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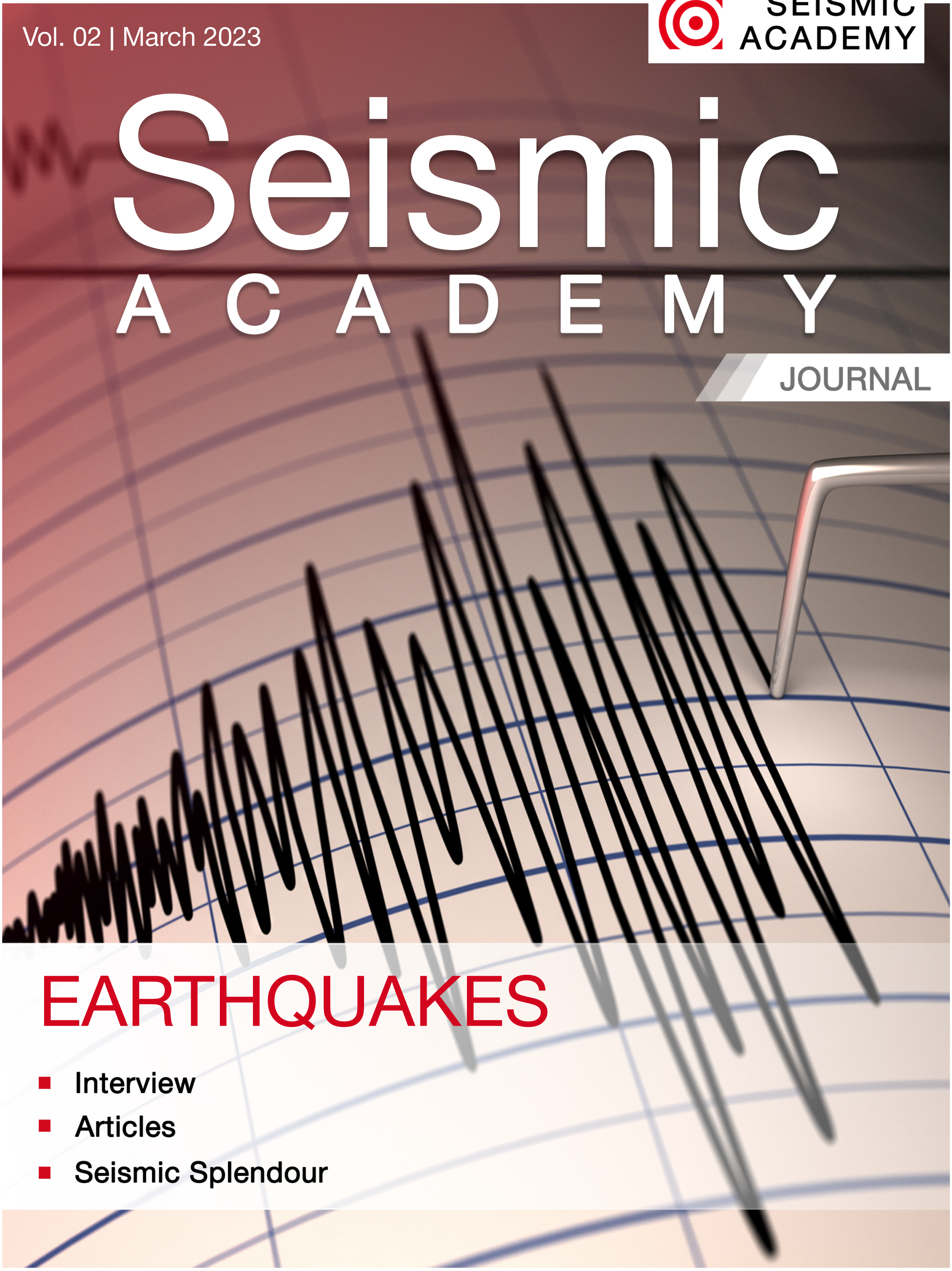
SEISMIC ACADEMY

Seismic ACADEMY

JOURNAL



EARTHQUAKES

- Interview
- Articles
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SEISMIC ACADEMY

A forum for professionals, academicians, authorities and industry experts to interact and disseminate knowledge on various aspects of earthquake engineering with different stakeholders, with an intent to increase awareness and develop their expertise on the subject.

OUR VISION

To make seismic academy as one source of information and use it for promotion of all seismic initiatives in our country.

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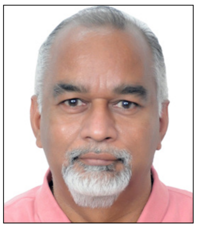

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SEISMIC ACADEMY

FROM THE DESK OF ADVISORY BOARD

INCORPORATION OF ROUTINE SEISMIC DESIGN FOR SUSTAINABILITY AND SAFETY

In earthquake engineering, sustainability considerations are side-lined in an effort to save time and money. The industry needs to realise that incorporating sustainability into routine seismic design makes sense and creates safety for the economic, social and environmental factors.

Sustainability means meeting present demands without compromising the needs of future generations. In the context of engineering, this can mean a range of things, from using recyclable materials which cause less waste and pollution to constructing buildings with higher resilience to natural disasters.

The major principle of earthquake design is to introduce resilience in buildings – typically, we achieve this by designing the foundations in such a way that during seismic incidents, the superstructure is affected before the substructure, avoiding foundational damage.

Resilience is a sustainable concept, but that does not mean seismic design is automatically sustainable. As engineers, we play a crucial and influencing role in making seismic design sustainable through astute assessment of seismic risk and careful judgment of the best ways to mitigate it.

There will always be conflicts when trying to match differing demands of stakeholders, the environment and economics in delivering earthquake resilience. Our challenge is to balance these demands in the most sustainable way.

Moreover, disruption caused by earthquake damage to infrastructure can have a major 'cascade failure' effect on businesses and people. By improving the seismic performance of infrastructure, we avoid or reduce earthquake damage, and significantly reduce seismic incidents' impacts on the environment, economy and community.

Keeping this in view, the role of SEISMIC ACADEMY is quite important to make the environment clean and green as well as sustainable for future generations, globally.

Dr. S. M. Ali
Vice President
Solar Energy Society of India

“Resilience is a sustainable concept, but that does not mean seismic design is automatically sustainable.”

TABLE OF CONTENTS

Er. Sanjay Pant
Deputy Director General (Stdzn-II)
Bureau of Indian Standards

"**India is a disaster-prone country with 59% of its land mass susceptible to earthquake events.**"

Seismic Academy: What is your input on our Indian building codes with respect to speculations about impending earthquakes in India?

Sanjay Pant : India is a disaster-prone country with 59% of its land mass susceptible to earthquake events. The Bureau of Indian Standards (BIS), as the National Standards Body of the country, therefore, initiated the standardization activity in this area quite early with first standard on Criteria for earthquake resistant design of structures along with the seismic zoning map of India brought out as early as in 1962. Subsequently, the above standard was revised and updated number of times to absorb the latest knowledge and developments and the experience gained in the use of preceding versions of the standard. The latest version is IS 1893 (Part 1): 2016 dealing with 'General provisions and buildings' and other parts of this standard similarly detail provisions for seismic safety for Liquid Retaining Structures, Bridges and Retaining Walls, Industrial and Stack like structures, etc. The standard divides the country into 4 seismic zones, namely Zone II, III, IV and V, the Zone II being least vulnerable and Zone V the most.

BIS has also brought out a series of other associated standards on earthquake resistant design and construction of masonry buildings (IS 4326), ductile design and detailing of reinforced concrete structures (IS 13920), improving earthquake resistance of earthen buildings (IS 13827) and improving earthquake resistance of low strength masonry buildings (IS 13828). Also, standards have been developed for improving seismic performance of masonry and RC buildings, namely seismic evaluation, repair and strengthening of masonry buildings (IS 13935) and seismic evaluation and strengthening of existing reinforced concrete buildings (IS 15988).

The structures designed and maintained as per the aforementioned standards will be able to withstand the expected seismic forces in the respective zones with no damage or with collapse prevention of the buildings / structures.

Seismic Academy: Taking in view the recent global catastrophes, what is your advisory to the government bodies, engineers and architects in terms of maintaining structural integrity of buildings?

Sanjay Pant: It is important to not only construct the buildings as per the stipulations of the relevant Indian Standards but also ensure their maintenance for the sustained structural performance during the life of the buildings. Also, those buildings which are found to be structurally deficient need to be immediately retrofitted to improve their seismic performance. The National Building Code of India, 2016 (NBC 2016) also recommends periodic renewal certification of high rise and special buildings by the authority from structural safety, fire safety, electrical safety and health safety point of view. As mentioned earlier, BIS has formulated IS 13935 on seismic evaluation, repair and strengthening of masonry buildings and IS15988 on seismic evaluation and strengthening of existing reinforced concrete buildings. Provisions of these standards should be utilized by the authorities and building professionals in examination and strengthening of buildings.

Seismic Academy: How is BIS planning to introduce newer amendments in the existing norms for making resilient structures?

Sanjay Pant: The work in this area is done by the Earthquake Engineering Sectional Committee, CED 39 of BIS. This standing technical committee regularly reviews and updates existing standards and develops required new standards in this field. CED 39 has already taken up revision of IS 1893 (Part 1) along with the seismic zoning map of India which would now be based on Probabilistic Seismic Hazard Analysis (PSHA). New standards have also since been brought out on Base Isolated Buildings [IS 1893 (Part 6)] and on Confined Masonry (IS 17848). While the standards on seismic evaluation and strengthening are under revision, newer standards on criteria for earthquake resistant design of steel buildings and pipelines are on the anvil. R&D for development of new standards on performance based design of RC buildings has been carried out and draft standard is under progress. A new standard on post-earthquake safety assessment of buildings is also under development.

Seismic Academy: What as per your opinion should be done to ensure enforcement of the developed standards at all level?

Sanjay Pant: In order to ensure safety of structures, an effective implementation of Indian Standards in their planning, design and construction is very important. It requires a multi-pronged strategy particularly as construction is a state subject under the Constitution of India. These standards should be implemented through their mandatory reference for compliance in the building regulations by the state / local bodies, by the government construction departments / agencies in their construction programmes, by the private construction agencies / builders / developers / contractors in their works, by the building professionals like architects, civil engineers and structural engineers in their professional practice, by the building material and technology manufacturers / suppliers in their manufacturing / applications, by the research institutions in their R&D for product and technology development activities, and by the faculty members and students of technical education in their curriculum so that we bring out future professionals duly trained in earthquake engineering aspects.

As already mentioned above, the implementation is to be effected through a multi-pronged strategy. It is here worth mentioning that BIS has also formulated the National Building Code of India 2016 (NBC 2016) which not only covers earthquake resistant design of buildings based on the above Indian standards on earthquake engineering but also covers the administrative provisions for implementing the entire stipulations on planning, design, construction and maintenance of buildings. NBC 2016 is an instrument which helps in regulating the building construction activity across the length and breadth of the country. It is utilized for revising and revamping the building regulations by the states / local bodies where it should be ensured to give copious reference to its various provisions for ensuring orderly, safe, robust, accessible and sustainable buildings and built environment.

“ **Newer standards on criteria for earthquake resistant design of steel buildings and pipelines are on the anvil.** ”

Seismic Academy: How are you planning to disseminate the knowledge about new standards to practicing engineers?

Sanjay Pant: BIS has been approaching all the State / UT governments and their local bodies for effective implementation of NBC 2016 and earthquake engineering standards. BIS has been regularly organizing awareness and implementation workshops in various cities across the country, for state regulatory authorities like town and country planning departments, municipal corporations, municipalities, development authorities; government departments like PWDs, housing boards, housing corporations; builders / developers / contractors; building professionals like town planners, architects, urban designers, civil and structural engineers, etc who have been attending these events in large numbers. But India is a vast country with so many departments and professionals working in this field of built environment. This dissemination is, therefore, being aggressively pursued in different parts of the country with good results. In addition, BIS has also initiated a training programme covering capsule courses on NBC 2016 and especially on the structural design aspects covering earthquake resistant design of structures at the National Institute of Training for Standardization (NITS), Noida, the popular training arm of BIS. All departments and professionals are invited to join these courses.

Indian Association of Structural Engineers

IAStructE

PANEL DISCUSSION ON

Turkey Earthquake - Lessons for India

Tuesday, 07 March 2023, 04:00 PM to 06:00 PM (IST)

ABOUT THE PANEL DISCUSSION

Recent major earthquake and subsequent aftershocks have devastated Turkey with more than 45,000 casualties and innumerable property losses. Recorded ground accelerations are as high as 1.8 g and for a wide range of natural periods, acceleration values are more than 1g. Losses are attributed to mainly two reasons viz., a) unusually high acceleration and b) poor quality of construction. While 60 per cent of India is prone to moderate-to-severe earthquake events, most of the built environment is not code compliant. In this regard, there is an urgent need to understand the consequences if a similar earthquake occurs nearby a densely populated area in India. What would be the scenario and how the country would face the situation? To discuss the same, IAStructE is proposing a panel discussion on "Turkey Earthquake - Lessons for India" on 7th March 2023.

SPEAKER

Dr. Alp Caner
Professor, METU, Turkey

PANELISTS

Mr. Kamal Kishore
Member Secretary, NDMA

Prof. Mahesh Tandon
Past President & GC member, IAStructE

Prof. CVR Murthy
Professor, IIT Madras

Ms. Sangeeta Wij
GC member, IAStructE

Prof. Raghukanth
Professor, IIT Madras

Mr. Manoj Mittal
President, IAStructE

Mr. Alok Bhowmick
Immediate Past President, IAStructE

MODERATOR

Dr. R. Pradeep Kumar
Vice-President, IAStructE (South)

https://theseismicacademy.com/event-detail/turkey-earthquake---lessons-for-india

AN INITIATIVE TO DELVE INTO PREPAREDNESS & MITIGATION BY IASTRUCTE

Nature's Fury Devastates Lives of Thousands

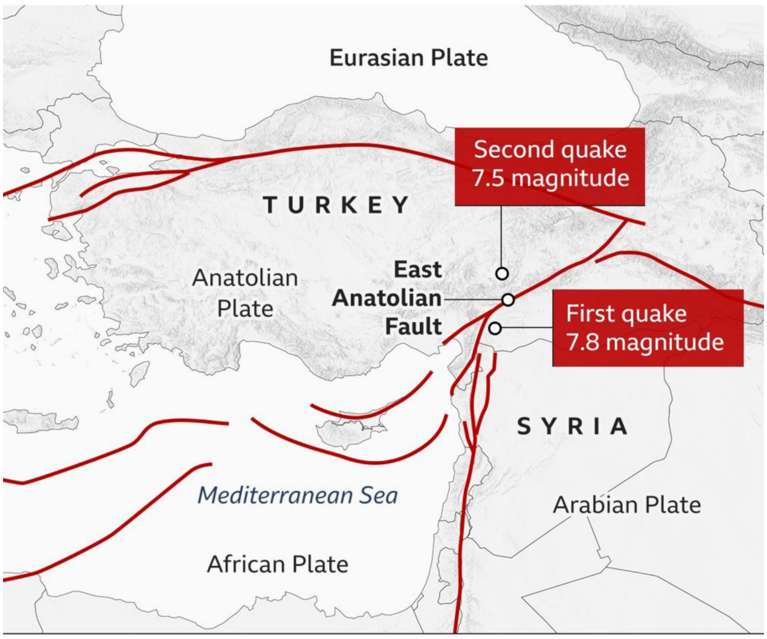
A 7.8 Richter Scale Magnitude Earthquake jolted Central and Southern Turkey and Western Syria on 6th February'23 in the local early hours laying a trail of catastrophe to be hit again by an unusual and powerful main shock of 7.5 Magnitude. A unanimous take on this is still awaited in the global platform to understand the second ones nature – was it an aftershock or was it another major earthquake triggered by the first one. The first quake occurred 11 miles below the surface, 34 km West of Gaziantep city, Turkey causing structural damage as far away as Israel and Cyprus. The second temblor occurred 60 miles North, 9 hours after the first one.

Leaving destruction, death and despair – the Turkiye-Syria Earthquake – has been one of the deadliest and strongest earthquakes to hit Turkey in modern times. The relative motions of three major tectonic plates (Arabian, Eurasian, and African) and one smaller tectonic block (Anatolian) are responsible for the seismicity in Turkey.

As per reports, there were atleast 48,448 deaths and 115,000 injured across the 11 provinces of Turkey and an approximate 13.5 million people and 4 million buildings affected. The disaster led to the damage of around 345,000 apartments with many up for demolishing owing to the risk factors. By 23 Feb. '23, the Ministry of Environment, Urbanization and Climate Change conducted damage inspections for 1.25 million buildings; revealing 164,000 buildings were either destroyed or severely damaged. A further 150,000 commercial infrastructure were at least moderately damaged. The International Organization for Migration estimated about 2.7 million people were made homeless.

Since the epicenter was very shallow, the intensity of the ground shaking made the earthquake more damaging. The large number of very strong aftershocks also destroyed buildings already weakened by the first event. The region is also prone to the risk of seismic liquefaction and landslides.

Fault lines around Turkey and Syria



Source: British Geological Survey

With such a large number of infrastructure and building collapse, resulting in loss of masses, the Turkey-Syria Earthquake has raised questions in the minds of people – Building Safety: Codes and Adherence. Modern construction techniques should mean buildings can withstand quakes of this magnitude. And regulations following previous disasters in the country were supposed to ensure these protections were built in.

Failure to Enforce Building Regulations

Construction regulations have been tightened following previous disasters, including a 1999 earthquake around the city of Izmit, in the north-west of the country, in which 17,000 people died. But the laws, including the latest standards set in 2018, have been poorly enforced where over half of all buildings were put up illegally.

Construction safety requirements vary depending on a building's use and its proximity to areas most at risk of earthquakes: from simple strengthening, to motion dampers throughout the building, to placing the entire structure on top of a giant shock absorber to isolate it from the movement of the ground.

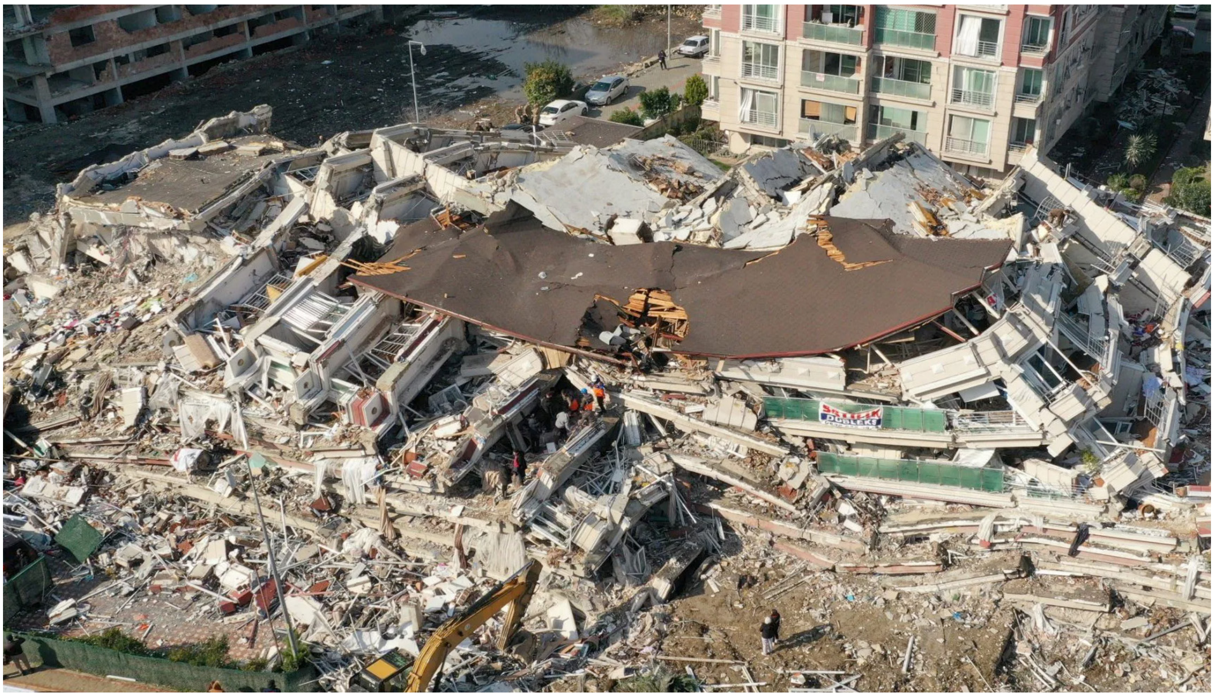
Lessons for India

To create more awareness on the topic by learning from the disaster in Turkey and to highlight on the seismic design requirement in India to build a safe built environment, a panel discussion was organized by Indian Association of Structural Engineers (IAStructE) on 7th Mar. '23. The panel has the lights of Dr. Alp Caner, Professor, METU, Turkey; Prof. Mahesh Tandon, Past President & GC Member, IASrtuctE; Prof. CVR Murthy, IIT Madras; Ms. Sangeeta Wij, GC Member, IAStructE; Prof. Raghukanth, IIT Madras; Mr. Manoj Mittal, President, IAStructE; Mr. Alok Bhowmick, Immediate Past President, IAStructE and Dr. R. Pradeep Kumar, Vice-President, IAStructE – South.

Few points which were captured during the session are as follows:

Sh. Manoj Mittal, President, IAStructE commenced the webinar with his presidential address. He stressed on the importance of Building Codes and specially, on adherence/compliance to such codes to enable maximum possible mitigation in such seismic catastrophes. He enumerated various earthquakes that have hit India and how one of them, Bhuj Earthquake, became the tuning point for the industry which led to renewed & improvised codal system in the country. He raised a few thought provoking questions as to even after strict revision, thorough checks being made mandatory, incorporating disaster management infra; is India really safe? Are we prepared to handle such a devastating earthquake as Turkey faced? Is the Indian infrastructure, earthquake resistant and code compliant and several others. He emphasised on the crucial role played by the civil engineers to deal with such situations where it is required to handle comprehensively. He pointed out some major challenges such as: quality standards of engineering graduates; effective regulatory mechanism of engineering profession; competence based registration and licensing of engineers; capacity building; development of code and commentaries; promoting and ensuring ethical practice by engineers; identifying high risk structures and undertaking audit, retrofiring of such structures; increasing earthquake literacy of architects and general public. It is required to work on these aspects with greater commitment and mission mode manner.

Prof. Dr. Alp started with a background of movement of tectonic plates which led to the occurrence of the Turkey earthquake. He mentioned that India also has an active fault line and this can be of problem in future if proper mitigation measures are not adopted during design and construction. A storm of earthquakes were observed in and around Turkey in a region 700 km in length and 200 km in width in the last 30 days. After the earthquakes, 11 cities have been reduced to emergency states.



His key observations were soil related problems caused considerable damage on many structures and also the earthquake design response spectra curves had underestimated the earthquake storm. New buildings which were designed considering non-linear analysis were found to undergo severe damage and in some cases collapse. He touch based upon the seismic performance levels of structures as per the seismic design standard in Turkey (namely, immediate occupancy, minimum damage, repairable damage, life safety). He identified few reasons for buildings suffering extensive damage like lack of shear walls, vertical or plan irregularities, construction on slope, soil conditions, poor construction practices (e.g., use of rounded aggregates from rivers, improper reinforcement details, etc.) and near fault location. Structures like bridges and tunnels, which were in the near fault locations and/or constructed on poor soil, were found to undergo significant damage.

Prof. Alp also added that structures with flat slabs do not perform well in earthquakes and the same was observed in Turkey earthquake as well. Most of the structures with provision of shear walls to render stiffness were not observed to collapse and the ones which failed were primarily due to the extensive soil displacement. He mentioned that the current standard in Turkey highlights requirement

A sequence of images shows workers demolishing a quake-damaged building in Malatya, Turkey, on March 7, 2023. More than a thousand damaged buildings in the region have been demolished since the February 6 earthquake

of shear walls in building structures but does not spell out very explicitly on the extent of provision. Hence, the same is sometimes left to engineering judgments. He also added that in business units in the ground floors, it often happens that the owner explores non-engineered solutions (to the extent of removing columns in the ground floor) which are extremely detrimental to the structural stability. In certain cases, the failure is attributed to use of poor building materials. Also, poor construction practice was another probable reason for failure, since ductility requirements are very detailed and labour intensive; these are sometimes not precisely followed and the desired performance might not be achieved. Prof. Alp added that base isolated structures survived the earthquake and were immediately occupied.

Prof. Raghukant in his deliberation on the Turkey earthquake and reference to the Indian scenario, mentioned that looking at the strong motion data and report of the Turkey earthquake, it is evident that earthquakes are capable of producing PGA of more than 1g in the near field region and earlier earthquakes like the Assam earthquake, Gujarat earthquake have experienced very high PGA in the near field region. His recommendation was to design the important structures to withstand this kind of high ground motion. He also mentioned that it would be interesting to study the complex fault geometry

and understand how these are translated to ground motion values. His recommendation also was to derive near field correction factors based on the spectra.

Prof Mahesh Tandon, in his presentation on the geotechnical aspect referred to the preliminary report published by METU and enumerated that there is evidence of loss of strength of soil, occurrence of liquefaction in the soil at many places and high settlement (up to 80 cm) of few buildings. Buildings appeared to be affected the most with slope failure observed in many cases, while tunnels deep excavated walls, mechanically stabilized walls continued to perform without much signs of distress. He mentioned that the zone factors suggested in IS 1893 part 1 are at the base rock level and in far-field conditions. His recommendation to the standardization body for the development of next revision of earthquake design standard is to include a suitable amplification factor (in line with FEMA -P 750) for PGA values for ground motion due to overlying site soils. Prof. Mahesh Tandon added that it is always recommended to refer to specialized agency to develop site specific spectra and the same should be considered in design. If the recommendation of the site specific spectra is lower than the code, the codal provision has to be followed. Non-compliance to the same can eventually lead to disaster.

Prof. CVR Murty in his observation, mentioned that near fault effects were predominantly observed in Turkey and asked whether any action would be proposed to account for near fault effects in the future standards in Turkey. About 4000 km of the landmass in India is also having near fault effects and would also require to be prepared for the same. He also requested to share more insight on the performance of non-linear analysis based buildings during the earthquake. He emphasized that lack of structural walls in buildings was one of the major reasons for their poor performance during the quake and took reference of the Mexico earthquake where use of flat slabs, absence of structural walls caused extensive failure in structures.

He insisted that in high seismic regions, flat slabs are not encouraged and are not the greatest of structural systems - in the inelastic zone, the flat slabs due to their limited geometry would crack and the columns are rendered cantilever behavior, which is not considered in design philosophy. In case of accommodating adequate parking space in the ground storey of a building, Prof. Murty mentioned that it is required to provide adequate structural walls or structural bracings to ensure that the building does not become weak due to provision of open (ground) storey. In absence of comprehensive course content on non-linear analysis in college, his recommendation was to adopt the good part of configuration, stiffness, strength, ductility requirement of linear analysis in design process. To address the concern regarding feasibility of performance based design (PBD) for composite structures, Prof. Murty mentioned that PBD is a process to understand the behavior of the structure and is independent of the type of material being used. The challenge with dissimilar materials will be due to the fact that they have different strength, stiffness, deformability, ductility and this will call for comprehensive experimental data to support the particular combination, generation of realistic backbone curve and cyclic hysteresis rules for such situations. He also added that plane (unreinforced) masonry structures are less to survive in high seismic regions. In such cases, the preferred approach is to either adopt confined masonry or reinforced masonry and the same will be captured in upcoming revision of earthquake standards in India.

Er. Sangeeta Wij mentioned that lack of code compliance has come out as the main reason for mass destruction in Turkey & Syria. She recommended that in the current Indian scenario, there is an urgent need to review all existing buildings for their performance levels. She made reference to the National Building Code 2016 which has clearly spelled out the requirement in this regard. She expressed her serious concern about the growing number of non-compliant buildings in the country. She pointed out that, structures with large cantilevers, irregular geometry, soft storeys, mass irregularities, flat slabs, floating columns, etc. as some of the major reasons which may lead to extensive distress in the event of earthquake. She highlighted that during the Covid-19 pandemic, many hospitals were built to address the increasing demand for healthcare facilities. However, many of them did not have adequate stiffness in the form of shear walls. Hospital, schools and all public buildings should be audited and retrofitted to avoid any chaos post disaster and also help in mainstreaming the relief activities. She took reference to NDMA Guidelines for Hospital Safety in this regard and encouraged implementation of the guidelines for new and as well as for existing healthcare facilities. She also shared that the awareness and implementation of the tall building standard (IS 16700-2017) among practicing engineers has not been very encouraging. She also encouraged the adoption of IS 13920 for ductile detailing by practicing engineers.

Ultimately, building codes are the minimum design and construction requirements to ensure safe and resilient structures. These codes reduce casualties, costs and damage by creating stronger buildings designed to withstand disasters. The purpose is to protect public health, safety and general welfare as they relate to the construction and occupancy of buildings and structures.

In Sh. Alok Bhowmick's concluding remarks, he conveyed his condolences to the people of Turkey and India's solidarity in such a despairing situation. He proceeded to summarise the webinar by thanking the esteemed speaker and panellists. He pointed out the PM's 10 Point Agenda on Disaster Rate Risk Reduction on NDMA's website from where he selected one to highlight: Make use of every opportunity to learn from disasters and to achieve that there must be studies on the lessons after every disaster.

He proceeded on to highlight the Preliminary Recognition Report available on the public domain where the first lesson learned is the use of digital technology in data collection from the disaster which was carried out in Turkey within just 15 days. The second learning is the Emergency Response System which did not perform satisfactorily in Turkey earthquake. Are we prepared to cater to such situations? The third lesson was the Ground Motion Data which has indicated that the earthquake demands were much higher than expected in the median period range where PP ground accelerations as well as PGB was much higher along with the vertical seismic even if it was a strike slip kind of a fault zone. He emphasised on some needs other than the codes such as upgrading the quality of construction; making sure that there are some techno-legal regime in the country that is licensing and enforcement; making sure that the codes are understood by the most of the people who are actually designers and is implemented as per code.

To view, click - https://cdnapisec.kaltura.com/html5/html5lib/v2.96.2/mwEmbedFrame.php/p/1858191/uiconf_id/29529811/entry_id/1_h2us49ou?wid=_1858191&iframeembed=true&playerId=obj_KalturaPlayer&entry_id=1_h2us49ou

HOSPITAL SAFETY AND EARTHQUAKES: DO WE MATCH GLOBAL STANDARDS?

Er. Sangeeta Wij
Managing Partner
SD Engineering Consultants

INTRODUCTION

As this Article goes to print, Toll in the most unfortunate, recent Turkey and Syria Earthquakes has crossed 33000 and no. of missing/injured is mounting. Loss of large no of Buildings and key infrastructure remains to be assessed, while the rescue operations are on, on a big scale, assisted by multi country teams. All of this is a grim reminder that it's poorly designed and poorly constructed buildings that kill people and not the Earthquakes.

It thus becomes critically important for us to review how safe is our built environment against a likelihood of a serious earthquake, especially our healthcare facilities to assist in any post-disaster rehabilitation and recovery. India is located in a seismically active zone and almost 66% of it is prone to earthquakes. Bureau of Indian Standards (BIS) and National Building Code (NBC) provide guidelines for earthquake resistant design of buildings in India, and the objective of this article is to look at the provisions of the current Codes and see how far away we are from global standards for earthquake-resistant design of hospitals.

In National Building Code of India (NBC) and BIS-1893 (Part-1)-2016 guidelines for the design and construction of buildings are general and not specific for hospitals, although the last revision of the Code enhances the Earthquake Base Shear by 50% for hospitals, by suggesting an Importance Factor of 1.5. However, it does not provide exhaustive or special recommendations for seismic design, detailing and construction practices specific to Hospitals including the design/anchorage of non-structural elements.

Besides, in many parts of India, these guidelines may not be strictly followed and enforcement of BIS codes maybe lax, as the BIS Codes are recommendatory and need to be formally adopted by States to make them mandatory. In addition, BIS Codes do not carry any recommendations for ensuring Compliance to revised Code provisions in a given time frame, thus rendering a large no of buildings Non-Compliant. This may make hospitals more vulnerable to collapse during an earthquake, putting patients and staff at risk, as unfortunately happened during the Nepal Earthquakes of 2015.

> **India is located in a seismically active zone and almost 66% of it is prone to earthquakes.**

As a result of these earthquakes, 446 public health facilities (including five hospitals) and 16 private hospitals were completely destroyed, and 765 health facilities were partially damaged; 84% of completely destroyed facilities were located in the 14 districts most affected by the crisis, resulting in a severe inability to treat the injured.

It is thus, vitally important that hospitals are designed and constructed according to the latest seismic safety standards, and that regular structural audits, retrofitting and maintenance are carried out to ensure their continued safety.

NBC recommends a full scale structural safety audit and retrofitting of all important public buildings, every 3 to 5 years, in its Chapter 2 titled Administration. It clearly recommends that authorities, lacking in adequate technical manpower, may seek assistance from experienced structural engineering professionals and allow continued operation of buildings only once the retrofitting has been completed satisfactorily. This important provision, if implemented in totality, will ensure the safety and well-being of all important buildings including healthcare facilities.

All stakeholders related to any healthcare facility planning and design must also look at and adopt completely the provisions of Hospital Safety Guidelines by NDMA, published in 2016, giving exhaustive guidelines on choice of Structural systems, analysis, design and detailing of new hospital buildings including the non-structural elements (NSEs). This document also spells out very clear recommendations for immediate Audit and strengthening of existing hospitals in India.

GUIDELINES FOR HOSPITAL BUILDINGS AS PER NDMA (HOSPITAL SAFETY)

SALIENT FEATURES

In a hospital building two type of elements are there a) Structural Elements (SEs) b) Non Structural Elements (NSEs). Structural elements are components of buildings, which resist the loads imposed by external load effect and support all Non Structural Elements and NSEs do not resist the loads imposed by external load effect, but are supported by SEs of building; they fulfill the necessary architectural and functional requirements.

Building units of a Hospital campus shall be classified under two groups a) Critical unit of hospital buildings b) Other units of hospital buildings. Critical units of building and structures (SEs and NSEs) provide medical services essential in the immediate aftermath of disasters and other unit of building and structures (SEs & NSEs) that provide all the other service that may not be required in the immediate aftermath of disasters.

No damage is permitted in SEs and NSEs of hospital building when subjected to load other than earthquake. But under the action of earthquake effects two cases arise for SEs and NSEs.

Critical Units		Other Units	
SEs	**NSEs**	**SEs**	**NSEs**
Structural damage commensurate with Immediate Occupancy (IO) performance level is permitted.	Structural damage commensurate with Life Safety (LS) performance level is permitted.	Structural damage commensurate with Immediate Use (IU) performance level is permitted.	Structural damage commensurate with Dysfunctional State (DS) performance level is permitted.

Four aspects shall be addressed to ensure safety of SEs and NSEs of Hospital Buildings:

1. In New Buildings
   (i) Structural Design and Construction
2. In Existing Buildings
   (i) Pre-Disaster Safety Assessment
   (ii) Retrofitting
   (iii) Post-Disaster Damage Assessment

Presently very few documents are available worldwide for architects and engineers to undertake the above activities.

DESIGN STANDARDS

Structural Elements (SEs) of all Critical Units and Other Units of the new Health Facilities shall comply with requirements of NDMA (Hospital Safety) Guidelines in addition to all relevant existing national standards and guidelines laid down by various statutory bodies, non-statutory bodies as well as client owner of health facility. The latest versions of national documents currently in use are:

1. New Hospitals: NBC, IS:875, IS:1893(1), IS:1893(4), IS:456, IS:800, IS:13920, GSDMA Guidelines, IPHS and
2. Existing Hospitals: NBC 2007, IS:875, IS:1893(1), IS:456, IS:800, IS:1905, IS:13920, IS:13935, IS:15988 and GSDMA Guidelines.

STRUCTURAL ELEMENTS

Structural elements of critical units are designed for extreme load effects which are given in this section beyond those specified in the relevant national standards.

New Health Facilities

A new health facility means:

1. A new construction and
2. A reconstruction of an existing facility at the same site or new site.

a) Site Selection

The following sites shall be prohibited for locating a hospital:

- Liquefiable ground;
- Hill slopes (Stable or unstable) or land adjoining hill slopes known to have rolling debris; (whether sloped or flat)
- Flood or tsunami prone areas;
- Adjoining unsafe buildings and structures;
- Poor accessibility in post-disaster situations.

b) Structural Systems

Material - Structural Elements of all new hospital structures shall be made of Reinforced Concrete and/or Structural Steel, except for structures in seismic zone II, where Reinforced Masonry may be used.

Use of Structural Walls - The structural system of new hospital buildings shall NOT be Moment Resisting Frames alone. It should Structural Walls in each of the two mutually perpendicular plan directions of the building in addition to Moment Resisting Frames.

- The structural system of Moment Resisting Frames with Structural Walls shall be designed as a DUAL SYSTEM (as defined in IS:1893 (Part 1).
- The Structural Walls shall be made of

Reinforced Concrete (RC) and provided in select bays running through the full height of the building, irrespective of choice of material of the basic structural system adopted for the hospital, namely RC or Structural Steel.

- The total cross-sectional area of all RC Structural Walls shall be at least 4% of the plinth area of the building, along each of the two mutually perpendicular principal plan directions.
- RC Structural Walls shall be designed in accordance with IS:13920 or specialist literature more stringent than IS:13920.
- At each joint of Moment Resisting Frames, the design moment capacity of column section shall be at least 2 times design moment capacity of beam section.

Base Isolation Systems - Base Isolation System is an expensive technology option though effective to counter ill effects of strong earthquake shaking in new hospital buildings. Hence, Base Isolation System may be adopted in important hospitals in seismic zones IV and V. But, this shall be adopted only when safety of such hospital buildings is established by

- Analytical Methods, through nonlinear pushover analyses and nonlinear time history analyses under a suite of appropriate earthquake ground motions and
- Full-scale experimental testing of base isolation devices demonstrating that they are capable of resisting expected strong earthquake shaking.

Prohibited Structural Systems - The following structural systems shall be prohibited for use in new hospitals:

- Flat Slab buildings, with or without central core;
- Prestressed floor systems;
- Precast constructions (with natural or man-made materials), in part or whole of the structure and
- Pre-engineered structures, in part or whole of the structure.

c) Structural Configuration

- Regular Structural Configurations: All new hospital buildings shall have regular structural configuration only. Buildings shall be deemed to be regular when they meet requirements laid out in Clause 7.1 of the Indian Seismic Code IS:1893 (Part 1). Floating and setback columns shall not be allowed in buildings.
- Structural Configurations Prohibited: Structural configurations with open ground storeys or flexible or weak storeys at any other level shall be prohibited in hospital buildings.

> **“Base Isolation System may be adopted in important hospitals in seismic zones IV and V.”**

(d) Structural Analysis

- Multiple 3D models shall be considered in the analyses of Critical Units of Hospital Buildings to estimate the effects on strength and deformation demands of these Critical Units of Hospital Buildings.
- Individual footing shall be checked for uplift actions under the action of extreme load effects.

(e) Structural Design

SEs of Critical Units of Hospital Buildings shall be designed to resist elastically the expected load actions on them, including those due to earthquake effects. Hence, the design lateral earthquake forces prescribed in this guideline are much larger than those currently employed in design of buildings (including hospitals), to meet the requirement of immediate use of the hospital building structure and fully functional performance of the NSEs within the hospital building. Here, “designed to resist elastically” shall imply that the stress-resultant demands (namely P, V, M and T) on each structural element is less than its associated nominal capacities (as defined by IS:456 and IS:800 for structural elements made of RC and Structural Steel, respectively).

The design horizontal acceleration coefficient Ah given in Clause 6.4.2 of IS:1893 (1)-2016 for design of SEs shall be replaced by

$$A_h = \frac{ZI}{R}\left(\frac{S_a}{g}\right) \quad (1)$$

Where, Z is the Seismic Zone Factor, I the Importance Factor, Sa/g the Design Acceleration Spectrum for three different soil conditions, and R the Response Reduction Factor, all as defined in IS:1893 (1)-2016.

Effects of vertical earthquake ground shaking also shall be considered in the design of SEs.

As per IS1893 (4)-2015 the Hospital Buildings are kept under Category 2 for which Importance factor is 1.5

Existing Health Facilities

An existing health facility means:

- All existing health facilities that do not meet the standards mentioned in this guideline,
- A reconstruction of an existing facility at the same site or new site, and
- An existing commercial, office or residential buildings designed and built for other functional use, but now intended to be used as a hospital facility.

(a) Building Configuration
The building structure of retrofitted hospitals shall meet the criterion specified in this section.

Originally REGULAR or IRREGULAR Buildings: Buildings shall deemed to be REGULAR or IRREGULAR when they meet requirements laid out in the current Indian Seismic Code IS:1893 (Part 1)-2016). The retrofitted regular or irregular building shall meet the following criterion:

- Structural analysis shall be performed as given in IS:13935 or IS:15988 for seismic safety assessment of retrofitted Regular Buildings, to assess (i) the stress resultant demands (of axial load, shear forces and bending moments) on different structural elements in the existing building, and (ii) the lateral drift demand on the different storeys of the building.
- These stress resultants demands imposed by the level of shaking considered shall not exceed the design capacity of any structural element of the existing building with the considered retrofit scheme.
- The storey lateral drift demand in the existing building for regular building shall not exceed 0.4% of the height of the storey and 0.35% of the height of storey for irregular building using un-cracked section properties.

(b) Structural Design
Making existing Critical Units of Hospital Buildings meet requirements laid down for new hospitals in this Guideline can be difficult – it can be too stringent to meet the specifications corresponding to new buildings, or even too expensive do so. When existing deficient Critical Units of Hospital Buildings are to be retrofitted, they shall be designed to resist the effects of earthquake shaking given by the design horizontal acceleration coefficient A_h given in Clause 6.4.2 of IS:1893 (1)-2016 for design of SEs given by:

$$A_h = \frac{ZI}{2R}\left(\frac{S_a}{g}\right) \quad (2)$$

where, Z is the Seismic Zone Factor, I the Importance Factor, Sa/g the Design Acceleration Spectrum for three different soil conditions, and R the Response Reduction Factor, all as defined in IS:1893 (1)-2016.

Non Structural Elements

NSEs of all new hospital and all existing hospital building shall comply with all relevant existing national standards and NDMA Guidelines.

Design Strategy - NSEs shall be classified into three types depending on their earthquake behaviour, namely:

a) Acceleration-sensitive NSEs: The lateral inertia forces generated in these NSEs during earthquake shaking cause their sliding or toppling to the level of their base or lower.

b) Deformation-sensitive NSEs: The relative lateral deformation in these NSE spanning between two SEs (e.g., a pipeline passing between two parts of a building with a separation joint in between) or between an SE and a point outside building (e.g. an electric cable between the building and ground/pole outside the building), causes them move or swing by large amounts in translation and rotation under inelastic deformations of SEs imposed on them during earthquake shaking; and

c) Acceleration-and-Deformation-sensitive NSEs: Both of the conditions described in (a) and (b) above are valid.

Non Structural Elements Prohibited:

The following systems shall be prohibited for use as NSEs and its connections to the SEs in new hospitals:

- False ceilings hung from soffit of RC roof or floor slabs with anchor fasteners embedded in concrete portion of RC slabs; when false ceilings are required from medical safety point of view, exceptions shall be allowed subject to requirements given in NDMA Guidelines.
- Tiles pasted on unreinforced load-bearing masonry walls, unreinforced masonry infill walls or RC walls.
- Glass façade made of stone, ceramic, glass, etc.; when glass facades are required from medical safety point of view, exceptions shall be allowed subject to requirements given in NDMA Guidelines.
- Any NSE nailed to or supported by the Unreinforced Masonry Infill walls made of any material.

Design Guidelines – Acceleration Sensitive NSEs

The design lateral force Fp for the design of acceleration-sensitive NSEs may be taken as:

$$F_p = Z\left(1+\frac{x}{h}\right)\frac{a_p}{R_p} I_p W_p \quad (3)$$

Where, Z is the Seismic Zone Factor (as defined in IS:1893 (Part 1)), I_p the Importance Factor of the NSEs (Table 1), R_p the Component Response Modification Factor (Table 2), a_p the Component Amplification Factor (Table 2), Wp the Weight of the NSE, x the height of point of attachment of the NSE above top of the foundation of the building, and h the overall height of the building.

Table 1- Proposed Importance Factors I_p of NSEs

NSE	I_p
Component containing hazardous contents	2.5
Life safety component required to function after an earthquake (e.g., fire protection sprinklers system)	2.5
Stroage racks in structures open to public	2.5
All other components	2.0

Table 2- Coefficient a_p and R_p of Architectural, Mechanical and Electrical NSEs

S No.	Item	a_p	R_p
1.	**Architectural Component or Element**		
	Interior Non-structural Walls and Partitions		
	Plain (unreinforced) masonry walls	1	1.5
	All other walls and partitions	1	1.5
	Cantilever Elements (Unbraced or braced to structural frame below its center of mass)		
	Parapets and cantilever interior non-structural walls	2.5	2.5
	Chimneys and stacks where laterally supported by structures	2.5	2.5

	Cantilever Elements (Braced to structural frame above its center of mass) Parapets Chimneys and stacks Exterior non-structural walls	 1 1 1	 2.5 2.5 2.5
	Exterior Non-structural Wall Elements and Connections Wall element Body of wall panel connection Fasteners of the connecting system	 1 1 1.25	 2.5 2.5 1
	Veneer High deformability elements and attachments Low deformability and attachments	 1 1	 2.5 1.5
	Penthouses (except when framed by and extension of the building frame)	2.5	3.5
	Ceilings All	 1	 2.5
	Cabinets Storage cabinets and laboratory equipment	 1	 2.5
	Access Floors Special access floors All other	 1 1	 2.5 1.5
	Appendages and Ornamentations	2.5	2.5
	Signs and Billboards	2.5	2.5
	Other Rigid Components High deformability elements and attachments Limited deformability elements and attachments Low deformability elements and attachments	 1 1 1	 3.5 2.5 1.5
	Other flexible Components High deformability elements and attachments Limited deformability elements and attachments Low deformability elements and attachments	 2.5 2.5 2.5	 3.5 2.5 1.5
2.	**Mechanical and Electrical Component/Element**		
	General Mechanical Boilers and furnaces Pressure vessels on skirts and free-standing Stacks Cantilevered chimneys Others	 1 2.5 2.5 2.5 1	 2.5 2.5 2.5 2.5 2.5
	Manufacturing and Process Machinery General Conveyors (non-personnel)	 1 2.5	 2.5 2.5
	Piping Systems High deformability elements and attachments Limited deformability elements and attachments Low deformability elements and attachments	 1 1 1	 2.5 2.5 1.5
	HVAC System Equipment Vibration isolated Non-vibration isolated Mounted in-line with ductwork Other	 2.5 1 1 1	 2.5 2.5 2.5 2.5

	Elevator Components	1	2.5
	Escalator Components	1	2.5
	Trussed Towers (free-standing or guyed)	2.5	2.5
	General Electrical Distributed systems (bus ducts, conduit, cable tray) Equipment	 2.5 1	 5 1.5
	Lighting Fixtures	1	1.5

Design Guidelines

Displacement Sensitive NSEs

The NSE can be supported between two levels of the same building, or between two different buildings, between a building and the ground, or between building and another system (like an electric pole or communication antenna tower). The design relative displacement D shall be estimated as below:

i) Design HORIZONTAL and VERTICAL relative displacements DX and DY, respectively, between two levels of the same building (Building A), one at height hz1 and other at height hz2 from base of the building at which the NSE is supported consecutively, shall be estimated as:

$$D_X = 1.2\left(\delta_{z1}^{AX} - \delta_{z2}^{AX}\right)$$

$$D_Y = 1.2\left(\delta_{z1}^{AY} - \delta_{z2}^{AY}\right) \qquad (4)$$

Where,

$$\left(\delta_{z1}^{AX} \text{ and } \delta_{z2}^{AX}\right) \;\&\; \left(\delta_{z1}^{AY} \text{ and } \delta_{z2}^{AY}\right) \qquad (5)$$

These are the design HORIZONTAL and VERTICAL displacements, respectively, at levels z1 and z2 of the building A (at heights hz1 and hz2 from the base of the building) under the application of the load effects.

ii) HORIZONTAL and VERTICAL relative displacements DX and DY, respectively, between two levels on two adjoining buildings or two adjoining parts of the same building, one on the first building (Building A) at height hz1 from its base and other on the second building (Building B) at height hz2 from its base, at which the NSE is supported consecutively, shall be estimated as:

$$D_X = \left|\delta_{z1}^{AX}\right| + \left|\delta_{z2}^{BX}\right|,$$

$$D_Y = \left|\delta_{z1}^{AY}\right| + \left|\delta_{z2}^{BY}\right|, \qquad (6)$$

Where,

$$\left(\delta_{z1}^{AX} \text{ and } \delta_{z2}^{AX}\right) \text{ and } \left(\delta_{z1}^{AY} \text{ and } \delta_{z2}^{AY}\right) \qquad (7)$$

These are the design HORIZONTAL and VERTICAL displacements, respectively, at level z1 (height hz1) of building A and at level z2 (height hz2) of building B, respectively, at which the two ends of the NSE are supported.

CONCLUSION

Safety of all critical infrastructures in India against Earthquakes needs to be ensured by enforcing strict implementation of the design guidelines by NDMA and relevant BIS Codes. A Safe design has to start with correct site selection, following regular geometry as well as the design performance levels as stipulated in the Guidelines. However, the Guidelines and BIS Codes for Hospital Design must be upgraded further to match Global Safety standards of Operational Category as adopted globally for all critical units.

SEISMIC DESIGN CONSIDERATIONS IN HIGH RISE BUILDINGS – A STANDARD'S PERSPECTIVE

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INTRODUCTION

Due to rapid urbanization, shortage of land and continuous growth of population, there has been significant rise in the construction of tall buildings, especially in the urban areas to cater to the associated need for shelter spaces, office spaces and other commercial spaces. Tall buildings are designed not only by considering structural safety criteria but also ensuring the required serviceability aspects, especially under the conditions of lateral loads such as wind and earthquakes.

Although, design of tall buildings in mainly governed by wind loads, in regions of higher seismic zones earthquake loads become prominent which needs to be considered in the planning and design of buildings before construction. In order to ensure safety as well as serviceability aspects of tall buildings, Bureau of Indian Standards (BIS) had formulated an indigenous standard, IS 16700: Criteria for Structural Safety of Tall Concrete Buildings, which provides prescriptive requirements for the design and construction of RC tall buildings in the country. As far as earthquake resistant design of tall buildings is considered, IS 16700 should be read in conjunction with IS 1893 (Part 1) which lays down general provisions and guidelines for design of all buildings.

OVERVIEW OF THE STANDARD

IS 16700 covers the design aspects of RC buildings of height greater than 50 m and less than or equal to 250 m. This standard is applicable only for buildings with equal to or less than 20,000 occupants inhabiting the building. The standard covers various design aspects of tall buildings such as selection of appropriate structural systems, geometric proportioning, integrity of structural system, resistance to wind and earthquake effects and other special considerations related to tall buildings. The standard also provides general procedure to be adopted to proportion, analyze, design, detail and gain approval for construction of buildings that do not conform to the requirements prescribed in the standard. This standard provides additional requirements to be used in the design of tall buildings in addition to the ones prescribed by other Indian Standards used for structural design of buildings.

> **"IS 16700 covers the design aspects of RC buildings of height greater than 50 m and less than or equal to 250 m."**

For buildings that do not conform to the prescriptive requirements of IS 16700, the general guidelines to proportion, analyze, design, detail, gain approval and construct such buildings as given in Annex A of IS 16700 should be adopted. Performance objectives or procedures are more stringent than those specified in Annex A may be specified by the client and/or owner of the building or by the tall building committee appointed by the local authority administering the building project.

"IS 16700 provides various limitation on different structural parameters based upon the seismic zones."

GENERAL REQUIREMENTS FOR TALL BUILDINGS

IS 16700 provides various limitation on different structural parameters based upon the seismic zones [as in IS 1893 (Part 1)] in which the buildings are located.

a) The maximum building height (in m) is one such parameter which should not exceed the values given in Table 1 for buildings with different structural systems.

Table 1: Maximum Values of Height H above Top of Base Level of Buildings with different Structural Systems, in m

Sl No.	Seismic Zones	Structural System				
		Moment Frame	Structural Wall Well Distributed[1]	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	V	NA	120	150	150	180
ii)	IV	NA	150	200	200	225
Iii)	III	60	200	225	225	250
iv)	II	80	250	250	250	250

[1] Structural walls are considered to be well-distributed when structural walls that are outside of the core are capable of carrying at least 25 percent of the lateral loads.

b) Slenderness of buildings is another important parameter whose maximum value (the ratio of height to minimum base width) shall not exceed the values given in Table 2.

Table 2: Maximum Slenderness Ratio

Sl No.	Seismic Zones	Structural System				
		Moment Frame	Structural Wall Well Distributed	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	V	NA	8	8	9	9
ii)	IV	NA	8	8	9	9
Iii)	III	4	8	8	9	10
iv)	II	5	9	9	10	10

c) Building plans to preferably be rectangular (including square) or elliptical (including circular) to enable the structural members participate efficiently in resisting lateral loads without causing additional effects arising out of re-entrant corners and others. The plan aspect ratio has a critical limit which should be adhered.

d) For design earthquake force, the maximum inter-storey drift shall be $h_i / 250$ where h_i is inter-storey height of i^{th} floor in the building.

e) Cast in-situ floor slabs are preferable. Where precast floor systems are used, a minimum structural topping of 75 mm concrete with reinforcing mesh is essential in Seismic Zones III, IV and V, which can be reduced to 50 mm in Seismic Zone II.

f) The minimum grade of structural concrete shall be M30 while the suggested maximum grade is M70. However, higher grades are permitted, wherein; the designer shall ensure through experimentation that such concretes shall have at least a minimum crushing strain in compression of 0.002.

g) Specific reinforcing steel as per IS 1786:2008 and conforming to the provisions of IS 13920 are to be used.

h) All the load combinations shall be taken in accordance with IS 875 (Parts 1 to 5), IS 1893 (Part 1), IS 456 and IS 13920.

For design earthquake force, the maximum inter-storey drift shall be h_i/ 250 where h_i is inter-storey height of ith floor in the building.

EFFECTS OF EARTHQUAKE FORCES TO BE CONSIDERED IN DESIGN

As per IS 1893 (Part 1), the four main desirable attributes of an earthquake resistant building are:

a) Robust structural configuration,
b) At least a minimum elastic lateral stiffness,
c) At least a minimum lateral strength, and
d) Adequate ductility.

In addition to the above, the other aspects to be considered for resisting the effects of lateral forces due to an earthquake as laid down in IS 16700 are given as under:

a) Vertical shaking shall be considered simultaneously with horizontal shaking for tall buildings in Seismic Zone V.
b) For buildings in Seismic Zone V, deterministic site-specific design spectra may preferably be estimated and used in design. When site-specific investigations result in higher hazard estimation, site-specific investigation results shall be used.
c) Design base shear coefficient of a building under design lateral forces, shall not be taken less than that given in Table 3.

d) For buildings of height 50 m and more, the fundamental Period T (in second) for a structure shall be determined by accounting for all structural properties and inherent stiffness of the building through rigorously validated structural analysis procedures. The fundamental period shall however not exceed the value obtained from the approximate fundamental translational natural period Ta (in second) of oscillation, estimated by following expression:

$$Ta = 0.0644H^{0.9}$$

for concrete moment resisting frame systems, and

$$Ta = 0.0672H^{0.75}$$

for all other concrete structural systems

STRUCTURAL DESIGN CONSIDERATIONS

The design of the following structural systems falling under different seismic zones should be done in accordance with the provisions of IS 16700 in addition to the requirements given in IS 1893 (Part 1) and IS 13920.

a) Framed Buildings
b) Moment Frame - Structural Wall Systems
c) Structural Wall Systems
d) Flat Slab – Structural Wall Systems
e) Framed Tube System, Tube-IN-Tube System and Multiple Tube System

Buildings with simple regular geometry and uniformly distributed mass and stiffness in plan and in elevation, suffer much less damage, than buildings with irregular configurations. All efforts shall be made to eliminate irregularities by modifying architectural planning and structural configurations. Limits on irregularities for Seismic Zones III, IV and V and special requirements are given in Tables 5 and 6 of IS 1893 (Part 1).

Earthquake resistant design of tall buildings shall be performed using Dynamic Analysis Method as given in IS 1893 (Part 1). Dynamic analysis may be performed by either Time History Method or Response Spectrum Method. IS 16700 also provides recommendations

Table 3: Minimum Design Base Shear Coefficient (Percent of Seismic Weight)

Sl No.	Building Height, H	Seismic Zone			
		II	III	IV	V
(1)	(2)	(3)	(4)	(5)	(6)
i)	$H \leq 120$ m	0.7	1.1	1.6	2.4
ii)	$H \geq 200$ m	0.5	0.75	1.25	1.75

NOTE – For buildings of intermediate height in the range 120 m – 200 m, linear interpolation shall be used.

> **Earthquake resistant design of tall buildings shall be performed using Dynamic Analysis Method as given in IS 1893 (Part 1).**

for design of Non-Structural Elements (NSEs) in both new as well as existing buildings. Also, for monitoring deformations in buildings, all tall buildings in Seismic Zone V and tall buildings exceeding 150 m in Seismic Zone III and IV shall be instrumented with tri-axial accelerometers to capture translational and twisting behaviour of buildings during strong earthquake shaking.

NATIONAL PERSPECTIVE

The basic tools for land and building development rely very much on the Building Bye-laws which are evolved basically out of another premium publication of BIS, namely the National Building Code of India 2016 (NBC 2016) which in turn refer copiously to over 1,000 Indian Standards as accepted standards and good practices. Part 6 of NBC 2016 provides the guidelines for structural design of buildings.

Various other related Indian Standards including those under development should also be considered for implementation such as: IS 1893 (Part 6):2022 Criteria for earthquake resistant design of structures: Part 6 Base isolated buildings; Part 4 'Fire and life safety' of NBC 2016; IS/ISO 15392:2019 Sustainability in buildings and civil engineering works — General principles (first revision); Doc: CED 43 (21409) on 'Design and Construction of Combined Piled Raft Foundation'; ultrafine materials in concrete such as [silicafume (IS 15388:2003), metakaolin (IS 16354:2015), ultrafine GGBFS (IS 16715:2018), ultrafine flyash [Doc: CED 2 (17395)] towards ensuring that apart from the structural safety aspects, fire safety, life safety and public safety aspects are also addressed in achieving disaster resilient tall buildings in the country.

CONCLUSION

In India, land development and building construction is mainly regulated by the local building authorities or municipal corporation, who can incorporate the guidelines of Part 6 Structural Design of NBC 2016 in their building byelaws, which in turn cross refers to the other Indian Standards for ensuring earthquake safety of the buildings. Part 2 'Administration' of NBC 2016 also stipulates periodic audit for structural sufficiency of special buildings including high rise (> 15m) buildings. Thus, it is expected that all important buildings and structures are to be periodically verified, particularly against the standard used for the initial design. This will help in achieving safe, sustainable, robust and reliable design of the buildings.

REFERENCES

1. IS 16700: 2017 Criteria for structural safety of tall concrete buildings, Bureau of Indian Standards, New Delhi, India
2. National Building Code of India 2016, NBC 2016.
3. IS 1893 (Part 1) Criteria for earthquake resistant design of structures Part 1 General Provisions and Buildings

TWO-DAY ONLINE WORKSHOP ON "SUSTAINABLE CONSTRUCTION FOR DISASTER MITIGATION" held on **23rd and 24th March '23.**

RECENT TEMBLORS AROUND THE WORLD!

6th February '23

KAHRAMANMARAŞ, TURKEY-SYRIA BORDER
Magnitude: 7.8 with 7,930 Aftershocks
Damages: Turkey - Deaths: 43,000+; Apartments: 6,00,000+; Commercial Premises: 1,50,000+ Syria – Deaths: 3600+

20th February '23

UZUNBAĞ, HATAY, TURKEY – SYRIA BORDER
Magnitude: 6.3
Damages: Turkey – 8-10 People hurt and trapped under rubble, collapsing building Syria – 6-7 People hurt due to falling debris

23th February '23

MURGHOB, GORNO-BADAKHSHAN, TAJIKISTAN
Magnitude: 6.8
Damages: None reported

24th February '23

TOBELO, MALUKU UTARA, INDONESIA EARTHQUAKE
Magnitude: 6.2
Damages: None reported

25th February '23

KUSHIRO, HOKKAIDO, JAPAN
Magnitude: 6.0
Damages: None reported

1st March '23

KANDRIAN, WEST NEW BRITAIN, PAPUA NEW GUINEA
Magnitude: 6.5
Damages: None reported

4th March '23

KERMADEC ISLANDS, NEW ZEALAND
Magnitude: 6.9
Damages: None reported

16th March '23

KERMADEC ISLANDS, NEW ZEALAND
Magnitude: 7.1
Damages: None reported, Tsunami Warning Issued

18th March '23

BALÁO, ECUADOR
Magnitude: 6.8
Damages: 14 deaths, 380+ injured; structural damage homes, schools and medical centers

21st March '23

BADAKSHAN, AFGHANISTAN
Magnitude: 6.5
Damages: 13 deaths, 100+ injured; structural damage to infrastructure

Reference - https://earthquaketrack.com/

SEISMIC DESIGN OF STEEL STRUCTURES – A BRIEF OVERVIEW

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INTRODUCTION

This article gives a preliminary overview on the intent and basis for seismic structural design, followed by an introduction to different types of steel structural systems used for seismic force resistance, codal provisions to ensure ductility at material, section, component and system scales and ductile detailing requirements. Various codes, standards and guidelines are referenced and discussed preliminarily. However, the referenced codes should not be interpreted as the representative list of standards to be used for seismic design. Utmost care should always be taken to follow all provisions and requirements applying to a project's jurisdiction, including the codes and standards governing at that location. This article is intended to be used for academic purposes only.

HISTORICAL BACKGROUND

Preliminary structural studies on major earthquakes in Japan, New Zealand and USA in the 1920s and 1930s revealed that structures designed to withstand wind loads generally performed better under seismic loads as well. Based on this observation, the first edition of the Uniform Building Code published in 1927 included lateral earthquake loads for structural design, equaling 6-10% of the structural weight. [1]

Theoretical developments in structural dynamics led to the understanding that structural response to ground motion is frequency dependent. However, elastic analysis predictions for peak lateral forces exceeded design capacities typically by a factor of 4, [2] which indicated that portions of a structure were yielding and dissipating energy through inelastic response under earthquakes.

Using Newmark's numerical integration scheme to solve the fundamental equation of motion, [3] it was demonstrated by [2] that inelastic action reduces peak loads due to seismic ground motion. Consider a single degree of freedom (SDOF) oscillator under a ground motion time history. The peak displacement of the oscillator under a seismic ground motion record is approximately in the same range whether it remains elastic or inelastic, and is independent of the yield strength of the oscillator. This observation, known as the "equal displacement approximation", forms the basis for modern force-based seismic design. Although an analytical proof of the equal displacement approximation has not been found, it has been extensively verified numerically (see [4] for review) and experimentally (e.g.). [5]

The equal displacement approximation suggests that an oscillator having an yield capacity equal to the elastic load, and a second oscillator having an yield capacity of $1/R$ times the elastic load, produce similar peak displacements under an acceleration time history.

"The referenced codes should not be interpreted as the representative list of standards to be used for seismic design."

Therefore, it is acceptable to design the oscillator for a force that is reduced by a factor of *R* compared to elastic demands, if and only if the oscillator has a ductility capacity equaling or exceeding its yield displacement times *R* (see Fig. 1). This quantity *R*, known as response reduction factor, has traditionally been prescribed in design codes based on past engineering experience, and is estimated by an incremental dynamic approach [6] outlined in [7] for new structural systems.

> **The observation, known as the "equal displacement approximation", forms the basis for modern force-based seismic design.**

RESPONSE REDUCTION '*R*' FACTOR BASED APPROACH TO SEISMIC DESIGN

Force based design that is commonly used in earthquake resistant design standards including IS 1893 (Part 1):2016 [8] and ASCE 7-2016, [9] utilizes a response reduction factor *R* which is explained in Fig. 1. The elastic base shear expected on a system under a design earthquake is denoted as V_E. If the entire structural system remained elastic under the effect of an earthquake, the shear force generated at its base would equal V_E. However, material strength or section size requirements to resist forces resulting from elastic base shear V_E are usually so large, that they are impractical or unfeasible to provide in real structures. Therefore the philosophy for designing such structures is that portions of the system will yield and undergo plastic response under design earthquakes. It is through this plastic response that structural systems dissipate energy inputted by earthquake ground motion.

Accordingly, a designated portion of the structural system, known as the lateral force resisting system (LFRS) or the energy dissipative system, is designed to plastify under earthquake loads. This system acts as a "Structural Fuse" and limits force demands on parts of the structural system that are in series in its load path. Structural components in series with the LFRS are subjected to forces equaling the maximum capacity of the LFRS, which equals the LFRS yield capacity multiplied by an appropriate overstrength factor Ω_0 (see Fig. 1). This design approach is known as "Capacity Design" and is described in IRC SP-114:2018 Section 7.3. [10]

To account for deviations from the equal displacement approximation, a displacement amplification factor C_d (see Fig. 1) is provided in US design standards. Portions of the structural system other than the designated LFRS, for example gravity columns, are to be designed for the imposed peak inelastic displacement of the LFRS. Fig. 1 explains response reduction, overstrength and deflection amplification factors as described in FEMA P-695. [7]

The designated lateral force resisting system or "Structural Fuse" needs to possess adequate

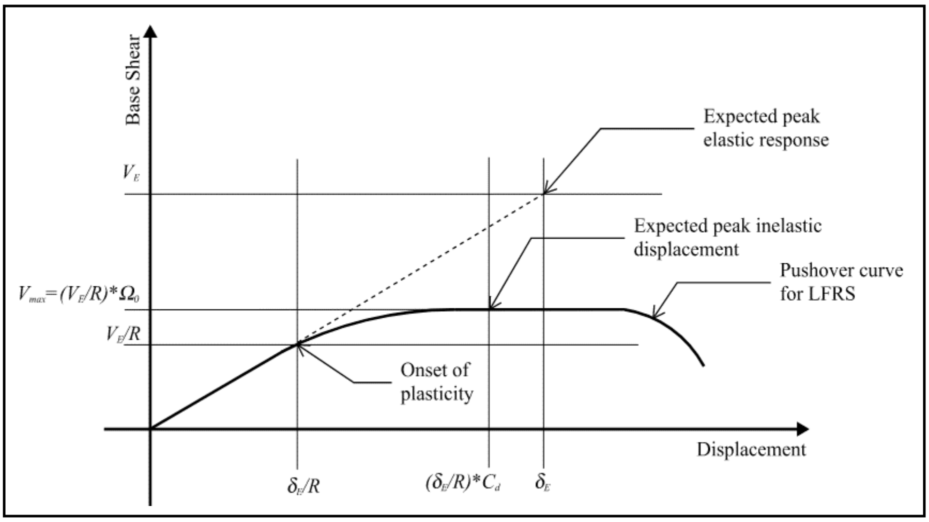

Fig. 1: Graphical representation of response reduction factor *R*, overstrength factor Ω_0 and deflection amplification factor C_d

ductility to inelastically dissipate the energy input from seismic ground motion without undergoing rupture, instability or collapse. In the following section, representative energy dissipative systems for steel structures are introduced.

STEEL SYSTEMS COMMONLY USED FOR SEISMIC ENERGY DISSIPATION

Designated lateral force resisting systems for steel structures are listed in Fig. 2, including response reduction factors per IS 1893 (Part 1):2016 and ASCE 7-2016. Also included are deflection amplification factor C_d and overstrength factor Ω_0 per ASCE 7-2016. Overstrength factor for steel systems is uniformly recommended as 1.25 in IRC SP:114-2018 Section 4.2.4 Note v.

DUCTILITY AND DETAILING REQUIREMENTS FOR ENERGY DISSIPATIVE SYSTEMS BUILT USING STRUCTURAL STEEL

Steel material used for seismic energy dissipative elements should conform to codal requirements to ensure adequate ductility for the required energy dissipative capacity. Typically, standard material permitted to be used for structural steel elements (for example, steel complying with IS 2062) [12] are permitted to be used for seismic applications due to their adequate ductility. Per IS 800:2007 section 4.5.2, the stress-strain diagram for the steel at yield stress is required to have a plateau extending for at least six times the yield strain to ensure plastic section behaviour. Bracing members used in Special Concentrically Braced Frames (SCBF) and members used in Special Moment Frames (SMF) are required to be constructed of E250 steel per IS 800:2007.

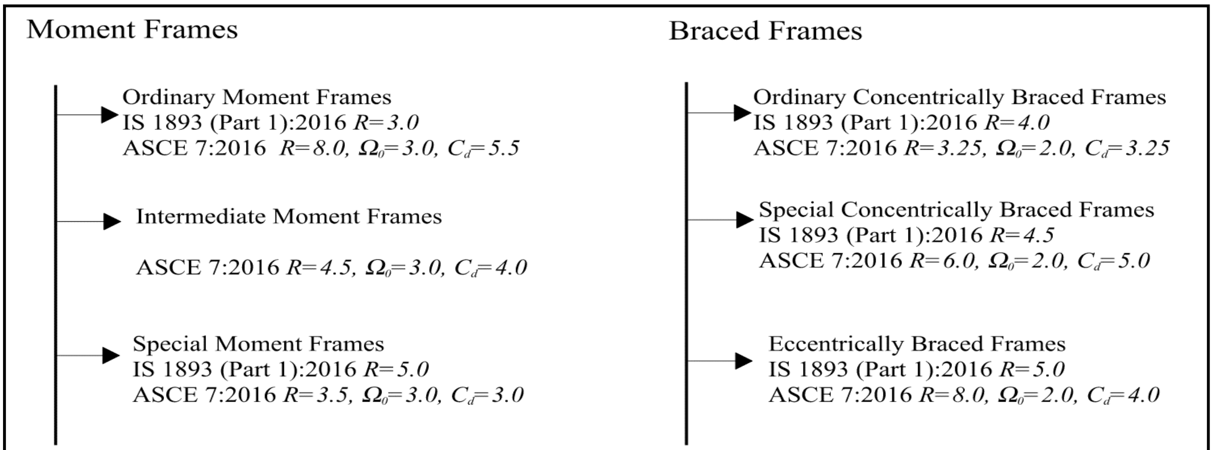

Fig. 2: Steel LFRS and associated factors per Indian and American design standards

In addition to the systems listed in Fig. 2, shear wall systems such as special plate shear walls, composite ordinary shear walls, composite special shear walls and composite plate shear walls (either encased or filled with concrete) are covered in ANSI/AISC 341-16. [11] Composite systems consist of steel framing and/or sheets in addition to reinforced concrete.

Response reduction '*R*' factors for steel energy dissipative systems (Fig. 2) correspond to expected levels of ductility or energy dissipative capacities. Specific requirements to justify the given response reduction factors are rotational ductility at moment frame connections and axial force ductility in bracing components. A brief overview of codal provisions intended to ensure the availability of this ductility is discussed in the next section.

Similarly, material ductility is required at energy dissipative connection elements. Per IS 800:2007 provision 12.4.1, all bolts designed to resist earthquake loads are to be fully tensioned high strength friction grip bolts. Per IS 800:2007 provision 12.4.2, all welds used in seismic load resisting frames are to be complete joint penetration (CJP) butt welds, except in column splices, where partial joint penetration (PJP) butt welds are permitted if the joint strength is atleast twice the required strength, per section 12.5.2.2.

In the United States, welds where large inelastic strains are anticipated, are designated as "Demand Critical Welds". Such welds

> **In the United States, welds where large inelastic strains are anticipated, are designated as "Demand Critical Welds".**

are required to meet Chapter A provisions in ANSI/AISC 341-16 including 22% minimum elongation for 480 MPa welds, and specified Charpy V-Notch toughness. Demand critical welds are to be specifically identified on structural drawings. Further, connection details used in intermediate and special moment frames must conform with prequalified connection requirements described in ANSI/AISC 358-16,[13] or be tested to ensure adequate ductility per provisions given in Chapter K of ANSI/AISC 341-16.

In addition to material scale, adequate ductility needs to be ensured at section, component and system scales to justify response reduction factors explained in Fig. 1 and listed in Fig. 2. Steel sections that are used in energy dissipative systems are required to have sufficient compactness such that local buckling does not prevent the required energy dissipative capacity to be developed.

To ensure that local buckling does not prevent the steel section from dissipating the required amount of energy under earthquake loading, IRC SP:114-2018 stipulates that "only plastic and compact sections shall be used in potential plastic hinge formation zone". Section classification for Indian Steel Sections are provided in Table 2 of IS 800:2007. Similarly, ANSI/AISI 341-16 table D1.1 specifies width to thickness ratio limits for moderate and highly ductile members.

IS 800:2007 stipulates that bracing members shall mandatorily have plastic sections in Special Concentrically Braced Frames (SCBF), whereas they are permitted to have plastic, compact or semi-compact sections in Ordinary Concentrically Braced Frames (OCBF). Column sections used in SCBF are mandated to be plastic per IS 800:2007 Section 12.8.4.1.

It is to be ensured that structural components that are designated for energy dissipation do not undergo instability failure. Accordingly, per IS 800:2007, slenderness ratio of bracing members should not exceed 120 for OCBF and 160 for SCBF. Similarly, in ANSI/AISI 341-16, slenderness ratio of diagonal braces in SCBF is limited to 200. ANSI/AISI 341-16 also specifies bracing requirements for moderately and highly ductile members at specified maximum spacing noted in Chapter D. Bracing required in steel beams shall brace both flanges, or point-brace the cross section against torsion. Special bracing is required at locations where plastic hinges are expected to form.

Members designated as energy dissipative elements are required to fail in ductile modes only - brittle failures are absolutely not permitted. Accordingly, bracing elements in braced frames are to be designed such that gross tensile yielding is the governing failure mode. Net tensile rupture should never govern in such elements.

Designated energy dissipative locations should not undergo rupture or fracture due to stress concentration or initial 'weak spots'. To ensure this, ANSI/AISI 341-16 chapter D prohibits fabrication or erection procedures (such as welding) at locations identified as "protected zones" where plastic energy dissipative behaviour is expected (for example, plastic hinge location near moment connections on moment frame beams or axial yielding locations on bracing members).

Structural elements that are in series with the designated energy dissipative section are to be capacity designed to resist the maximum force that can be developed in the system, as discussed in Fig. 1. Examples of capacity designed elements include, but are not limited to:

1. Column bases (including anchor bolts) are to be capacity designed for moment and shear equaling at least 1.2 times the full plastic moment capacity and shear capacity of the column respectively, per IS 800:2007 section 12.12.
2. Bracing connections in OCBF and SCBF are to be designed to withstand minimum

of (a) 1.2 and 1.1 times the brace gross section yielding capacity respectively and (b) maximum force that can be transferred to the brace by the system, per IS 800:2007 Sections 12.7.3 and 12.8.3

3. Rigid moment connections in ordinary moment frames (OMF) and SMF are to be designed to withstand 1.2 times the full plastic moment capacity of the connected beam, per IS 800:2007 Section 12.10.2.1 and 12.11.2.1
4. The summed moment capacity of columns above and below beam centerline in SMF are required to be designed for capacity greater than or equal to 1.2 times the summed moment capacities of beams at the connection intersection per IS 800:2007 Section 12.11.3.2. This is known as "strong-column weak-beam" concept.

CONCLUSIONS

The basis for ductile design of seismic systems is to permit some plasticity and energy dissipation, with a primary requirement of adequate ductility at designated energy dissipative elements. In addition, it is of critical importance that a continuous load path for seismic force flow is identified and properly designed. The load path should initiate at the point of generation of inertial forces and should be continuously followed through the diaphragm, to collector elements, the designated energy dissipative system and all the way to the foundation. All elements in this load path are to be capacity designed for the maximum expected capacity of the energy dissipative system (including overstrength). The energy dissipative system is to be designed for adequate ductility per relevant codal provisions, some of which were briefly introduced in this paper. Displacement compatibility should be adequately considered by designing all elements for expected imposed deformations, including unusual effects such as torsion, higher mode effects or soft story modes. Precise engineering judgment along with close adherence to all applicable and available design standards and technical literature is crucial to ensure safety from structural collapse due to seismic loads.

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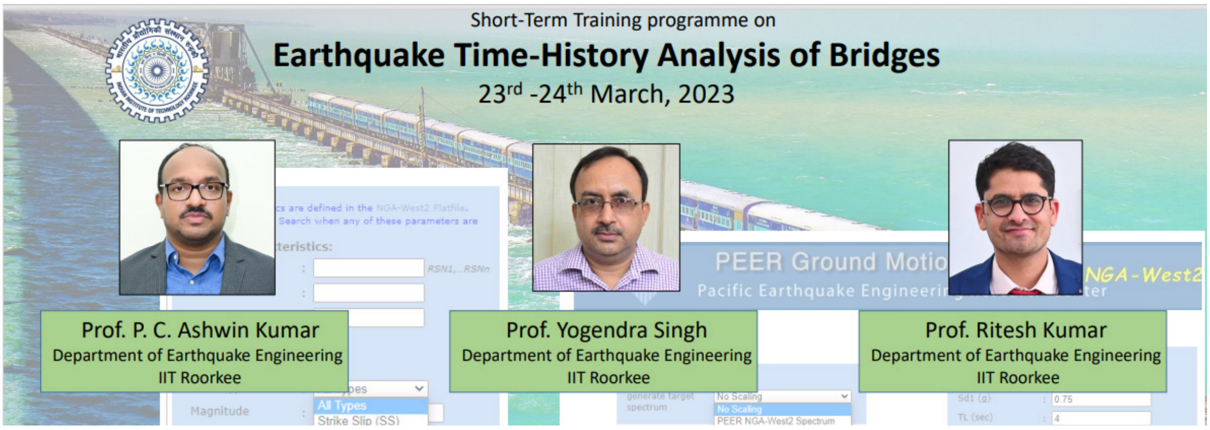

WORKSHOP ON - EARTHQUAKE TIME-HISTORY ANALYSIS OF BRIDGES

Department of Earthquake Engineering, **Indian Institute of Technology (IIT) – Roorkee** organised a short term training programme on "**Earthquake Time-History Analysis of Bridges**" on 23rd & 24th March '23.

The Course Content included –

Introduction to Seismic Response of Bridges, Selection & Scaling of Earthquake Time Histories, Structural Modelling of Bridge Structure and Substructure, Geotechnical Modelling of Bridge Foundations, Hands on training on Selection, Scaling, and Spectral Matching of Ground Motions, Case studies on Time History Analysis of Different Types of Bridges

WORKSHOP ON - "SEISMIC SAFETY OF NON-STRUCTURAL ELEMENTS" AND "RETROFIT OF STRUCTURES"

With the objective of "**Educate to Elevate**", a full day workshop was conducted by Hilti India Pvt. Ltd. under the aegis of Seismic Academy on 25th March '23 at **Birla Institute of Technology & Science (BITS) Pilani** on "**Seismic Safety of Non-Structural Elements**" and "**Retrofit of Structures**". The session was attended by more than 60 higher degree students and faculty members of BITS and other nearby engineering colleges. The session was highly engaging, interactive and created lot of enthusiasm among the participants.

The workshop was conducted under the inspiration of Dr. Anupam Singhal – Head of Dept., Civil Engineering BITS Pilani & Dr. Muthukumar G. – Asst. Professor, Civil Engineering Dept., BITS Pilani.

GROUND MOTION SELECTION AND SCALING METHODS FOR SEISMIC DESIGN: EXISTING GUIDELINES AND THE WAY AHEAD

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INTRODUCTION

Seismic provisions in current model building codes and standards include rules for design of structures using nonlinear response-history analysis which are based, in large part, on recommendations for analysis of seismically isolated structures from more than 20 years ago. In Indian scenario, unfortunately, there is currently no consensus in the earthquake engineering community on how to appropriately select and scale earth-quake ground motions for code-based design and seismic performance assessment of buildings using nonlinear response-history analysis.

Ground motion selection provides the necessary link between seismic hazard and structural response, the first two components in Performance Based Earthquake Engineering (PBEE).[1] It determines input ground motion for a structure at a specific site for nonlinear dynamic analysis (i.e., response history analysis). As non-linear dynamic analysis becomes more common in research as well as in practice, there is a need for a clear guidance on appropriate ground motion selection methods. [2-4]

One common state-of-the-art practice in performance-based earthquake engineering is Incremental Dynamic Analysis that scales the same suite of ground motions up and down to cover a range of ground motion intensity levels. [5]

> **Ground motion selection provides the necessary link between seismic hazard and structural response.**

RESPONSE HISTORY ANALYSIS

Response history analysis is a form of dynamic analysis in which response of the structure to a suite of ground motions is evaluated through numerical integration of the equations of motions. In nonlinear response history analysis, the structure's stiffness matrix is modified throughout the analysis to account for the changes in element stiffness associated with hysteretic behaviour and P-delta effects.

Nonlinear response-history analysis is performed for a number of reasons, including:

- Designing new buildings, especially those equipped with seismic isolators or energy dissipation devices.
- Designing seismic upgrades of existing buildings per ASCE 41-17,[6] Seismic Rehabilitation of Existing Buildings (ASCE, 2017).
- Designing non-conforming framing systems in new buildings per ASCE 41-17.

- Assessing performance of new and existing buildings per ATC-58-1,[7] Seismic Performance Assessment of Buildings (ATC, 2011).

PERFORMANCE OBJECTIVES

Performance objectives are always associated with Non-Linear Time History Analysis (NLTHA) and Performance based Design (PBD) methods. ASCE 7-05 and ASCE 7-10,[8] specified that nonlinear response history analyses be performed using ground motions scaled to the design earthquake level and that design acceptance checks be performed to ensure that mean element actions do not exceed two-thirds of the deformations at which loss of gravity-load-carrying capacity would occur. [9]

In ASCE 7-16,[10] a complete reformulation of these requirements was undertaken to require analysis at the Risk-Targeted Maximum Considered Earthquake (MCER) level and also to be more consistent with the target reliabilities as shown in Table 1.

Table 1: Target Reliability (Conditional Probability of Failure) during an MCER Earthquake

Risk Category	Member Category	ASCE 7-10	ASCE 7-16
I or II	Critical	10%	10%
	Non-critical	25%	25%
III	Critical	6%	5%
	Non-critical	15%	15%
IV	Critical	3%	2.5%
	Non-critical	10%	9%

GROUND MOTION SELECTION

The selection and scaling of earthquake ground motions serves as the interface between seismology, thus, playing a key role in determination of seismic load to a structure. Ground motions are generally selected from previous recorded earthquake events or generated by physics-based simulations where there is a lack of appropriate recordings, such as large magnitude earthquakes at short site-to-source distances.

One of the most common concern of every designer is how many ground motions to be selected (3, 5, 7, 11, 22 or more).[11] Ground motions have different characteristics and there also exists record to record variability in structural response. ASCE 7-05 and ASCE 7-10 suggest to use of either three (or more) or seven (or more) appropriate ground motions for analysis. If 3 sets of ground motions were used and analyses were performed, then maximum value of peak response among three were used for component checking. If seven set of ground motions are used, then average value of the seven peaks is used for component checking. ASCE 7-16 the minimum number of motions is increased to 11. Larger number of motions is to properly identify the performance level of the structure that the structure is not allowed to shown unacceptable response in more than one motion; this would indicate that the structure fails to meet 10% target collapse reliability. However, this rule doesn't have statistical or technical basis, moreover to estimate mean response with confidence it requires goodness of fit of the scaled motion to the target spectral shape.

> **"The selection and scaling of earthquake ground motions serve as the interface between seismology and seismic design."**

Section of ground motions generally occurs in two steps. Step 1 involves factors such as Source Mechanism, Magnitude, Site Soil Conditions, Usable Frequency of ground motion, Period Sampling and Site to Source Distance. Step 2 involves evaluating the selected ground motion based on the Spectral Shape, Scale Factor and Motions from single event.

GROUND MOTION SCALING

Period Range for Scaling or Matching

A period range is needed to be determined which corresponds to the vibration period that significantly contribute to the building's lateral dynamic response. The period range for scaling of ground motions is selected such that the ground motions accurately represent the MCER hazard at the structure's fundamental response periods, periods somewhat longer than this to account for period lengthening effects associated with nonlinear response and shorter periods associated with a higher mode response.

In ASCE 7-05 and ASCE 7-10 ground motions were required to be scaled in between 0.2T to 1.5T, where T used to be the fundamental period of the structure in the fundamental mode for the direction of response being analysed. In ASCE 7-16 edition, the upper bound has been increased to 2.0T, where T is maximum fundamental period of building in both transitional direction and in torsion. Increment in upper bound to capture the increment in time period due to ductile frame structures.[12] For lower bound period of 0.2T, an additional requirement is put that it needs to capture 90% of mass participation in both the directions and T is redefined for lower bound as the smallest fundamental period among the two horizontal directions.

Two procedures for modifying ground motions for compatibility with the target spectrum are available: amplitude scaling and spectral matching.

Amplitude Scaling

Amplitude scaling consists of applying a single scaling factor to the entire ground motion record such that the variation of earthquake energy with structural period found in the original record is preserved. Amplitude scaling preserves record-to record variability; however, individual ground motions that are amplitude scaled can significantly exceed the response input of the target spectrum at some periods, which can tend to overstate the importance of higher mode response in some structures.

“Amplitude scaling consists of applying a single scaling factor to the entire ground motion record”

Method adopted and requirements for amplitude scaling are shown in Table 2. It could be seen in Table 2 that conservatism is being removed in 2016 edition which arises due to average spectrum being greater than target spectra at every period with in the range.

SPECTRUM MATCHING

Spectral matching is introduced in 2016 edition of ASCE 7. In spectral matching shaking amplitudes are modified by differing amounts at differing periods, and in some cases additional wavelets of energy are added to or subtracted from the motions, such that the response spectrum of the modified motion closely resembles the target spectrum. Spectral matching captures the mean response but is incapable of preserving record to record response variability and velocity pulses in near field ground motions. So, it is recommended not to use spectrum matching for near fault sites. In spectral matching technique it's

Table 2: Amplitude Scaling Criteria's in American Standards

Code Edition	Method Adopted	Requirements for Amplitude Scaling
ASCE 7-05	SRSS	Average of SRSS spectra ≥ 1.3 times design response spectra for scaled period
ASCE 7-10	SRSS	Average of SRSS spectra ≥ design response spectra for scaled period
ASCE 7-16	Maximum directional spectrum	Average spectrum does not fall below 90% of the target spectrum in entire period range

> **It is recommended not to use spectrum matching for near fault sites.**

required to have each pair of ground motion scaled such that average of average of the maximum-direction spectra for the suite equals or exceeds 110% of the target spectrum over the period range of interest. This is more stringent requirement as compared to amplitude scaling so as to avoid lower prediction of mean response.

CONCLUSION

This paper provides guidance to professionals and basis of current guidelines of ASCE/ SEI 7-16 on selection and scaling of ground motions for nonlinear response history analysis. This paper also shows modifications in previous editions of ASCE/SEI 7 and the technical basis of these changes.

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MAN MADE LAKE CAUSES STRANGE EARTHQUAKES IN SOUTH CAROLINA

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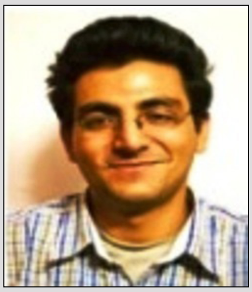
As per research, a man-made lake which was built over 40 years ago in the northwest of Columbia, South Carolina is causing multiple small earthquakes. South Carolina’s Lake Monticello has time and again recorded rare earthquakes solely owing to its man-made nature of existence. These earthquakes – though low in magnitude – are numbered in thousands which have startled geologists.

Something called reservoir-induced seismicity is the reason behind these quakes. It’s extremely rare, occurring at just a few man-made lakes around the world. It happens when the reservoir is built over rocks that have tiny fractures. The weight of the water forces it to down into those cracks, which builds up pressure until, ultimately, that pressure forces the rocks to move - and that is what creates an earthquake.

SEISMIC CONSIDERATIONS IN UNDERGROUND STRUCTURES



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Underground structures such as tunnels are constrained by and bedded in rock/soil. An independent movement of the underground structures e.g. final lining to the ground is unlikely. Hence underground structures have to be capable to deform as constrained by the surrounding ground. The load transfer mechanism between underground rock/soil and structures is mainly governed by the relative stiffness between the structure and the surrounding ground.

Earthquake loads are applied by means of the static equivalent loading method as per IS 1893:2002.[5] The design horizontal seismic coefficient, A_h is determined by the following expression:

$$A_h=(Z/2) * (Sa/g) * (I/R) \quad (1)$$

(As per clause 6.4.2 of IS 1893: 2016) [5]

Where, Sa/g is the average response acceleration coefficient whose value is determined by STAAD using the internally calculated fundamental period of vibration of the structure. The value of the design vertical seismic coefficient is taken as two-thirds of the horizontal seismic coefficient, as per clause 6.4.2 of IS 1893: 2002.

As per clause 6.3.4 of IS 1893: 2002, if earthquake forces are applied in two or more directions, then in one direction the maximum contribution has to be considered and only 30% contribution has to be taken from other directions. Hence the vertical component is reduced to 30% of the calculated value.

For underground structures and buildings whose base is located at depths of 30m or more, Ah shall be taken as half the value as given above as per clause 6.4.2, in accordance with Clause 6.4.5 of IS 1893 Part-1:2016. [5] and for structures and foundations placed between the ground level and 30m depth, the design horizontal acceleration spectrum value shall be linearly interpolated between A_h and $0.5 \cdot A_h$.

The effect of seismic loadings due to earthquake is considered in shallow sub-surface structures. The effect in cross sectional direction is to be considered by application, either pseudo-statically, horizontal and vertical accelerations loads or by free-field shear deformation method. This approach assumes that the deformation of the structure should conform to the deformation of the soil in the free field under the design earthquakes.

For deep tunnels, the seismic effects are significantly reduced as per various literature and research papers. A few of these are quoted in the following paragraphs. The effect in the longitudinal direction is deemed to be insignificant due to the following aspects.

- The waterproofing membrane between primary and secondary lining prevents frictional forces in longitudinal direction of the tunnel.
- The secondary lining is constructed with single element blocks with a designed length of 12.5m. Construction joints are

> **Underground structures have to be capable to deform as constrained by the surrounding ground.**

designed between the element blocks. The reinforcement layer is not continuous in longitudinal direction. Only compressive forces are transferred over the construction joints and consequently no tension constraints in longitudinal direction are generated.

Dowding & Rozen (1978) [1] and Sharma & Judd (1991) [2] studied several responses of tunnels during earthquake (approx. 250 tunnels). There was no visible damage of the tunnel final lining in cases where the horizontal peak ground acceleration was lower than 0.2g. In most cases damage was reported where the horizontal peak ground acceleration was higher than 0.4g. In general, the data shows, that in shallow tunnels the probability and intensity of damage is higher than in tunnels at greater depths.

In general, subsurface structures are subjected to much less stress in earthquake than buildings/structures above ground. These stresses reduce with increase in depth. So, it can be assumed that earthquake induced stress in tunnel are much lower due to earthquakes. As a rule, tunnels are not designed for earthquake forces. (As per "Guide 853.9120 to 853.2001 DB directive", concerning paragraph 16 DS 853). [3]

Further, to verify this assumption, effect of seismic forces on tunnel can be evaluated as described in literature by YMA Hashish et al. [4] To summarize, the effects of seismic forces in surface structures, shallow underground structures and deep underground structures shall be evaluated carefully to simulate the actual conditions.

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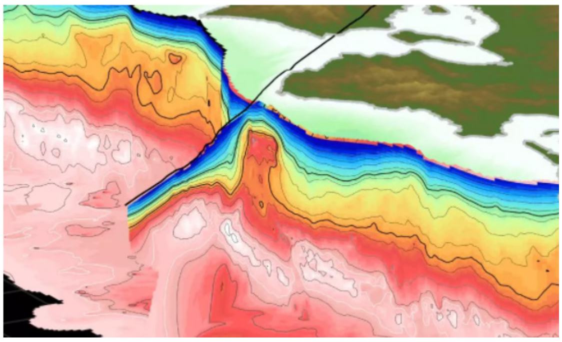
DATA IMAGING REVEALS OUNTAIN SIZE ROCK CHANNELLING EARTHQUAKES IN JAPAN



The Kumano Pluton, a mountain sized rock is buried a mere 5 km down the coast of Southern Japan claims a new study and with years of data processing and technological upgradations, scientists have been able to create its first complete, 3D visualization.

The dense igneous rock sits in the crust of the continental Eurasian plate. Under this slab of continental crust, the oceanic Philippine plate is taking a dive toward the Earth's mantle. Research indicates that the heavy pluton within the Eurasian plate changes the slope of that dive, forcing the Philippine plate down more steeply.

Because the Kumano Pluton is so dense and rigid, it is also likely playing a significant role in tectonic activity. In 1944, a magnitude-8.1 quake started on the edge of the pluton and shook the ground to the northeast. Two years later, a magnitude-8.6 earthquake started close to the epicenter of the first quake but ruptured in the southwest direction.
Given that subducting slabs are highly sensitive to variations in structure, the pluton is likely having a profound effect on both the geometry and tectonic activity in the region.

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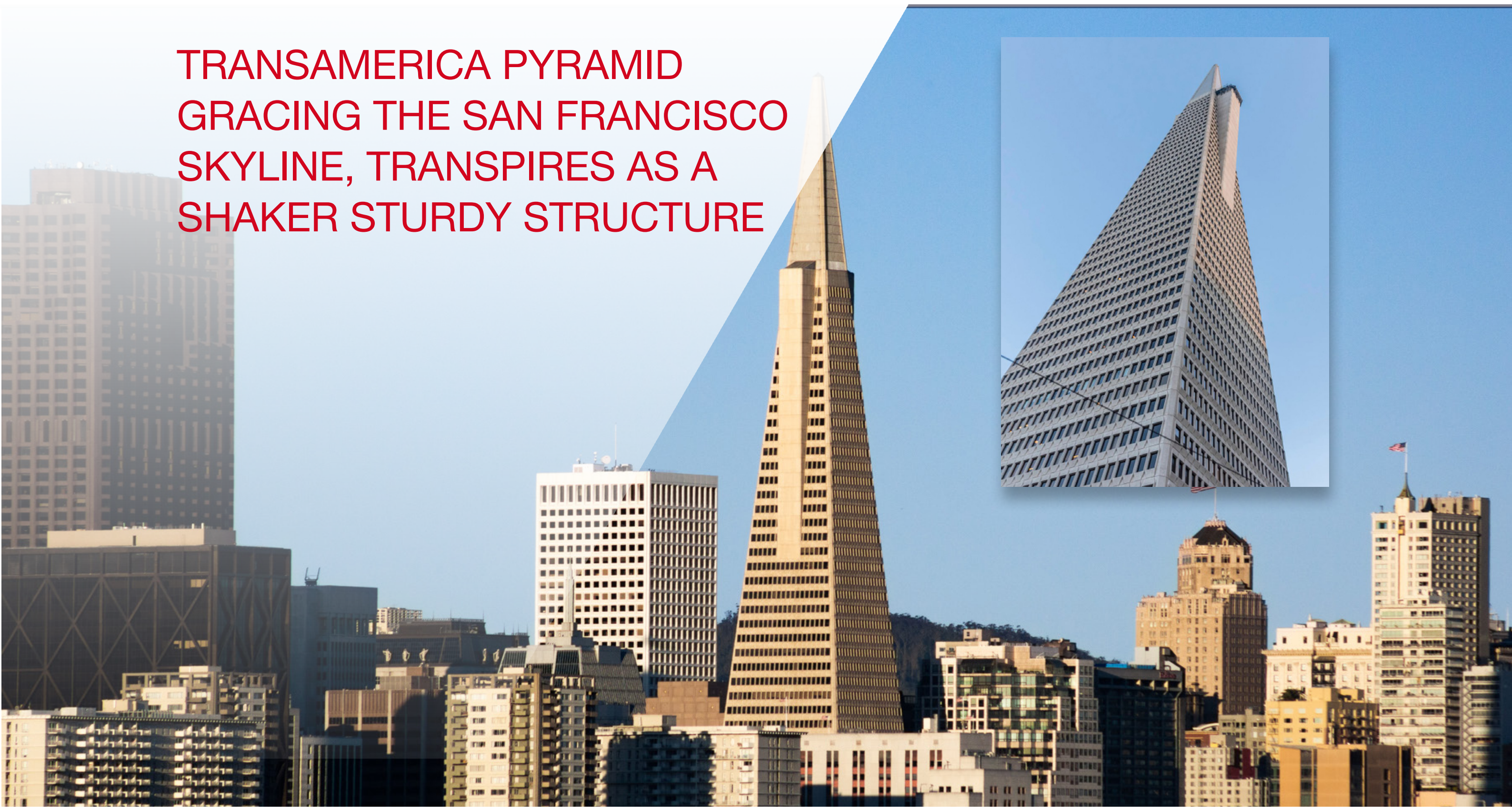
TRANSAMERICA PYRAMID GRACING THE SAN FRANCISCO SKYLINE, TRANSPIRES AS A SHAKER STURDY STRUCTURE



The phenomenal city of San Francisco, famous for the Golden Gate Bridge and Alcatraz Tower, is a bustling city of Northern California which houses the spectacle - Transamerica Pyramid. Though, it no longer houses the headquarter of the Transamerica Corporation, the building has retained its association by being depicted in the company logo.

A 48-storey, modernist architectural skyscraper, boasts to be the soaring 2nd tallest building in whole of San Francisco which was constructed 51 years ago! With a height of 260 m, the building houses multiple retail and office spaces.

Basis estimation by seismologists, there is a 72% probability of a magnitude 6.7 or greater earthquake in San Francisco's Bay Area in the near future. Earthquake hazard is spread throughout San Francisco Bay Area. There is a 3 out of 4 chances of the Bay Area to be struck by disastrous earthquakes in the next 30 years. U.S. Geological Survey names the prime 'Earth Movers' as the San Andreas Fault, the Calaveras Fault and the Hayward Fault.

Damages from a Hayward Fault rupture alone could shake one million homes with 77,000 to 152,000 households displaced. It is not just the Earth's shaking that could lead to billions in damages and lead to tens of thousands of Bay Area residents becoming homeless. When earthquakes occur in San Fransisco, they cause liquefaction of soil and pose a high risk to neighbouring areas as well.

Such catastrophic geological situations can only be mitigated and not completely avoided. This is where earthquake resilient buildings such as the Transamerica Pyramid play a significant role in safeguarding lives, infrastructure and economy when faced with such catastrophes. The Transamerica Pyramid successfully withstood the 1989 Loma Prieta earthquake of magnitude 7.1 which struck the Santa Cruz Mountains

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in California. 96.5 km away, in downtown San Francisco, the 48 storey Transamerica building shook for over a minute.

During the quake, the top story swayed over 12 inches from side to side. Yet the building was undamaged and no one was seriously injured.

The success of this building goes to Architects - William Pereira & Harry D. Som, Structural Engineer - Walter Hensolt and Engineering Firm - Chin & Hensolt.

"The building's exterior framework is reinforced with additional interior frames providing resistance to torsional movements."

Structural System & Seismic Design

The Transamerica Pyramid in San Francisco was built with the possibility of future devastating shocks in mind. The building's concrete and steel foundations are designed to move with any earthquakes and reach as far as 15.8 m deep. This base allows for stability and the absorption of shock waves.

The building's seismic defences include a four-storey steel and concrete base rising from a 2.7 m thick foundation, and two sets of internal framework. To construct this advanced building, the team first excavated the site and undertook a lengthy continuous concrete pour to build its foundation.

From there, they established the skyscraper's main structural support; the four-storey steel and concrete truss webbing that wraps around the base of the building and extends approximately 15.5 m below ground.

Rising from this formidable foundation, the building's exterior framework is reinforced with additional interior frames that rise to the 17th and 45th floors providing resistance to torsional movements. As the skyscraper began to take its place on the skyline, its two distinctive "wings" steadily emerged from the 29th floor.

Providing both form and function, these extrusions actually help to make the building's height economically feasible. With its pyramid design creating a floor-plate that reduces in area with increase in height,

Image: sanfranciscobusinesstimes.com/photos these fins carry elevators, stairways and services to the top of the structure while keeping them out of the lettable floor space. Clad in white precast quartz window frames, the pyramid was topped with a 65 m illuminated spire and capped with a beacon known as the "crown jewel".

Possibly, the most visually recognizable seismic safety feature of tall buildings is the truss. The Transamerica Pyramid in San Francisco is famous for its architecture: a wide base that narrows as it goes up increases the building's stability. A network of diagonal trusses at its base supports the building against both horizontal and vertical forces.

Specs and Facts

- The building's façade is covered in crushed quartz, giving the building its light color.
- The four-storey base contains 12,000 m^3 of concrete and over 480 km of steel rebar.
- The building's foundation is 2.7 m thick, the result of a 3-day, 24-hour continuous concrete pour.
- Only two of the building's 18 elevators reach the top floor.
- The building is on the site that was the temporary home of A.P. Giannini's Bank of Italy after the 1906 San Francisco earthquake destroyed its office. Giannini founded Transamerica in 1928 as a holding company for his financial empire. Bank of Italy later became Bank of America.
- The aluminum cap is indirectly illuminated from within to balance the appearance at night.
- The two wings increase interior space at the upper levels. One extension is the top of elevator shafts while the other is a smoke evacuation tower for fire-fighting.
- A glass pyramid cap sits at the top and encloses a red aircraft warning light and the brighter seasonal beacon.
- Because of the shape of the building, the majority of the windows can pivot 360 degrees so they can be washed from the inside.
- The spire is actually hollow and lined with a 30.5 m steel stairway at a 60 degree angle, followed by two steel ladders.
- Construction began in 1969 and the first tenants moved in during the summer of 1972.

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ANNUAL CONFERENCE 2022

10TH NOVEMBER '22, NEW DELHI

Seismic Academy held its first Annual Conference on 10th November '22 at India Habitat Center, New Delhi and was attended by more than 75 professionals from across the country from standardization bodies, practicing engineers, academicians and research scholars involved in the field of earthquake engineering.

We have with us a few, notable feedback from our esteemed guests enumerated hereunder:

"We are very glad and appreciate the initiative taken by a well esteemed organisation HILTI INDIA for research and development in various fields like Seismic Academy, Fire Protection Academy, Anchor and Rebar Systems.

It's very important to bridge gap between industry, academia and hands on experience to students as well as industry readiness. We are very grateful as an academician to Research and Development team of HILTI INDIA.

Thanks."

Prof. Sudhir Patil
MIT WPU – Pune

Seismic Academy provides a common platform where we can interact with experts in the earthquake engineering area and receive the latest information about various research and industrial advancements in the area. Furthermore, various initiatives taken by the Seismic academy, such as organizing conferences and courses, can provide significant exposure to geotechnical, structural, and seismological aspects of earthquake engineering for people from academia and industry.

Moreover, Seismic Academy can help establish a link among researchers, national standard bodies and industries.

Thank you.

Kusum Saini
PhD Research Scholar,
Multi-Hazard Protective Structures (MHPS) Laboratory,
Department of Civil Engineering,
Indian Institute of Technology (IIT) Delhi

The Seismic Academy Conference was very intriguing as I had the chance to learn the latest development in earthquake resistance design. The lecture sessions were very informative and had a balanced mixture of theoretical and experimental presentations. It is a great initiative where academia, BIS and industry will complement and benefit from each other. Expanding the conference duration to two days for subsequent edition may be considered.

Prof. Subhasis Pradhan
BITS Pilani

Seismic academy has shown a great start in bringing together industry and academia under a common cause. Looking forward to more interactive sessions and collaborations.

Devyani Tewatia
IIT Roorkee, Research Scholar

The Seismic Academy Conference held on 10th November 2022, was good. I have the following observations:

1. The Proceedings of the Conference should be brought out (soft copy & hard copy). The Proceedings may include:
   - The deleberations of the experts (technical part) including the questions from the audience & answers by the experts.
   - Keynote lecture of Prof. Mahesh Tandon
   - Research work of Prof. Pankaj Agrawal and Sh. Shounak Mitra

   The Proceedings should be circulated to practicing engineers.
2. The practicing engineers of the country should know that, M/S Hilti (India) Pvt. Ltd. is not only equipment suppliers, but also carry out R&D work on Earthquake Engineering, specially to increase awarness and develop expertise on the subject of 'Seismic Safety'.

Dr. S.C. Maiti
Ex-Joint Director
National Council for Cement and Building Materials

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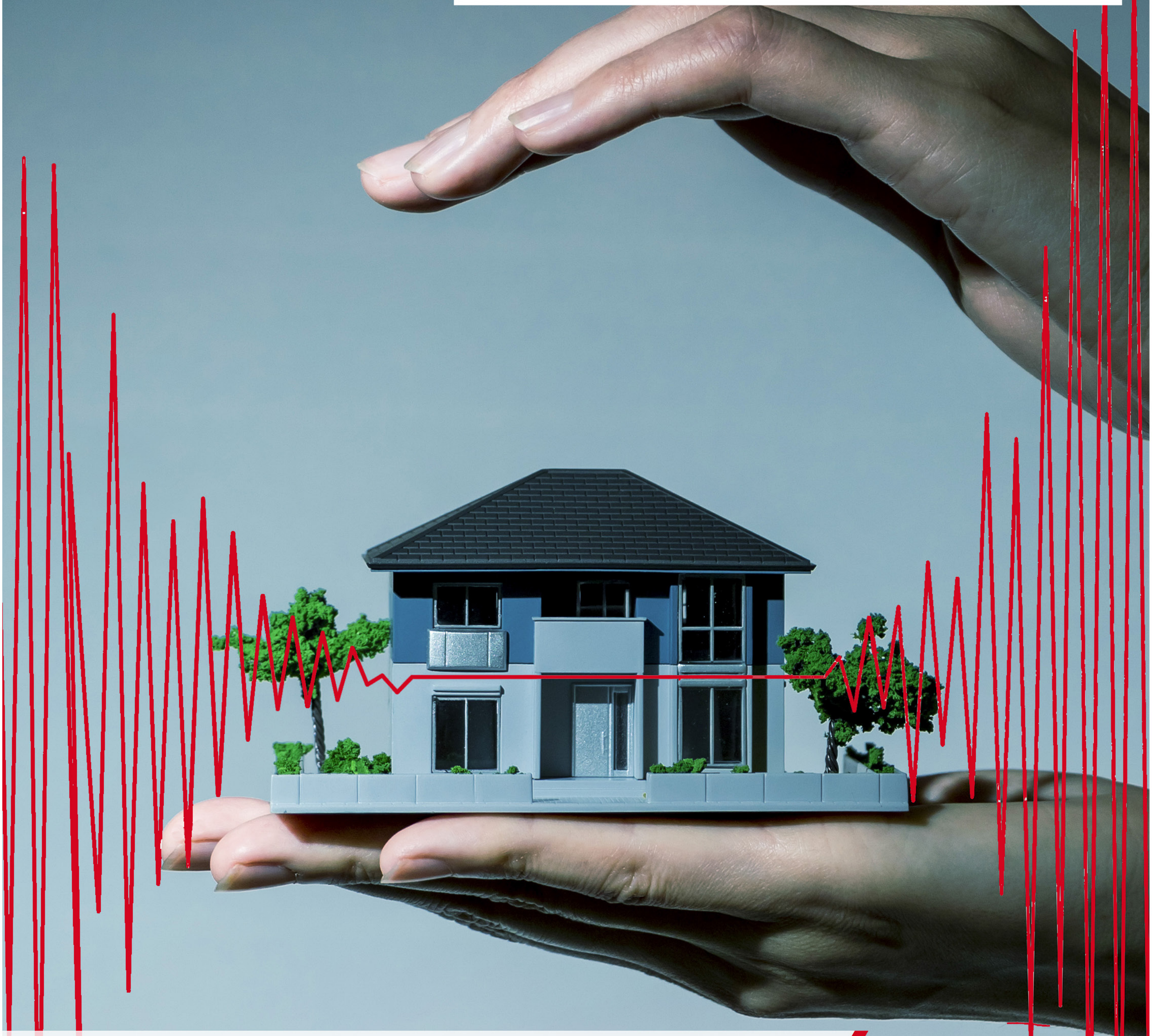
SEISMIC ACADEMY



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