सत्यमेव जयते

NATIONAL DISASTER MANAGEMENT GUIDELINES

SEISMIC RETROFITTING OF DEFICIENT BUILDINGS AND STRUCTURES


June 2014

NATIONAL DISASTER MANAGEMENT AUTHORITY
GOVERNMENT OF INDIA

National Disaster Management Guidelines

Seismic Retrofitting of Deficient Buildings and Structures

National Disaster Management Guidelines – Seismic Retrofitting of Deficient Buildings and Structures

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National Disaster Management Guidelines on Seismic Retrofitting of Deficient Buildings and Structures are formulated by NDMA, in consultation with various stakeholders, academic experts, subject specialists from across the country and officials from concerned Ministries and Departments of Government of India.

Contents

Glossary of Terms

Term		***Description***
Architects	:	Persons trained in the subjects related define the form of buildings, functional use, choice of building materials, methods of finishing, and other aspects related to construction of buildings
Artisans	:	Persons with technical skills, like welding, bar-bending, masonry and carpentry
Delhi Schedule of Rates	:	Cost of materials and undertaking specific elements of work of construction activity, as published by the Central Public Works Department (CPWD) for the city of Delhi, with correction factors for other towns and cities in the country
District DMAs	:	District Disaster Management Authorities
EOCs	:	Emergency Operation Centres
Engineered Building	:	Building built with formal engineering inputs, in accordance with the prevalent national standards or more stringent
Engineers	:	Persons trained in the subjects related ensuring safety of buildings under the action of the applied loads
IS Codes	:	Specifications, Guidelines and Codes of Practice laid down by Bureau of Indian Standards, New Delhi
Lateral Stiffness of Building	:	A measure of how much the building moves in the horizontal direction under a known level of horizontal force applied on it
Lateral Strength of Building	:	A measure of the maximum horizontal force that the building can resist in the horizontal direction before it collapses
Licensing of Engineers	:	Legal mechanism to professionalise engineering practice in India, empower engineers and make them accountable for structural safety
Managers	:	Persons coordinating the work of undertaking seismic retrofitting
NDMA	:	National Disaster Management Authority
No Collapse	:	Building does not fall down during earthquake shaking
Non-Critical Building	:	Building that do not house services that are necessary in the post-earthquake response, or personnel who are key stakeholders to undertake post-earthquake response activities

Term		***Description***
Non-Engineered Building	:	Building built without any formal engineering inputs (usually by common man)
National Earthquake Rapid Damage Assessment Teams	:	Teams of professionals trained to examine earthquake damaged buildings, and to declare them unsafe for occupancy or otherwise
Open Ground Storey Buildings	:	Buildings made of concrete or steel members, which have masonry walls in upper storeys and none/few masonry walls in the ground storey; OR Buildings made of any material, which have large size and number of openings in the ground storey
RC	:	Material used to construct buildings and structures, comprised of steel reinforcement bars and structural concrete; the material is commonly referred to as Reinforced Concrete, and hence the abbreviation, RC
Retrofitting	:	Fitting a building or structure in retrospect (after it is built) to make it capable to withstand the effects of earthquake shaking expected in the region where the building is built
Schedule of Rates in the States	:	Cost of materials and undertaking specific elements of work of construction activity, as published by the designated departments of the State governments for different towns and cities in that State
State DMAs	:	State Disaster Management Authorities
Techno-Financial Mechanisms	:	Regulatory measures related to financial aspects enforced by statutory bodies to ensure earthquake safety of built environment
Techno-Legal Mechanisms	:	Regulatory measures related to legal aspects enforced by statutory bodies to ensure earthquake safety of built environment
Best practice	:	Retrofit scheme that physically modify the existing structure to make it earthquake resistant, which is arrived at based on evidence from extensive experimental studies on prototype structures along with those from analytical studies

Abbreviations

BIS	Bureau of Indian Standards
BMTPC	Building Materials & Technology Promotion Council
CBRI	Central Building Research Institute
CPWD	Central Public Works Department
CRRI	Central Road Research Institute
DCR	Development Control Regulations
DDMA	District Disaster Management Authority
DM	Disaster Management
DMA	Disaster Management Authority
DRM	Disaster Risk Management
DST	Department of Science and Technology
EOC	Emergency Operations Centre
EREC	Earthquake Risk Evaluation Centre
GOI	Government of India
GPS	Global Positioning System
GSI	Geological Survey of India
HSC	Hazard Safety Cells
HUDCO	Housing & Urban Development Corporation
IIT	Indian Institute of Technology
ITIs	Industrial Training Institutes
LPG	Liquefied Petroleum Gas
MP LAD	Member of Parliament Local Area Development
MLA LAD	Member of Legislative Assembly Local Area Development
MSK Scale	Medvedev–Sponheuer–Karnik scale
MoUD	Ministry of Urban Development
NICEE	National Information Center of Earthquake Engineering
NDMA	National Disaster Management Authority
NGOs	Non-Governmental Organisations
NIDM	National Institute of Disaster Management
NIT	National Institute of Technology
NITTR	National Institutes of Training of Teachers and Research
NSE	Non Structural Elements
R&D	Research and Development
RCC	Reinforced Cement Concrete
RDSO	Research Designs and Standards Organisation
RM	Risk Management
RVS	Rapid Visual Screening
SDMA	State Disaster Management Authority
SERC	Structural Engineering Research Centre
SOI	Survey of India
SOP	Standard Operating Procedure
ULBs	Urban Local Bodies
UT	Union Territory

1 Background

1.1 INTRODUCTION

1.1.1 A large number of existing buildings across the country do not seem to have adequate earthquake resistant features specified in IS Codes. Some reasons given for this include non-availability of competent technical manpower, lack of regulatory mechanisms to check earthquake resistance of proposed constructions, and economic constraints. The effort and technical input required to retrofit a building are much higher than that to make a new earthquake-resistant building. In the present scenario, sufficient technical manpower is not available even for designing and constructing new buildings! Further, infrequent occurrence of earthquakes (though devastating) has not helped the cause of making the country realise the extreme shortage of technical inputs to take corrective steps towards ensuring that the built environment is made capable to resist expected earthquake shaking in each region.

1.1.2 Over 95% of fatalities in past earthquakes in India have occurred in non-engineered houses and structures; significant gains can be made towards reducing (if not eliminating) loss of life by undertaking seismic strengthening of these non-engineered structures. This is by far the most critical step in earthquake disaster mitigation in India.

1.1.3 Further, a special class of buildings has emerged in a big way across the country, called *Open Ground Storey Buildings* (or *Buildings on Stilts*). These do not conform to prevalent Indian Standards for earthquake safety. These buildings are *flexible* and *weak* in the open ground storey compared to the storeys above. A large number of these low-strength reinforced concrete (RC) buildings collapsed during 2001 Bhuj earthquake. Most of these buildings, not designed properly, may be able to carry gravity loads, but could be deficient in strength to withstand deformations imposed on them during strong earthquake shaking. During the 2001 Bhuj earthquake, many such buildings with open ground storey, owned by government did not collapse, because they were designed as per Indian Seismic Code. A large number of similar buildings exist in urban and semi-urban areas of India, which require seismic retrofitting, at least to prevent collapse during the next earthquake.

1.2 EARTHQUAKE RISK OF HOUSING IN INDIA

1.2.1 The projected aggregate effect of expected number of lives likely to be lost, persons injured, property damaged and economic activity disrupted due to an expected strong earthquake in an area, is the *earthquake risk* of that area.

1.2.2 India has experienced several major earthquakes in the past few decades and according to IS 1893 (Part I:2002), around 56% (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 25 years, several large to moderate earthquakes have occurred in the country (Table 1) (Bihar-Nepal border (M6.4) in 1988, Uttarkashi (M6.6) in 1991, Killari (M6.3) in 1993, Jabalpur (M6.0) in 1997, Chamoli (M6.8) in 1999, Bhuj (M6.9) in 2001, and Kashmir (M7.6) in 2005, which have caused more than 25,000 fatalities due to collapse of buildings.

1.2.3 The Tsunamis generated by the Sumatra Earthquake of M 9.1 in 2004 also brought heavy damage to buildings in the entire South Indian coast.

1.2.4 The Bureau of Indian Standards (BIS) has been publishing seismic hazard maps of India since 1962. The fifth revision of IS 1893 (1): 2002, which took place immediately after the devastating 2001 Bhuj earthquake, has four zones (II, III, IV and V, Figure 1). The erstwhile areas under zone I were merged with areas in Zone II. Zone II is said to experience MSK intensity of VI or less and zone V to experience intensity of IX or more. Most of peninsular region is under zone II and III. In all, about 80% of India's population resides in Seismic Zones V, IV and III.

Table 1: Human fatalities during some past earthquake events in India

Year	Name of the Event	Casualties	Buildings Collapsed
1988	Bihar-Nepal Border	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
2005	Kashmir	~1,500	4,50,000
2004	Sumatra Tsunamis	>1,31,000	➢ 80,000

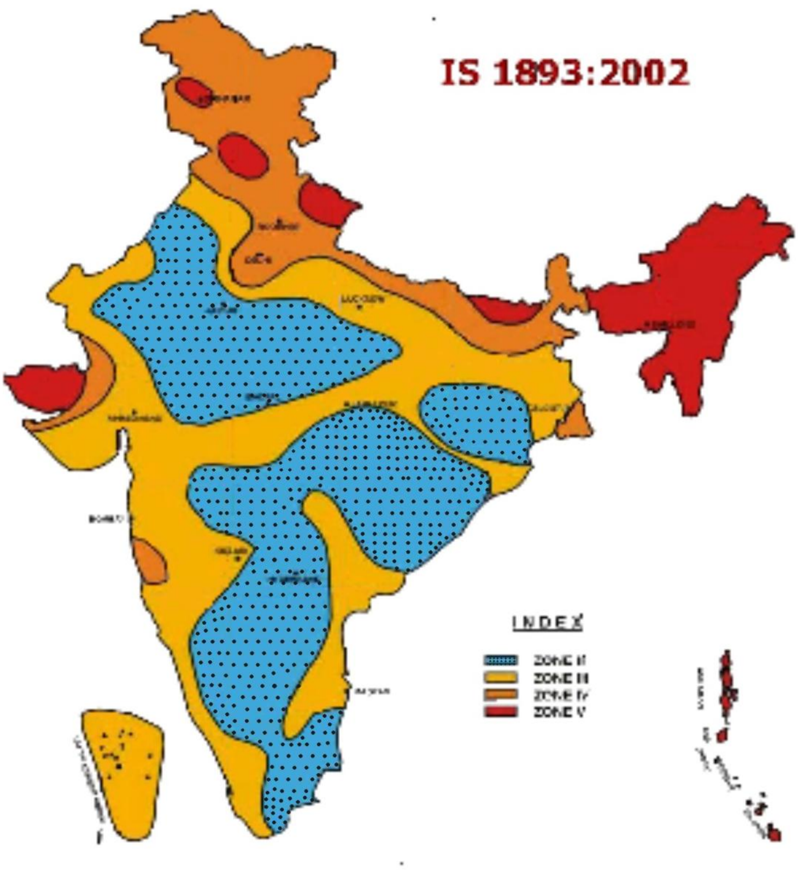

Figure 1: Seismic Zone Map of India based on IS 1893 (1): 2002

1.2.5 Currently, there are about 305 million houses as per Census 2011 of the country. The decadal increase in population is around 20-25% (Table 2). But, the absolute numbers are rising. Figure 2 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 14,000 persons per km^2 in some other districts. Figure 3 shows district-wise spatial distribution of housing densities. Rural districts have up to 100 houses per km^2, towns 1,000-1,500 houses per km^2, cities 1,500-2,500 houses per km^2 and urban centres and metro go as high as 7,000 houses per km^2. District-wise density of housing is higher near urban areas. Many of these high density areas also lie in moderate-high seismic zones.

1.2.6 Earthquake performances of buildings in the last 25 years indicate that more than 25,000 human fatalities were caused primarily by collapse of buildings (Table 1). Except for the 1993 Killari (Latur) 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. The observed performances of RC buildings are highly unsatisfactory. During the 2001 Bhuj earthquake, these RC buildings collapsed at an earthquake shaking of intensity VII on MSK scale; this is in contrast to the fact that MSK scale expects well-designed RC buildings to collapse only when earthquake shaking is of intensity IX or more on MSK scale. Thus, the housing risk in the country should be minimized to reduce losses to life and property in future earthquakes. Some trends on the use of building materials and building typologies are described below.

Table 2: Housing stock in India [*Source*: Census of India]

Census of India	*Houses*	*Increase (%)*
1961	10,98,00,000	-
1971	13,70,00,000	24.8
1981	17,08,00,000	24.7
1991	20,51,00,000	20.1
2001	24,88,00,000	21.3
2011	30,49,00,000	22.5

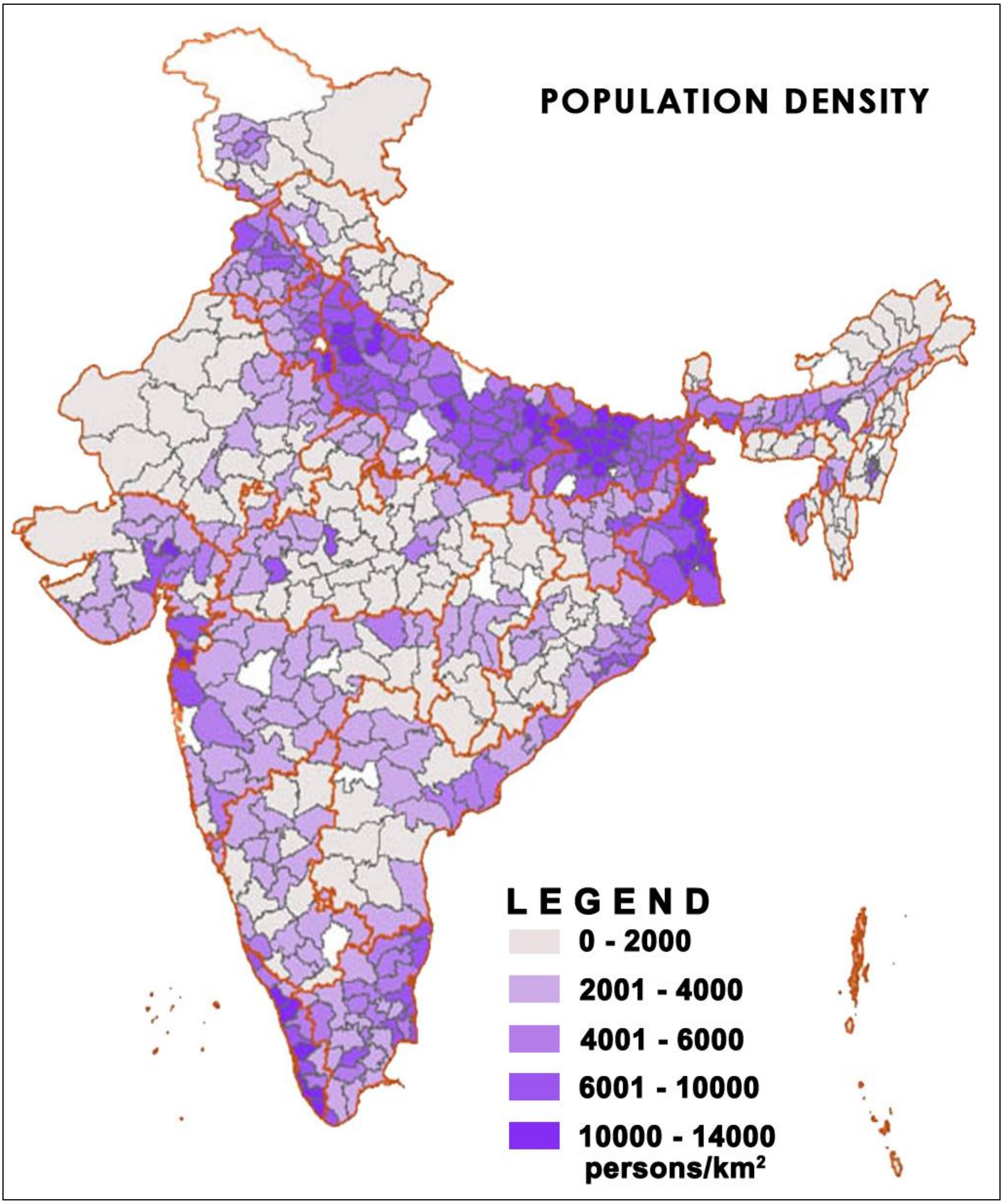

Figure 2: 2011 District-wise Population Density distribution [*Source*: 2011 Census of India]

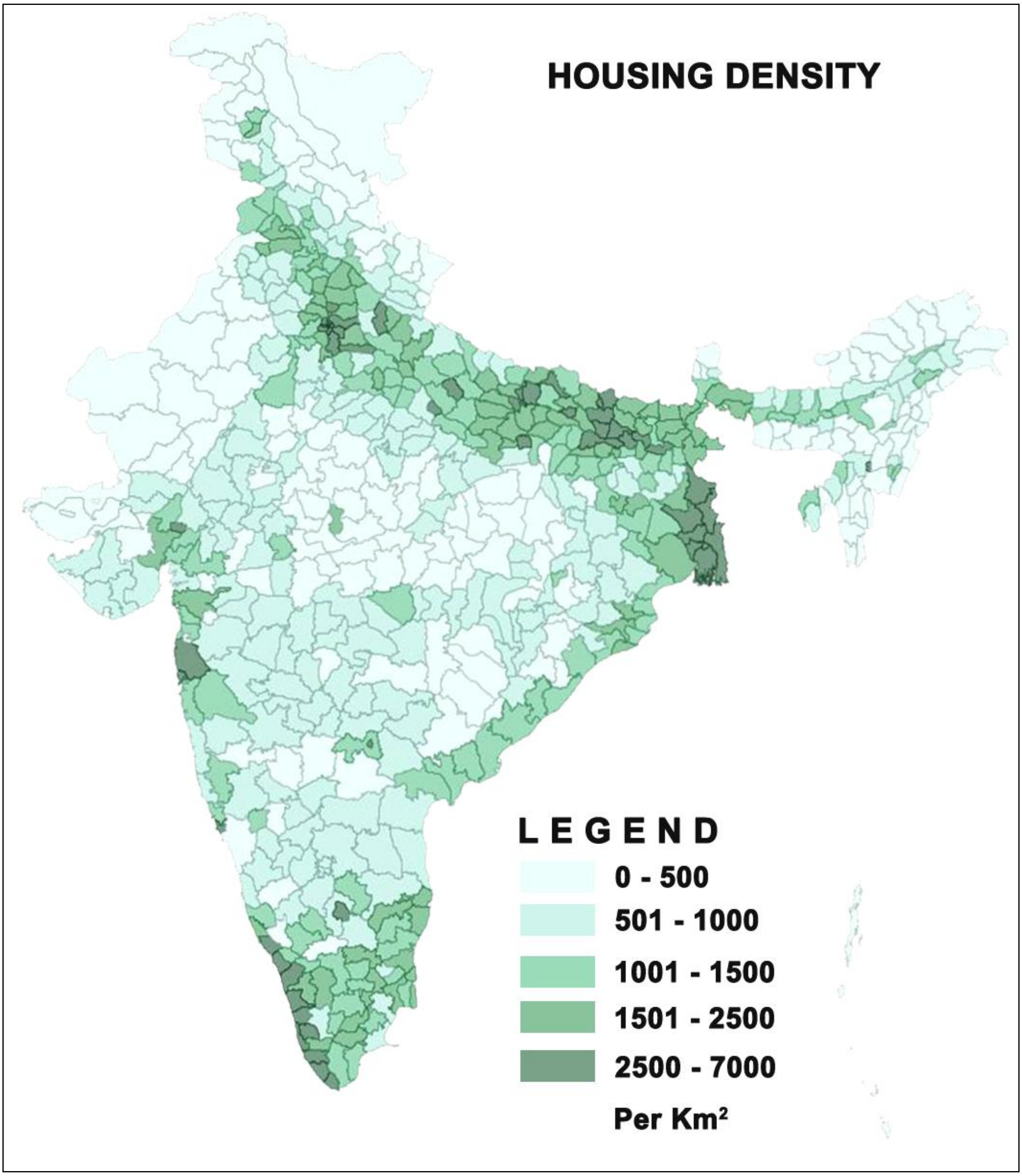

Figure 3: 2011 District-wise Housing Density distribution [*Source*: 2011 Census of India]

1.2.6.1 Buildings Materials

Natural materials (like mud, stone, bricks, timber and bamboo) form the major chunk of the buildings materials (up to about 95%) in construction across India. There is a larger use of cement based materials in urban areas than in rural areas. Over the last two decades, there has been an increasing trend of use of RC slabs in roofs; the sheet roofs in existing buildings are being replaced at a rapid pace with RC slabs. On the other hand, the buildings with modern materials (like reinforced concrete and structural steel) still constitute only about 3.6% of the entire building stock though their absolute number is on the rise. Table 3 shows the summary of choices of wall material in wall construction in rural, urban and entire country [Census 1991; 2001 and 2011]. The cumulative dominant materials of choice by 2011 are: (1) mud and un-burnt brick (about 22%), (2) burnt brick (about 48%); and (3) Stone (about 14%). These three materials together account for 84% of housing material used in the country. But, civil engineering and architecture education imparted across India does not account this in the curriculum. On the one hand, the housing construction materials listed above are reflected in only 3% of the courses taught to the undergraduate 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 3.6% of reinforced concrete houses in the country.

Recognizing the above skewed situation, clear understanding is required of this vulnerability of the building stock in the country by (i) identifying measures that can retrofit the existing building stock to earthquake-resistant standard, (ii) ensuring that new houses constructed are not vulnerable, and (iii) making systemic changes (as part of *capacity building* and *preparedness* initiatives of disaster management) towards mitigating impending earthquake disasters. Hence, a systematic methodology is required for

i. Documenting Housing Typologies in the Moderate-Severe Seismic Zones of India, with a view to understand the extent of loss that is expected in each existing housing type, and developing guidelines for all new constructions; and

ii. Retrofitting the vulnerable housing stock in the Moderate-Severe Seismic Zones of India.

1.2.6.2 Buildings Typologies:

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 typologies. 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 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 to rural areas. In many instances, these technologies were adopted in rural areas without understanding the implications. For instance, burnt clay brick walls in cement masonry were constructed in upper storey of 2-storey houses, when the lower storey walls were made in random rubble masonry in mud mortar. This may not result in an earthquake-resistant house, if the lower storey is weaker than the upper storey.

Table 3: 1991-2001-2011 Summary of choice of wall material used in house construction in India [Source: Census 1991, 2001and 2011]

S.No.	*Wall Material*	*Number of Houses as per 1991 Census*					
		Rural India	*%*	*Urban India*	*%*	*India*	*%*
1	Mud, Unburnt Brick	6,72,18,236	47.0	54,22,316	10.9	7,26,40,552	37.8
2	Burnt Brick	3,66,46,602	25.6	3,22,50,772	64.5	6,88,97,374	35.7
3	Stone	1,72,84,400	12.1	44,19,591	8.8	2,17,03,991	11.3
4	Grass, Thatch, Bamboo, etc.	1,70,56,489	11.9	25,31,939	5.1	1,95,88,428	10.2
5	Concrete	11,55,760	0.8	28,00,780	5.6	39,56,540	2.1
6	Wood	17,95,840	1.3	10,70,553	2.1	28,66,393	1.5
7	GI, Metal, Asbestos sheets	2,51,910	0.2	7,64,956	1.5	10,16,866	0.5
8	Ekra	2,01,039	0.1	53,869	0.1	2,54,908	0.1
9	Others	13,76,176	1.0	6,66,373	1.3	20,42,549	1.1
	Total	**14,29,86,452**	**100**	**4,99,81,149**	**100**	**19,29,67,601**	**100**
		Number of Houses as per 2001 Census					
1	Mud, Unburnt Brick	6,58,07,212	37.1	79,91,950	11.2	7,37,99,162	29.7
2	Burnt Brick	6,25,15,919	35.3	4,91,75,710	68.7	11,16,91,629	44.9
3	Stone	2,03,47,899	11.5	51,33,918	7.2	2,54,81,817	10.2
4	Grass, Thatch, Bamboo, etc.	2,21,62,932	12.5	25,74,189	3.6	2,47,37,121	9.9
5	Concrete	22,53,979	1.3	42,86,359	6.0	65,40,338	2.6
6	Wood	23,63,200	1.3	8,33,792	1.2	31,96,992	1.3
7	GI, Metal, Asbestos sheets	7,76,677	0.4	11,22,001	1.6	18,98,678	0.8
8	Plastic, Polythene	4,77,498	0.3	2,44,278	0.3	7,21,776	0.3
9	Others	5,32,197	0.3	1,96,159	0.3	7,28,356	0.3
	Total	**17,72,37,513**	**100**	**7,15,58,356**	**100**	**24,87,95,869**	**100**
		Number of Houses as per 2011 Census					
1	Mud, Unburnt Brick	58,330,614	28.2	8,119,213	8.3	66,449,827	21.8
2	Burnt Brick	83,618,436	40.5	62,927,369	64.0	146,545,805	48.1
3	Stone	28,685,790	13.9	14797142	15.1	43,482,932	14.3
4	Grass, Thatch, Bamboo, etc.	26,417,331	12.8	2,530,263	2.6	28,947,594	9.5
5	Concrete	3,699,096	1.8	7,284,583	7.4	10,983,679	3.6
6	Wood	2,132,342	1.0	648,929	0.7	2,781,271	0.9
7	GI, Metal, Asbestos sheets	1,269,359	0.6	1,062,510	1.1	2,331,869	0.8
8	Plastic, Polythene	762,256	0.4	335,575	0.3	1,097,831	0.4
9	Others	1,648,466	0.8	613,174	0.6	2,261,640	0.7
	Total	**206,563,690**	**100**	**98,318,758**	**100**	**30,48,82,448**	**100**

1.3 OPEN GROUND STOREY RC BUILDINGS IN INDIA

1.3.1 RC frame buildings are becoming common in urban India. Typical RC buildings in India (Figure 4) are made of (i) long vertical and horizontal members, called beams and columns, (ii) flat plate-like RC slabs, and (iii) vertical unreinforced masonry (URM) walls filled in spaces between beams and columns to divide building spaces into various functional areas. Usually, burnt-clay bricks are used in cement mortar for infill masonry walls. Also, other masonry units (*e.g.,* laterite stone, cement blocks, and sandstone units) are used as infill masonry walls.

1.3.2 Across urban India, most multi-storey buildings are made of *reinforced concrete* (RC) – a composite material made of *cement concrete* embedded with small diameter *steel reinforcement bars*.

Be it *small* buildings or *large* buildings, *apartment* buildings or *office* buildings, or *commercial* buildings or *industrial* buildings only a small fraction of these buildings are made of steel or other materials. Many reasons are given for this bias (though not substantiated) in favour of use of RC buildings, such as:

i. it is easy to construct buildings of arbitrary shapes of members with RC than with steel or masonry;

ii. relatively lower level of technical inputs are required to make buildings in RC than in steel;

iii. the Indian building industry is not equipped to use steel and masonry properly; and

iv. design and construction of RC structures do not require technically competent civil engineers, and can be done by head masons.

Figure 4: Typical RC Frame Buildings with Open Ground Storey

1.3.3 A special class of RC buildings is being constructed across the country, which have three distinct features, namely

i. *Open Ground Storey* – this is a solution provided by architects to solve the parking crisis in urban India (Figure 5), but it does not address earthquake safety of these buildings;

ii. *230mm width Narrow Columns* – this predetermined size is irrespective of (i) number of storeys they support above them, (ii) location of building with respect to the seismic zones, (iii) type of soil strata underneath the building, and (iv) distance between adjacent columns in the building.

iii. *Prescriptive Design of Building* – the design and detailing for beams and columns is not too different from that adopted for buildings designed for load effects other than earthquakes.

1.3.4 Unplanned development is on the rise, with minimal or no engineering inputs. Entry of many unprofessional and unscrupulous players in the real-estate development industry has led to sub-standard civil engineering services and products, thereby diluting the standards of many technical aspects of civil engineering (Figure 6) that in turn affect seismic safety. This unprofessional approach coupled with the fact that about 60% of India's land area hosts about 80% of India's population, has placed a question mark on the capacity of the buildings to resist effects of moderate to severe seismic shaking.

Figure 5: RC Frame Buildings with columns in open ground storey of 230mm width

Figure 6: 230 mm wide columns in ground storey of RC Frame Buildings: damaged column in Bhuj town during 2001 Bhuj earthquake

1.4 SELECTIVE RETROFITTING

1.4.1 India has witnessed several moderate earthquakes in the last two decades causing over 25,000 fatalities and innumerable house collapses. The prevalent high earthquake hazard, large exposure and high vulnerability indicate that urgent proactive action is necessary to save lives. *Thus, retrofitting is not just an option, but a national urgency.*

1.4.2 Every year a large number of new houses are getting added to existing stock of the country. Each earthquake in the last 25 years has identified some major deficiencies of the existing large stock of housing across the country. Seismic strengthening of these existing houses is a technological challenge as well, in addition to being a social, economic and governance challenge. A comprehensive approach is required for promoting systematic, formal and technically sound retrofitting of deficient houses. For this, systemic changes are required, with precise measures for *quality control* and *quality assurance*. These include *comprehensive continuing education programmes*, *stringent techno-financial* and *techno-legal regimes* and *improved contracting practices*. Intervention of relevant statutory bodies is a critical step here.

Valuable experiences have been gained in some countries (*e.g.,* USA, New Zealand, Turkey and Italy), which undertook the large programs for seismic retrofitting of buildings and structures spreading over decades. This document is sensitive to the challenges experienced in those seismic retrofitting programs.

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2 The Vision

2.1 THE INTENT

The Guidelines for Seismic Retrofitting of buildings and structures in India address the reduction (if not elimination) of loss of life owing to collapse of houses/residential structures, buildings and structures in impending future earthquakes. *All buildings and structures that pose high risk* to *LOSS OF LIFE* are identified. Table 4 provides the *high priority category* of buildings and structures other than houses/residences that pose such a threat; Vulnerable buildings and structures retrofitted to meet performance requirements (laid down in this document) during and after expected severe earthquakes. These Guidelines address:

i. Seizing the problem of seismic risk of buildings and structures in India,
ii. Preparing a priority of structures,
iii. Determining extent of intervention required, and
iv. Identifying suitable method of retrofitting to be adopted.

The principal stakeholders, who will benefit most from the Guidelines, are Governments of the States and of the Union Territories, and Ministries of the Government of India.

Table 4: Tentative list of high priority category of buildings and structures, other than houses/ residential structures, to examine for seismic safety and possible retrofitting, if found deficient (Referred in Sections 2.1.2, 3.2.1, 3.2.2, 3.2.3 and 4.13.1 of this document)

S.No.	*Description*
1(a)	High grade *critical lifeline buildings* that serve as nerve centres to host public congregations or large number of persons, and as important functions and services required in the aftermath of earthquakes towards ensuring *governance and business continuity*. Some examples of this set of structures are: District Magistrate's office and residence, office of Superintendent of Police, fire stations, food stocking and distribution centres, shopping centres, banks (including *Reserve Bank of India* and headquarters of all banks), telecommunication facilities (including all buildings that host telecommunication towers at the top), commercial centres, and sport stadia/arenas
1(b)	Lifeline structures and critical facilities, *namely* telecommunication systems, transportation systems including highway systems (*e.g.,* Golden Quadrilateral System, and North-South and East-West Corridors) airport control towers and railway station buildings, fire services, and pipelines carrying water, oil and gas from large distances (both buried and surface pipes) along with LPG distribution networks for consumers.
2	Buildings and structures of *hospitals* and *health facilities*, designated as *critical medical facilities* by the city/district/block
3	National defence and security-related most critical facilities, strategic assets and choke points
4	National, prestigious and historic buildings and monuments
5	Important buildings of government that ensure governance continuity in the aftermath of earthquakes, including offices of NDMA, State DMAs, District DMAs, and EOCs
6	Buildings and structures of *schools* and *academic institutes/universities*, including those designated to be used for post-earthquake temporary rehabilitation of affected persons and operations
7	Panchayat Office and Post Office buildings in villages
8	Critical industries that have bearing in the post-earthquake management activities

The vision of the Guidelines on Seismic Retrofitting in India is that:

2.1.1 Mandatory seismic retrofitting shall be undertaken in a prioritized manner of seismically deficient existing *government-owned* buildings and structures by respective governments, and *select privately-owned* buildings and structures by concerned owners. The prioritization should be based on *earthquake risk assessment* of buildings and structures. Section 3 of this document gives the procedure to be adopted.

2.1.2 *Highest priority* is accorded to large scale seismic retrofitting of

i. *Residential* buildings and structures that are deemed to have high risk of loss of life and
ii. High priority buildings and structures as listed in Table 4.

2.1.3 Retrofitting of existing deficient buildings shall be undertaken:

i. To prevent loss of life in housing, and
ii. To ensure *Governance and Business Continuity*, and to avoid handicap due to loss of critical & lifeline structures required to be functional in the aftermath of earthquakes. Retrofitting shall ensure that users of the said facilities can immediately occupy these buildings and structures. Identification of buildings that require retrofitting for specified performance level requires specific technical inputs.

2.1.4 Cost of retrofitting shall be critically examined when deciding to undertake retrofitting.

i. *Buildings:*
   If the building is *not of heritage value* (as determined by the competent statutory authority), the decision of seismic retrofitting of the building can be based on *Cost of Retrofitting* as a percentage of *Cost of Reconstruction* at current rates, as per Table 5 and depending on whether it is or it is not part of a critical and lifeline facility.
ii. *Critical and Lifeline Structures:*
   Threshold cost below which retrofitting can be undertaken shall be determined by competent statutory authority.

Table 5: Cost-based decision making of three levels of technical options

S. No.	*Decision*	*Cost of Seismic Retrofitting as a percentage of Cost of Reconstruction (including demolition, removal of debris and construction) at Current Rates*	
		Buildings part of Critical & Lifeline Facilities	Office and Residential Facilities
1.	**Retrofit**, if cost of retrofitting is	< *50%*	< 30%
2.	**Detailed technical assessment** to determine vulnerability of the building or structure (including analysis of the implications on cost; age; heritage value/importance; proximity to archaeological structure; criticality of building; current and projected Floor Area Ratios; residual life; disruption, expansion, and upgradation of services; and improved function), if cost of retrofitting is in the range	50% – 70%	30% – 50%
3.	**Reconstruct**, if cost of retrofitting is	> 70%	> 50%

2.1.5 Level of retrofitting should be based on the expected earthquake performance of the building or structure. Quantitative (analytical and experimental) research is necessary to study impact of different levels of retrofitting on earthquake performance of retrofitted building.

2.1.5.1 Buildings (other than Schools, Hospitals, and Critical & Lifeline Buildings):

i. In *non-engineered and non-critical buildings*, *NO COLLAPSE* is the expected target performance. When a large number of non-engineered houses and buildings have the same or almost same typology (including the vernacular and traditional ones that are being practiced for a long time), *a generic retrofit scheme may* be sufficient. It is necessary to build confidence on such generic retrofit schemes through *experiments on full scale specimen*. Experimental research on full-scale houses (single storey, or at best two storey) should ensure that generic retrofit schemes being proposed, protect the groups of prevalent houses and structures in different regions of the country. Until these tests are conducted, guidance can be sought from peer reviewed literature on techniques for seismic retrofitting. Institutes of national importance and repute, like IITs and NITs, should be supported urgently to develop such cost-effective facilities, and use them to develop the required cost-effective seismic retrofit technologies.

ii. In *engineered buildings* also, NO COLLAPSE is the expected target performance. When a large number of engineered houses and buildings have the same or almost same typology, *a generic retrofit measure* should be adopted in all of them. It is necessary to build confidence on such proposed generic retrofit schemes through *analytical research and limited experimentation*. This research should verify that select proposed generic retrofit schemes are sufficient to protect groups of prevalent buildings in different regions of the country. In particular, the buildings commonly built across the country with *Open Ground Storey* buildings and prescriptive details, should be retrofitted to eliminate the unusually lower lateral stiffness and strength in ground storey.

2.1.5.2 Schools, Hospitals, and Critical and Lifeline Buildings:

To begin with, irrespective of whether the building is *non-engineered* or *engineered*, expected target performance can be NO COLLAPSE condition. When the technology of retrofitting is understood better by larger number of practicing engineers, expected target performance can be raised to IMMEDIATE OCCUPANCY condition. This timeline can be reduced by focused efforts by all stakeholders to help engineers internalize seismic retrofitting. As mentioned at 2.1.5.1, *prescriptive retrofit measure* should be adopted including a possible *generic retrofit scheme* for a group of simple structures with similar typology, provided the building has three storeys or less. When the building is taller, the retrofit scheme should be developed for each structure independently. This effort will require higher level of technical inputs.

2.1.6 Method of retrofitting can be determined by implementing agencies in keeping with the requirements given in Section 2.1.3 of these Guidelines.

2.1.7 Seismic retrofitting invites attention to prevailing bye-laws on alteration and modification of building bye-laws. Thus, municipal local bodies should amend the same by embedding various technical requirements related to seismic retrofitting of buildings and structures, and modify those that affect or are affected by seismic retrofitting. Also, municipal local bodies should adopt *Peer Review* by competent professionals of proposed *Retrofit Scheme*.

2.1.8 Large base of technical manpower should be created with competencies in various facets of retrofitting. Capacity building programs should be undertaken towards sensitization, awareness, technical education, training of practicing engineers, architects and managers involved in seismic retrofitting, and skill development of artisans.

2.1.9 Considering limited availability in India of technical manpower and financial resources for undertaking seismic retrofitting of large stock of deficient buildings and structures, priority should be given to

i. Government structures over private structures;
ii. Non-engineered structures over engineered structures; and
iii. Non-compliant structures over partially compliant to prevalent standards.

2.2 SCOPE

These Guideline cover both *structural elements* and *non-structural elements* as defined in sub-sections below.

2.2.1 Buildings and Structures covering structural aspects of retrofitting.

i. *Buildings*, including public and private housing, schools and hospitals;
ii. *Critical buildings* required for governance continuity after earthquake events;
iii. *Electrical power systems*, including thermal, hydro- and petroleum power plant structures; and power transmission and distribution structures, buildings and switch yards;
iv. *Telecommunications systems*, including control panel buildings and antenna towers;
v. *Transportation systems*, including bridges especially all critical bridges, bridges on National and State Highways, toll booths, critical airports, railway stations, bus stations, sea ports, and signalling system structures of road, train, air and sea transportation networks;
vi. *Water Storage and Supply Systems*, including water controlling structures (*e.g.,* dams and sluice gates), water distribution systems (*e.g.,* elevated and ground supported water tanks), and distribution pipe systems (*e.g.,* penstocks);
vii. *Drainage and Sewage Systems*, including sewage piping systems;
viii. *Fuel Storage and Supply Systems*, including fuel processing structures like refinery structures, fuel distribution systems like trans-country pipelines – buried or surface, LPG distribution networks for consumers, and fuel storage systems like liquid and gaseous petroleum tanks - ground supported or elevated;
ix. *Buried Structures*, including strategic underground bunkers and facilities; and
x. *Historic Sites and Monuments*, including all international and national heritage sites and structures.

2.2.2 Non-structural Elements of Buildings and Structures

i. *Contents;*
ii. *Appendages, finishes and facades; and*
iii. *Services and utilities.*

2.2.3 Though the Guidelines primarily address safety of *structures* and *non-structural elements* during earthquakes, implementing these Guidelines provide an opportunity to address effects of other natural or manmade hazards also. Generally, compliance of design standards has not been ensured by the municipal and urban bodies across the country in the past through implementation of *mandatory* techno-financial and techno-legal mechanisms. Hence, it is not possible to prescribe prioritization of structures for retrofitting using the date of construction as the cut-off. These Guidelines expect that all buildings and structures meet the provisions of current relevant design and construction standards, as at least a *minimum requirement*.

3 The Strategy

3.1 REALISING THE VISION

Two-pronged approach is required to reduce earthquake risk in India, namely

3.1.1 Ensure *all NEW constructions are earthquake-resistant:*

New constructions should be built with at least the level of knowledge currently available in prevalent Indian standards, and hence made code-compliant. To ensure that no new vulnerable structures are added to the existing stock of structures in the country, it is essential to improve regulatory framework so that all new constructions are code-compliant. For this, mandatory techno-financial and techno-legal mechanisms should be adopted by municipal and urban bodies across the country. In future, it is hoped that all new buildings and structures meet prevailing provisions given in relevant design and construction standards, as a minimum requirement. Reasonable but short timelines should be projected for enforcing such a techno-legal regime and thereby reducing additional earthquake vulnerability of the new built environment being added in the country. Government should embark on large scale capacity building of construction sector engineers, architects, artisans, builders and developers in construction sector, update techno-legal regime and provide financial support to key stakeholders to achieve the above goals. Continued sensitization of stakeholders especially the house owners and making available technical literature and ensuring local technical help of village engineer, should be mandatory to achieve the stated goals.

3.1.2 Ensure seismic retrofitting of *identified vulnerable construction* are seismically retrofit:

Vulnerable buildings should be upgraded to meet specifications of prevailing Indian standards or other specifications laid down by statutory bodies and Ministries of the Union and State Governments. Retrofitting of existing vulnerable structures will mitigate losses during strong earthquake shaking. The objectives of this effort are to ensure following three aspects:

i. *Safety*: prevent loss of lives and property owing to collapse of buildings;
ii. *Governance Continuity*: avoid handicap due to loss of critical and lifeline structures required in the aftermath of earthquakes; and
iii. *Economic Loss Reduction*: make chosen structures including industrial structures meet certain stringent earthquake performance requirements towards maintaining business continuity and national productivity.

Seismic retrofitting is needed for ensuring safety of both structural elements and of non-structural elements.

3.1.3 National Retrofit Program

Objectives mentioned in Section 3.1.2 are the focus of this document. Considering gigantic number of buildings and structures to be retrofitted countrywide against seismic effects, a *National Program on Seismic Retrofitting of Buildings and Structures in India* should be launched with central coordinating office to address the issues of seismic retrofitting, like disruption planning, availability of funding and technology, designing, implementing and monitoring.

3.1.4 These Guidelines

i. Seek mandatory seismic retrofitting in a phased manner of all existing *government-owned constructions* and select existing *privately-owned constructions*, and
ii. Encourage seismic retrofitting of all existing *privately-owned constructions*, other than those identified under item (i) above. Appropriate incentive schemes are necessary to ensure that owners of private constructions take

up seismic retrofitting of existing constructions, a key component of earthquake risk reduction in the country.

3.1.5 Special Initiatives

Towards this end, Union and State Governments should undertake a host of initiatives in association with appropriate organisations and bodies, including

i. Offering support to all stakeholders on *Seismic Retrofit Technologies* for various construction typologies;
ii. Providing incentives in terms of smaller municipal taxes, lower interest rates for bank loans intended for seismic retrofitting of buildings and structures; and
iii. Creating a mechanism for building a *Seismic Retrofit Fund*, for undertaking seismic retrofitting of public interest government and private structures identified in item 3.1.4 (i) above.

3.1.6 Who should be concerned with Seismic Retrofitting?

Seismic Retrofitting should be a concern for

i. Principal stakeholders (including Ministries of Central Governments, State Governments, and key private sector industries and organisations) in seismic zones V, IV and III; also, principal stakeholders in seismic zone II should be encouraged to undertake seismic retrofitting of their buildings and structures, if found deficient to resist seismic shaking expected in seismic zone II;
ii. Owners of (a) unreinforced masonry buildings without any seismic features, especially seismic bands; and (b) reinforced concrete buildings with open ground/intermediate storeys that do not have RC structural walls; and
iii. Owners/societies of buildings and structures, not designed by competent engineers but built based on prescriptive detailing or buildings and structures whose designs have not been examined by competent engineers through a process of *Peer Review*.

3.2 STEP-WISE PROCESS FOR MASS RETROFITTING STRATEGY

Considering the large existing building stock that does not necessarily have the required earthquake resistant features, a systemic approach should be adopted to retrofit the large building stock in an efficient manner. Such a process of retrofitting a large building stock should be based on the sequence of activities discussed in sub-sections below. These activities should be organised at a municipal level through a technical group of professionals with competence in the subject of seismic retrofitting of building.

3.2.1 Document TYPOLOGIES

A nationally coordinated project is required to understand and document the spectrum of typologies that have been adopted in seismic areas across the country for housing & other buildings and structures. This exercise of documentation of a structure from seismic safety standpoint is a technical effort. For a house, it provides an opportunity to describe an *Ideal House* of the typology in focus, and identifying deficiencies in earthquake-resistant features of an existing house with respect to the *ideal house*. This effort will help to identify *dominant housing typologies,* being adopted in each geographical region and their deficiencies in the country. An added advantage of such an effort is the assessment of seismic safety of *non-structural elements* (NSEs) of these structures. The said documentation of the NSEs should indentify deficiencies of structures constructed, and thereby lead to improving the earthquake safety of buildings and structures. Further, a similar effort would be required to document typologies of the other buildings and structures listed in Table 4.

3.2.2 **Develop Inventories**

In the government sector, each Ministry or Department of the Union and State Governments should undertake this exercise to have the precise enumeration of all structures under its purview of the different sets of typologies identified. Similarly, various private sector organisations and agencies should be encouraged to prepare lists of their inventories. Table 4 shows a list of typical sets of buildings and structures, which should be inventorized.

3.2.3 **Conduct Risk Assessment and Prioritise Inventory of Structures**

Seismic risk assessment should be conducted for all sets of buildings and structures identified in Table 4. The number of structures in each category listed in Table 6 is large for entire country, or even seismic zones V, IV and III covering about 80% of India's population. Risk analysis will help to assess and prioritize these large numbers of structures for retrofitting.

3.2.3.1 Overall *Risk Assessment* should be undertaken of the built environment consisting of all inventory listed in Section 3.2.2. This risk assessment should consider *hazard* prevalent in the geographical region, *vulnerability* of typologies of construction that are likely to face expected shaking intensity, and *exposure* of the construction to life and property. The assessment should identify constructions with high risk. Thus, a *prioritised* list can be prepared for buildings and structures based on the level of risks. The priority list can be prepared (i) building- or structure-wise or (ii) village-, town-, city- or metro–wise. This risk-based approach is a more rational approach than to adopt a hazard-only/seismic zone based selection of buildings and structures.

3.2.3.1 First-order risk assessment methodology should be adopted based on *broad vulnerability characteristics* of buildings and structures reflected in the broad sense. The following step-wise approach can be adopted for assessing risk:

i. *Step 1*: Review seismic hazard to locate areas with high hazard, and identify important/high-grade buildings that should be considered for retrofitting;
ii. *Step 2:* Review structural characteristics of the building, including its as-designed and as-built status. Also consider vulnerability of buildings, considering its building typology and modifiers;
iii. *Step 3:* Evaluate economic factors considering the building age, condition and occupancy, and select performance objective as per Section 2.1.5;
iv. *Step 4:* Assess expected performance-level of building using simplified and/or systemic analysis techniques. If found deficient, consider analyzing various retrofitting measures, including changing of building occupancy to reduce its importance; and
v. *Step 5:* Carry out cost-benefit assessment of various retrofitting measures, their complexity and other factors (like extent of disruption during retrofit process) to determine the most suitable measure to reduce risk to building's functionality.

Table 6: List of inventory sets of buildings & structures in a village/town/city in Seismic Zones III, IV and V (with no order of priority)

S.No.	*Description*
1.	National, prestigious and heritage buildings and monuments
2.	National defence and security related critical facilities, strategic assets and choke points
3.	Important buildings of government that ensure governance continuity in the aftermath of earthquakes, including offices of NDMA, State DMAs, District DMAs and EOCs
4.	High-grade lifeline buildings that serve as nerve centres, housing large number of persons and important functions and services required in the aftermath of earthquakes, *e.g.,* all important public buildings and structures that have mass human congregation, like schools, police stations, food centres & milk vending areas, shopping centres, banks including *Reserve Bank of India* and headquarters of all banks, telecommunication facilities including all buildings that host telecommunication towers at the top, commercial centres and c LPG distribution networks.
5.	Lifeline structures and critical facilities, *e.g.,* telecommunication systems, transportation systems including highway systems *e.g.,* Golden Quadrilateral System and North-South & East-West Corridors, airport control towers, railway station buildings and fire services
6.	Buildings and structures of schools and academic institutes including universities and national institutes of all *designated* major academic institutes or schools in a village/town/city, as determined by competent authority, even though they may not have large number of students
7.	Buildings and structures of hospitals and health facilities tertiary care centres, secondary care centers or all *designated major hospitals* in a village/town/city, as determined by competent authority, even though they may not have large number of beds
8.	Utility structures, *e.g.,* water mains, water treatment plants, sewer mains, sewer treatment plants and electricity generation & distribution networks and systems
9.	Important buildings that ensure business continuity in the aftermath of earthquakes, *e.g.,* stock exchange buildings
10.	Vital installations that cause a secondary disaster, *e.g.,* dams, hydro-power plants, thermal-power plants, petroleum-power plants, petrochemical facilities and trans-country & urban fuel pipelines
11.	Hotel buildings with more than 100 rooms or with 5 or more storeys, and those hosting international dignitaries
12.	Primary School, Primary Health Centre, Panchayat Office and Post Office buildings in all villages in seismic zones III, IV and V
13.	Multi-storey buildings with 5 or more storeys in housing development colonies
14.	Sport stadiums and arenas with congregation of more than 5000 people
15.	Office and commercial buildings with 5 or more storeys
16.	Schools, academic institutes, hospitals and health facilities not covered under items 6 and 7 above
17.	Critical industries that affect post-earthquake management activities

3.2.4 **Undertake PRELIMINARY SEISMIC ASSESSMENT**

Buildings and structures found to be deficient in the overall risk assessment should be retrofitted to comply with Indian Standards for retrofitting. This exercise is expected to be within the current capacity of existing group of technical professionals, architects and engineers in the country, and based on *simple* assessments of both (a) *qualitative* for non-engineered constructions, and (b) *qualitative and quantitative* for engineered constructions. This assessment should be done only for buildings and structures rendered to have *highest risk* as referred at Section 3.2.3. Assessment to ensure code-compliance and identification of deficiencies will clearly bring out a *list of seismically deficient buildings and structures* that should be retrofitted. After retrofit of these structures is completed, the next set of buildings and structures may be taken up, which have a lower level of seismic risk. Technical documents should be prepared for *Preliminary Seismic Assessment* of different buildings and structures.

3.2.5 **Perform DETAILED SEISMIC ASSESSMENT to Determine SEISMIC RETROFIT Option**

Detailed Seismic Assessment should be undertaken of buildings and structures found to be deficient in the *Preliminary Seismic Assessment* undertaken in Section 3.2.4 and those that are required to demonstrate higher level of earthquake performance (Refer to Section 2.1.5). Out of this inventory of buildings and structures, a priority list should be drawn up and *detailed assessment* of their earthquake safety undertaken. Specifications and rigour of this detailed safety assessment in this step would be more *stringent* than those employed under Section 3.2.4. Here, international state-of-the-art may be considered, until indigenous research provides guidance through appropriate documentation. At present, this exercise may be beyond the current capacity of many professionals architects and engineers. Hence,

i. Only select buildings and structures identified or *shortlisted as seismically deficient buildings and structures* can be examined;
ii. A special effort of capacity buildings is required to increase the number of professionals who can undertake this;
iii. Prescriptive retrofit methods can be developed for common typologies of engineered buildings with similar features to reduce the overall effort of seismic retrofit of buildings across the country; and
iv. Prescriptive retrofit methods can be adopted for non-engineered buildings built across the country, to ensure that more vulnerable buildings are seismically retrofit at the earliest.

3.2.5.1 Once detailed assessment is conducted and deficiencies identified, the next step would be to decide the retrofit scheme. At this stage, the advantage of adopting a retrofit scheme should be demonstrated *QUANTITATIVELY* through detailed engineering analyses and calculations, based on sound engineering principles. In prescriptive retrofit, experiments should be done with the proposed prescriptive retrofit, and quantitative advantage arising from the proposed scheme demonstrated explicitly. In the absence of quantitative evidence of the advantage, the retrofit scheme may not be adopted. Also, the *quantitative approach* will help choose between two retrofit schemes that are *claimed* to be equally efficient. Once the retrofit scheme is finalised, the necessary construction drawings should be prepared.

3.2.5.2 Caution should be exercised when massive retrofitting effort is launched to address a large number of similar buildings of the same architectural configuration, material choices and quality of construction. For *non-engineered construction* built with little or no engineering input, significant input may be available on effectiveness of some retrofit measures from experimental studies, *e.g.,* shake table, shock table and horizontal pull tests conducted by some national agencies on scale-model and prototype buildings; the same may form the basis for developing prescriptive details. Keeping in view the national interest, more experiments may be conducted to quantify the effectiveness of the proposed retrofit scheme as detailed above.

3.2.5.3 On the other hand, for semi-engineered structures, *e.g.,* contractor-driven generic construction using modern engineering materials, namely concrete and reinforcement bars, and for engineered construction that are usually large in size and of varied plan and elevation shapes and sizes, prescriptive details developed for simple structures may not be applicable. But, in each of these structures, quantitative assessment of the effectiveness of proposed retrofit scheme should be demonstrated by the structural engineer undertaking the task.

3.2.6 **Undertake SEISMIC RETROFIT**

Taking seismic retrofit scheme from *construction drawing stage* to *implementation stage* requires financial allocation, engineers who can supervise the work, contractors and artisans who can undertake the work with appropriate equipment and expertise in their use, and above all the will of stakeholders to undertake seismic retrofit. Critical steps needed include:

i. Allocation of finances to undertake seismic retrofit; and

ii. Development of requisite technical manpower (construction engineers, contractors and artisans) to undertake the technical work.

3.2.6.1 For G*overnment-owned* buildings and structures, retrofitting should be made mandatory with financial projection and necessary annual budgets. For this, a phased effort with budgets and timelines should be drawn to announce Central Government funded plan schemes during various five year plan periods. Also, while distributing net proceeds of taxes every five years between the Central and the State Governments as mandated in Article 280 of the Constitution of India, Finance Commissions should consider making special allocation for States to undertake seismic retrofitting of government-owned buildings under non-plan side of the revenue resources. Also, State Governments may independently allocate financial resources for seismic retrofitting under their respective five year plans as well as in their state specific Finance Commission recommendations.

3.2.6.2 For *privately-owned* buildings and structures, different strategies may be required. Incentives, techno-legal and techno-financial instruments and mandatory laws may have to be brought in towards ensuring safety of buildings during incidence of future earthquakes.

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4 Implementing Seismic Retrofitting

4.1 SPECIFIC INITIATIVES

4.1.1 Retrofitting of exiting buildings is an uphill task. Significant changes are required in the prevalent eco system, to enable *all stakeholders involved* to find seismic retrofitting financially viable and beneficial. Requisite changes are sought at the *techno-financial*, *techno-legal* and *capacity building* fronts. This chapter presents the Guidelines for implementing the actionable items to achieve the stated intent and scope of *Seismic Retrofitting in the country* and outlines *Strategy* presented in Chapters 1 and 2.

4.1.2 The seismic retrofit effort in seismic areas will be meaningful, only if all NEW constructions are made earthquake-resistant. Making new constructions meet the performance objectives, as mentioned at section 2.1.5, requires a number of *quality control* and *quality assurance* initiatives to be put in place. These include *comprehensive continuing education programmes*, *stringent techno-financial* and *techno-legal regimes* and *improved contracting practices*. For this, many interventions are needed relevant statutory and institutional bodies.

4.1.3 The technical base required is small to implement seismic retrofitting of buildings and structures. Therefore, a number of aspects have to be improved in the eco-system to establish an enabling mechanism for mandatory seismic retrofit in India. These include:

i. Necessary knowledge systems and dissemination to ensure that engineers recommend the most efficient retrofit scheme that requires least resources without compromising end objectives,
ii. Human resources development and up-gradation through a formal indigenous capacity building effort,
iii. Legal standing of mandatory seismic retrofit requirements that includes revision of *techno-legal* and *techno-financial regimes* to forge success in seismic retrofitting,
iv. Coordination amongst stakeholders involved in seismic retrofit,
v. Ownership of Governments and business houses,
vi. Verification of non-prescriptive seismic retrofit scheme adopted in buildings and structures through a Government-approved process, and
vii. Sustainability of the mission through improvised schemes.

4.2 TECHNOLOGY OPTIONS – CHALLENGES

4.2.1 Any technique of retrofitting can be admitted, so long as it is demonstrated by professionally competent engineers to *quantitatively* meet the performance requirements laid down in relevant standards. While meeting the said requirements, first the overall safety of the structure should be ensured, and then attempts should be made to ensure safety of occupants. P*rescriptive retrofitting schemes*, which may be applicable for a certain typology of houses in a specific location with similar tectonic, geotechnical and structural conditions, should be taken up in areas of constructions of houses, schools, police stations, and panchayat offices that are largely non-engineered constructions.

Proposed prescriptive measures should be verified by testing on prototype houses of the said typology. Some work may have been done in this direction, and the same may be used. For housing typologies, where such past experimental studies have not been done, retrofit work can begin with guidance from subject specialists until inputs are available from detailed experimental investigations on those typologies.

4.2.2 Municipalities can make suitable arrangements to institutionalise review of retrofit technologies. Arrangements can be made with available large-scale national seismic testing facilities, like the shake/shock table facilities at Central Power Research Institute Bangalore, Structural Engineering Research Centre Chennai, Indian Institute of Science Bangalore, Central Building Research Institute Roorkee and Indian Institutes of Technology Kanpur and Roorkee, to develop testing programs that will address all vulnerable buildings typologies and structural systems. Further, available technical professionals in the country with background in seismic testing of structures should be consulted to create more national testing facilities that can offer services of full-scale seismic testing of buildings and structures. Such national testing facilities can be distributed across various seismically vulnerable regions of the country to strengthen select regional technical institutes and agencies that have good understanding of constructions in these regions.

4.2.3 It is important to compile significant experimental and analytical studies conducted so far in the country towards (i) knowing the available technical human resource, *i.e.,* academics, professional engineers and architects who are active and interested in the subject of seismic retrofitting, (ii) understanding the type of work done so far, (iii) challenges in experimental and analytical studies related to seismic retrofitting, (iv) gap areas that should be addressed urgently. Towards this end, *National Research Centers* should be commissioned at IITs, NITs and some leading engineering institutes, for *studying Seismic Retrofitting of Buildings* in the country towards institutional strengthening for earthquake risk mitigation. Findings of such research may be disseminated through technical meetings held *at both national and state levels*. This can lead to recommending good seismic retrofitting practices.

4.3 STANDARDS AND REQUIREMENTS FOR ASSESSMENT AND STRENGTHENING

4.3.1 Currently, very few design documents are available that address seismic retrofitting of buildings and structures in the country. Special efforts are required for preparing such documents. Also, the Bureau of Indian Standards (BIS) can be requested to bring out required documents urgently. Two documents currently available are: (a) IS:13935-2009 *Indian Standard Guideline for Seismic Evaluation, Repair and Strengthening of Existing Masonry Buildings*, and (b) IS:15988-2013 *Indian Standard Guideline Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings*. There is urgency for developing more such documents, including those for pre- and post-earthquake *Assessment of Buildings and Structures*. Many documents have been published by different national agencies and academic bodies across India towards seismic strengthening of non-engineered constructions. Future seismic retrofitting efforts should take advantage of these.

4.3.2 The exercise of developing these documents involves: (i) consensus among experts having understanding of international practices and overall building construction scenario of the country in both the *organised engineered construction* and *un-organised non-engineered construction* sectors, (ii) employing provisions under international practices, (iii) indigenous research on country-specific issues, and (iv) pragmatic approach for determining way forward when a building cannot be demolished and nor there are adequate funds to undertake full retrofitting to meet certain performance objective(s). Draft retrofit schemes proposed by consensus of subject area specialists can be placed in public domain to seek inputs from other specialists, who may have experience in a certain specific aspect of retrofitting.

4.3.3 In the interim period, until formal documents become available for seismic strengthening of buildings and structures from the statutory bodies, provisional requirements and specifications should be issued for the said purpose, with the understanding that they will be replaced by the appropriate formal documents as and when these become available. The following provisional technical documents should be prepared for the express purpose of giving impetus to the retrofit of buildings in the country:

i. Assessment and Strengthening of RC and Masonry Bridges;
ii. Assessment and Strengthening of Non-Structural Elements;
iii. Assessment and Strengthening of Hospitals Buildings made of RC and of Masonry; and
iv. Assessment and Strengthening of School Buildings made of RC and of Masonry.

4.4 DEVELOPMENT CONTROL REGULATIONS AND BYE-LAWS FOR RETROFITTING

Current Development Control Regulations (DCRs) and Bye-laws are largely geared to address new constructions. Seismic retrofit of existing buildings should be formally included in the DCRs and Bye-laws. Clear *qualitative* and *quantitative* guidance should be provided in the provisions related to seismic retrofitting. Further, each municipality or village should archive documents relating to planning, designing and implementing seismic retrofit of each building or structure for all future reference. Good practices should be included in DCRs and Bye-laws by frequently revising them, In particular, the verification of structural designs submitted to statutory bodies, should be examined for structural safety of the building under ground earthquake shaking expected at the site of the building in focus.

4.5 COMPREHENSIVE CAPACITY BUILDING PROGRAM

A comprehensive capacity building program should be launched towards easy implementation of these Guidelines by building large number of quality human resources required to implement such a gigantic effort. Such a program should cover:

i. Awareness generation amongst all stakeholders in the country;
ii. Education of the teachers and students in technical colleges architecture and engineering across the country;
iii. Research on aspects related to retrofit technologies;
iv. Training of practicing architects and engineers; and
v. Skill development of contractors and artisans in retrofit technologies.

4.5.1 Recognising that retrofitting is a relatively new activity for technical personnel of the country, sustained and significant education and intensive sensitization of the policy makers is crucial. Public awareness documents and technical literature should be liberally distributed among all stakeholders. Besides, codes and standards on seismic retrofitting developed by BIS and other similar government agencies can be placed in public domain (say on Internet) so that these are available free of cost for larger accessibility by all stakeholders of construction sector. Also, priority should be given to build aptitude and capacity among government engineers and architects, and thereby demonstrate the seriousness of retrofitting.

4.5.2 Implementing specific initiatives urgently to improve the eco-system for being able to undertake seismic retrofitting at the national level, should include:

4.5.2.1 Launch of *National Programmes*

i. Earthquake Engineering Education and Research,
ii. Earthquake-Resistant Construction Skill Development, and
iii. Earthquake Safety Awareness;

4.5.2.2 Commission Research Centers in the country with special emphasis on retrofit technologies;

4.5.2.3 Start specialised training, education and research programs on *Seismic Retrofit Technologies*, like

i. One-semester programs for teachers and practicing engineers and architects,
ii. Post-graduate Diploma in Earthquake-Resistant Construction and Retrofit Technologies, and
iii. Earthquake Engineering Research Fellowships.

This will require a strong network of technical institutes, like Indian Institutes of Technology (IITs), National Institutes of Technology (NITs), select other colleges, National Institutes for Training of Teachers and Research (NITTRs), Indian Technical Institutes (ITIs) and national laboratories like Central Building Research Institute (CBRI), Central Road Research Institute (CRRI) and Structural Engineering Research Center (SERC) and the Central Public Works Department (CPWD).

4.5.2.4 Formal plan is necessary for a sustained national effort for upgrading capabilities of architects, engineers, technicians, artisans, contractors and managers for effectively and efficiently handling seismic retrofitting activities in India. This will require IITs, NITs and some leading technical institutes to play a pivotal role in creating required technical capacity in education institutes. State Governments should take advantage of these institutes and build their engineering cadres. In addition, Union Government and its Ministries should undertake R&D that would be beneficial to State Governments for implementation. Engineering Departments of State Governments should have the special teams in their Public Works Departments (some States have already formed such teams and named them as *Hazard Safety Cell* or specifically *Retrofit Cells)* for understanding, implementing and monitoring of various seismic retrofit projects.

4.5.2.5 Norms should be developed for incremental constructions that are typically undertaken by owners over a long period of time. Municipal authorities should ensure that these norms are implemented.

4.6 MARKET CREATION

Generic simple retrofit options will allow greater commercialisation of the seismic retrofit activities. At least, for generic constructions, efforts should be made to identify retrofit solutions that are near similar for the mass housing of the same typology and size. This will help in creating a small scale industry for vendors to provide structural elements and/or services necessary for seismic retrofitting of housing.

4.7 PROFESSIONAL RESPONSIBILITIES

The roles and responsibilities of various stakeholders should be articulated as a step towards increased accountability of professional services. These governing clauses should be elaborated in *Development Control Regulations* and *Building Bye-Laws* of States and UTs, including of Urban Local Bodies.

4.8 AVAILABILITY OF FINANCIAL SUPPORT AND INCENTIVE

4.8.1 Special efforts are required to make available financial resources at individual and institutional level through long term soft loans with low interest rates for seismic retrofitting. Discussions are needed with various financial institutes to prepare the necessary technical basis for justifying the offer of low interest rates. Alongside, there is a need to encourage insurance organisations to provide insurance coverage to housing and commercial properties against earthquake damages, if the building is seismically retrofitted.

4.8.2 Incentives should be provided for earthquake-resistant construction of government buildings and structures through centrally sponsored schemes and central sector schemes and programs, like *Sarva Siksha Abhiyaan*, *Rashtriya Madhyamika Shiksha Abhiyan*, *Indira Awas Yojana*, *Rajiv Awas Yojana*, *National Health Mission*, and *Jawaharlal Nehru National Urban Renewal Mission.* This can ensure that no additional vulnerable buildings and structures supported under Government schemes are added.

4.9 QUALITY CONTROL AND QUALITY ASSURANCE MEASURES

4.9.1 Ensuring that civil engineers have the requisite background to undertake seismic retrofit work marks the basis of *Quality Control*. And, ensuring that competent civil engineers undertake the necessary steps as intended especially in seismic retrofitting process marks the basis of *Quality Assurance*. The key challenge in *Quality Control* is to improve *competence* of large number of *qualified engineers* in India. In addition to improving the quality of construction, these *competent engineers* should be the active partners in *Quality Assurance* during seismic retrofitting.

4.9.2 Both architects and engineers participate in buildings and construction projects. Hence, capacity building on seismic retrofitting of these professionals is a must for ensuring building competence of professionals for successful implementation of retrofitting projects. A massive continuing education exercise should be undertaken through Council of Architecture, *Indian Institute of Architects*, *Institution of Engineers (India)* and other national professional bodies to upgrade the background of practicing architects and engineers. Professionals should undergo minimum units of such continuing education exercises to be eligible to participate in retrofit projects. Guidance can be sought from international bodies, like Earthquake Engineering Research Institute (EERI), USA and Structural Engineers Association of California (SEAOC), USA, on understanding their successful continuing education practices.

4.9.3 In the long run, it is expected that the *Licensing of Engineers* can be taken up both at the National and State levels. As an interim step, States can be encouraged to start conducting examinations towards licensing the engineers, with appropriate legal instruments put in place.

4.9.4 Special services are required for rapid visual assessment of buildings in areas affected by earthquake, with a view to give them *red*, *yellow* and *blue* tags indicating the urgency to undertake detailed retrofitting, prescriptive retrofitting and minimal/no retrofitting before allowing the use of these buildings. This is a specialised effort and significant training is required in earthquake performance of housing of different typologies under different levels of ground shaking. Similarly, in a proactive community, such an effort is required before the earthquake to identify and prioritize vulnerable buildings.

4.9.5 In the national context, accurate post-disaster damage assessment of buildings is vital for: (i) ensuring safety of the occupants of damaged buildings, (ii) assessing the extent of damage and loss due to the event, and (iii) formulating policies for assistance by Government. Technical, rigorous procedures should be applied for post-disaster damage assessment of different structures. Different levels of procedures should be developed so that all structures are assessed within a reasonable time-frame following a large disaster using very simple methods, while more elaborate methods should be used on high priority buildings. This exercise requires detailed understanding of local construction typologies. Specialised training of the post-earthquake damage assessment teams is required for undertaking this work, especially when vernacular non-engineered buildings (a) go beyond technical aspects that are known to common engineers, (b) based on urban constructions, and (c) influenced, constrained or controlled by social, economical and environmental aspects.

4.9.6 Professional business houses can offer services towards *detailed damage assessment* of buildings and structures. Professionals should be trained to undertake the damage assessment based on this procedure, because of (a) lack of suitable curriculum in technical colleges, (b) the large stock of buildings and structures not designed for seismic effects, and (c) the sophistication in the subject of seismic design & retrofitting. The results of the damage assessment can become the basis for decisions that the government may take. *National Earthquake Rapid Damage Assessment Teams* should be commissioned, who on completion of their training can be on standby, and in the aftermath of an earthquake disaster, be pressed into service in the earthquake affected areas for earthquake damage assessment on behalf of Central Government and/or State Governments. Such teams should consist of persons with requisite technical and administrative backgrounds drawn from different national and state agencies.

4.9.7 Quality assurance is required at all stages of projects, namely planning, design, construction and maintenance. In this regard, self-regulation has been successful in many countries that have managed to implement and continually improve earthquake safe practices related to the built environment. Already, third-party graded peer-review process is in place in many metropolises. Similar approach should be extended to retrofitting activity as well. Thus, approvals should be sought by the following bodies:

i. Government-constituted *Panel of Technical Professionals with Standing* Constructions in larger cities and metropolises with urban development authorities or municipal corporations;
ii. Government-constituted *Committee of Professionals with Standing* Constructions in towns with municipal offices; and
iii. Government-constituted *Committee* or *Panel* of the nearest town or city/metropolis for constructions in areas that are not technically and legally under any of the areas listed in (i) and (ii) above.

4.10 TECHNO-FINANCIAL FRAMEWORK

Consensus should be arrived with the relevant National Ministries and bodies, like *Ministry of Finance (MoF)*, *Ministry of Urban Development (MoUD)*, *Reserve Bank of India (RBI)* and *Insurance Regulatory Development Authority (IRDA)*, to explore ways of providing incentives to those complying with formal safety requirements during retrofitting. For instance, low interest rates on long term soft loans and government subsidies to undertake seismic retrofitting works could be one such way.

4.11 TECHNO-LEGAL FRAMEWORK

Retrofitting of existing structures should be *mandatory* for

(a) All public buildings, either Government-owned or otherwise as per strategy proposed in these Guidelines (Section 3.2); and
(b) All schools and hospitals, either Government-owned or otherwise as per strategy proposed in these Guidelines (Section 3.2).

4.11.1 Further, the following activities should be taken up with bodies mentioned below towards easy implementation of the retrofit projects:

i. Affect appropriate changes in bye-laws of municipal areas and metropolises, to introduce *quality control* and *quality assurance* provisions to encourage and allow retrofitting with no legal blocks; and

ii. Add items of construction involved in retrofitting of buildings and structures in the *Delhi Schedule of Rates* prepared by CPWD *and Schedule of Rates* prepared by State PWDs.

4.12 PILOT PROJECTS & CASE STUDIES

4.12.1 Pilot projects should be undertaken that will be fore-runners for the massive effort of seismic retrofitting in India. As part of this pilot, schools and hospitals can be taken up as the demonstration structures for greater visibility, impact and use. Each step of the retrofitting process should be documented in detail and shared with all stakeholders through a national information clearing house, like the *National Information Center of Earthquake Engineering (NICEE) at IIT Kanpur,* in soft form as well as hard copy. Other examples of *small* demonstration-type pilot projects should include retrofit of a Panchayat Bhavan, School or Health Center in Seismic Zone; especially where a recent earthquake has caused damage. Large demonstration-type pilot projects should include *r*etrofit of a District Magistrate's Office and House in a severe Seismic Zone.

4.12.2 The available limited professionals conversant with the subject of seismic retrofit have undertaken some retrofit projects in the past especially after the 2001 Bhuj earthquake. These projects include buildings, bridges, water tanks and jetties. These professionals may be invited to share their experiences at National level conferences to: (i) compile all significant retrofit projects done so far, and (ii) encourage engineers of select projects to publish the same for the benefit and education of others interested in the subject.

4.13 TIMELINES FOR IMPLEMENTING RETROFIT PROJECTS AND CONSEQUENCES

4.13.1 Significant mobilisation of the existing manpower is needed in various Ministries and Departments at the Union and State levels to give impetus to the implementation of the seismic retrofitting in the country. The timeframe decided for this exercise should be based on a number of factors, *e.g.,* availability of funds, availability of trained contractors to undertake such works, and availability of architects and civil engineers capable of providing the required technical expertise. Out of the categories listed in Table 4 and prioritised as per procedure presented under Section 2.1 of this document, a possible target could be to work towards seismically retrofitting 10% of all seismically deficient buildings and structures in the first decade, 20% in the second decade, 30% in the third decade, and remaining 40% in the fourth decade. These targets could be at State level rather than at individual village, town, city or metro-levels. Nationally coordinated efforts are required to explain these time targets and how to achieve them at the levels of Ministries of Government of India and State Governments. Alongside, States should endeavour to meet this target, with high priority to capacity building of architects and engineers towards making them capable of confidently undertaking *design* and *execution* of seismic retrofitting of buildings and structures.

4.13.2 Distinction may be made between buildings made of RC and masonry, because the approach to be adopted can be *validated-prescriptive retrofitting* for masonry buildings, while *detailed non-prescriptive retrofitting* is required for RC buildings of at least three storeys. Buildings to be retrofitted in the jurisdiction of Urban Local Bodies (ULBs), can be displayed with RED and YELLOW tags marking the location coordinates (latitudes and longitudes) on each building, where RED tag would represent high level of seismic un-safety of the building and YELLOW represent moderate level of un-safety. This exercise should be undertaken by concerned ULBs. Also, such tagging may be updated later on by marking the buildings on high resolution freely available imageries on internet in collaboration with concerned ULBs wherever possible. ULBs may hire professional agencies for locating and tagging of the existing buildings to be retrofitted using the modern GPS technologies. Such an initiative should promote the market for undertaking earthquake resistant construction and lay emphasis on need for seismic retrofitting at individual as well as community levels.

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