Protecting the Built Environment from Earthquakes

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in

The Journal of Governance

Report No: IIIT/TR/2021/-1

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Hyderabad - 500 032, INDIA
January 2021

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Abstract: Earthquakes cause disasters only when the built environment fails to resist the earthquake shaking experienced in the affected area, thereby causing losses of life and property. Ensuring structural safety of the built environment alone will result in earthquake safety of India. India needs sufficient number of competent structural, geotechnical engineers and architects to design and construct its new earthquake resistant buildings and facilities and to retrofit its existing ones. This paper urges quantum changes in the educational, social, technical, financial, techno-legal, industrial and administrative governance systems of the country, and re-iterates the stand of the nation of zero tolerance to avoidable deaths due to earthquakes.

Key words: Mitigation, Technical Competence, Retrofitting, Safety Audit, Regulatory System

1. INTRODUCTION

In the last 3 decades, India has seen at least 10 earthquakes that caused losses and damages. And, the story of earthquakes together is dramatic – ~50,000 human lives lost, ~5,00,000 humans injured, ~10,00,000 houses collapsed and ~50,00,000 houses damaged [Sebeer *et al*, 1993; Jain *et al*, 1994; Jain *et al*, 1997; Jain *et al*, 1999; Jain *et al*, 2001; Jain *et al*, 2005; Murty and Rai, 2005; Murty, 2007; Murty *et a*l, 2011; Murty *et al*, 2012]. But, one item is common to all earthquakes – this huge loss of lives is attributable completely to collapse of the physical built environment. Even today, the large

stock of buildings and structures standing has high vulnerability of earthquake ground shaking. The reasons for this are:

(a) Lack of competent technical human resources, and

(b) Absence of systems and processes which overlooks the addition of more vulnerable buildings and structures.

About 4/5th of the built environment is in Seismic Zones III, IV and V (moderate to severe earthquake shaking areas), even though only about 57% land area falls in these zones [BMTPC, 2017]; therefore, about 100 Crores of people are at risk. Of the three contributors to risk: (a) **Hazard** needs to be estimated as accurately as possible, and earth scientists are the best set to provide this accuracy; (b) **Vulnerability** needs to be reduced, and engineers and architects are best suited to do this, and (c) **Exposure** needs to be limited, and the municipal authorities are best placed to guard this by not unduly increasing the FAR.

Earthquake safety of India can be ensured by:

(a) *People* – long-term investment to create a large pool of technical competent engineers, architects and artisans;

(b) *Processes* – urgent action to put in place systems and procedures that address and guarantee earthquake safety of the built environment; and

(c) *Products* - programmed action to ensure that every new structure built is earthquake-resistant and to replacing vulnerable buildings and structures, at least those of high priority to begin with.

To make the above happen, a whole ecosystem of earthquake safety is required. This paper elaborates on the activities, initiatives, programs and structural changes necessary to make *Earthquake Disaster Management (EDM)* effective – a litmus test for *EDM* is the number of buildings and structures that collapse in the next damaging earthquake of MSK intensity VII or higher.

2. EARTHQUAKE SAFETY OF INDIA

The matter of **earthquake safety is a structural safety**

(technology) matter – a matter of civil engineering and architecture to begin with. Thus, in addition to the DM Act, 2005 [DMA, 2005], DM Policy [DMP, 2009] and DM Plan [DMP, 2019], the *National Disaster Management Guidelines* on *Management of Earthquakes* [NDMG-ME, 2007] seeks through its Vision, *"Zero Tolerance to Avoidable Deaths due to Earthquakes."* Hence, all efforts should be made to reduce the collapse of buildings and structures during earthquakes. And so, if collapses of buildings and structures are avoided during earthquakes, the earthquake disaster would be eliminated. In this regard, the NDMA published the following documents:

(1) Guidelines for banks and lending institutions to make loans contingent on compliance of Disaster Resilience Standards [NDMG-BLI, 2010];

(2) Guidelines for Seismic Retrofitting of Deficient Buildings and Structures [NDMG-SR, 2014];

(3) Guidelines for Hospital Safety [NDMG-HS, 2016] to make all hospitals in India to be structurally and functionally safer from disasters;

(4) Guidelines for School Safety [NDMG-SS, 2016] to make all children and their teachers, and other stakeholders in the school community safe from any kind of preventable risks due to natural hazards that may threaten their well-being during the pursuit of education;

(5) Home Owner's Guide for Earthquake and Cyclone Safety [NDMA, 2019a], to guide those who wish to construct a house, and buy a house or a flat in a multi-storey building; and

(6) Earthquake Disaster Risk Index Report [NDMA, 2019b] to forecast the relative earthquake risk within a city and across cities.

(7) A Primer on Rapid Visual Screening (RVS) – Consolidating Earthquake Safety Assessment Efforts in India [NDMA, 2020] to forecast the relative earthquake risk within a city and across cities.

On the capacity development side, the *Ministry of Home Affairs, Government of India*, conducted two national programs NPCBAERM

and NPCBEERM for Architects and Engineers, respectively, during 2004-2006. Alongside, the Ministry of Human Resource Development conducted another National Program NPEEE during 2003-2007 for capacity development of technical institutions and enhancing facilities therein. But, there was no follow up program after these initiatives organized in the aftermath of the 2001 Bhuj Earthquake. Towards capturing and documenting perishable lessons from earthquakes, the NDMA constituted Post-Earthquake Reconnaissance Teams after the 2011 Sikkim, 2013 Doda, 2015 Nepal and 2016 Manipur earthquakes. But, the R&D Institutes did not capitalize on these post-earthquake reconnaissance studies to undertake detailed follow up studies. These discrete products and initiatives did not mange to create a momentum to gather the needed technical human resources and to establish the systems and processes. Earthquake disaster mitigation in India is waiting at the starting blocks.

3. EARTHQUAKE DISASTER MANAGEMENT

Disaster Management (DM) hinges on six aspects in the cycle of each hazard, namely *Prevention*, *Mitigation* and *Preparedness* before the event, and *Response*, *Rehabilitation* and *Reconstruction* after the event. Because earthquakes are natural events, *Prevention* is not in focus in *Earthquake DM (EDM)*, even though *earthquake forecasting* has been attempted for a century with rare success. Thus, only 5 aspects are in focus in EDM, namely *Mitigation*, *Preparedness*, *Response*, *Rehabilitation* and *Reconstruction*; these 5 aspects are inter-related (**Table 1**). The elements on the diagonal boxes of the table are the main thrusts of EDM, namely:

(1) **Safe Constructions**: Focus should be on ensuring that all *new constructions* are earthquake resistant and *existing constructions* are retrofitted to become earthquake resistant;

(2) **DM Plans**: *EDM Plans* are different for national, state, district and town levels across the country. And, Plans at each level should flow from the plan at the next higher level;

(3) **Search & Rescue**: The emergency period of Earthquake Response is dominated by the effort to identify and save

survivors trapped under the rubble of collapsed structures;

(4) **Livelihood Restoration**: Re-starting economic activities at the earliest opportunity is critical after the earthquake emergency is over; and

(5) **Built Environment Restoration**: Providing all persons who lost their houses during the earthquake to have their own roofs, and restoring all civic infrastructure are signs of restoring normalcy to the affected community.

And, the elements in the off-diagonal boxes are the minimum mandatory actions that should be undertaken to work towards establishing earthquake safety in India.

Table 1: Inter-related elements in the five aspects of *Earthquake Disaster Management*

Aspects	**Mitigation**	**Preparedness**	**Response**	**Rehabilitation**	**Reconstruction**
Mitigation	**Safe Constructions**	Technical Education	Damage Assessment	Temporary Shelters	Permanent Shelters
Preparedness		**DM Plans**	Active EOCs & Mock Drills	Community Engagement	Owner Driven Reconstruction
Response			**Search & Rescue**	Trauma Counselling	In-situ or Relocate
Rehabilitation				**Livelihood Restoration**	Loss Compensation
Reconstruction					**Built Environment Restoration**

3.1 Earthquake Mitigation

Earthquake Disaster Mitigation hinges on 5 aspects, namely *Typology*, *Education*, *Safety*, *Practice* and Policy; these aspects are inter-related (**Table 2**). The elements on the diagonal boxes of the table are critical to Earthquake Disaster Mitigation, namely:

(1) **Typologies of Structures**: Documenting typologies of different structures built is critical, because it will help in understanding their earthquake resistance, options to retrofit existing structures (where required) and improvements needed to make new structures earthquake resistant. For example, India

has about 30 broad typologies of houses. Only a few of them are safe, namely the traditional typologies built over centuries along the Himalayas. But, these 30 odd typologies have not been studied quantitatively through experimental studies on full-scale houses and associated analytical studies. A long-term program is required to study and set standards for the complete set of typologies adopted in the construction of buildings and structures across the geographical spread of India, especially *material preferences* and *design requirements*.

(2) **Technical Education**: Technical education pertaining to earthquake safety is a serious concern in India. Attention is fading from fundamental aspects that ensure holistic safety of structures, and moving to new technologies that provide speed and economy. Also, hands-on laboratory experience is diminishing owing to lack of resources to maintain and run teaching laboratories. Currently, at the undergraduate level, only 7 government colleges in the State of Gujarat have earthquake safety as mandatory part of the civil engineering curriculum. With about 82% of the people if India (about 100 Crores) living in seismic zones III, IV and V, the subject of earthquake safety should find place in the mandatory part of civil engineering and architecture education.

(3) **Full Scale Testing**: Earthquake resistant constructions do undergo damage when shaken by earthquakes that produce large intensities of ground expected at the site. It remains to be examined if the said damage is life threatening in a given typology of the structure. Only full-scale testing can demonstrate quantitatively the likely damage in such situations. Currently, India has two facilities existing in the country for testing full-scale buildings (up to 3 storeys) and bridge piers (up to 10 m height). To cater to the needs of 100 Crore people living in moderate-to-severe seismic zones, more full-scale testing facilities need to be established, at least region-wise to begin with, towards making testing affordable and equitable. A multi-agency collaborative project is required to undertake full-scale earthquake testing of structures, so that eventually all

buildings and structures of different typologies adopted in the country are evaluated.

(4) **Safety Standards**: India had a separate standard (IS 1893) for earthquake resistant design of structures from the early 60s. But, this standard was revised after long periods of time, especially during 1980s to 2015. Many provisions need to be updated. Internationally, such important standards are revised once in 3 years. Also, new standards need to be authored pertaining to earthquake safety of the built environment. For instance, an Indian Standard is not available for earthquake safety of coastal structures. Preparation of earthquake safety standard based on R&D work in the country should be taken up as a national mission for academia, R&D organizations and Industries to meet in the next 5 years; and

(5) **Structural Safety Act**: Structural safety compliance of all new constructions cannot continue with the IIT-NIT approval system, as is the current practice in most government projects. India should move to a more sustainable peer review approach in the matter of structural safety. A strong Structural Safety Act is required to set right many aspects of how structural safety is addressed in India, especially earthquake safety. Urban Local Bodies, Municipalities and Panchayats should put in place systems and processes for a Third Party Peer Review of the Structural Safety of all new constructions and retrofit of existing structures. Urgently, India should strengthen existing Laws and their implementation, or have a new Structural Safety Act. It should resolve all contentious issues, including: (i) competency based structural safety related services to be provided by civil engineers and architects, and (ii) professional consulting services related to peer-review, proof check, field tests, etc.

And, the elements in the off-diagonal boxes are the minimum mandatory actions that should be undertaken to work towards establishing earthquake safety in India.

Table 2: Inter-related elements in the five aspects of *Earthquake Disaster Mitigation*

Aspects	**Topology**	**Education**	**Safety**	**Practice**	**Policy**
Topology	**Typologies of Structures**	Manuals of Good Practice	Regulate Unsafe Typologies	Skilled Artisans	Change Bye-laws
Education		**Technical Education**	New technology	Continuing Education	Licensing of Engineers
Safety			**Full Scale Testing**	Retrofitting	Peer Review
Practice				**Safety Standards**	Risk Indexing
Policy					**Structural Safety Act**

3.2 Earthquake Preparedness

Earthquake Disaster Preparedness hinges on 5 aspects, namely *Content*, *Sensitization*, *Facilities*, *People* and *Systems*; these aspects are inter-related (**Table 3**). The elements on the diagonal boxes of the table are critical to Earthquake Disaster Preparedness, namely:

(1) **Mass Media Communication Material**: DM is every citizen's subject. Disasters can be managed better with improved awareness and preparation by each citizen. Hence, impact of disasters, ways of mitigating their negative consequences, role of each citizen, and benefits of undertaking mitigation measures needs to be showcased to the nation. Content should be carefully prepared to suit different target audiences in different languages. And, a comprehensive mass media campaign should be launched;

(2) **Risk Communication**: Communicating facts to the citizens based on quantitative projections derived from risk assessments exercises related to each hazard are precursors to allocation of resources and focused efforts by governments. Currently, assessment of risk is in the nascent stages in India. But, a start should be made, even though imperfect; it will evolve with increase in competence and experience. The method of

assessing risk should be updated continually and the revised numbers projected. But, communicating risk should be with a focused goal of achieving a predetermined change. Scales of assessing risk should be start from local level and grow to region and national levels. Changes are easy to bring about immediately after the earthquake; it is prudent to be ready ever with risk communication content and plans;

(3) **Emergency Operations Center**: Emergency Operations Center (EOC) plays a crucial role in DM. All operations required to be performed in the golden hour should be rehearsed in peace time by communicating social events like seasonal large scale festivities of the village or town. Good forecasting of the likely disaster is the key to making EOCs successful. They should be equipped with state-of-the art facilities and manned by competent manpower. SDMAs should ensure that the State EOC as well as the District EOCs are established and functional fully immediately;

(4) **Mock Drills**: An effective way of helping each citizen internalize DM is by performing Mock Drills at regular intervals in all academic institutes, housing colonies, and offices. This is a centerpiece of DM planning. This could be done at predetermined days of the year, at least one in a quarter, and on a surprise date in a year. Mock drills help understand reaction time and shortcomings in the preparedness; and

(5) **Active SDMAs and DDMAs**: The key to DM Preparedness is a vibrant SDMA, which will motivate and inspire the DDMA to become action centers. Seamless, goal-driven partnerships are needed between NDMA and SDMAs, and between SDMAs and DDMAs. The success of DDMAs will depend on how well they partner with local NGOs and voluntary groups in implementation of the DM plans.

And, the elements in the off-diagonal boxes are the minimum mandatory actions that should be undertaken to work towards establishing earthquake safety in India.

Table 3: Inter-related elements in the five aspects of *Earthquake Disaster Preparedness*

Aspects	Sensitization	Content	Facilities	People	Systems
Sensitization	**Risk Communi_ cation**	Risk Index	DM Plans	Media Linkage	Policy Makers
Content		**Mass Media Communi_ cation Material**	Print, Audio and Video Documents	Media Campaign & Events	Public Awareness
Facilities			**Emergency Operations Centers**	Disaster Response Network	Stockpile Rescue Facilities
People				**Mock Drills**	Chain of Command
Systems					**SDMAs and DDMAs**

3.3 Earthquake Response

Earthquake Disaster Response hinges on 5 aspects, namely *Systems*, *Emergency*, *Logistics*, *Medical Response* and *Community*; these aspects are inter-related (**Table 4**). The elements on the diagonal boxes of the table are critical to Earthquake Disaster Response, namely:

(1) **Emergency Operations Centers**: EOCs that have rehearsed adequately during *DM Preparedness* will become the nerve centers during *DM Response*. Because EOCs serve these two major aspects of DM, EOCs should be up and running immediately;

(2) **Search & Rescue**: Saving the people alive and trapped under the rubble of collapsed buildings and structures is a scientific activity. S&R Teams should have knowledge of structural engineering, orthopedics and robotics to undertake the task. They should be trained on judging when to intervene in person and when to access through robots. Well trained SDRFs will be of high value, which are propositioned in strategic locations of each state.

(3) **Civil Supplies**: Earthquakes can severely impair transportation system, and providing civil supplies in such a situation can be a

challenge. To ensure at least basic supply of essential items in the aftermath of damaging earthquakes, communities need to be sensitized on the need to have emergency supplies (for a week at least) of essentials, which include medical items, food and water, along with other useful items like footwear and torchlight.

(4) **Triage**: With injured patients at emergency at a hospital, prioritizing which condition (cardiac, orthopedic, surgery or trauma) of the patient needs first decision making. Triage is vital here to determine the order in which the ailments will be treated. Emergency bays of hospitals should practice triage in their normal functioning. Training of personnel, especially the non-medical support staff, is vital; and

(5) **Golden Hour Response**: Generally, about 72 hours after an earthquake event are crucial. The chances of survival can be increased substantially, if the injured can be given timely and appropriate support. Also, affected persons need to be given care and personal counseling. Communities need regular and accurate updates.

And, the elements in the off-diagonal boxes are the minimum mandatory actions that should be undertaken to work towards establishing earthquake safety in India.

Table 4: Inter-related elements in the five aspects of *Earthquake Disaster Response*

Aspects	**Systems**	**Emergency**	**Logistics**	**Medical Response**	**Community**
Systems	**Emergency Operations Centers**	Disaster Response Force	Standard Operating Procedures	Infrastructure	Information Dissemination
Emergency		**Search & Rescue**	Incident Command Sys.	Paramedics	Community Responders
Logistics			**Civil Supplies**	Equipment & Manpower	NGO Coordination Center
Medical Response				**Triage**	SH groups (Red Cross Trained)
Community					**Golden Hour Response**

3.4 Earthquake Rehabilitation

Earthquake Disaster Rehabilitation hinges on 5 aspects, namely *Compensation*, *Temporary Shelters*, *Psycho-Social Trauma*, *Livelihood* and *Community*; these aspects are inter-related (**Table 5**). The elements on the diagonal boxes of the table are critical to Earthquake Disaster Rehabilitation, namely:

(1) **Ex-Gratia**: Rehabilitation after an Earthquake is complex task and it needs a comprehensive and collective effort. Giving Ex-gratia (given out of empathy to fellow human beings though not as compensation) to kith-kin of persons dead during the earthquake helps the poor. But, this is only a starting point of Rehabilitation process in DM;

(2) **Health Standards**: Temporary Shelters provided should meet the WHO standards laid down to ensure basic hygiene and prevent additional challenges arising out of lack of cleanliness and medical safety;

(3) **Medical Support**: While rehabilitating affected persons after earthquakes, their past medical record should be considered. Often, such medical records are not available. Hence, only experienced doctors should give personalized solutions. Such a system needs to be developed over a period of time. Standard operating procedures should be developed by foreseeing the post-earthquake situation. A review of the current medical practices and facilities is necessary, to plan how this medical system will service the sudden spike in the medical support needed;

(4) **Economic Activities**: After an earthquake, all employment activities are expected to be stalled for some time. The most crucial element of rehabilitation after an earthquake is restoring economic activity. The affected people feel reassured that they can rebuild their lives if their employment is restored. The ensuring minimum wages is essential for unskilled workers. Bringing skilled men/women back to their regular economic activities at the earliest opportune time is a central part of the rehabilitating communities; and

(5) **Social Activities**: While disaster recovery is a time consuming process, the engagement with the community should start as soon as possible; it gives hope and strength to people and helps them come back to normal condition. For this to happen, planned social engagements can be helpful. Communities should be encouraged to have religious congregations, mass prayers, festivals, etc. This will help in re-establishing the human bonds within the community, and recovery can be made smoother.

And, the elements in the off-diagonal boxes are the minimum mandatory actions that should be undertaken to work towards establishing earthquake safety in India.

Table 5: Inter-related elements in the five aspects of *Earthquake Disaster Rehabilitation*

Aspects	**Compensation**	**Temporary Shelters**	**Psycho-Social Trauma**	**Livelihood**	**Community**
Compensation	**Ex-Gratia**	Civil Supplies	Orphan Support	Minimum Wage	Donations
Temporary Shelters		**Health Standards**	Rehabilitation Centre	Aanganwadi Activities	Community Spaces
Psycho-Social Trauma			**Medical Support**	Unskilled workers	Privacy for Counselling
Livelihood				**Economic Activities**	Employment Guarantee
Community					**Social Activities**

3.5 Earthquake Disaster Reconstruction

Earthquake Disaster Reconstruction hinges on 5 aspects, namely *Technology*, *Money*, *People*, *Site* and *Safety*; these aspects are inter-related (**Table 6**). The elements on the diagonal boxes of the table are critical to Earthquake Disaster Reconstruction, namely:

(1) **Safe Type Designs**: Each region has certain types of houses built commonly. The unsafe typologies should be outlawed. These designs are likely to be more readily accepted during reconstruction. Hence, it is better to identify 2-3 type designs, especially for the *Low Income Group* category, and prepare earthquake resistant structural designs of these structures for

different soil conditions in the region. After an earthquake, these designs will be the starting points when discussing with the beneficiaries; the iterations will be reduced and time for finalization will be shortened;

(2) **Compensation**: When houses are damaged partially, compensation is paid to owners to restore them. The amount of compensation depends on the grade of damage. Categorizing buildings depending on the damage sustained by them is a formal structural engineering exercise. *Damage Assessment Teams (DATs)* need to be formed, which are trained formally on the nuances of the damages and their implications on life safety. Alongside the needed techno-financial and techno-legal systems should be put in place before the earthquake, to make damage assessment after the earthquake a legally protected technical exercise. Compensation should be paid only after a formal certification by the DATs. This damage assessment is not the Rapid Visual Survey that is understood commonly;

(3) **Owner or Contractor Driven Reconstruction**: Even if the type designs are acceptable to the community, social dynamics will determine the choice, whether post-earthquake reconstruction will be owner driven or contractor driven. Specially trained NGOs should mediate this decision making process and assist the government in speeding up the decision making and starting of the reconstruction;

(4) **In situ or New Sites**: Two thoughts may arise in communities after earthquakes where there is extensive collapse of houses – to build at the same site where the houses collapsed, or to go to a new site build afresh. If there is no special issue with the previous site (like permanent deformations of ground, liquefaction, fall of debris, and landslides), only then the in-situ option should be allowed. It may happen that only some would like to move to new site, while others may want in situ reconstruction. Again, a mediator NGO is necessary to help communities to take this decision; and

(5) **Permanent Shelter**: Even with the above four crucial contentious issues sorted out, the realization of the permanent

shelters should be a guided process. A construction management group is needed to keep track of the progress and complete the work on time.

And, the elements in the off-diagonal boxes are the minimum mandatory actions that should be undertaken to work towards establishing earthquake safety in India.

Table 6: Inter-related elements in the five aspects of *Earthquake Disaster Reconstruction*

Aspects	**Technology**	**Money**	**People**	**Site**	**Safety**
Technology	**Safe Type Designs**	Cost-Effective Design	Artisan/Owner Training	Local Materials	Testing
Money		**Compensation**	Compensation Policy	Land Title	Legalized Damage Assessment
People			**Owner or contractor driven**	Customization	Peer Review
Site				**Insitu or New Sites**	Land Use Planning
Safety					**Permanent Shelter**

4. PRIORITY INITIATIVES TOWARDS EARTHQUAKE RISK REDUCTION

Earthquake safety is a **technology problem**. Hence, technology upgrade across the nation at relevant levels can solve it. There are three urgent requirements to make earthquake disaster mitigation to get off the starting blocks and to reduce earthquake disaster risk, namely: (1) strong national will to address earthquake safety, (2) sustained national earthquake technology program to implement measures towards ensuring structural safety, and (3) national program for earthquake engineering education and research to prepare the hands that will implement structural safety. Details of some top priority initiatives are given hereunder. Only if **all** these are implemented, DM will switch to the **(bottom up)** *pull model*, much away from the current **(top down)** *push model***.**

4.1 Long-Term Implementation

(a) Overhaul Technical Education and build Competent Technical Manpower

Unless the over 32 Crore existing constructions and all new constructions are made earthquake resistant, post-earthquake Response will not end. Leadership in the country (senior academics, bureaucrats and policy makers) needs to take bold steps to prepare large manpower over the next two decades, which is necessary to address earthquake safety of the country. Also, even it is an imperfect start with the available technical hands, Mitigation actions (*i.e.,* making safer constructions) need to be taken urgently, if India wishes to reduce the loss of life in upcoming earthquakes. Books on earthquake resistant design and constructions, focused development of teachers of civil engineering and architecture colleges in the domain of earthquake resistant design, mandatory architecture and engineering education curriculum, degree relevant programs, competent graduates, regulated practice and then earthquake resistant constructions – is the sequence of building an earthquake safe nation.

(b) Develop Capacity in Practicing Structural Engineers and Architects

With the ever changing landscape of technical education, technical component in the undergraduate education will continue diminish. Specialist knowledge can be imparted only at the levels of Masters and Doctoral degree program. This will be a threat to providing the needed precious **technical knowledge** to local and state governments towards implementing earthquake safety across the country, because most of them at the entry level will have only a bachelor's degree. A national program is needed on *earthquake engineering education*, with focus on enhancing competence of the practicing structural engineers and architects, to prepare at a faster pace the needed hands that can build earthquake safety in India. The program should emphasize specific competencies related to earthquake-resistant *design*, *construction* and *retrofitting*.

(c) Undertake Nationally Relevant Earthquake Research & Development

It is time for the nation to capitalize on the limited service-minded technical hands and establish a truly national center for R&D in earthquake safety. It should be charged with pointed terms of reference related to built environment of India – *earthquake hazard monitoring*, earthquake *hazard assessment*, earthquake *safety assessment* & earthquake *retrofitting technologies* for existing structures, and earthquake *resistant design technologies* for new structures.

(d) Develop Safety Standards at a Steady Pace

Even though the development of standards for earthquake resistant design and construction started in 1962, the progress in the last 58 years has been sluggish. Standards are available only for a limited set of structures, and that too only for earthquake hazard estimation and earthquake resistant design of buildings and a few other structures. Also, design of earthquake retrofit is missing for most structures. A formal and comprehensive plan should be rolled out for a steady development of earthquake standards, weeding out all deficient typologies and mandating on such structural typologies that are least likely to collapse during earthquakes.

4.2 Short-Term Implementation

(a) Need Bold Leadership

This is required to catapult out of the current quagmire of low motivation and limited resources gazing a high risk situation of earthquake safety of India. Leadership should:

(i) Embark on modest starts, how much ever imperfect they are, along different verticals discussed in the paper.

(ii) Shed generic Disaster Management solutions, which are drawn up at the center for all states, districts and towns, towards making India safer from future earthquakes, decentralize Earthquake Disaster Management to DDMAs, strengthen **Local Governance**, and provide *technical support* from NDMA and *financial support* (for the government-owned structures) from SDMA.

(b) Establish Strong Regulatory System

Four primary legal tools are required to ensure earthquake resistance in the built environment of the country, namely:

(1) Establishing the system of Licensing of Engineers,

(2) Mandatory requirement to verify structural safety before starting construction of any structure,

(3) Dropping the mandatory requirement in all government projects, which is imposed through orders by Government Departments and Ministries of Central and State Governments and UT Administrations across the nation, of seeking approval of structural safety from Faculty Members of IITs and NITs (This will help teachers do teaching and research, their primary tasks!), and

(4) Make compliance of all Indian Standards mandatory in all projects across the country, instead of their current recommendatory status.

(c) Undertake Selective Earthquake Retrofit

Undertake Retrofitting of select structures – say, all government-owned *schools* and *hospitals*. Also prepare a comprehensive plan for promoting systematic, formal and technically sound retrofitting of *houses* of all typologies, as it not only involves technology issues but also social issues.

(d) Launch Model District Program

Do it differently!! Begin in 1 of the 720 districts the work of Earthquake Disaster *Mitigation* based on understanding of best practices in India and worldwide. Then, improve the systems and processes and adapt/adopt the best practices in the remaining 719 districts of the country. Implement this blitzkrieg *Earthquake Resistant Model District Program (ERMDP)*, in a crisp 1 Year and share the success with the rest of the country. The goal of ERMDP should be to ensure that all new structures are earthquake resistant. And, the focused agenda items of the ERMDP should be Items 4.2(a), (b) and (c) described above.

(e) Document Lessons from Earthquakes

Post-earthquake Reconnaissance Surveys by experienced multi-disciplinary teams are valuable to capture perishable lessons that earthquakes leave behind for us to learn from. Such teams should be dispatched at the earliest, with a mandate not to disturb the emergency Response work. Also, after the emergency is over, younger competent Damage Assessment Teams should be sent to the affected area to gather more details on the certain items that were identified in the Post-earthquake Reconnaissance Surveys.

5. THE WAY FORWARD…

The environment is appropriate to launch in national interest a national program on earthquake safety. As part of this, the three primary stakeholders should rise to the occasion – Academia, Government and Industry. They need to affect the needed change by their dedicated, committed and focused roles in their respective domains of work. Change is inevitable...!! But, it will be sustainable only if all efforts from today are pegged on one basic premise – *Life of each Indian is precious*.

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