earthquake intensity. The earthquake performances of the buildings, especially in the last two decades (Table 1), indicate around 40,000 human fatalities caused primarily by collapse of buildings. Except for Killari earthquake, all other events occurred in known moderate to high seismic zones. Damage caused to these buildings is unreasonably high compared to any other country for similar level of ground shaking. Serious departures are observed especially in performance of RC buildings. During the

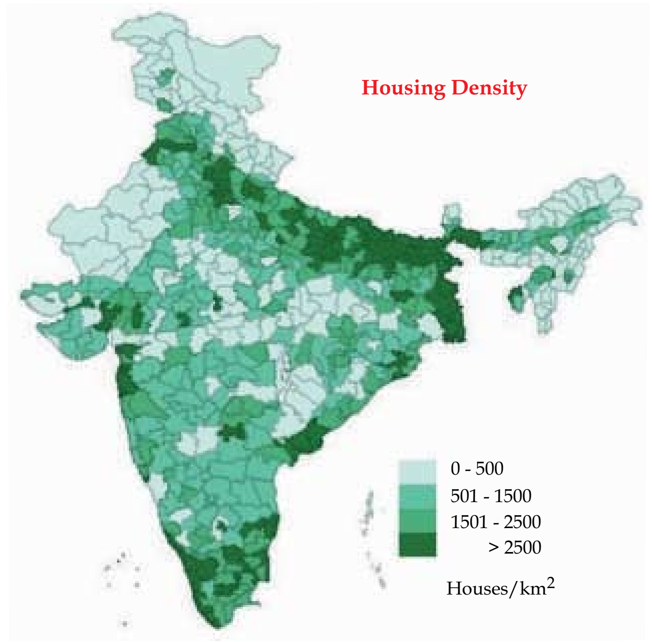


*Figure 5. Housing density in districts of India (Based on census of India, 2011)*

**Table 4. Housing with roof and wall material from 2011 census of India**

| S.No | Item | Number of Houses (Census 2011) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rural | % | Urban | % | India | % |
| | **Roof Material** | | | | | | |
| 1 | Grass/Thatch/Bamboo/Wood.. | 33,126,016 | 19.94 | 3,611,906 | 4.60 | 36,737,922 | 15.02 |
| 2 | Plastic/ Polythene | 1,047,533 | 0.63 | 500,251 | 0.64 | 1,547,784 | 0.63 |
| 3 | Hand made Tiles | 30,386,085 | 18.29 | 4,863,880 | 6.20 | 35,249,965 | 14.41 |
| 4 | Machine made Tiles | 17,307,198 | 10.42 | 5,503,054 | 7.01 | 22,810,252 | 9.32 |
| 5 | Burnt Brick | 11,990,029 | 7.22 | 4,231,255 | 5.39 | 16,221,284 | 6.63 |
| 6 | Stone/Slate | 14,746,138 | 8.87 | 6,222,441 | 7.93 | 20,968,579 | 8.57 |
| 7 | G.I./Metal/Asbestos sheets | 26,522,852 | 15.96 | 12,476,710 | 15.90 | 38,999,562 | 15.94 |
| 8 | Concrete | 30,423,701 | 18.31 | 40,764,887 | 51.94 | 71,188,588 | 29.10 |
| 9 | Any other | 607,051 | 0.37 | 310,595 | 0.40 | 917,646 | 0.38 |
| | **Grand Total** | **166,156,603** | **100.00** | **78,484,979** | **100.00** | **244,641,582** | **100.00** |
| | Wall Material | | | | | | |
| 1 | Grass/thatch/bamboo etc. | 26,417,331 | 12.79 | 2,530,263 | 2.57 | 28,947,594 | 9.49 |
| 2 | Plastic/ Polythene | 762,256 | 0.37 | 335,575 | 0.34 | 1,097,831 | 0.36 |
| 3 | Mud/unburnt brick | 58,330,614 | 28.24 | 8,119,213 | 8.26 | 66,449,827 | 21.80 |
| 4 | Wood | 2,132,342 | 1.03 | 648,929 | 0.66 | 2,781,271 | 0.91 |
| 5 | G.I./metal/asbestos sheets | 1,269,359 | 0.61 | 1,062,510 | 1.08 | 2,331,869 | 0.76 |
| 6 | Burnt brick | 83,618,436 | 40.48 | 62,927,369 | 64.00 | 146,545,805 | 48.07 |
| 7 | Stone | 28,685,790 | 13.89 | 14797142 | 15.05 | 43,482,932 | 14.26 |
| 8 | Concrete | 3,699,096 | 1.79 | 7,284,583 | 7.41 | 10,983,679 | 3.60 |
| 9 | Any other | 1,648,466 | 0.80 | 613,174 | 0.62 | 2,261,640 | 0.74 |
| | **Grand Total** | **206,563,690** | **100.00** | **98,318,758** | **100.00** | 304,882,448 | 100.00 |

**Table 5. Housing with roof and wall material from 2001 census of India**

| S.No | Item | Rural | | Urban | | Total | |
|---|---|---|---|---|---|---|---|
| | | No. of Houses | % | No. of Houses | % | No. of Houses | % |
| **Roof Material** | | | | | | | |
| 1 | Gross, thatch, bamboo, wood… | 4,88,12,470 | 27.49 | 45,73,534 | 6.94 | 5,33,86,004 | 21.19 |
| 2 | Tiles, slates or shingles | 6,52,99,492 | 36.78 | 1,25,91,573 | 19.12 | 8,11,44,290 | 32.21 |
| 3 | Brick, stone lime | 2,18,34,160 | 12.30 | 41,47,242 | 6.30 | 3,12,28,354 | 12.40 |
| 4 | GI metal, asbestos sheets | 1,86,65,296 | 10.51 | 1,18,21,919 | 17.95 | 3,04,87,215 | 12.10 |
| 5 | Concrete, RBC/RCC | 2,10,61,294 | 11.86 | 3,17,77,933 | 48.25 | 5,28,39,227 | 20.98 |
| 6 | Plastic, Polythene | 6,69,815 | 0.38 | 5,03,956 | 0.77 | 11,73,771 | 0.47 |
| 7 | All other material not stated | 11,94,986 | 0.67 | 4,50,682 | 0.68 | 16,45,668 | 0.65 |
| 10 | **Total** | **17,75,37,513** | **100** | **6,58,66,839** | **100** | **25,19,04,529** | **100** |
| **Wall Material** | | | | | | | |
| 1 | Gross, thatch, bamboo, wood… | 2,21,62,932 | 12.50 | 25,74,189 | 3.60 | 2,47,37,121 | 9.93 |
| 2 | Mud, un-burnt bricks | 6,58,07,212 | 37.13 | 79,91,950 | 11.17 | 7,37,99,162 | 29.63 |
| 3 | Wood | 23,63,200 | 1.33 | 8,33,792 | 1.17 | 31,96,992 | 1.28 |
| 4 | Burnt Brick | 6,25,15,919 | 35.27 | 4,91,75,710 | 68.72 | 11,18,91,629 | 44.92 |
| 5 | GI Sheets of other metal Sheets | 7,76,677 | 0.44 | 11,22,001 | 1.57 | 19,98,678 | 0.80 |
| 6 | Stone | 2,03,47,899 | 11.48 | 51,33,918 | 7.17 | 2,54,81,817 | 10.23 |
| 7 | Cement Concrete | 22,53,979 | 1.27 | 42,86,359 | 5.99 | 65,40,338 | 2.63 |
| 8 | Plastic, Polythene | 4,77,498 | 0.27 | 2,44,278 | 0.34 | 7,21,776 | 0.29 |
| 9 | All other material not stated | 5,32,197 | 0.30 | 1,96,159 | 0.27 | 7,28,356 | 0.29 |
| 10 | **Total** | **17,72,37,513** | **100** | **7,15,58,356** | **100** | **20,90,95,869** | **100** |

**Table 6. Housing with roof and wall material from 1991 census of India**

| S.No | Item | Rural | | Urban | | Total | |
|---|---|---|---|---|---|---|---|
| | | No. of Houses | % | No. of Houses | % | No. of Houses | % |
| **Roof Material** | | | | | | | |
| 1 | Gross, thatch, bamboo, wood… | 5,32,76,234 | 37.26 | 58,27,404 | 12.56 | 5,91,03,638 | 29.46 |
| 2 | Tiles, slates or shingles | 5,49,23,205 | 38.41 | 1,22,86,604 | 26.49 | 6,72,09,809 | 33.50 |
| 3 | Bricks, stone or lime | 1,36,04,738 | 9.51 | 56,35,042 | 12.15 | 2,45,29,786 | 12.23 |
| 4 | GI metal, asbestos sheets | 99,28,111 | 6.94 | 45,67,502 | 9.85 | 2,04,32,153 | 10.19 |
| 5 | Concrete, RBC/RCC | 64,45,758 | 4.51 | 1,63,11,517 | 35.16 | 2,27,57,275 | 11.34 |
| 6 | All other material not stated | 48,08,404 | 3.36 | 17,59,044 | 3.79 | 65,67,448 | 3.27 |
| 7 | **Total** | **14,29,86,450** | **100** | **4,63,87,113** | **100** | **20,06,00,109** | **100** |
| **Wall Material** | | | | | | | |
| 1 | Gross, thatch, bamboo, wood… | 1,70,56,489 | 11.93 | 25,31,939 | 5.07 | 1,95,88,428 | 9.55 |
| 2 | Mud, un-burnt bricks | 6,72,18,236 | 47.01 | 54,22,316 | 10.85 | 8,48,10,594 | 41.34 |
| 3 | Wood | 17,95,840 | 1.26 | 10,70,553 | 2.14 | 28,66,393 | 1.40 |
| 4 | Burnt Brick | 3,66,46,602 | 25.63 | 3,22,50,772 | 64.53 | 6,88,97,374 | 33.59 |
| 5 | GI Sheets of other metal Sheets | 2,51,910 | 0.18 | 7,64,956 | 1.53 | 10,16,866 | 0.50 |
| 6 | Stone | 1,72,84,400 | 12.09 | 44,19,591 | 8.84 | 2,17,03,991 | 10.58 |
| 7 | Cement Concrete | 11,55,760 | 0.81 | 28,00,780 | 5.60 | 39,56,540 | 1.93 |
| 8 | Ekra | 2,01,039 | 0.14 | 53,869 | 0.11 | 2,54,908 | 0.12 |
| 9 | All other material not stated | 13,76,176 | 0.96 | 6,66,373 | 1.33 | 20,42,549 | 1.00 |
| 10 | **Total** | **14,29,86,452** | **100** | **4,99,81,149** | **100** | **20,51,37,643** | **100** |

2001 Bhuj earthquake, they collapsed at an intensity of shaking of VII, when MSK scale expects them to collapse only after intensity IX of ground shaking. Thus, there is urgent need to understand the housing risk in the country to minimize the future losses of life and property.

### 1.3.1 Choice of Building Materials

The choice of materials used in construction throughout the country is shown in Table 4; the choice for natural materials is high. In the choice of roofing material, around 75% of houses in rural areas use natural and locally available material for construction; in the remaining 25% houses cement-based materials are used. On the contrary, in urban areas, cement-based materials are upto 50% and naturally available material the remaining 50%. For the wall, 90% of houses use natural material only, But, in urban areas, it is up to 10%. Tables 5 and 6 describe the materials used in construction of roof and wall in 2001 and 1991 respectively. Comparing the materials used, use of grass, thatch, bamboo and wood in roofing dropped from around 30% in 1991 census to 21% in 2001 census. During the same period, usage of concrete increased from 11.34% to 20.98%. Also, plastics have found place in construction in 2001 which were absent earlier. A similar situation is seen also in the choice of material for wall construction. But, earthquake resistance of the newly introduced materials remains to be understood when used for structural purposes. The dominant materials of choice for roofing in rural areas are: 27.49% of grass, thatch, bamboo, wood; 36.78% of slates & shingles; 12.3% of mud stone or lime and 11.86% of concrete. In urban areas, concrete is used for roofing in 48.25% cases. And, the dominant material of choice for walling in rural areas is: 12.5% of grass, thatch, bamboo, wood; 37.13% of slates & shingles; 35.27% of burnt brick; and 1.27% of concrete. And in urban areas burnt and un-burnt brick together is 75.55%.

### 1.3.2 Choice of Building Systems

In India, numerous housing typologies are adopted; each of them has many sub-typologies. In early years after Independence, artisans, and carpenters, were easily available with hands-on experience having constructed houses of certain typology. They had skills and know-how on traditional technologies of house construction with different materials e.g., brick walls in mud/lime mortar, tiled roofing on wooden rafters, and doors and windows made out of local wood. These technologies were cost effective and were especially suited to rural areas. Most materials used were available locally, like bricks stones, lime wooden joinery roofing tiles, and flooring stones. These houses stood for decades, and many were environment friendly and conserved energy. But, over the last two decades, many new materials and building technologies were introduced first in urban areas and later they found their way in rural areas. While taking these technologies to rural areas, adequate caution was not exercised. Hence, in many instances, advanced technologies were thrust into rural areas without preparing the people on the consequences of poor implementation without engineering judgment. For, instance, burnt clay brick in cement masonry was used in constructing walls and RC slabs in roofs, in the second storey of a house made in random rubble masonry in mud mortar in the first storey.

## 2. HOUSING THREAT FACTOR (HTF)

Housing threat factor is defined as the cumulative of the hazard at the site and exposure in the housing. This definition is necessary to understand a possible scenario where the housing in the country without earthquake resistant feature is fully vulnerable to seismic shaking. This is supported by the fact that 95% of the losses of lives are generally in low rise housing and that about 97% housing in India are masonry and non-engineered.

A housing threat factor is used to understand the overall status of housing in India. This factor is obtained by multiplying seismic zone factor (Z) of the seismic zone by number of houses per km$^2$ for each district in India (Figure 6). Table 7 shows typical values of some districts in India. The country is divided into four threat levels, i.e.,

Level IV : Very high threat (HTF 2,00,000-6,00,000)

Level III : High threat (HTF 1,00,000-2,00,000)

Level II : Moderate threat (HTF 20,000-1,00,000)

Level I : Low threat (HTF < 20,000)

Level IV threat areas are those with high hazard and higher population densities. Low housing risk areas are those with low hazard and moderate to low population densities.

## 2.1 How to Use the HTF Index

Threat assessment results in a quantitative index (it does not have any physical significance) that gives a qualitative feel of the level of severity of the problem. The actual process of risk assessment is a detailed exercise and time consuming. Even to begin such an exercise, a basis is needed to start work of risk assessment from one quarter and move forward. For instance, it is necessary to know which districts have relatively larger problem compared to all the districts in seismic zones III, IV and V. Therefore, a simple measure is required to set a priority for starting the formal initiatives of quantification of risk and then taking up the mitigation initiatives. Proposed Housing Threat Factor gives a broad idea of relative status of each district (and not about individual houses) and where the work can be started urgently.

The HRF index should be employed only to prioritize the districts of the nation, so that national agencies can concentrate their efforts and resources to build earthquake resistance in housing in these districts to begin with. Based on lessons learnt while implementing specific housing initiatives in these districts, necessary changes

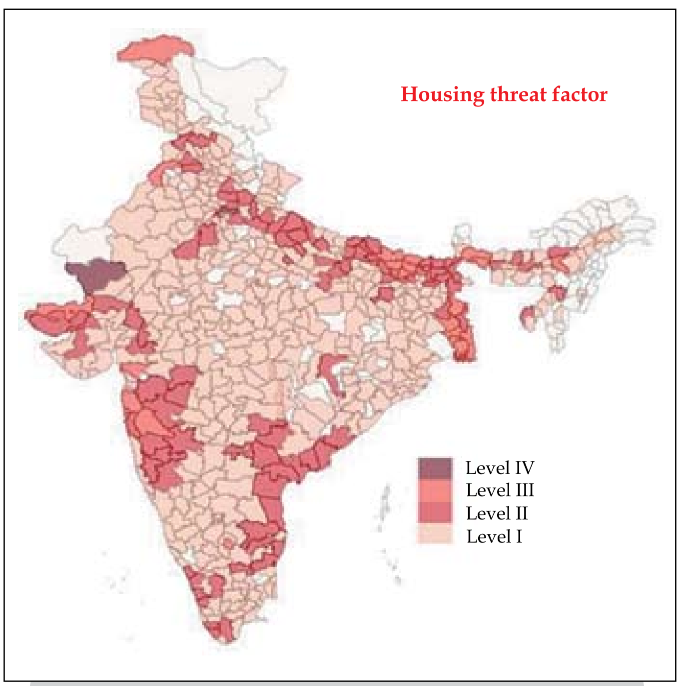


*Figure 6. Housing threat factor of districts in India*

may be made in strategies, methodologies and resource allocation to improve the implementation of housing safety initiatives. The Housing Threat Factor index may be used by:

(a) Housing ministries of central and state governments in India,

(b) District Magistrates of critical districts with high housing risk,

(c) NDMA, SDMAs, DDMAs, and municipal bodies,

(d) NGOs working in housing sector,

(e) architect and engineer professionals, and

(f) architects and civil engineering academia.

## 3. UNDERTAKING MITIGATION EFFORTS IN INDIA

With 65 years gone after India's independence, the subject of earthquake safety is still NOT in the mandatory part of the architecture and engineering education curriculum across India. The matter re-iterated to the senior academics, bureaucrats and policy makers to build the requisite

**Table 7. Housing threat factor of select districts of India**

| District | State | HRF |
|---|---|---|
| Greater Bombay | Maharashtra | 544,735 |
| North 24 Panganas | West Bengal | 446,074 |
| Pune | Maharashtra | 413,882 |
| Medinipur | West Bengal | 394,542 |
| Thane | Maharashtra | 377,690 |
| South 24 Panganas | West Bengal | 330,041 |
| Barddhaman | West Bengal | 284,887 |
| Murshidabad | West Bengal | 277,718 |
| Jalpaiguri | West Bengal | 270,831 |
| Madhubani | Bihar | 269,774 |
| Ahmadabad | Gujarat | 245,830 |
| Purbi Champaran | Bihar | 238,538 |
| Muzaffarpur | Bihar | 233,549 |
| Kamrup | Assam | 216,099 |
| Surat | Gujarat | 214,061 |
| Darbhanga | Bihar | 212,412 |
| Haora | West Bengal | 212,324 |
| Samastipur | Bihar | 208,974 |
| Koch Bihar | West Bengal | 208,110 |
| Hugli (Chunchura) | West Bengal | 207,631 |

systems to develop over the next two decades the large manpower necessary to address earthquake safety of the country. Post-earthquake emergency response alone (which is the current strategy) will not solve the problem; mitigation (i.e., safer constructions) actions need to be taken urgently, if the country wishes to reduce the loss of life in upcoming earthquakes.

### 3.1 Bottlenecks in Implementation in the Past

Impediments to successful implementation are many. It would be unfair to claim that there is a single list of bottlenecks that arise in implementing mitigation initiatives. In this paper, a partial list is presented of some of the important concerns that arise on the various mitigation initiatives. Table 8 presents this representative list.

### 3.2 Appeal to Urgently Implement Mitigation Initiatives in India

The earthquake risk to housing in India is largely attributed to the choice of building material and typologies. Around 90% of houses in the country were made with natural materials. But, this is in great contrast with the emphasis of the current civil engineering and architectural education imparted across India. In light of this the following critical initiatives are re-iterated:

#### 3.2.1 Overhaul of Curriculum

The construction material is taught in at best 1 course out of 30 plus courses credited by (~3% of the courses) undergraduate civil engineering students. In particular, the course on masonry is almost extinct in the curriculum across the engineering colleges in the country. On the other hand, 97% of the curriculum is addressing the small minority of 2.6% of reinforced concrete houses in the country. This is when masonry is still the most widely used material in construction of houses and other buildings. The present undergraduate courses provide almost no exposure to structural design of masonry. Recent advances in masonry units and use of reinforcement in masonry requires students to be formally trained in behavior and design of structural masonry. Further, many heritage structures built with variety of masonry types used to be preserved for future generations. These require greater skill and understanding of behavior of masonry. And hence there is a great need to reflect this need in undergraduate curriculum. Variety of Civil engineering curricula are practiced by various universities and institutes across the country. Comprehensive review of these curricula is required to include a) traditional construction technologies and b) at least a minimum mandatory curriculum that prepares graduates to meet the needs of the nation.

#### 3.2.2 Train Manpower

There is a serious shortage of quality trained manpower, from faculty members, engineers, architects who are familiar with best housing practices. After 2001 Bhuj Earthquake, MHRD supported an initiative for 3 years to train teacher of engineering colleges in earthquake engineering. Many faculty members and students got benefitted through the program, the National Program on Earthquake Engineering Education (NPEEE). The duration of the program was not sustained long enough to create requisite human resources to address the needs. Another such effort was made by Ministry of Home Affairs (MHA) to train large number of architects and engineers, but was again for limited duration. Some agencies like National Academy of Construction initiated certificate programs for masons and bar-benders. But, this needs to reach the larger populace of the artisans. All relevant ministries of central government of India should undertake long term program to train (in many cycles) the professionals and artisans. Focused PhD program with the housing agenda should be launched.

#### 3.2.3 Share Best Practices

Technology development paves way to all-round growth. Although the triumphs of technology marvels are celebrated, maintaining technology to the contemporary needs and its sustainability is often ignored. Current construction practices are not in consonance with the required pace of sustainable development. Large workforce is shifting from rural to urban areas, and with this the art of traditional construction is lost. At the same time, these workers are not trained enough to handle the new materials. As a result, best construction practices are being lost and/or not imparted. There is a great need to preserve the good construction practices. Processes of constructing houses of different typologies need to be

**Table 8. Some impediments to implementing earthquake disaster mitigation initiatives in India**

| S.No. | Item to be implemented | Bottleneck | Way forward... |
|---|---|---|---|
| **A. Technical Issues** | | | |
| **A.1 CAPACITY BUILDING :: Introducing Earthquake Engineering Components in Technical Education** | | | |
| 1 | Change curriculum | Lack of slots in B.Tech. and B.Arch. programs for introducing additional technical content related to earthquake safety | |
| 2 | Train teachers | Cannot get leave to attend extended programs of up to 1 year | Undertake a national campaign to recruit additional teachers, who will be training before joining the university/institute |
| 3 | Prepare teaching resource materials | Lack of even basic books on earthquake hazard, behaviour of structures, design and construction of new structures and assessment of existing structures | Commission a few faculty members with competence to undertake this critical work |
| 4 | Augment library and laboratory infrastructure | Expensive equipment requiring high maintenance, and so cannot be afforded by all colleges | Develop regional facilities with separate teaching and research laboratories |
| 5 | Initiate research in universities/ institutes | Lack of research ethos, and large distraction with consultancy | Academic administrations (especially in IITs and NITs) to prioritize addressing national interests to be one of the critical responsibilities of senior faculty members |
| **A.2 CAPACITY BUILDING :: Continuing Education of Practicing Engineers and Architects** | | | |
| 1 | Find alliance partners to undertake the massive effort | Professional civil engineering and architecture societies have not developed a long term commitment to undertake this gigantic task across the country | A non-profit industry-academia CONTINUING EDUCATION CENTER to be created at regional level with practicing engineers and architects as master trainers; distance education technology to be leveraged to improve efficiencies; coordination to be done by professional societies |
| 2 | Identify Master Trainers | Professional engineers too busy with daily work to undertake this long term effort, and faculty members overloaded in their universities/institutes | Undertake a national campaign to recruit additional teachers, who will be training before joining the university/institute |
| 3 | Prepare teaching resource materials | Lack of even basic books on earthquake-resistant design and construction of new structures and seismic assessment of existing structures | Commission a few practicing engineers and architects with competence along with faculty members to undertake this critical work |
| 4 | Undertake training | Need many batches of engineers and architects to be training in each major town/ city | Develop city level master trainers to undertake this activity in the evenings on weekdays |
| **3. CAPACITY BUILDING :: Training of Artisans** | | | |
| 1 | Find alliance partners to undertake the massive effort | NAC, NICMAR, NITTRs, HUDCO, BMTPC, CIDC, Polytechnics and ITIs are yet to work together to create standard training modules for masons, bar-benders, welders, carpenters, plumbers, electricians, etc. | FICCI and CII to undertake this effort under CSR to coordinate the potential partners, and work with NDMA and SDMAs to pursue national and local governments to prioritize this to allocate funds |
| 2 | Develop training centers | HUDCO training centers that exist are too few for the country; lack of passion of the persons manning the centers and lack of hand holding by construction companies to encourage higher wages for trained manpower has impeded this training effort | Construction companies to advertise that skilled labor rates are higher and the expectation of skilled labor is certification from one of the standard training centers; housing NGOs to play a critical role in steering these programs to grassroots level |

**Table 8. Continued**

| S.No. | Item to be implemented | Bottleneck | Way forward... |
|---|---|---|---|
| 3 | Prepare teaching resource materials | Lack of training material and modules in local languages and dialects; lack of adequate field level trainers | Commission a special effort through the governments to undertake the translation work to prepare the training materials as required; encourage more housing NGOs to participate in this effort of training of masons |
| 4 | Undertake training | Participation in one program is seen to be sufficient by the trainee | Certification should be introduced by the state governments to examine skill levels of trained artisans; this will require sometimes more than one programs to be attended by some artisans |
| **B. Legal Issues** | | | |
| 1 | Undertake post-earthquake damage assessment of buildings | All government departments and private organizations keen to escalate damage assessment figures | Governments to stop paying compensations for reconstruction; Formal teams to be assembled by NDMA and SDMAs to undertake post-earthquake damage assessment, and give legal standing to the assessment made by these teams, with checks and balances |
| 2 | Update bye-laws at all municipal government levels | Most publicly elected leaders have vested interest to not allow updating of bye-laws that ask for stringent performance standards, which will require them to improve their standards | A white paper should be developed on all such bye-laws that are detrimental to earthquake safety; Courts have to be moved to intervene to seek the urgent updating of bye-laws in national interest |
| 3 | Penalise violations from approved construction | A strong nexus exists between municipal offices and builders to eventually legalise the illegal and unapproved constructions, and this is happening through some existing bye-laws approved by the publicly elected local representatives; there is no field inspection by neutral parties on the accuracy of constructions as per approvals | Quality assurance systems to be put in place for all constructions |
| **C. Administrative Issues** | | | |
| 1 | Constitute State Disaster Management Authorities and State Executive Committees in all states and hold meeting regularly | Governments lack priority on Earthquake Safety of its people | Chairman, NDMA, to take steps to push states to mainstream disaster management |
| 2 | Development of strong techno-legal regime | Absence of Peer Review (verification of earthquake safety) by independent professionals enlisted by local governments | Local governments to implement peer review system |
| 3 | Retrofit existing lifeline structures | No expertise in the country to support the exercise | Major effort of developing capacity in professional engineers and architects to be undertaken urgently by NDMA |
| **C. Financial Issues** | | | |
| 1 | Financial lending institutions to independently verify earthquake safety of the constructions, before approving the loans | Banks seem to think that is too much work to do, and that the municipality will verify safety | RBI to initiate a strong techno-financial system related to earthquake safety in all banks in the country |

documented. For this, first the housing typologies being practiced need to be understood and documented in detail. High quality cartoons/animation strategies may be adopted to do this.

**3.2.4 Undertake selective Retrofitting**

Every year a large number of new houses are getting added to existing stock of the country. Its absolute number is large, even though small in percentage of the already existing stock. Each earthquake in the last 23 years demonstrated the major deficiencies of the existing stock of housing across the country. Seismic strengthening of these existing houses is a technology challenge at this time. A comprehensive plan is required for promoting systematic, formal and technically sound retrofitting of houses, as it not only involves technology issues but also social issues.

**3.2.5 Commission Post-Earthquake Housing Assessment Teams**

After every earthquake, many teams carry out reconnaissance survey to understand the behavior of houses. But, houses which performed poorly and those that survived pose one question-which of them can be occupied after the earthquake. There is an urgent need to study the performance of houses with following objectives:

1. Houses that did not comply existing provisions,
2. Houses that complied with provisions,
3. Houses collapsed and
4. Houses that did not collapse.

Results in these studies will be valuable inputs for (a) revising code provisions, (b) improving construction practices, and (c) training engineers, architects and artisans.

The task is tricky of assessing immediately after an earthquake the damaged houses standing in the epicentral region. There are safety, legal and financial implications of any decision taken on these houses. Therefore, formal teams should be commissioned well before the next event in the country, trained in the methodology of assessment, and empowered to provide formal technical assessment that has legal sanctity. This aspect requires deep discussion and quick action to prepare sufficient number of groups of the post-earthquake housing assessment teams.

## 4. CONCLUDING REMARKS

India has witnessed several moderate earthquakes in the last two decades causing around 40,000 fatalities and innumerable house collapses. The prevalent high earthquake hazard, large exposure and high vulnerability indicates that urgent action is necessary in 20 districts of the country, as shown using index 200000. It is time to assign value to the life of each Indian and take urgent proactive actions. Five capacity building and mitigation initiatives are presented in this paper, namely (1) overhaul of curriculum, (2) train manpower, (3) share best practices, (4) undertake selective retrofitting, and (5) post-earthquake damage assessment teams. These items have been oft repeated at meetings and in papers. Unfortunately, there is a great mismatch between need of the country in terms of earthquake safety on one hand and number of available trained professional on another. After 2001 Bhuj Earthquake, there are some initiatives on items 2~5. But, all these solutions were short-lived due to lack of long term vision. Hence, there is a need to speak on these issues.

The lack of implementation of the much needed steps is attributed to a system failure of all stakeholders in the country, and cannot be attributed to any one set of stakeholders; virtually, every stakeholder group has defaulted. Of all the defaulters, three significant defaulters are:

1. Academics in architecture and engineering colleges (who failed to upgrade the curriculum and teach the much needed background to graduates),
2. Bureaucrats (who are generalists and fail to apply themselves to specialized information of disaster management, and always addressing the day to day chores, than to long-term but critical needs of the nation), and
3. Publicly elected policy makers all levels (who have vested interests of running construction

contracts of all major projects across the country with profit maximization motive, and no respect for adherence to the design and construction standards and to quality control and quality assurance practices needed in the development of built environment).

This paper attempts to bring to the public eye the urgency of the matter, and develop a pressure group that can sensitize these three critical groups of stakeholders to undertake the measures that are in their purview.

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