Design of Earthquake Resistant Buildings : Useful Guidelines

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Abstract

Incidents of earthquake of severe intensity are in news every now and then in various parts of world. In the recent past, Turkey witnessed a severe earthquake suffering loss of life and damage of buildings and public properties. India also bears severe risk for seismic tremors as almost 58% of the total area falls in active seismic zones. According to the latest seismic zone data published, Zones 2,3,4 and 5 are the active seismic zones where structures should be invariably designed considering Earthquake loads (EL) apart from normal loads like Dead load (DL), Imposed load (IL), Wind load (WL), Snow load , and Accidental loads as applicable.

In cities, the practice of multi-storey buildings and high rise buildings is picking up very fast. Earthquake failures in buildings never remain confined to its built up area alone, rather it adversely affects the safety of buildings in its near vicinity by pounding effect.

Therefore, future constructions in vulnerable cities must be subjected to certain statutory bindings to follow norms for Earthquake Resistant Designs as applicable for the seismic zones in a particular city/town. For High Importance Factor buildings like hospitals, nursing homes, schools /colleges, office buildings /administrative buildings, the design norms still become inescapable.

With pace of growth in economy, construction activities are likely to zoom in almost all states and major cities and towns. Therefore, it is high time that Earthquake Resistant Design norms are publicised and strictly enforced in letter and spirit.

Earthquake resistant design needs certain general tips like symmetry in construction, avoiding practice of floating columns in super structure, placing heavy loads on roof like water tanks without well designed supporting structure for resisting lateral forces, practice of stilt floors at ground level, providing Soft Storeys at intermediate floors which are more vulnerable to earthquake induced lateral shear.

The concept of shear walls has been found to be quite effective in resisting lateral shear induced by high intensity earthquake forces. Shear walls in longitudinal as well as transverse directions, symmetrically placed in plan can prove to be a boon in facing multidirectional lateral forces generated by earthquake tremors. The only watchword in shear wall concept is that it must start at foundation level well tied up and run right up to the roof level and remain well integrated with moment resisting RC frame of the building.

The next important aspect in earthquake resistant design is a careful and thorough soil exploration to determine the most suitable foundation option. The soil characteristics, sandy and high water table may cause Liquefaction, which is dangerous for safety of buildings. In such adverse situation, it is desirable to lay deeper foundation or substitute sandy strata with granular material. Pile foundation in such cases can be a safe option.

Concept of Base Isolation and use of damping devices are other options to keep the building structure safe from seismic tremors. Use of elastomeric pads, rollers at foundation base of column footings helps in absorbing the energy generated by seismic tremors by damping devices/pads. The super structure of the building remains unaffected by earthquake forces. Such measures involve higher cost but can be cost effective in case of important functional buildings like hospitals, office complex, and industrial buildings.

Keywords : Earthquake resistant, seismic

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NOMENCLATURE

MSK	Medvedev- Sponheuer- Karnik ; scale a macro seismic intensity scale used to evaluate the severity of ground shaking during earthquakes.
RC	Reinforced Concrete.
SBC	Safe Bearing Capacity.
SPT	Standard Penetration Test.
CPT	Cone Penetration Test.
SMEC Inc	Snowy Mountain Engineering Corporation Australia.
NRIDA	National Rural Infra Structure Development Agency.
MES	Military Engineers Service, Ministry of Defence.

I. INTRODUCTION

The Indian subcontinent has a history of devastating earthquakes. Geographical statistics of India show that almost 58% of the land is vulnerable to earthquakes. A World Bank and United Nations report shows estimates that around 200 million city dwellers in India will be exposed to storms and earthquakes by 2050.

HISTORY OF MAJOR EARTHQUAKES IN INDIA

2015 India/Nepal Earthquake	**1991 Uttarkashi Earthquake**
2011 Sikkim Earthquake	**1941 Andaman Islands Earthquake**
2005 Kashmir Earthquake	**1975 Kinnaur Earthquake**
2004 Indian Ocean Earthquake	**1967 Koynanagar Earthquake**
2001 Bhuj Earthquake	**1956 Anjar Earthquake**
1999 Chamoli Earthquake	**1934 Bihar/Nepal Earthquake**
1997 Jabalpur Earthquake	**1905 Kangra Earthquake**
1993 Latur Earthquake	

The latest version of seismic zoning map of India given in the earthquake resistant design code of India [IS 1893 (Part 1) 2002] assigns four levels of seismicity for India in terms of zone factors. The earthquake zoning map of India divides India into 4 seismic zones (Zone 2, 3, 4 and 5).

Zone 5 covers the areas with the highest risk of suffering earthquakes of intensity MSK IX or more significantly. The IS code assigns a zone factor of 0.36 for Zone 5. It is referred to as the Very High Damage Risk Zone.

The regions of Kashmir, Western and Central Himalayas, North, and Middle Bihar, the North-East Indian region, the Rann of Kutch, and the Andaman and Nicobar group of islands fall in this zone.

Zone 4 is also a High Damage Risk Zone and covers areas liable to intensity MSK VIII. The IS code assigns a zone factor of 0.24 for Zone 4.The regions of Jammu and Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, parts of the Indo-Gangetic plains (North Punjab, Chandigarh, Western Uttar Pradesh, Terai, a major portion of Bihar, North Bengal, the Sundarbans), and the capital city Delhi, the Patan area (Koynanagar) in Maharashtra fall in Zone 4.

Zone 3 is classified as a Moderate Damage Risk Zone which is liable to intensity MSK VII. The IS code assigns a zone factor of 0.16 for Zone 3. Cities like Chennai, Mumbai, Kolkata and Bhubaneswar, Jamshedpur, Ahmadabad, Pune, Surat, Lucknow, Vadodara, Mangalore, Vijayawada, and the entire state of Kerala fall in zone 3.

Zone 2 is liable to have earthquake intensity MSK VI or lower and is considered as the Low Damage Risk Zone. The IS code assigns a zone factor of 0.10 for Zone 2. Cities like Bangalore, Hyderabad, Visakhapatnam, Nagpur, Raipur, Gwalior, Jaipur, Tiruchirappalli, and Madurai fall in this zone.

Zone 1 stands removed as per latest seismic zoning of India and regions not falling in Zone 2, 3, 4 and 5 fall in this zone. The IS code assigns no zone factor for Zone 1 as such.

Viewing the risks involved, it is essential for India to have strict statutory provisions so that all future buildings and infrastructure structures are designed and constructed as Earthquake Resistant structures to minimise the risk of damages due to earthquakes in future.

II. EARTHQUAKE RESISTANT DESIGN OF STRUCTURE

A. Applicable Indian Standard Codes

The earthquake resistant design of structures, particularly high-rise buildings needs reference to certain BIS Standard latest publications. Some of them are as follows:

1)

a) *Criteria for Earthquake Resistant Design of Structures (General requirements)*, IS 1893.

b) *Criteria for Earthquake Resistant Design of Structures (Fifth Revision),* IS: 1893 (Part-I), 2002.

c) *Criteria for Earthquake Resistant Design of Structures (Industrial Structures),* IS 1893 (Part 4).

2)

a) *Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces - Code of Practice,* IS 13920, 1993.

3) *Earthquake Resistant Design and Construction of Buildings - Code of Practice (Second Revision)*, IS 4326, 1993.

4) *National Building Code of India*, IS-NBC-2005:

5) *Code of Practice for Plain and Reinforced Concrete*, IS 456, 2000.

6) *Code of Practice for Structural Safety of Buildings: Foundation*, IS 1904, 1986.

7) Code of Practice for Structural Safety of Buildings: Masonry, IS 905, 1980.

8) IS 875-1, 875-2, 875-3, and 875-5, Design Loads-Dead Load, Imposed Loads, Wind Loads, and Various Load Combinations, 1987.

9) *Recommendations for detailing of reinforcement in reinforced concrete works*, IS 5525, 1969.

III. EARTHQUAKE FORCES ASSESSMENT AND DESIGN

Earthquake Load is covered under IS 1893 of 2002 which specifies Earthquake Zone Factors like 0.36 for Zone 5, 0.24 for Zone 4, 0.16 for Zone 3, and 0.10 for Zone 2. The structure is designed for various load combinations such as Dead Load (DL), Imposed Load (IL), Wind Load (WL),Earthquake Load (EL), and other special loads like Snow Load, Temperature Load for finding the worst cases of load combinations and designing the structural elements accordingly. IS 875-5 of 1987 deals with the recommended load combinations to be taken for designing the earthquake resistant structures.

Design Software like STAAD PRO has provisions to have complete Structural analysis and Design of structures and the foundation also.

IV. COMMON CONCEPTS IN EARTHQUAKE RESISTANT DESIGN

***A. Shear Wall Concept*:** Shear wall buildings are a popular choice in many earthquake prone countries like Chile, New Zealand, and USA. Shear walls are especially important in high-rise buildings that are subject to lateral wind and seismic forces. In the last two decades, shear walls have became an important part of mid and high-rise residential buildings.

Reinforced concrete buildings are provided with vertical plate-like RC walls called Shear Walls in addition to slabs, beams, and columns. These walls generally start at the foundation level and are continuous throughout the building height. Their thickness can be as low as 150mm, or as high as 400mm in high rise buildings. Shear walls are usually provided along both length and width of buildings. Shear walls are like vertically-oriented wide beams that carry earthquake loads downwards to the foundation. Shear walls are designed to resist bulk of horizontal shear force induced by seismic tremors and prevents the buildings from getting de-shaped.

A shear wall is generally placed symmetrically along external face of buildings, in longitudinal as well as transverse direction. Most RC buildings with shear walls also have columns and beams. These columns primarily carry gravity loads (i.e., those due to self-weight and imposed loads. Shear walls provide large strength and stiffness to buildings in the direction of their orientation,

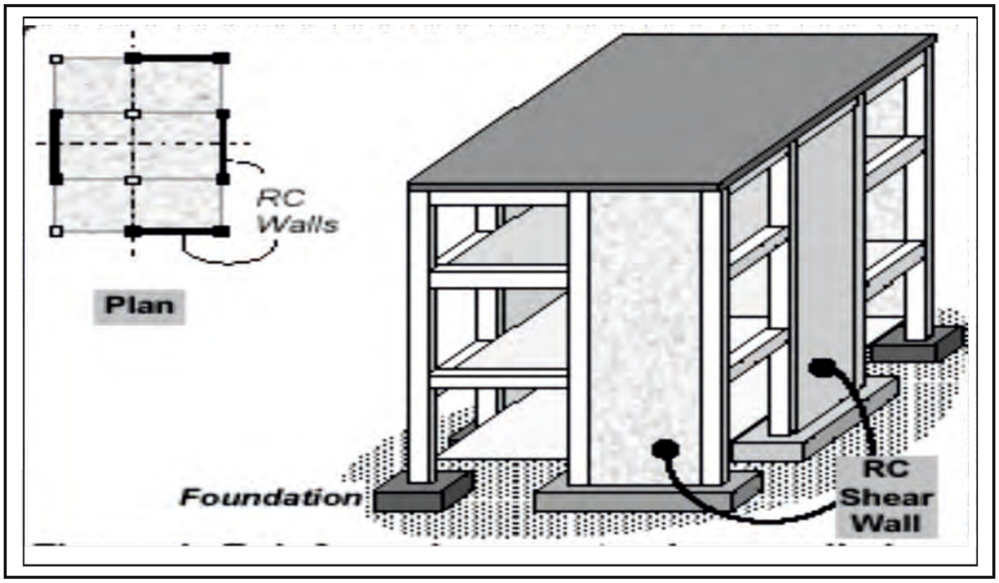

Fig. 1. Typical Layout - Shear Walls in Buildings

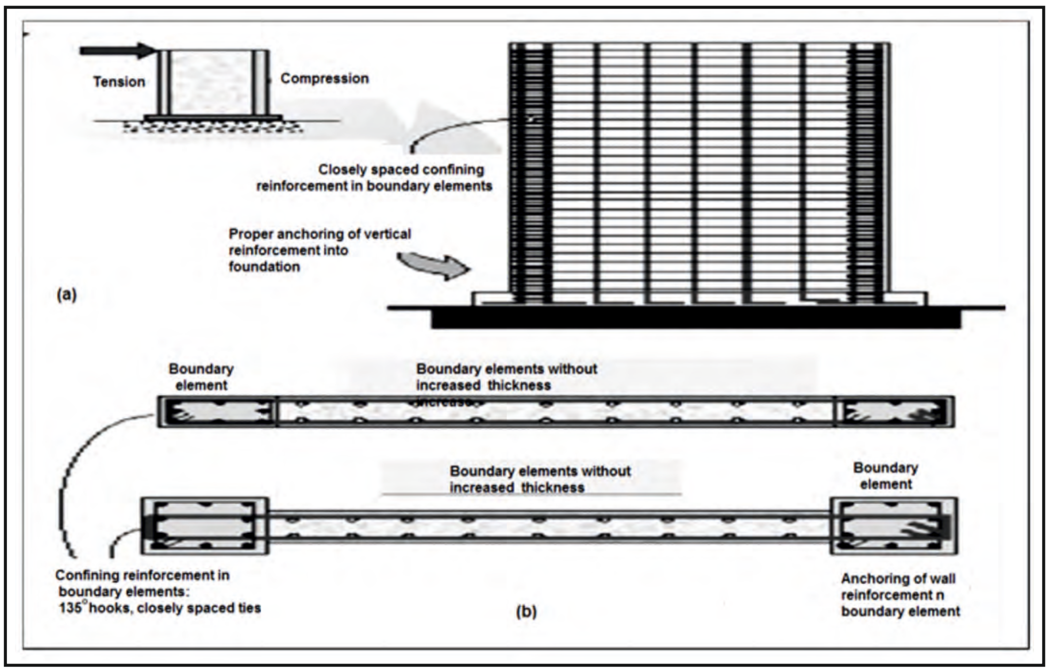

Fig. 2. A typical ductile detailing of reinforcements in shear wall

which significantly reduces the lateral sway of a building and thereby, reduces damage to structure and its contents.

Since shear walls intended to carry large horizontal earthquake forces, these shear walls are subjected to the overturning effects of seismic forces which induce uplift of shear wall ends. Thus, design of the foundations for shear walls requires special attention.

Shear walls should be provided along preferably both length and width. However, if they are provided along only one direction, a proper grid of beams and columns in the vertical plane (called a moment-resistant frame) must be provided along the other direction to resist strong earthquake effects.

Normally, openings in shear walls are avoided as they weaken the structural effectiveness of shear wall while resisting earthquake forces. However, in unavoidable situations, door or window openings if required are to be provided in shear walls, their size must be kept small to ensure least interruption to force flow through the walls. Moreover, openings should be symmetrically located. Special design checks are required to be done to ensure that the net cross-sectional area of a wall at an opening is sufficient to carry the assessed horizontal earthquake force.

To insure optimum structural performance of shear walls, it is essential to have ductility while designing the walls like other elements like beams and columns. Overall geometric proportions of the wall, types, amount of reinforcement, and the connection with remaining elements in the building help in improving the ductility of shear walls. The Indian Standard Ductile Detailing Code for RC members (IS:13920-1993) provides special design guidelines for ductile detailing of shear walls. A typical way for ductile detailing of shear wall shown in Fig. 2.

Fig. 4. Failure - Soft Ground Floor

B. Avoiding Stilt Floor Garages and Soft Storeys

Open ground storey (stilt floor) is a very common construction practice in cities, but it is the most damaging factor when buildings are subjected to earthquake tremors. Stilt floors cause severe irregularity of sudden change of stiffness between the ground storey and upper storeys. This results in stress concentration in stilt floors, damage, large scale deformation, and collapse of columns.

Sometimes, space between columns provided with unfilled brick walls increases the lateral stiffness of the frame to some extent but grossly lacks in dynamic ductility demand during the earthquake. It gets concentrated stresses which becomes the cause of failure of ground soft storey. Mostly, it has been observed that the upper storeys tend to remain elastic whereas, the 'soft' storey is severely strained causing its total collapse and much smaller damages occur in the upper storeys. The pattern of such failures are quite evident in real-time photographs given in Fig. 3 and 4.

Fig. 3. Failure - Stilt Floor

Therefore, provisions of stilt floor in high rise constructions should be avoided or else the ground floor should be safeguarded adequately by provisions of ductile shear walls along external walls in both longitudinal and transverse directions. If plan area of the building is large, even internal wall may be designed as shear walls.

C. Earthquake Resistant Design Should Avoid "Soft Storeys"

Generally, high-rise buildings need provision of large halls, restaurants, and conference rooms on intermediate floors. Such constructions restrict provisions of columns, walls, and beams in floor space. Such floors are termed as Soft Storeys, and are found to be more vulnerable to damages during high intensity earthquakes. Such soft storeys in buildings are found to have collapsed in Kutch and Kobe earthquakes.

In case such soft storeys cannot be avoided due to functional reasons, the moment resisting frame of beams and columns should be specifically designed to withstand

2.5 times earthquake shear in the floor. The design must be based on a dynamic analysis by standard design software.

D. Floating Columns in Upper Floors: More Vulnerable to Earthquake Forces

It is seen that just to achieve larger floor area in upper floors, builders provide floating columns in upper storeys. Such structural provisions of columns which do not fall in direct load path from roof to foundation suffer badly when subjected to lateral shear induced during earthquakes. Likewise, sometimes similar situations arise within the frames where for any reason, either the beam is missing or a column is missing. These are structural discontinuities and should better be avoided as far as possible. Such irregularities are also defined in Tables IV and V of IS: 1893-2002 (Part 1). They become the cause for large tensional moments and stress concentration in buildings which should better be avoided by the architect and structural engineer in the initial planning of the building configuration.

Otherwise, they should be carefully considered in structural analysis and properly detailed in the structural plan.

V. FOUNDATION DESIGN FOR EARTHQUAKE RESISTANT BUILDINGS

A well designed foundation is a prerequisite for any earthquake resistant building. Therefore, thorough soil exploration at the building site needs to be carried out at sufficient points and upto sufficient depth. The following data needs to be ascertained which helps in the process of earthquake resistant design of buildings:

(i) Soil classification tests in various layers to know properties like grain size distribution, fields density, angle of internal friction and cohesion index, plastic and liquid limits, and coefficient of consolidation.

(ii) Essential to know precise position of ground water table before and after monsoon.

(iii) SPT values and CPT values.

(iv) Safe Bearing Capacity(SBC) and recommended type of foundation to be adopted: Individual column footings/combined row footings/ raft foundation/ pile foundation. Most preferred options for earthquake resistant buildings are Raft Footings and Pile Foundation.

VI. DETAILED ANALYSIS FOR LIQUEFACTION POTENTIAL

Presence of sandy soil and a high water table is a dangerous combination which results in liquefaction during seismic tremors. With water level rising, the soil strata loses its shear strength and the foundation is unable to transmit the structural load causing unequal settlements of large magnitude. Liquefaction is a major cause behind foundation failures.

Liquefaction is covered in IS 1893-2002 Cl 6.3.5.2 and Table I for minimum N (corrected values) for safety and carrying soil liquefaction analysis by standard procedures available in literature. The adverse effects of liquefaction may be seen in Fig. 3.

The recommended steps to prevent Liquefaction Risks during high intensity earthquakes is to substitute undesirable soil layers by stable granular material upto required depth or design pile foundation to transmit loads to deeper and hard rock/soil strata.

VII. CONCEPT OF BASE ISOLATION DEVICES AND SEISMIC DAMPERS

In cases of high intensity earthquakes, certain buildings

Fig. 5. Settlement Foundation

Fig. 6. Rigid structure tilted and raft foundation getting lifted

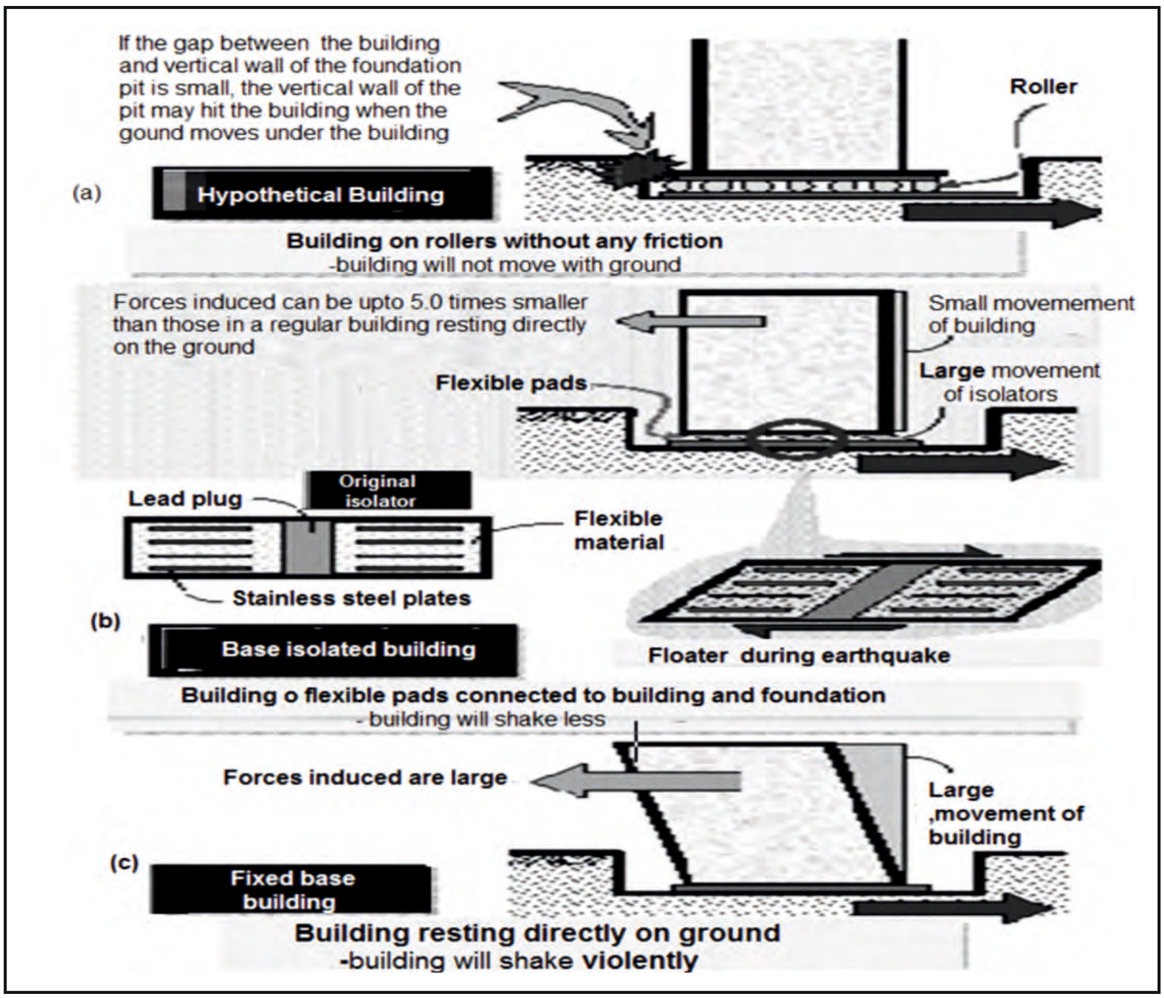

Fig. 7. Diagrams for Base Isolation Devices - Rollers, Damping Pads

even having earthquake resistant provisions in design suffer partial damages like smashing of glass facades, damage of decorative furnishings, and even certain structural elements. Such damages may render the building non-functional for some time after the earthquake. However, in case of buildings with High Importance Factor like hospitals and important administrative buildings, certain special techniques are required to be adopted in design of such buildings so that they remain practically undamaged even in severe earthquakes. Buildings with such improved seismic performance usually cost more than normal buildings but this cost is justifiable on grounds of improved earthquake performance.

Two basic technologies are used to protect building super structure from damage due to earthquake effects:

1) Base Isolation Devices

2) Provision of Seismic Dampers

The idea behind base isolation is to isolate the building from the ground in such a way that earthquake tremors/motions are not transmitted upto super structure of the building. The effects of tremors are damped/reduced, the energy generated is absorbed by deformations in Seismic dampers fixed at foundation level similar to provisions of shock absorbers in motor vehicles that absorb the impacts of undulations on road.

VIII. CONCLUSION

As most cities in India carry a very high risk of seismic disturbances in future, it is desirable that all major constructions projects for high rise buildings and buildings with High Importance Factors invariably be based on Earthquake Resistant Design Norms. Here are a few guiding points that can be helpful for designers/architects and builders in this direction to give adequate safety to buildings against unforeseen natural calamities like earthquakes.

It is imperative for Governments/Municipal Corporations to introduce statutory provisions in this respect to insure discipline in construction practices regarding safeguard against earthquake damages.

AUTHOR'S CONTRIBUTION

The author confirms that he is the sole author of the paper. He conceptualized and finalized the research idea and the study.

CONFLICT OF INTEREST

The author confirms that there is no conflict of interest regarding any involvement of any person or organization in publication of the paper.

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Mahesh Prasad, B.E. Civil Engineering (1972), M.E. Structural Engineering (1993), MBA (1997), started his career as Assistant Professor (Civil Engineering) in 1972 with Department of Technical Education (Bihar).Thereafter, he remained associated with erstwhile Central Water and Power Commission, Flood Forecasting Division at Patna (1975). He further served in Military Engineer Service and Ministry of Defence from 1976 to 2010, where he retired from the post of Chief Engineer (2010). After superannuation, he remained associated with SMEC International, an Australian MNC as Senior Consultant (Structural Design expert), where he got associated with prestigious projects like AIIMS at Rishikesh, ESIC Hospital at Lucknow, Tourism Infra-Projects in Sikkim (2016). In the year 2016, he got empanelled for the role of National Quality Monitor (NQM) with Ministry of Rural Development, NRIDA, PMGSY. He is presently associated with National Rural Infrastructure Development Agency (NRIDA) as NQM emeritus.