



## Earthquake Disaster Risk Index – A Simple Method for Assessing Relative Risk in a Country

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### Abstract

UN World Conference on *Disaster Risk Reduction* held in 2015 at Sendai, Japan, reiterated the need for substantial reduction in loss of life and property. Thus, assessing disaster risk and identifying key items for risk mitigation are in focus. Assessment of disaster risk is a multidisciplinary effort, which includes expected tangible physical loss, such as collapse and damage to built environment. In countries with limited resources, prioritizing risk reduction effort across the different parts of the country needs a quantitative (yet simple) approach to bring objectivity into the decision-making process.

This paper presents a simple method, called *Earthquake Disaster Risk Index (EDRI)*, for estimating relative earthquake risk across the different regions in a country; it uses three major constituents of risk, namely *Hazard*, *Exposure* and *Vulnerability*. *Hazard* is taken as the acceleration hazard specified in the national earthquake design standard, *Exposure* as per the permitted occupancy in the Local Municipal By-laws, and *Vulnerability* through a *Level 2 Detailed Qualitative Assessment* of buildings built in the Town or City (with penalty points for missing features of earthquake resistance compared to an *Ideal Building*). First, the EDRI of a Town or City is estimated for each typology of building in the Town or City, and then the net EDRI of the Town or City is obtained as a weighted average of the EDRI of each typology of buildings using the number of buildings of each typology present in the city.

The EDRI of a city so estimated can be compared with that of another city. Also, disaggregation of risk through its three major constituents of EDRI will increase awareness of the factors which contribute to risk – from expected intensity of earthquake ground shaking, to exposure of people in each building type, to vulnerability of each building typology. The exercise can be undertaken at a large scale across the country. Policy Makers of a prefecture or a state in a nation will find the results of EDRI to be a useful tool for prioritising allocation of earthquake risk mitigation resources and effort across Towns and Cities.

**Keywords:** *Earthquake Risk; Disaster, Resilience, Vulnerability, Risk Index*



## 1. Introduction

### 1.1 Earthquake Safety Worldwide

Physical Infrastructure is built across the world to meet the needs of the people. But, often, sufficient attention is not paid to the overall safety of structures during their design and construction stages, jeopardising their resistance to natural hazards. In particular, earthquake vulnerability of buildings poses a critical safety concern. Countries, like USA, Japan and New Zealand, have managed to reduce the risk due to built environment. Experiences from the past earthquakes show an increasing trend of earthquake risk of buildings. In 1950s, one in four persons living in the 50 largest cities in the world were under earthquake risk, but, in 2000s, it has risen to one in two persons [1]. *While developing nations bear a disproportionate burden of earthquake risk, very little of world's spending on earthquake engineering research is aimed at their needs* [2]. And, only 15% of the world's annual earthquake engineering research is focused on the needs of improving the safety of developing countries over the last 50 years. And, the number of fatalities has not reduced in developing countries from the first half of 20<sup>th</sup> Century to the second half of 20<sup>th</sup> Century, while it has reduced drastically in industrialized countries.

### 1.2 Earthquake Safety in India

The state of earthquake safety in India is not too far from that in other seismically active developing countries. By the end of 2020, 40% of the population concentrated in urban areas may contribute to the 70% of GDP of India [3] (Figure 1). An important factor that critically affects earthquake safety is making people aware of negative fallouts of disasters. In India, most buildings are constructed by individual owners without much guidance on earthquake safety measures required in them. Even when the contractor constructs buildings, only the *functional* and *aesthetic* aspects are addressed, which are demanded by owners, and not *structural safety*; often, no engineer or architect is engaged by them. Such buildings are called *non-engineered* constructions, which demonstrate poor behaviour during earthquake shaking, and result in severe damage or even collapse of structures.



**Figure 1.** World's urban population under the threat of earthquakes [GHI, 2001]

In the last three decades, India has witnessed many earthquakes that caused significant loss of life and property (Table 1). The losses were largely because of non-engineered building typologies in practice in the country. For instance, the 2001 Bhuj M6.9 earthquake caused about 13,800 deaths, whereas the 1993 Killari (Maharashtra, India) M6.1 earthquake alone caused about 8,000 deaths; in both cases, the loss of life was because of collapse of buildings. Another major concern in India is the lack of a professional environment to ensure safe construction – a system that enforces builders and contractors to comply with earthquake safety standards during design and construction, and levies penalties for any non-compliance of the same. In the recent times, construction practices of different countries are being practiced without examining their suitability to India. Earthquake risk mitigation efforts should account for local building materials, traditional construction practices, capacity and nature of the local construction industry, local geotechnical conditions, and regional geological and seismological settings.

**Table 1.** Brief overview of Earthquakes in India [Jain, 2016]

<i>Date</i>	<i>Location</i>	<i>Magnitude MSK Intensity</i>	<i>Remarks</i>
8 Feb. 1900	Coimbatore	6.0 VII	Shock felt throughout south India Coimbatore and Coonoor worst affected
4 Apr. 1905	Kangra	8.0 X	~19,000 deaths. Considerable damage in Lahore High intensity around Dehradun and Mussorie VIII
15 Jan. 1934	Bihar and Nepal	8.3 X	~7,000 deaths in India and ~3,000 deaths in Nepal Liquefaction in many areas
26 Jun. 1941	Andaman & Nicobar Islands	7.7 VIII	Triggered Tsunami 1.0m high on the east coast, causing many deaths
15 Aug. 1950	Assam and Tibet	8.6 XII	About 1,500 deaths in India and ~2,500 in China. Caused landslides that blocked rivers & later caused flood
21 Jul. 1956	Anjar, Gujarat	6.1 IX	About 115 deaths. Part of Anjar on rocky sites suffered much less damage comparatively.
10 Dec. 1967	Koyna, Maharashtra	6.5 VIII	About 180 deaths. Caused significant damage to the concrete gravity dam.
21 Aug. 1988	Bihar-Nepal	6.6 IX	About ~709 deaths
20 Oct. 1991	Uttarkashi	6.4 IX	~750 deaths. 56m span Gawana bridge collapsed
30 Sep. 1993	Killari, Maharashtra	6.2 IX	~8,000 deaths. Houses built with rounded random rubble stone masonry and in mud mortar collapsed
22 May 1997	Jabalpur	6.0 VIII	~40 deaths and ~1,000 injured. RC buildings with open ground storey suffered damage.
26 Jan. 2001	Bhuj, Gujarat	7.7 X	~13,800 deaths. Over 430 RC multi-storey buildings collapsed.
26 Dec. 2004	Sumatra	9.4 VI (in ANI)	Caused ~17,000 casualties, mostly owing to Tsunamis
8 Oct. 2005	Kashmir	7.6 VIII	Poor performance of masonry buildings caused many life losses.
28 Sep. 2011	Sikkim	6.9 VI	~80 deaths. Large number of landslides, significant damage to the buildings and infrastructure.

### 1.3 Need for an Earthquake Disaster Risk Index

The experiences from past earthquakes reiterate that unless earthquake safety is ensured, future earthquakes will continue to cause severe social and economic losses in the country. This is compounded by: infrequent revision of design codes and municipal bye-laws; sporadic capacity building of architects, engineers & other stakeholders of the construction industry; poor awareness about negative effects of disasters; and lack of a quantitative feel of the possible loss of life and economic losses (*i.e.*, loss of time, and business) during future events. To counter this situation, earthquake risk of cities should be assessed periodically, which will help mitigate negative consequences, prepare, and respond to the next event. Thus, there is a need for a method of assessing *Earthquake Risk* of each city or town, which is simple to estimate and addresses the above needs.



## 1.4 Utility of the Earthquake Disaster Risk Index

Before embarking on undertaking a detailed risk assessment, attempt should be made to quantify risk through a *Risk Index* (as against a *Risk Value* given by *detailed risk assessment*), which includes the vulnerability factor quantitatively. The *Earthquake Disaster Risk Index (EDRI)* of Towns and Cities in seismic areas will provide:

- (1) A *simple, quantitative* method for understanding the impending overall earthquake disaster risk and its variation over time across a large number of cities or even regions in a country;
- (2) Factors that contribute to earthquake risk, and projected losses of life and buildings;
- (3) Awareness that urban regions with low seismic hazard also pose earthquake risk, if *Exposure* and *Vulnerability* are high;
- (4) Insights (which are factors contributing to risk, which is the *low hanging fruit* that will bring best results in short time) and guidance (how to prioritise; which action to take; and how to use efficiently the limited fund available with them) to governmental agencies and decision makers in earthquake disaster *mitigation, preparedness* and *response* measures in the more vulnerable cities;
- (5) Gaps in earthquake risk assessment methods, by re-evaluating the index periodically over time, improved tools for risk assessment towards better management of the prevalent earthquake risk; and
- (6) Clarity that resilience to face the future events can be built in a country by proactive mitigation actions.

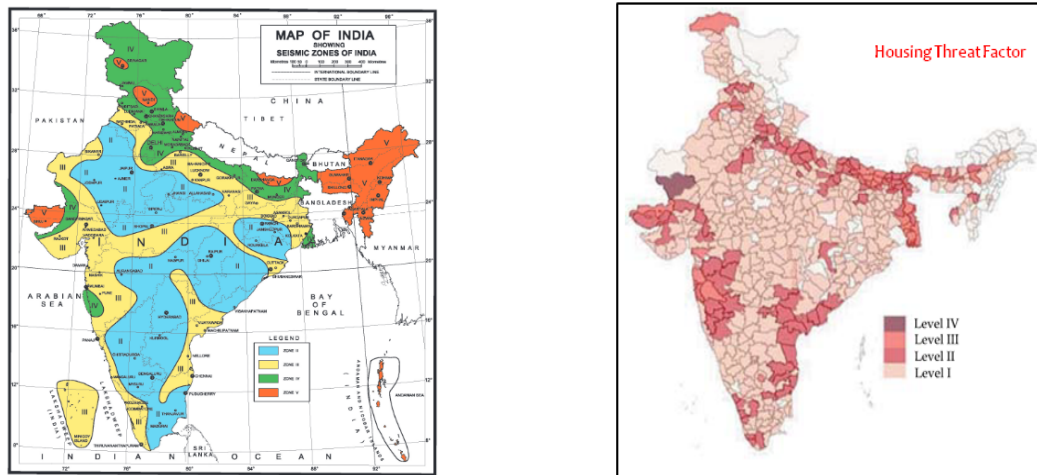
## 2. Review of Risk Assessment Methods Used so far

Internationally, many methods were proposed to arrive at a disaster risk index, which used different levels of vulnerability assessment [4, 5, 6, 7, 8, 9, 10]. These methods largely considered the *physical built environment* (buildings and infrastructure systems) of select cities from select regions of Asia, Europe, the Middle East, Africa, and Latin America [Radius, 1999]. One significant effort of developing an overall *risk index* was initiated in USA, where *social fragility* and *resilience of the society* were considered along with *physical risk* [8]. It was used to compare relative risk of different cities, but not to compare the risk of urban fabrics within a city. Further, socio-economic aspects of urban earthquake risk, buildings, lifelines, transportation and infrastructure were not incorporated by FEMA in developing a software, HAZUS [5]. But, the methodology of HAZUS is involved for urban earthquake risk assessment approach, and its application is limited to the physical and social conditions of USA. Several initiatives are underway in Europe to develop earthquake risk assessment and loss estimation methodologies across the Euro Mediterranean region. Usually, the final products of these studies were software packages for assessing the seismic risk and earthquake losses. A holistic seismic risk analysis method was developed for urban centres [6], which accounts for physical risk, exposure and socio-economic characteristics of the different units of the city and their disaster coping capacity or *degree of resilience*. *Relative Seismic Risk Index (RSRi)* method was applied in the Tehran city of Iran [10]. Other methods, such as DRI developed by UNDP and World Bank hotspot study were used for mapping the natural disaster risk of countries [6].

The above methods were fine tuned to their respective built environments and social status of the country in focus; they cannot be used in any other country. In the Indian context, where most of the buildings constructed were unregulated, the behaviour of buildings in past earthquakes showed that they were vulnerable. Thus, there is a need to develop an earthquake risk index specifically for India to begin a formal mitigation effort. Thus, a first step was taken in India towards assessing earthquake risk in buildings, the *inventory* of the built environment was made. In 2007, the *Building Materials and Technology Promotion Council (BMTPC)* listed the number of houses built in each District of the country, and categorized them based on the type of material used in construction of roofs and walls. This inventory showed that assessing *earthquake risk* is crucial, because 82% of the population lives in 56% of India's landmass that is prone to moderate-to-severe earthquake shaking (Figure 2.1a) [12], wherein over 90% of the building stock is non-engineered. Thus, a second step was taken by computing the *Housing Threat Factor (HTF)* (Figure 2 (b)) as a product of *earthquake hazard* in an area and *exposure* of population (*i.e.*, reflected by housing density)



[13]. The base unit of the area was a municipal District, which is the formal administrative unit in India with a single administrator. The HTF gave a way to prioritize the Districts of the country for earthquake risk mitigation projects. Next, the *vulnerability* of the building stock needed to be included in a quantitative way, because the relative earthquake risk of different cities or towns needed to be compared in a quantitative way. Therefore, a third step was taken in 2019 by the National Disaster Management Authority through a study of 50 cities, wherein risk was quantified through an *Earthquake Disaster Risk Index* [14], which considered vulnerability quantitatively. This method provided an opportunity to compare *quickly* the relative risk across cities and towns, and to launch earthquake risk mitigation programs in areas with high Risk Index.



**Figure 2.** (a) Seismic Hazard Map [IS 1893 (Part 1):2016], and (b) Housing Threat Factor [Ramancharla and Murty, 2014]

### 3. Proposed Methodology

Risk evaluation requires consideration of the expected *physical loss* (such as the number and type of buildings collapsed, number of persons injured and dead owing to collapse of structures, and the monetary loss due to damage or collapse of structures), *social fragility* and *community resilience* to respond when the expected hazard is realized. The risk assessment method is proposed here considers the *physical loss* only; the same is described through the following step-wise procedure.

#### 3.1 Earthquake Disaster Risk Index $EDRI_b$ of a Building

The buildings in a Town or City are grouped into different building *typologies* (like load bearing or wall buildings, frame buildings, braced buildings, and mixture of these three); buildings of each typology are further sub-grouped into *Sub-Typologies* for analysis after the risk index is arrived at. The *Earthquake Disaster Risk Index* ( $EDRI_b$ ) is estimated of a each building as a product of the earthquake *hazard* factor  $H_b$  prevalent in the area, the population *exposure* factor  $E_b$  in each building, and the *vulnerability* factor  $V_b$  of the building (when the earthquake prevalent hazard is realized), as:

$$EDRI_b = H_b \times E_b \times V_b. \quad (1)$$

The components of  $EDRI_b$  are bias to one dominant characteristic, namely hazard is biased *spatially*, vulnerability of buildings *thematically* and exposure *temporally*.

##### (a) Seismic Hazard $H_b$ of a Building

Rational estimate (by a consistent procedure) of the earthquake hazard  $H_b$  at a building is critical to a meaningful risk assessment exercise. It is taken as the product of expected intensity of ground shaking (reflected by Seismic Zone Factor  $Z$ , which is a measure of the PGA at the building site), the Soil Type

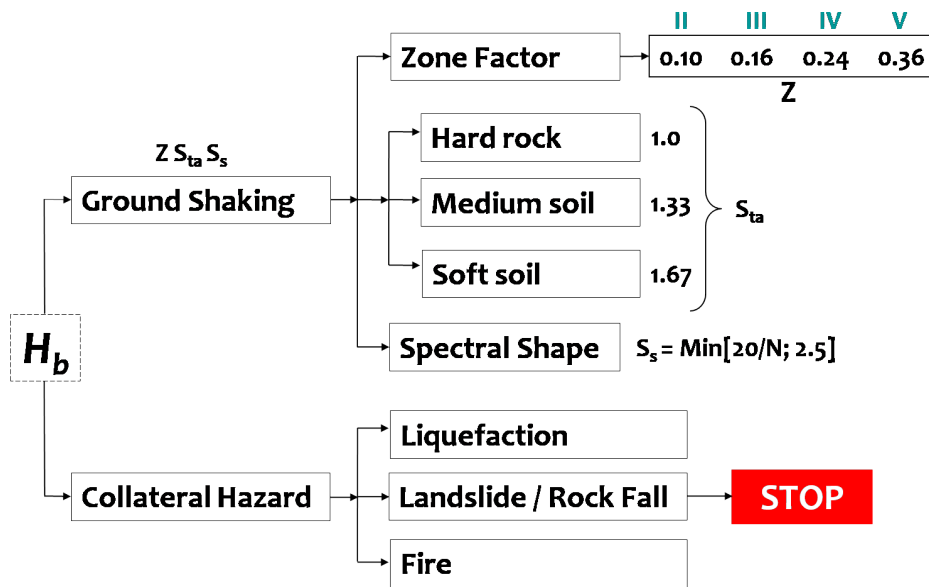




Factor  $S_T$  (reflecting the soil amplification), and Spectral Shape Factor  $S_A$  (reflecting the amplification of shaking within the building from that at its base) [Figure 3] as:

$$H_b = Z S_T S_A, \quad (2)$$

where  $Z$ ,  $S_T$  and  $S_A$  are taken as given in the Indian earthquake code IS 1893 (Part 1);  $H_b$  lies in the range 0.2-1.5. Further, if the building is located in a region susceptible to surface fault rupture, soil liquefaction, slope failure, landslide or rock fall, or fire hazard (which is determined independently), the building is declared as one with 100% risk; no further calculation is done.



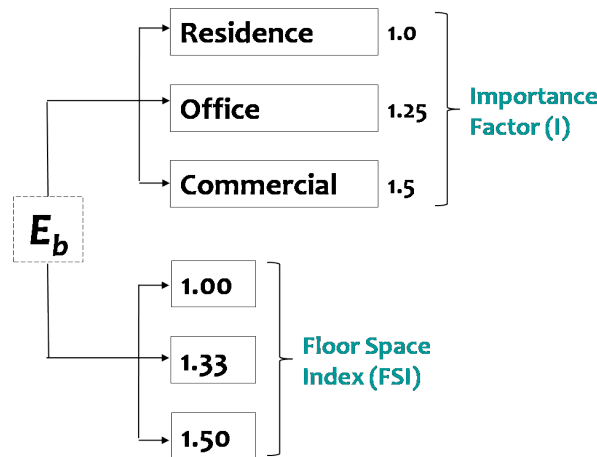
**Figure 3.** Flowchart for estimating *Earthquake Hazard* at a Building

### (b) *Earthquake Exposure* $E_b$

The exposure of a building is reflected by the importance of the building and the number of people likely to live in it. Exposure  $E_b$  of a building to the prevalent earthquake hazard is assessed as:

$$E_b = I \times FAR, \quad (3)$$

where  $I$  is Importance Factor of the building and  $FAR$  the Floor Area Ratio, the ratio of sum of carpet area in all the floors and the total plot area. IS 1893(1) gives Importance Factor  $I$  as 1 for ordinary residential buildings, 1.25 for office buildings and 1.5 for important buildings (Figure 4). And, the Municipal bye-laws specify the  $FAR$  as 1.0 for regular buildings and 1.5 for in prime locations of the town. Thus,  $E_b$  lies in the range 1.33-4.00.  $E_b$  reflects the number of persons occupying the building and its importance.



**Figure 4.** Flowchart for estimating *Earthquake Exposure* at a Building

### (c) *Vulnerability* $V_b$

Earthquake vulnerability of a building is the extent of damage expected to be induced to it when the expected intensity of earthquake shaking is realized. It can be quantified through *Life Threatening Factors* (LTFs) and *Economic Loss Inducing Factors* (ELIFs).

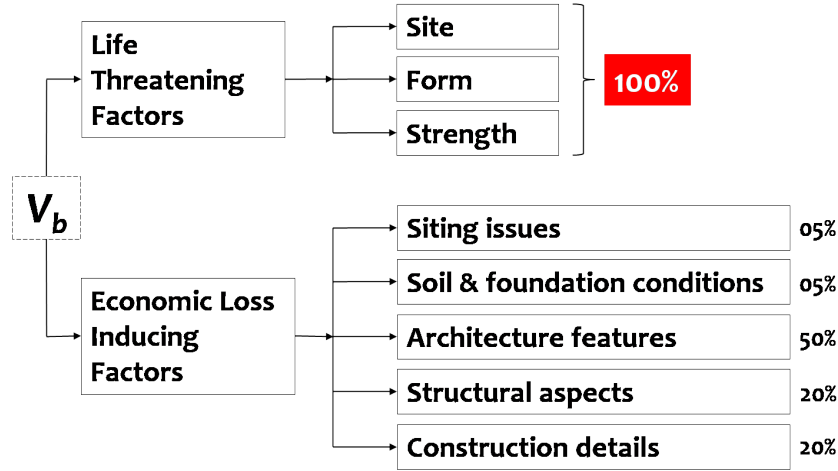
#### *Life-Threatening Factor (LTF)::*

It is the unsafe condition of the building that jeopardizes life. Two types of *life-threatening factors* are considered, namely: (i) *Life Threatening Building Structure Factors*  $L(S)$  related to the structure of the building, and (ii) *Life Threatening Building Contents & Utilities Factors*  $L(C)$  related to the contents and utilities of the building. LTF is considered through: (i) Siting issues, (ii) Architecture features, and (iii) Structural aspects. If any of these factors is present in the building, then that building is declared as one at 100% risk, i.e.,  $EDRI_b$  is taken as the maximum; the process is terminated of estimating  $EDRI_b$  of the building.

#### *Economic Loss Inducing Factor (ELIF)::*

An *Ideal Building* is identified in each building typology. If any building in focus departs in any condition from that of the ideal building, it is expected to attract direct economic loss by requiring retrofitting or reconstruction of the building to make it earthquake-resistant. Again, two types of *economic loss-inducing factors* are considered, namely: (i) *Economic Loss Inducing Building Structure Factors*  $E(S)$ , and (ii) *Economic Loss Inducing Building Contents and Utilities Factors*  $E(C)$ . These factors are assessed based on the provisions of the relevant Indian Standards, which are required to be complied with in the design and construction of a building of that typology. *ELIFs* are quantified as the algebraic sum of the departures along 5 factors, namely: (1) Siting issues, (2) Soil and foundation conditions, (3) Architecture features, (4) Structural aspects, and (5) Construction details. Based on the Del-Phi Method, experts were consulted to arrive at the maximum weights for the said five considerations. For instance, for RC frame buildings, these factors were 5%, 5%, 50%, 20% and 20%, respectively. These weights vary with building typology, and to some extent over time with the experts gaining experience of earthquake risk assessment. Thus, the Vulnerability factor  $V_b$  is in the range 0-1.0, 0 for a resistant building and 1.0 for a fully vulnerable building (Figure 2.4).

$$V_b = 1 - \sum_{i=1}^5 (ELIF_i). \quad (3)$$



**Figure 5.** Flowchart for estimating *Earthquake Vulnerability* of a Building

### 3.2 Earthquake Disaster Risk Index of a Building

Finally,  $EDRI_b$  of a building is estimated as by Eq.(1). Substituting the minimum and maximum values of hazard, exposure and vulnerability in Eq. (2.3), the  $EDRI_b$  is in the range 0-9.0, i.e.,

$$EDRI_b = \begin{bmatrix} 0.2 \\ 1.5 \end{bmatrix} \times \begin{bmatrix} 1.33 \\ 6.0 \end{bmatrix} \times \begin{bmatrix} 0 \\ 1.0 \end{bmatrix} = \begin{bmatrix} 0 \\ 9.0 \end{bmatrix}. \quad (4)$$

### 3.3 Earthquake Disaster Risk Index of a Town

It is not possible to survey each building in a city and obtain the  $EDRI_b$  of every building. Thus, the method requires that at least 100 representative buildings are surveyed of each building typology. Further, after evaluating the average  $EDRI_{Typ}$  of the sample buildings of one typology, the Earthquake Disaster Risk Index  $EDRI_{Town}$  of a Town is obtained as:

$$EDRI_{Town} = \frac{\sum_{i=1}^{N_T} N_{Typ,i} EDRI_{Typ,i}}{\sum_{i=1}^{N_T} N_{Typ,i}}, \text{ and} \quad (5)$$

where  $N_{Typ,i}$  is the number of buildings of typology  $i$  and  $EDRI_{Typ,i}$  is average  $EDRI$  of buildings of typology  $i$ , given by:

$$EDRI_{Typ,i} = \frac{\sum_{j=1}^{N_{Typ,i}} EDRI_{Typ,i,j}}{N_{Typ,i}},$$

in which  $N_T$  is the total number of typologies, and  $EDRI_{Typ,i,j}$  is the  $EDRI$  of sample building  $j$  surveyed of typology  $i$ .





## 4. Example

As per the Census of India, the towns in the country are categorized based on population into three classes, namely (i) semi-urban centers, having population in the range 10,000–99,999, (ii) urban centers, having population in the range 1,00,000–9,99,999, (iii) metro Cities, having population more than 10,00,000. For demonstrating the method of estimating EDRI, 2 Towns and 2 Cities are selected, of which 2 are located in the plains and 2 in hilly areas. Details of the Towns and Cities are given in Table 2.

**Table 2. Selected Cities Located in Hilly and Plain areas**

S.No.	City or Town	Region	Population	Total Number of Buildings	Number of Buildings Surveyed
1.	City A	Hilly	10,70,602	224,736	596
2.	Town B	Hilly	1,00,286	28,672	183
3.	Town C	Plain	1,43,286	32,681	722
4.	City D	Plain	16,84,222	2,81,986	488

### 4.1 Building Information of a Town or City

The EDRI of a city depends not only on the vulnerability of individual building typologies in that city, but also on factors such as topography of city, earthquake hazard, soil conditions, population, possibilities of collateral hazards (*e.g.*, liquefaction of soil, landslides and fire), use of buildings (*e.g.*, residential, office and commercial uses), and FAR (*i.e.*, floor area ratio). In addition, quality of construction alone does not ensure safety of a building. For example, in the construction of a G+5 storey RC framed building, if all guidelines are followed in its design, but is built on granular soil strata or on a vulnerable hill slope, it could be safe under normal loading but is clearly unsafe under severe earthquake shaking. This is because, during earthquake shaking, the granular soil may undergo liquefaction, resulting in severe damage and even collapse of the building. Further, landslides may occur in the vulnerable hill slope during earthquake shaking and the building may collapse and slide into the valley.

### 4.2 Data Collection

The survey was performed in the 2 towns and 2 cities. First, information is collected on the Town and City and the buildings. The parameters involved are dependent on geology, site conditions, overall built environment, and typologies of the building. The data was provided online by the Nodal Officers of each city (who were identified by local governments). The online data was sent as soft copy through an *eMail* to concerned Nodal Officers and the District Collector.

### 4.3 EDRI

Next, the EDRI is estimated *of individual buildings*, and then of the whole Town or City. For this, a series of questions are answered as *Yes* or *No* on *individual buildings*. The questions address all three components of EDRI, namely *hazard*, *exposure* and *vulnerability* of the building, especially all five broad domains related to the vulnerability of building, namely site issues, soil and foundation condition, architectural features, structural aspects and construction details. To begin with, each building of a typology is given a score of 100, and each question is given a negative penalty if the building departs from the ideal. Building earns penalties for the questions whose answers are YES and earns no penalties for those whose answers are NO. Proper and detailed inspection of each feature of a building is required to understand the functionality of the building. Building typology with maximum questions answered as *YES* gets the highest total vulnerability score, a quantitative value. Then, the EDRI is estimated of all buildings surveyed of that typology. Finally, the typology-wise score collected over sample buildings (at least 100) is extrapolated to all buildings in the city of that typology. Thus, the final EDRI of city is estimated considering all buildings in the city. A sample result of the calculation is presented in Table 3. In general, EDRI of a city indicates levels of damage expected ranging from *No Damage* (0%) to *Collapse* (100%), and varies between towns and cities. It is a simple and quantitative method.

**Table 3.** EDRI of all Surveyed Buildings and of Cities A and D, and Towns B and C

Building Typology	EDRI <sub>SB</sub> of Surveyed Buildings			EDRI <sub>Town</sub> of all Buildings in Town		
	Number of Buildings surveyed	EDRI <sub>Typ</sub>	EDRI <sub>SB</sub>	Number of Buildings in Town	Number of buildings with Life Threat	EDRI <sub>Town</sub>
City A						
Reinforced Concrete Building	187	0.39	0.33	9,763	3,844	0.31
Brick Masonry Building with Concrete Roof	382	0.31		1,66,496	50,879	
Town B						
Reinforced Concrete Building	145	0.67	0.67	5,825	3,910	0.68
Brick Masonry Building with Concrete Roof	38	0.68		11,330	7,724	
Town C						
Reinforced Concrete Building	580	0.19	0.18	11,298	2,167	0.17
Brick Masonry Building with Concrete Roof	142	0.13		6,585	849	
City D						
Reinforced Concrete Building	359	0.77	0.70	11,779	9,105	0.53
Brick Masonry Building with Concrete Roof	129	0.52		1,82,994	94,248	

The EDRI of City A is 0.31. Masonry Buildings dominate the stock of buildings. But, as both RC and Masonry Buildings have same EDRI at a typology level, the net EDRI is similar. The overall construction quality and construction techniques employed in these buildings are in order, but there is scope for the improvement. The major factors causing earthquake risk in these buildings are large window and door openings, large overhangs & projections, and split roof. On the other hand, the EDRI of City D is 0.53. Even though RC Buildings are nearly 72% at risk, their number is small, and hence, the overall EDRI is controlled by that of the masonry buildings. The increased risk compared to that of City A is unregulated constructions that do not follow the municipal bye-laws.

The Town B has an EDRI of 0.68; it is located in the seismic zone V. Most buildings were constructed as per the code provisions; the on-going constructions also were found to comply with the code provisions. The major factors contributing to such high risk are local soil and foundation conditions. The EDRI of Town B is large because of the following critical factors, namely (a) in RC buildings: large area window openings, staircase not adequately separated from building frame, unsymmetrical location of staircase with respect to plan, large projections/overhangs and irregular structural grid, and (b) in Masonry buildings: no lintel, sill and plinth bands, large window openings, and no roof bands with flat roof. On the other hand, Town C has an EDRI of 0.17. Even though RC buildings have open ground storeys and are vulnerable under strong earthquake shaking, their number is small. Hence, it is clear that small EDRI does not mean that the city will not have losses; the losses may be restricted to a certain typology. The new constructions are observed to have been built better with good RC framing system and earthquake resistant features. Majority of masonry buildings are more than 2-storey tall. Burnt brick is the most common material used as wall material for the construction of these houses. Also, nearly half of the surveyed buildings were not plastered on the outside walls and built close to each other.



## 5. Closing Comments

The *Earthquake Disaster Risk Index* proposed in this paper for Cities and Towns is simple to estimate. The EDRI will help in:

- (1) Comparing quantitatively the relative earthquake risk in different cities and towns in the country, and thereby guiding rational allocation of available limited mitigation resources and effort; and
- (2) Disaggregating the major factors contributing to risk, thereby improving the awareness of the stakeholders to take urgent actions to correct the same.

Four examples are shown, where EDRI is able to place them on an equal platform for comparison, and identify actionable items.

Rapid urbanization of Indian cities in last few decades has put large pressure on the housing industry to speed up the development. This fast pace of construction is causing serious threat to life and property, owing to limited planning and unregulated development of low-to-medium rise buildings in its towns and medium-to-highrise buildings in cities. Mitigation effort is minimal. The method proposed to estimate the *EDRI* can be employed effectively to assess the relative earthquake risk of cities and towns in India, to mitigate negative consequences, prepare, and respond to the next earthquake event. The method is generic enough to be used in any country, based on an initial effort to identify the *LTFs* and tune the penalty *ELIFs*.

## 6. Acknowledgements

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