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SEISMIC ACADEMY

Seismic ACADEMY

JOURNAL

EARTHQUAKES

- Interview
- Articles
- Seismic Splendour

Seismic Academy Journal

An Initiative by HILTI
Building Benchmarks for Industry and Academia

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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.

OUR ADVISORY BOARD

A CE&CR PRODUCTION

IN THIS ISSUE - Total No. of Pages: 42 (Including Cover)

FROM THE DESK OF ADVISORY BOARD

We all know that operating in the construction industry comes with a lot responsibility where disseminating proper knowledge to the stakeholders is extremely important, while we run the business. For the last 25 years, Hilti India has been at the vanguard of nation building through its expertise in research and innovation. Maintaining a strong focus on effective collaboration with the industry experts and academia is also one of the guiding principles for us. This is intertwined with the sentiment of building a better future for all.

A few years back, the Seismic Academy was established for professionals, academicians, authorities and industry experts to interact and share knowledge on various aspects of seismic to increase the awareness and develop their expertise on this subject. Our vision is to make Seismic Academy as one source of information and use it for promoting of all seismic initiatives in our country.

Acknowledging the fact that India is prone to earthquakes, we need institutions which can help guide the construction industry professionals to understand the best seismic standards, know about the on-going research and bring it successfully into practice. Fortunately, the Seismic Academy today in India, is catering to all these needs and increasing awareness among many like-minded stakeholders. Through this academy, we are continuously encouraging high-level interactions to bring transformation in earthquake engineering through increased knowledge dissemination as well capacity building. As a result of this, over the last couple of years, we have been able to engage with relevant stakeholders via interactive webinars in association with bodies like IAStructE, IEI, ICI, ISET delivered by national and international experts.

On behalf of the advisory board, I welcome all you to utilize this platform to learn and contribute and create a sustainable value for the society.

Jayant Kumar
Managing Director
Hilti India Pvt. Ltd.

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Our vision is to make Seismic Academy as one source of information and use it for promoting of all seismic initiatives in our country.

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TABLE OF CONTENTS

Prof. (Dr.) Chandan Ghosh
Professor & Head
Resilient Infrastructure Division
National Institute of Disaster Management (NIDM)
Ministry of Home Affairs
Govt. of India

"A sense of urgency and compliance can be created through repeated trainings and capacity building of practicing engineers at all levels."

Seismic Academy: Share your vision for the Indian and Global Seismic Infrastructure.

Prof. (Dr.) Chandan Ghosh: Earthquake engineering is in today's context a very pertinent topic in Indian infrastructure and requires lot of attention. There has been significant progress in terms the standard development, keeping in conjunction with the changing scenario. The global safety standards in terms of earthquake stability have been very streamlined and can inspire us to adopt similar approach, tailored to meet the Indian framework.

We should also put adequate emphasis on the site-specific measures while dealing with earthquake resistant construction. It is important that we have to go an extra mile in bringing experts' contribution in the field evaluation of the existing as well as upcoming infrastructure in the country.

Seismic Academy: Highlight the need of periodic seismic upgrades?

Prof. (Dr.) Chandan Ghosh: It is extremely important that the seismic standards are getting upgraded on a regular basis, in line with the changing demands. It is to be noted that BIS has been very up-to-date in revising many standards. These details also need to be implemented and maintained during actual execution. A sense of urgency and compliance can be created through repeated trainings and capacity building of practicing engineers at all levels. The continuous changes also need to be communicated effectively to the students through competence enhancement sessions and regular update in the curriculum.

Seismic Academy: One of your areas of expertise is seismic microzonation. Kindly elaborate and share your thoughts.

Prof. (Dr.) Chandan Ghosh: Seismic microzonations are routinely in practice since 1990's and many cities have tick marks in these exercises. Delhi-NCT has been completed in 2015, Sikkim in 2005, Guwahati in 2005 and many more have completed the process. However, it is to be noted that these are the study reports based on ground characteristics, which is to be looked after by the municipalities while sanctioning plans and more so by the construction fraternities for due changes or modification in the design procedure as well as corrective measures, e.g. adoption of liquefaction mitigation measures.

Issues lie in the interpretation of Microzonation findings with building performance, where complexities of structural geometry, architectural hegemonies and extra sense of safety factor based on judgmental-superstitions among the experts are excessively out-powered by even by an M5 earthquake event.

Seismic Academy: To aid in earthquake management, what ground improvement techniques will you lay stress upon for the industry to ponder over diligently?

Prof. (Dr.) Chandan Ghosh: Ground improvement measures are very much enriched in the construction fraternity yet majority of the decisions on the seismic performance of a built up facility lies on the factual situation of foundation.

Appropriate measures for the ground improvement must be done and in many cases, e.g. instead of avoiding liquefaction potential areas as per Microzonation report, simple densification of the ground or micropiling of the shallow ground with proper evaluation of the ground improvement by SPT, CPT would be a good demonstration of the best practice.

Seismic Academy: What will be your recommendations to make built-infrastructures disaster resilient?

Prof. (Dr.) Chandan Ghosh: In order to make built-infrastructures disaster resilient it is recommended that:

- All state governments and all local bodies (urban & rural), development authorities, special and new town development agencies, etc. need to modify, revise and revamp the existing building byelaws; development control rules; planning standards; town planning rules; special regulations for fire, structural, health, construction, electric and life safety, in line with the NBC 2005, 2016 by suitably adopting fully or adapting it with such local variation as may be needed.
- NBC 2005, 2016 to be adopted as the basis for all structural design, fire protection, building and plumbing services, building materials & practices (and construction safety) and for proper protection, upkeep & maintenance of water bodies by modifying the departmental construction codes/specifications/ manuals of government construction departments.
- The strengthening of all building development and regulating agencies with the right level of professional human resources to deal with proactive responses needed with the building professionals and builders. The professional human resource pooling for contiguously situated human settlements and the related regulating agencies should be attempted, considering the socio-economic and budgetary constraints of smaller level local bodies dealing with building regulation work.

Seismic Academy: What in your opinion is required to unleash India's full potential in the infrastructural sector?

Prof. (Dr.) Chandan Ghosh: India's software part of physical infrastructure (like telecom, air and port services) performed well, thus not only helped the country to maintain a faster growth but also integrated the economy with the world market at a faster pace.

At the same time the hardware component of the country's physical infrastructure (e.g. road, rail, power) comparatively grew slowly, thus, negated the country's development process. Therefore, in order to unleash India's full potentials, development of the hardware component of the country's physical infrastructure (e.g. road, rail, power) perhaps deserves utmost attention. This also indirectly indicates high investment potentials in roadways, railways, power and the associated components in India.

Seismic Academy: Your recommendation for ensuring the need to address the areas of seismic safety to be taken up for future establishments.

Prof. (Dr.) Chandan Ghosh: There is a need for a more systematic, holistic and integrated effort to address the critical areas of concern responsible for fragile seismic safety in India. These can be achieved by:

- Sensitizing stakeholder groups on prevalent seismic hazard and potential loss due to lack of earthquake resistance in buildings and structures;
- Implementing structural mitigation measures through formal education and research in earthquake-resistant design and construction, beginning with faculty members of colleges of civil engineering and architecture made competent in associated subjects, and then modifying the undergraduate curriculum to include mandatory elements of earthquake-resistant design and construction;
- Improving enforcement of building codes and town planning regulations related to earthquake-resistant design and construction;
- Encouraging earthquake-resistant features in non-engineered construction in suburban and rural areas;
- Organizing formal technical training of architects and engineers on earthquake-resistant construction best practices.

> **“There is a need for a more systematic, holistic and integrated effort to address the critical areas of concern responsible for fragile seismic safety in India.”**

EARTHQUAKE ENGINEERING – A STANDARDS PERSPECTIVE

Arun Kumar S.
Director & Head
Civil Engineering Dept.
Bureau of Indian Standards

Jitendra Kumar Chaudhary
Assistant Director
Civil Engineering Dept.
Bureau of Indian Standards

INTRODUCTION

In the present era, occurrence of seismic events has become very common all over the world in which minor earthquakes are occurring nearly every day in some parts of the world. Each earthquake of high to severe magnitude results in huge loss of human lives, destruction of properties, buildings and infrastructure, and affects transportation of goods and services. Large amount of money and manpower is required to recover with the widespread destruction caused. To avoid the vagaries of these seismic events, design and construction of buildings and structures to resist earthquakes become utmost essential. As we know that earthquake is a natural disaster which occurs due to the movement/drifting of tectonic plates, it is difficult to forecast it. Hence, we can only design 'earthquake resistant' structures not 'earthquake proof' structures. Earthquake resistant design of structures generally aims that damage(s) can occur in the members of the building without collapse. Standards, being a tool to address problems of repetitive nature, are used by countries world-over to address the risk due to earthquakes as well. In the country, the Bureau of Indian Standards has therefore formulated a series of Indian Standards in the field to ensure proper planning, design and execution of buildings and built environment taking into cognizance the potential of the buildings and infrastructure so built to counter the earthquakes in a sustainable manner. This article discusses some of such efforts.

EARTHQUAKE

Earthquake is a natural phenomenon which is caused by the movement of tectonic plates past each other. During an earthquake, large amount of strain energy is released which travels in the form of seismic waves leading to huge ground shaking. This ground shaking induces lateral force on buildings and structures and leads to their catastrophic failure. The point on the fault where the slip starts is called as 'Focus' and the point vertically above it on the surface of the Earth is called as 'Epicenter'. The depth of focus from the epicenter, called as 'Focal Depth', is an important parameter in determining the damaging potential of an earthquake.

> **"We can only design 'earthquake resistant' structures not 'earthquake proof' structures."**

PHILOSOPHY OF EARTHQUAKE RESISTANT DESIGN

The engineers do not attempt to make earthquake proof buildings that will not get damaged even during the rare but strong earthquake; such buildings will be too robust and also too expensive. Instead, the engineering intention is to make buildings earthquake resistant; such buildings resist the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake. Thus, safety of people and contents is assured in earthquake-resistant buildings, and thereby a disaster is avoided. This is a major objective of seismic design codes throughout the world. Broadly, ground shaking (Fig. 1) is classified on performance objectives as below along with their effect on buildings and structures:

a) Under **minor** but frequent shaking, the main members of the building that carry vertical and horizontal forces should not be damaged; however, building parts that do not carry load may sustain repairable damage.
b) Under **moderate** but occasional shaking, the main members may sustain repairable damage, while the other parts of the building may be damaged such that they may even have to be replaced after the earthquake; and
c) Under **strong** but rare shaking, the main members may sustain severe (even irreparable) damage, but the building should not collapse.

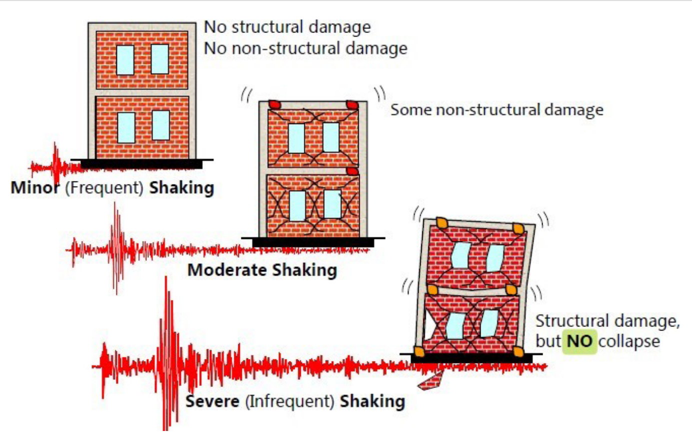

Fig.1: Performance objectives under different intensities of earthquake shaking

PREVENTION OF EARTHQUAKE AS PART OF DISASTER MANAGEMENT

The Disaster Management Act, 2005 of India defines Disaster Management (DM) as a continuous and integrated process of planning, organizing, coordinating and implementing relevant measures. Such activities are intended towards:

- Prevention;
- Mitigation (or risk reduction);
- Preparedness;
- Prompt response;
- Assessment of disaster effects; and
- Rehabilitation and reconstruction

Activities involved in the disaster management are categorized time wise as Pre-Disaster, During Disaster and Post Disaster. Pre-disaster activities are with a view to reducing the potential losses to men and material due to the hazard thereby minimizing losses during the onset of disasters. Activities that tend to the needs and provisions of victims with a view to alleviating and minimizing the suffering are classified as those during a disaster. Post-disaster activities involve all those performed to obtain rapid and durable recovery which does not replicate initial vulnerable conditions. The activities can therefore be indicated as in Table 1.

Table 1: Activities involved in Disaster Management

Phase	Activity
Pre-Disaster	Prevention and Mitigation Preparedness Early warning
During Disaster	Response (First stage after the Disaster Impact)
Post Disaster	Recovery Rehabilitation Reconstruction Development

Thus, it is evident that mitigating the effects of earthquake by way of designing the buildings and structures to resist such effects contributes significantly to the disaster management process. The same could potentially reduce the burden on the authorities and volunteers particularly in the post-disaster and so during disaster events.

ROLE OF STANDARDS IN EARTHQUAKE PREVENTION AND MITIGATION

Built environment, the abode to every individual and the network of infrastructure that support human activities and provide comfort, which are erected on/above/below surface of earth are subjected to earthquake ground motions.

An element of safety thus is pertinent to be intrinsically added right from the planning and design of buildings and structures, and the same needs diligent construction/erection in the site as intended. Standards, being technical documents frequently referred in the contracts ensure to instil a high level of confidence in the minds of parties concerned. Standards evolved on a consensus basis both at the national level (Bureau of Indian Standards) and at international level (International Organization for Standardization) thus serves as the right tool for the designers and practitioners.

National perspective

Geographically, for instance, India is bound on one side by the young but active mighty mountain range (Himalayas), by sea/ocean on three sides, and also within it contains the enormous Indo-Gangetic plains which pose a challenging soil type to the built environment. Considering the vast history of earthquakes recorded even before the 19th century, the ensuing devastation and failure of buildings and structures the then BIS (Indian Standards Institution) rightly codified the necessary engineering design requirements for earthquake resistant design as early as 1960s. In fact, in the field of cyclones, landslides, fires, etc. also the relevant guidelines were enshrined to be followed by the relevant professionals. A brief list of the relevant Indian Standards related to earthquake resistant design of new buildings and assessment & retrofitting of existing buildings is provided in Table 2.

Table 2: List of Indian Standards formulated by the Earthquake Engineering Sectional Committee, CED 39

Sl No.	IS Number	Title	No. of Amendments	Previous editions(s)
1	IS 1893:1984	Criteria for earthquake resistant design of structures (fourth revision)	2	1962,1966, 1970,1975
2	IS 1893 (Part 1): 2016	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (sixth revision)	2	2002
3	IS 1893 (Part 2): 2014	Criteria for earthquake resistant design of structures: Part 2 Liquid retaining tanks (fifth revision)	1	-
4	IS 1893 (Part 3): 2014	Criteria for earthquake resistant design of structures: Part 3 Bridges and retaining walls	-	-
5	IS 1893 (Part 4): 2015	Criteria for earthquake resistant design of structures: Part 4 Industrial structures including stack-like structures (first revision)	2	2005
6	IS 1893 (Part 6): 2022	Criteria for earthquake resistant design of structures: Part 6 Base isolated buildings	-	-
7	IS 4326:2013	Earthquake resistant design and construction of buildings — Code of practice (third revision)	1	
8	IS 4967:1968	Recommendations for seismic instrumentation for river valley projects		
9	IS 4991:1968	Criteria for blast resistant design of structures for explosions above ground	-	-
10	IS 6922:1973	Criteria for safety and design of structures subject to underground blasts	-	-
11	IS 13827:1993	Improving earthquake resistance of earthen buildings — Guidelines	2	-
12	IS 13828:1993	Improving earthquake resistance of low strength masonry buildings — Guidelines	3	-
13	IS 13920:2016	Ductile design and detailing of reinforced concrete structures subjected to seismic forces — Code of practice (first revision)	2	-
14	IS 13935:2009	Seismic evaluation, repair and strengthening of masonry buildings — Guidelines (first revision)	-	-
15	IS 15988:2013	Seismic evaluation and strengthening of existing reinforced concrete buildings — Guidelines	-	-
16	IS 17848:2022	Confined Masonry for Earthquake Resistance — Code of Practice	-	-
17	SP 22:1982	Handbook on codes for earthquake engineering (WITHDRAWN)		

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.

Apart from the Indian Standards, around 30 guidelines related to disasters, templates for preparing Disaster Management Plans (including at District level), and guidelines on Medical Preparedness and Mass Casualty Management have since published by the National Disaster Management Authority (NDMA). Also, to guide the current and potential homeowners towards reducing losses in future in the aftermath of negative fallout of the earthquake, the Simplified Guidelines for Earthquake Safety of Buildings' had been published by NDMA and BIS visit: https://ndma.gov.in/Governance/Guidelines

Various guidelines on disaster management issued by the NDMA available at:
https://ndma.gov.in/ReferenceMaterial/NDMAGuidelines are with a view to propagate the importance and reflectance of the safety in the built environment.

International scenario

The International Organization for Standardization (ISO) supported by various National Standards Bodies (including the Bureau of Indian Standards, the National Standards Body of India) across the world has a dedicated technical committee on 'Security and Resilience' ISO/TC 292 operating with the scope: "Standardization in the field of security to enhance the safety and resilience of society". Also, ISO/TC 262 deals with 'Risk Management' within in scope, "Standardization in the field of risk management".

A list of some of the important standards relevant to the theme of response and recovery of Disaster Management is included in Table 3.

More details are available at:
https://www.iso.org/committee/5259148.html

Table 3 - List of International Standards related to Disasters

Under ISO/TC 292 Security and Resilience	
ISO 22315:2014	Societal security — Mass evacuation — Guidelines for planning
ISO 22316:2017	Security and resilience — Organizational resilience — Principles and attributes
ISO 22319:2017	Security and resilience — Emergency management — Guidelines for monitoring facilities with identified hazards
ISO 22320:2018	Security and resilience — Community resilience — Guidelines for planning the involvement of spontaneous volunteers
ISO 22322:2015	Security and resilience — Emergency management — Guidelines for incident management
ISO 22324:2015	Societal security — Emergency management — Guidelines for public warning
ISO 22325:2016	Societal security — Emergency management — Guidelines for colour-coded alerts
ISO 22326:2018	Security and resilience — Emergency management — Guidelines for capability assessment
ISO 22327:2018	Security and resilience — Emergency management — Guidelines for implementation of a community-based landslide early warning system
ISO/TR 22351:2015	Societal security — Emergency management — Message structure for exchange of information
ISO/TR 22370:2020	Security and resilience — Urban resilience — Framework and principles
ISO 22395:2018	Security and resilience — Community resilience — Guidelines for supporting vulnerable persons in an emergency
ISO 22396:2020	Security and resilience — Community resilience — Guidelines for information exchange between organizations
ISO 22398:2013	Societal security — Guidelines for exercises
ISO 28002:2011	Security management systems for the supply chain — Development of resilience in the supply chain — Requirements with guidance for use
Under ISO/TC 262 Risk Management	
ISO 31000:2018	Risk management — Guidelines
ISO/TR 31004:2013	Risk management — Guidance for the implementation of ISO 31000
IEC 31010:2019	Risk assessment techniques

International Standards relating to seismic resistant design of structures are formulated by ISO/TC 98 'Bases for Design of Structures' under which there are three subcommittees as given as follows:

- ISO/TC 98/SC1:
  Terminology and Symbols, visit:
  https://www.iso.org/committee/50936.html
- ISO/TC 98/SC2:
  Reliability of Structures, visit:
  https://www.iso.org/committee/50944.html
- ISO/TC 98/SC3:
  Loads, Forces and other Actions, visit:
  https://www.iso.org/committee/50958.html

CONCLUSION

The administrative set up in the country towards regulating land and building development already through the building byelaws requires compliance to Part 6 Structural Design of NBC 2016. NBC, in turn cross refers to, as also is supplemented by the Indian Standards on earthquake resistant design. Part 2 'Administration' of NBC 2016 also stipulates periodic audit for structural sufficiency of special buildings including high rise (> 15 m) 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. All the above not only help in ensuring structurally safe environment but reflect the commitment our nation has pledged under the Sendai Framework (2015–2030) and the United Nations Sustainable Development Goals.

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2. Publicly available resources of National Disaster Management Authority (NDMA), an apex Body of Government of India, New Delhi.
3. National Building Code of India 2016 (SP 7:2016), Bureau of Indian Standards, New Delhi.
4. Earthquake Tips, by IIT Kanpur and Building Materials and Technology Promotion Council (BMTPC), New Delhi, released every month from 2002 to 2004.

STRUCTURAL BEHAVIOUR OF SUSPENDED CEILING

Ajay Chourasia
Chief Scientist and Head of Structural Engg. & 3D Concrete Printing Group
CSIR-CBRI, Roorkee

Shubham Singhal
Assistant Professor
Amity School of Engineering and Technology
Amity University, Noida

INTRODUCTION

Recent events have demonstrated that ceiling damage can result in the loss of property and functionality, as well as injury or even death. This can occur at shaking levels that are less than necessary to cause evident structural damage. Although it is widespread in India, there is not sufficient seismic design or efficient installation of many suspended ceilings damaged by earlier earthquakes. The irregularity of the limit status employed in the ceiling design is also a growing concern.

The suspended ceilings are both acceleration and displacement sensitive architectural components. They are classified as perimeter fixed or floating systems depending on the structure and load-bearing system. As shown in Fig. 1, the perimeter-fixed suspended ceiling is attached on every side of the structure around. This setup was later adjusted to be fastened on two sideways while the two other ends on the outer support are free. (Fig. 1) This layout transfers the inertial force created by the ceiling system to perimeter attachments, which make them the most vulnerable components of the system. The floating suspended ceiling as illustrated in Fig. 1(c) is supported by braces to the structure above and is therefore separated from the surrounding construction. The bracing system carries the forces and accelerations from the upper floor.

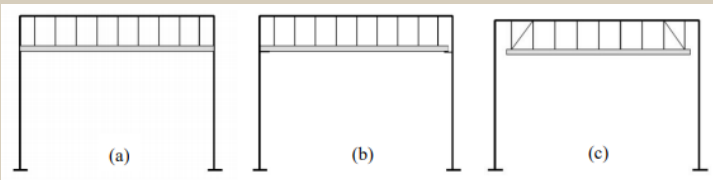

Fig.1: Schematic of a & b) Perimeter fixed and c) Floating suspended ceiling (Pourali, 2014)

The applicability and details of both systems depend on the construction and size of the ceiling as a result of the seismic request. For example, for all suspended ceilings in seismic category D-F, ASTM E580 requires the use of lateral restrictions if the ceiling size exceeds 1000 ft^2 (93 m^2).

> **The suspended ceilings are both acceleration and displacement sensitive architectural components.**

A common suspended ceiling is a grid system of inverted T-shaped beams that are perpendicular to each other and are made up of square or rectangular grids on which the lay-in panels can be installed. Cross slots are already established in the main tee's webs and are connected via the click-fit connectors to the next cross tee. In the grid system assembly itself, no additional mechanical fasteners are used. At fixed ends, the grid system is joined employing mechanical attachments such as rivets, screws or specific clips to the perimeter angle attachable to the surrounding walls. The tiles are not attached to the grids but are freely placed on the inverted tee flanges.

The company supports society and environment equally to actively pursue a better future both within and outside of the core business area. In addition to the charitable Hilti Foundation, the company's values of integrity, courage, teamwork and commitment are demonstrated every day in its interactions with team members, partners and customers in addition to the charitable Hilti Foundation.

The retainer clips for control upward movement of fittings are recommended by IS 2441: 1984. [9] However, because of installation challenges, these clips are not often used. The grid system is also connected at regular intervals to the upper structure through hanger wires. These vertical wires have no side resistance but their use has helped control the movement of the ceiling system and the damages that arise in the event of earthquakes, especially on perimeters. Four diagonal cables and a vertical strut can be used as a compression station. Instead of wires the diagonal channel or the strut can alternatively be utilized.

According to accounts of damage following earthquakes and especially recent in India, even if the building remains nearly undefeated hanging ceilings are significantly affected by earthquakes. In virtually all cases, the damage is comparable, which might be a good indication for identifying key components. Elements demonstrating significant susceptibility to soil movement excitement include rivet connections at perimeter fixtures, cross-tee connections and main-tees splitting.

Under compression, tees may buckle but mainly when the connections fail or when a perimeter contour is not sufficient, the system loses its integrity. In some cases, the lack of enough perimeter hanger wires and spacer bars causes tees to spread and tiles to fall. The damage also included damage due to different motions of the ceiling compared with the perimeter structure, the interaction with the services of the roofing and mechanical systems, the failure of independent support or heavy fixtures, fire-relief post-earthquake damage, hazardous material leak, etc. Other common forms of damage observe included damage. The combination of smaller ceilings and lighter tiles leads to lower demands for grid connections and connections leading to safer ceilings. [2,3,4]

PREVIOUS STUDIES

In recent decades, seismic research has gained popularity, especially on the performance of non-structural elements and suspended ceilings, following the extensive non-structural damage reported by recent seizures. Some of these studies have been briefly reviewed.

"Under compression, tees may buckle but mainly when the connections fail or when a perimeter contour is not sufficient, the system loses its integrity."

ANCO Engineers Inc.'s (ANCO 1983) industry tested a prototypical suspended ceiling. It was found that the couplers buckled and detach from the wall angle at wall-deck intersection. The most common damage points in suspended ceiling systems were located at the perimeter of a room. Furthermore, the investigations have shown that installation of the Pop Rivet is more important than sweeping wires and that swaying wires will not be active in lateral retention if installed with a perimeter fixing.

Satwant et al. (1984) studied the effectiveness of the current provisions on building code and installation practices in a series of dynamic tests for suspended braced and unbraced ceilings with and without partitions. The results showed less uplift of specimens with vertical struts. Deep damage has been observed to the ceiling on an unconnected perimeter. The addition of vertical cross-tees suspension wires of 8 inches maximum from an unattached perimeter prevented tiles from collapsing, but the cross-tee pounding caused damage to perimeter angles. The authors evaluated the effect of tile size and weight, the use of retainer clips, the installation of compression posts and the physical status of grid components on the performance of the ceilings during their full-scale earthquake and simulator tests. The damages observed in the systems were assessed in four limit states and accelerations of the threshold peak floor associated with each boundary state were identified.

The experimental process and the performance matrix, based on limited state evaluation and qualifying innovations, were developed for the evaluation and quantitative evaluation of the effectiveness of various code design and installation requirements in a series of studies by Gilani et al. (2012, 2017). [7,8] A study case showing that the intermediate substitution of heavy-duty main-racers does not adversely affect the system's seismic response was also tested for intermediate duty main runners in high seismic regions.

Grid members and their connections were tested in compression and tension in a study done by Paganotti (2011) [11] at the University of Canterbury.

CURRENT DESIGN AND INSTALLATION METHODOLOGY

Structure demand versus ceiling demand

In India, the suspended ceilings are mainly designed for a serviceability-limited State based on current standards in India (IS 2441: 1984) unless they are in buildings of high post-disaster importance such as hospitals and police stations. Recent seismic experiences have shown, however, that suspended ceiling damage can pose a life-threatening and cause significant financial loss. In many cases, suspended ceilings suffered considerable damage when the structure performed satisfactorily. The inevitable substitution then imposes large financial costs on the building owners and disrupts the building's operability, resulting in downtime and cumbersome. The roof has been reported to have been designed without proper accounting for seismic demand, or not properly installed in many buildings that have been evaluated following the Canterbury earthquake [2,3] due to a lack of consistent, clear design and installation guidelines for suspended roof systems. Even when the requirements were fully met, the ceilings were damaged because they were not intended to remain intact at this level of shaking.

“In India, the suspended ceilings are mainly designed for a serviceability-limited State based on current standards.”

“Recent seismic experiences have shown, however, that suspended ceiling damage can pose a life-threatening and cause significant financial loss.”

The hanging ceilings have no high ductility. Hence the loss of SLS - and the loss of integrity and the failure of its originally intended operation, thus threatening occupants - ULS - are rather close. The review and thorough assessment of design and installations in New Zealand, therefore, appears to be inevitable and highly useful in the prevention of future losses.

Review of standards

Indian suspended ceiling standard [9] lays down the minimum requirements for internal and outside suspended ceilings for use in commercial, industrial and domestic buildings for design, construction, installation, maintenance and testing. The standard includes design loads, limits and installation guidelines. The recommendations, however, are primarily qualitative rather than quantitative. The users are often referred to the specifications of the private manufacturer. More quantitative guidelines for seismical design and installation of suspended ceilings are also provided by other standards such as ASTM C635, C636, and E580, ASCE 7-05, FEMA, and CISCA. [1,5,6] For example, CISCA offers 45-degree socket bracing wires to be mounted in each direction at 4 m from center to center in seismic areas 3 and 4.

These wires are designed to provide the horizontal part of the earthquake force with resistance. Additionally, hanging wires are necessary for all runners on the walls to decrease ceiling perimeter damage within 20 cm of a wall. The ASTM E580 [1] stipulates the installation of suspended ceilings in the seismic category C areas as well as the D-F categories that include tee capacity, correct hanger wires spacing, clearing of wall grid components, sized and type of perimeter support contour-specified or free-etc.

SEISMIC BEHAVIOUR OF CEILING

The damage to the ceilings during the Northridge earthquake of 1994 was one of the most predominant damage. It was observed that the ceiling damage was more extensive near the top of building than at lower stories with failure of lighting, diffusers and suspended ceiling system. In 2010, Chile earthquake, the airport in Santiago was shut down for several weeks as most of the ceiling tiles collapsed and many of the supporting elements also collapsed.

Even in 2010, Haiti earthquake schools were closed because of damaged ceilings and collapse of air conditioning equipment. During 2011 Japan earthquake, very wide scale damage to suspended ceilings in large rooms like swimming pools, auditoriums, etc. were observed. (Fig. 2)

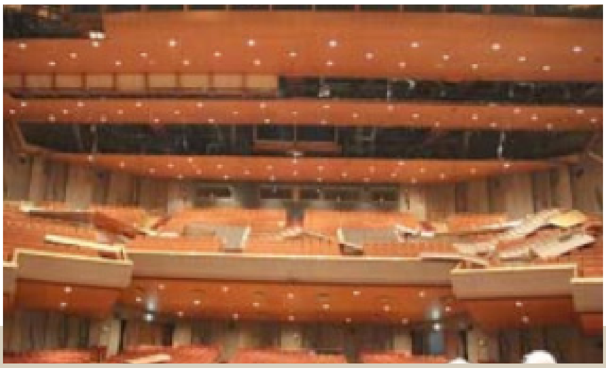

Fig. 2: Damaged ceiling at auditorium [10]

The ceiling boards at the gymnasium of a junior high school and swimming pool in Tochigi prefecture collapsed mainly because of the failure at the joints. It was observed that very long suspension length of ceiling usually used in auditoriums, make the ceiling system rather unstable and often cause failure of the ceiling.

Very heavy panels for the acoustics of ceiling may also cause early collapse of the system due to increased forces as shown in Fig. 3.

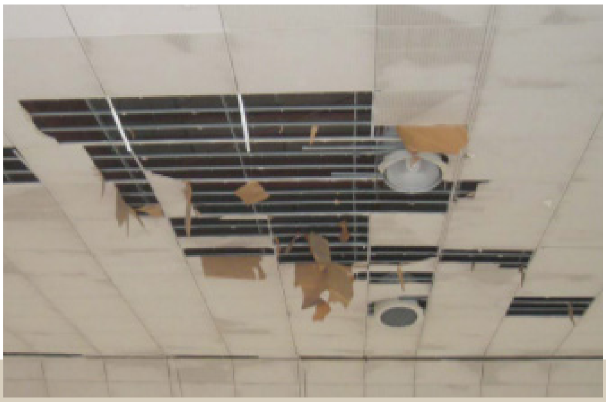

Fig. 3: Damaged ceiling in school gymnasium [10]

GAPS AND ISSUES

If completely complied with, the current design rules can adequately fulfil the demands for serviceability. However, the suspended ceilings cannot work adequately even when the structure suffers from little damage if the proposed system is subjected to a more severe earthquake. With substantial advances to date in the design and satisfactory seismic performance of structural components, the design of non-structural components has recently acquired increased importance. This sort of non-structural damage could put the lives of the inhabitants at risk, harm crucial and vital contents and installations or just temporarily render areas unusable. Big facilities, such as gyms and auditoriums, are important for the provision of shelter and refuge services in significant earthquakes where damages are extensive. Consequently, it is very important to operate immediately and continuously in these spaces. On the other hand, it is very difficult to ensure the safety and evaluate the quality of the systems sold on the market until there is a uniform conformity standard to identify the boundaries and the borders explicitly. Less well-known producers who may not necessarily and fully comply with the international codes could deliver suspended ceilings. Furthermore, the availability of a standard rule ensures that all companies compete on fair terms. The design and installation procedures must be coordinated to achieve a consistent level of quality and safety.

CONCLUSION

Damage to suspended ceilings has resulted in significant economic loss in the recent earthquakes, one of the most widely employed non-structural elements. In recent years, this observation has focused a lot on seismic performance and design research programs. This study examines briefly the relevant studies, recommendations, and standards concerning the design and installation of suspended ceilings. It can be concluded that the current systems should function satisfactorily under the seismic level of serviceability, if correctly implemented and installed. However, key components may achieve capacity that leads to system failure in case of greater excitations. Given the relevance of ceilings for continuous operation and structural safety, reconsiderations of specified limit statements in the code seem unavoidable for the design of suspended ceilings. The first results and the assessment of the existing codes illustrate the criticality of the problem and the need for further comprehensive, focused research in this field.

> **However, key components may achieve capacity that leads to system failure in case of greater excitations.**

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SEISMIC VULNERABILITY ASSESSMENT OF EXISTING RC BUILDINGS - COMPARATIVE STUDY OF CODAL PROVISIONS OF VARIOUS COUNTRIES

Rajeev Goel
Chief Scientist and Head, Bridge Engineering and Structures, CSIR-Central Road Research Institute

INTRODUCTION

In the past, during the earthquakes in several counties including India, loss of human lives and damage to property has occurred due to the collapse of existing buildings. Though, occurrence of an earthquake cannot be predicted and prevented, the loss of human life and damage to the property can be minimized by taking necessary steps on the existing buildings. Several countries have made codes of practices/guidelines for seismic vulnerability assessment of existing structures including RC buildings.

Out of the seven continents of the world, Asia is the most affected by earthquake. Most seismic prone countries include Japan, Nepal, India, Turkey, Ecuador, Philippines, Mexico and Indonesia. Global seismic hazard map is shown in Fig. 1. There is a growing perception that the built environment, both historic and recent construction, is characterised by an unacceptably high level of seismic risk. The efficient normative documents, allowing for rational and cost-effective interventions are required for mitigation of this risk.

REVIEW OF SEISMIC EVALUATION CODES AND GUIDELINES

Seismic evaluation codes and guidelines of USA, New Zealand, India, Europe and Turkey have been studied. A brief summary of reviewed seismic evaluation codes and guidelines is given below.

FEMA 310

The seismic vulnerability assessment of existing buildings is based on rigorous approach to determine their present condition. Existing buildings may be structurally damaged during the earthquake. The level of structural damage is predicted considering the importance of building and consequences of damage on human lives. For the existing buildings subjected to the design earthquake, two levels of performance defined as Life Safety and Immediate Occupancy are given in FEMA 310.

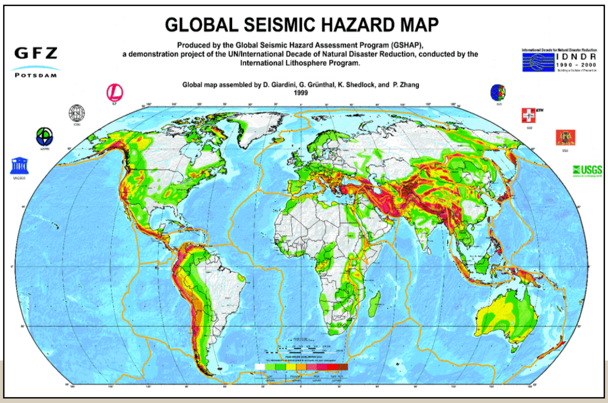

Fig. 1: Global Seismic Hazard Map

Under life safety performance, level of risk for life-threatening injury and getting trapped should be low, when there are significant damages to both structural and non-structural components of the building. For this, the structural system should have some margin, even after damages, against either partial or total structural collapse.

Under immediate occupancy building performance, there could be very limited damage to both structural and non-structural components during the design earthquake so that the building could be easily repaired during its occupancy. The structural members of the building may retain nearly all of their original strength and stiffness. However, there could be some minor injuries to human being.

For seismic vulnerability assessment, one of these performance levels needs to be selected. After that, three-tier assessment process of increasing detail and reducing margin of safety as summarized below needs to be followed.

> **There is a growing perception that the built environment, both historic and recent construction, is characterised by an unacceptably high level of seismic risk.**

Tier-1: Screening phase

Under this screening phase, data of structural, non-structural and foundation of the existing building is collected through checklists for the chosen level of performance and given region of seismicity. Based on this collected data, conformity of the building with the requirements of concerned buildings codes (i.e., Benchmark Building Criteria) is checked. After that, lists of non-compliant deficiencies are compiled for further evaluation. If non-compliant deficiencies do not exist, then it indicates that building is not vulnerable to earthquake and hence there is no need for further assessment.

Tier-2: Evaluation phase

In this evaluation phase, structural analysis and assessment of the adequacy of the lateral-force-resisting system is carried out by selecting either (a) complete analysis of the building considering all of the deficiencies identified in Tier-1 or (b) a deficiency only analysis, based on the requirements of evaluation identified in Tier-1. Structural analysis is limited to simplified linear analysis and could be done using one of the commonly available linear static or dynamic analysis softwares. Component-level analysis considering displacement-based lateral force procedure combined with ductility related factors on an element-by-element basis is also carried out. The acceptability criterion is that the existing structural members should be able to take the calculated forces safely.

Tier-3: Detailed evaluation phase

If some structural members are unable to take the calculated forces safely as per evaluation done in Tier-2 and it is observed that evaluations as per Tier-1 and/or Tier-2 are too conservative and there may be a significant economic or other advantage by carrying out a detailed study, then the detailed evaluation is carried out by using linear and nonlinear methods for static or dynamic analysis of buildings. Expected performance of existing structural members is evaluated by comparing calculated demands with their capacities.

For carrying out the evaluation of existing buildings under Tier-2 or Tier-3, only 75% values of the forces for which a new building is designed, are considered. This reduction is done due to following reasons:

- Actual strength of structural members will be greater than that used in the evaluation,
- Existing buildings do not need to have the same factor of safety as a new building since the remaining useful life of an existing building will be less than that of a new building.

ASCE/SEI 31-2003

This code has evolved from FEMA 310 and is intended to replace FEMA 310. This code provides the three-tier procedure for seismic vulnerability assessment of existing buildings. As the checklists and acceptance criteria are same as in FEMA 310, so this document is not discussed here.

> **Structural analysis is limited to simplified linear analysis and could be done using one of the commonly available linear static or dynamic analysis softwares.**

EUROCODE 8 PART-3

Eurocode 8 Part 3 (EN 1998-3:2005), which was adopted by EU and EFTA member countries, deals with the assessment and retrofitting of buildings subjected to seismic loads. This code adheres in full to the displacement-based approach. The hazard is described in the form of elastic, 5% damping response spectra having specified average return periods. To start with, three levels of hazard are selected, and a performance requirement is then associated with each of these levels. The earthquake forces are then applied to the structure without any ductility-related reduction factor and linear or non-linear analyses of the structure, depending on the characterisation of the structure and the choice of the engineer is carried out to find out the displacements and stresses. The verifications of the obtained results of structural elements/mechanisms of the structure vary, depending on their nature. For 'ductile' (bending with and without axial force) type elements/mechanisms, the calculated deformation (curvature, drift) should be within the admissible deformation for the considered performance level. For 'brittle' (shear, beam-column joints) type elements / mechanisms, their capacity in terms of strength should not be less than the corresponding forces transmitted to them.

The fundamental requirements refer to the state of damage in the structure, attention being focussed on the following three Limit States: Near-Collapse, Significant Damage and Damage Limitation. The return periods of the design action for these three limit states and for buildings of ordinary importance are 2475, 475 and 225 years, respectively. Four options for the analysis of the buildings are possible, i.e. linear and non-linear methods, either static or dynamic. The use of linear methods, however, is subject to more restrictive conditions than in the case of new buildings. When the linear methods of analysis are not applicable, then non-linear static method is generally used for a given much larger complexity of the nonlinear dynamic.

“The hazard is described in the form of elastic, 5% damping response spectra having specified average return periods.”

“The verifications of the obtained results of structural elements / mechanisms of the structure vary, depending on their nature.”

In linear analysis, the demands on 'ductile' and 'brittle' types of elements are evaluated differently according to a 'capacity design' philosophy. The demands on ductile mechanisms consist of the chord rotations at the ends of columns and beams, as taken directly from the analysis. The demands in the 'brittle' mechanisms are calculated by means of equilibrium conditions, considering the actions transmitted to them by the pertinent ductile components.

In non-linear method of analysis, the demands on both 'ductile' and 'brittle' mechanisms are directly taken from the analysis.

In this code, the most commonly used strengthening methods (concrete or steel jacketing and FRP plating and wrapping) are covered. Externally bonded FRP can enhance shear strength as well as flexural ductility at the member ends and prevent lap-splice failure through added confinement.

TURKISH CODE

Chapter 7 of the 2006 Turkish seismic code entitled “Assessment and Strengthening of Existing Buildings” sets procedure for the assessment and rehabilitation of existing buildings.

> **Four options for the analysis of the buildings are possible, i.e. linear and non-linear methods, either static or dynamic.**

Linear elastic and nonlinear static analytical procedures are proposed for structural evaluation. In the analysis, the considered material strengths are based on the statistical evaluation of field data. A performance-based evaluation is done under three levels of earthquake ground motion intensities with different return periods. The performance acceptance criteria are based on demand to capacity ratios at critical sections for the linear procedures, and material strains for the nonlinear procedures.

Depending upon the mode of failure of the structural, the members are classified as “ductile” and “brittle” for determining the damage limits. For ductile members, three damage limits namely minimum damage limit, safety limit and collapse limit are defined at the cross section level. Minimum damage limit defines the onset of significant post-elastic behaviour at a critical cross section. Brittle members are not permitted to exceed this minimum damage limit.

Linear elastic or nonlinear (pushover) procedures can be employed for analysis where the seismic intensity is defined by linear elastic response spectra representing three different intensity levels, with respective exceeding probabilities of 50, 10 and 2% in 50 years. The reference design spectrum in the Turkish code has 10% probability of exceeding in 50 years. Based on Turkish strong motion data, it is estimated that the spectral ordinates for 50% probability of exceeding in 50 years are half of the reference spectrum whereas the ordinates for 2% probability of exceeding in 50 years are 1.5 times that of the reference spectrum.

Seismic performance level of building is determined after determining the member damage states.

Performance Level-1

If in any story, in the direction of the applied earthquake loads, not more than 10% of beams are in the significant damage state whereas all other structural members are in the minimum damage state, then the building is said to be safe and requires no retrofitting measures.

Performance Level-2

If in any story, in the direction of the applied earthquake loads, not more than 20% of beams and some columns are in the extreme damage state whereas all other structural members are in the minimum or significant damage states and shear carried by those columns in the extreme damage state is less than 20% of the story shear at each story, then retrofitting of the building may be required depending on the number and distribution of members in the extreme damage state.

> **In the analysis, the considered material strengths are based on the statistical evaluation of field data.**

Performance Level-3

If in any story, in the direction of the applied earthquake loads, not more than 20% of beams and some columns are in the collapse state whereas all other structural members are in the minimum, significant or extreme damage states; shear carried by those columns in the collapse state is less than 20% of the story shear at each story; and such columns do not lead to a stability loss, then occupancy of the building should not be allowed. Decision on retrofitting or demolishing of the building depends on the feasibility of retrofitting.

Performance Level-4
If the building fails to satisfy any of the above performance levels, it is accepted as in the collapse state. Occupancy of the building should not be permitted. The building should be retrofitted; however its retrofit may not be economically feasible.

> **Decision on retrofitting or demolishing of the building depends on the feasibility of retrofitting.**

Other details
In any story, in the direction of the applied earthquake loads, inter-story drift ratios should satisfy the limits for each performance level.

Retrofit techniques are also given in the code for reinforced concrete buildings. These consist of detailing requirements for concentric and eccentric added shear walls; jacketing of beams and columns; and strengthening of masonry infill walls by adding new material layers.

ACI 369R-11
The guidelines for seismic rehabilitation of existing concrete frame buildings and commentary was published by American Concrete Institute in year 2011 under ACI 369R-11. Using these guidelines, results of research can be implemented more quickly. These guidelines update design professionals with the latest recommendations for the seismic assessment and rehabilitation of concrete buildings.

Most sections in this guide are similar to Chapter-6 of ASCE/SEI 41 Supplement-1 (ASCE / SEI Ad Hoc Committee 2007). These guidelines shall be used in conjunction with Chapters-1 to Chapter-4 of ASCE/SEI 41-06 which focus on general design requirements, geotechnical engineering provisions, detailed description of linear as well as non-linear analysis procedures, and rehabilitation requirements. Short descriptions of potential seismic rehabilitation measures for each concrete building system are given this guide.

Modelling procedures, acceptance criteria, and rehabilitation measures for precast concrete frames, infill frames, braced frames, shear walls, diaphragms, and foundations are not given in this guide. Repair techniques for earthquake-damaged concrete components are not included in ACI 369R. The design professional shall refer to FEMA 306, FEMA 307, and FEMA 308 for details on evaluation and repair of damaged concrete wall components.

INDIAN CODE
Indian code IS: 15988-2013 gives guidelines for seismic evaluation and strengthening of existing reinforced concrete buildings. As per this code, assessment of existing buildings under earthquake forces shall be done using the criteria, given in IS: 1893 (Part-1), for new reinforced concrete buildings. Seismic forces shall then be computed by following the provisions of IS: 1893 (Part-1). For preliminary as well as detailed assessments of existing buildings, modification factors to the computed seismic forces and material strengths shall be then applied.

> **In any story, in the direction of the applied earthquake loads, inter-story drift ratios should satisfy the limits for each performance level.**

Modification factor for lateral force
The lateral force shall be determined using provisions of IS:1893 (Part-1). For computing the base shear, to be resisted by existing building, this lateral force then shall be multiplied by the useable life factor U, which shall be determined as follows:

$$U = (Trem/Tdes)^{0.5} \geq 0.70 \qquad (1)$$

Where,
Trem = remaining useful life of the building; and
Tdes = design useful life of the building.

Modification factor for material strength
Probable or measured nominal strengths are the best indicator of the actual strength. Measured strength can be obtained by conducting field tests or lab tests on a series of samples. Probable strengths are either based on actual tests or the default values given in the code. Probable strengths may also be assessed from the values given in the structural drawings and designs. However, these values need to be further modified for the uncertainty regarding the reliability of available information and present condition of the component. The probable material strengths need to be multiplied with a Knowledge Factor K, given in the code.

“Measured strength can be obtained by conducting field tests or lab tests on a series of samples.”

Evaluation process
a) Preliminary evaluation
In preliminary evaluation of building, broad assessment of its physical condition, robustness, structural integrity, strength of structure and simple calculations are done. Based on site visit and collection of data, configuration-related checks (Load path, geometry, weak/soft storey, vertical discontinuities, mass irregularity, torsion, adjacent buildings, short columns) and strength-related checks (determination of modified demand lateral force considering occupancy risk factor and factor for useable life, shear stress check in columns and walls, axial stress check in moment frame columns) are then applied.

If the results of preliminary evaluation for strength, overall stability and integrity indicate no deficiency in the building, then no further action is required. Otherwise, detailed evaluation is to be carried out unless exempted. Exemption in carrying out detailed investigations is given to those single or two storey buildings (not housing essential services required for post-earthquake emergency response) whose total floor areas is less than 300 sq.m and where seismic retrofitting is carried out to remove these deficiencies.

b) Detailed evaluation
In detailed evaluation, numerical checks on stability and integrity of the whole structure as well as the strength of each member are done. The steps given below are followed in this detailed evaluation:

- Estimate the probable flexural and shear strengths of the critical sections of the structural members and joints of vertical lateral force resisting elements. These calculations shall be performed as per respective codes for various building types and modified with knowledge factor K.
- Calculate the total lateral force (design base shear) in accordance with IS:1893 (Part-1) and multiply it with U, a factor for the reduced useable life, given in the code.
- Perform a linear equivalent static or a dynamic analysis of the lateral load resisting system of the building in accordance with IS:1893 (Part-1) for the modified base shear determined in the previous step and determine resulting member actions for critical components.
- Evaluate the acceptability of each component by comparing its probable strength with the member actions.
- Calculate whether the inter-storey drifts and decide whether it is acceptable in terms of the requirements of IS:1893 (Part-1).

“Numerical checks on stability and integrity of the whole structure as well as the strength of each member are done.”

Acceptability criteria

A building is said to be acceptable if either of the following two conditions are satisfied along with ductility and detailing related evaluation:

- All critical elements of lateral force resisting elements have strengths greater than computed actions and drift checks are satisfied.
- Except a few elements, all critical elements of the lateral force resisting elements have strengths greater than computed actions and drift checks are satisfied. Non-linear analysis such as pushover analysis needs to be carried out up to the collapse load to ensure that the failure of these few elements shall not lead to loss of stability or initiate progressive collapse of the building.

Seismic strengthening

Following seismic strengthening options and strategies at a general level are described in detail:

- strengthening at member level
- eliminating or reducing structural irregularities
- strengthening at structural level
- use of supplemental damping and isolation

Strengthening of structural members can be done either by Jacketing of deficient structural members or by addition of new structural elements.

NEW ZEALAND CODE

New Zealand code "Seismic Assessment of Existing Buildings (Guidelines)", July 2017 provides guidelines to carry out seismic assessment of existing buildings. The guidelines provide two levels of assessment namely i) initial seismic assessment for a broad indication of the likely level of seismic performance of a building, and ii) detailed seismic assessment for a more comprehensive assessment.

> **Strengthening of structural members can be done either by Jacketing of deficient structural members or by addition of new structural elements.**

> **Both seismic assessment levels rate the existing building as a percentage of the minimum life safety performance requirements of Building Code.**

Both seismic assessment levels rate the existing building as a percentage of the minimum life safety performance requirements of Building Code, applied to an equivalent new building on the same site. The guidelines are structured in following three parts:

Part A: Assessment objectives and principles

This part outlines the scope and application of the guidelines, and provides an overview of the seismic assessment process. The linkage with the relevant requirements of the Building Act and the associated regulatory requirements is also described.

Part B: Initial seismic assessment

This part describes the method of application of the Initial Seismic Assessment (ISA) methodology (including the Initial Evaluation Procedure), which enables a broad indication of the likely level of seismic performance of a building.

Part C: Detailed seismic assessment

This part describes the method of application of the Detailed Seismic Assessment (DSA) methodology, which provides a more comprehensive assessment of the likely seismic performance of a building.

For DSA, the guidelines place greater emphasis on understanding the 'deformability' of the building in order to obtain more appropriate ratings, rather than assigning the overall building rating just on the basic strength of the weakest member or element. This focus on displacement capacity allows the capacity of different structural systems to be appropriately added together by providing direct allowance for non-linear behaviour. Emphasis is placed on the use of the simple lateral mechanism analysis at the initial stages of DSA.

“Emphasis is placed on the use of the simple lateral mechanism analysis at the initial stages of DSA.”

The guidelines also place particular emphasis on the need to assess the primary gravity structure as well as the primary lateral structure, recognising that it is the performance of the former and the degree of protection afforded to it by the latter that determines how well the whole building will meet its life safety objectives under different levels of earthquake shaking. Within Part C, a new section on Geotechnical Issues (C4) provides guidance on the geotechnical considerations in assessing existing buildings, including when they can be expected to significantly influence the overall behaviour of a particular building.

A further new development is the provision for an Assessment Summary Report to summarise the key points from both Initial Seismic Assessments and Detailed Seismic Assessments. This summary will provide more consistency both in the information provided and the way it is provided, and hence enable clearer communication between all parties, including situations where there is a need to reconcile different assessments.

ASCE/SEI 41-17

ASCE/SEI 41-17, “Seismic Evaluation and Retrofit of Existing Buildings”, describes deficiency-based and systematic procedures to evaluate and retrofit existing buildings to withstand the earthquake forces. Three-tiered process for seismic evaluation is given according to a range of building performance levels, by connecting targeted structural performance and the performance of non-structural components with seismic hazard levels. The deficiency-based procedures allow evaluation and retrofit efforts to focus on specific potential deficiencies deemed to be of concern for a specified set of building types and heights. The systematic procedure gives methodology to evaluate the entire building in a rigorous manner.

This code establishes analysis procedures and acceptance criteria, and specifies requirements for foundations and geologic site hazards; components made of steel, concrete, masonry, wood, and cold-formed steel; architectural, mechanical, and electrical components and systems; and seismic isolation and energy dissipation systems. Checklists are provided in this code for a variety of building types and seismicity levels in support of the Tier-1 screening process. This code updates the basic performance objectives for existing buildings and to the evaluation of force-controlled actions. It revises the nonlinear dynamic procedure and changes provisions for steel and concrete columns, as well provisions for unreinforced masonry.

“The systematic procedure gives methodology to evaluate the entire building in a rigorous manner.”

This code describes general requirements which includes evaluation and retrofitting process, seismic evaluation process and seismic retrofitting process; performance objectives and seismic hazards; evaluation and retrofit requirements; Tier-1 screening; Tier-2 deficiency-based evaluation and retrofit; Tier-3 systematic evaluation and retrofit;

analysis procedures and acceptance criteria; foundations and geologic site hazards; various construction materials such as steel, concrete, masonry, timber etc.; evaluation and retrofit procedures for non-structural components; seismic isolations; supplemental energy dissipation devices; etc.

DISCUSSIONS

In all the codes, seismic vulnerability assessment procedures for the existing buildings involve configuration-related and strength-related checks. There are no significant differences in which the configuration related assessments are carried out in various codes. However, considerable degree of non-uniformity is observed in the strength–related checks for the existing buildings in the codes of various countries.

Eurocode 8 describes mostly the principles of evaluation. Further, no guidance is given for the determination of the values for many parameters. Due to this, it is difficult to use.

In almost all the codes, the existing building needs to be classified into one of the specified building category for the evaluation. This becomes difficult to implement wherein the structural systems for building are vague and of mixed nature. In FEMA 310, assumption of ductility levels and hierarchical performance of structural elements is must, which may not necessarily occur in reality, and for which no alternate provisions are given.

All documents specify that there should be some reduction in the force level for analysis of existing building compared to new buildings (0.67 in New Zealand code, 0.70 maximum in Indian code). Eurocode 8 mentions that the effective peak ground acceleration should be reduced for redesign purposes, considering the reduced remaining life of the existing buildings, however, no details are given for the same. In FEMA 310, a reduction factor of 0.75 is explicitly applied to seismic forces in the Tier-3 evaluation; however, this reduction factor is implicitly present in m-factors Tier-2 analysis.

Fundamental differences in the Turkish Code compared to Part 3 of Eurocode 8 are less stringent requirements for linear elastic procedures, and the assembly of member performances for obtaining a global system performance level.

CONCLUSIONS

Brief summary of codes and guidelines of several countries (USA, New Zealand, India, Europe and Turkey) on Seismic Vulnerability Assessment of Existing Reinforced Concrete Buildings is presented in this paper.

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BEHAVIOR OF POST-INSTALLED CHEMICAL ANCHORS UNDER COMBINED LOADING

Devyani Tewatia
Research Scholar
Department of
Earthquake Engineering
IIT Roorkee

P. C. Ashwin Kumar
Assistant Professor
Department of
Earthquake Engineering
IIT Roorkee

INTRODUCTION

Retrofitting Reinforced Concrete (RC) frames using internal steel braces is suitable for maintaining or improving seismic performance. Internal steel bracing is placed inside the RC frame and is connected to the beam and column members directly to transfer the forces. They also help to increase the stiffness of the building, especially in the case of the Open Ground Story frame, where the stiffness irregularity is present due to the absence of a masonry wall on the ground floor.

However, for the steel braces to develop the desired performance as a part of the retrofitting scheme, the connection between steel and RC plays a crucial role. Currently, a well-defined procedure for designing these connections does not exist and the limited guidelines might result in over-designed connections leading to higher redundancy or maybe under-designed, which can lead to premature failure of the connections.[1,2] These anchors at the beam-column joint are subjected to combined tension and shear loading while transferring the axial forces from the brace. The failure modes of anchor in tension include steel failure, concrete pull-out, concrete breakout, bond failure and concrete splitting. In shear, the failure modes have been identified as steel failure, concrete pry-out and concrete breakout. As can be observed, failure in concrete is mostly the governing mode and it is necessary to check the quality and strength of existing concrete before selecting anchors for connections.

> **Failure in concrete is mostly the governing mode and it is necessary to check the quality and strength of existing concrete before selecting anchors for connections.**

ACI 318-19 [3] provides design against various failure modes in anchorage to concrete based on the concrete capacity method but is restricted to anchors placed in plain cement concrete on a planar surface instead of reinforced concrete making this code's design method highly conservative. Hence, as a part of developing design guidelines for the connection of steel braces to RC beam-column joint, an experimental investigation has been carried out to assess the capacity of the anchors, specifically the post-installed chemical anchors. The post-installed chemical anchors have been chosen for this study as they are the least invasive and less labour-intensive compared to other steel-RCC retrofitting techniques like peripheral steel frames. An RCC beam-column sub-assembly has been prepared and attached to the brace, similar to the actual retrofitting scenario. Thereafter, these joints have been tested under force-controlled conditions to assess the capacity of anchors and governing failure modes.

EXPERIMENT

A beam-column joint subassembly having a cross-section size of 230 mm x 350 mm has been cast as per the details in Table 1. To connect the steel brace to RC beam-column joint Hilti HIT-V-5.8 anchor bolt with HIT RE 500 V3 epoxy has been used as post-installed chemical anchors due to their seismic pre-qualification in accordance to ETAG001. [4] The concrete surface has been initially cleaned, and holes of the required diameter have been drilled. Thereafter, the holes have been filled with chemical epoxy before inserting the anchor rods as per guidelines. [5] The anchor plate placed over these bolts has been designed to remain elastic throughout the test.

Table 1: Beam-column sub-assembly detail

Item	Detail
Beam size	230 mm x 300 mm
Column size	230 mm x 300 mm
Beam - longitudinal reinforcement	4 nos-16ϕ bars (1.15%)
Column - longitudinal reinforcement	6 nos-12ϕ bars (1%)
Beam, column transverse reinforcement	8 mm dia. bars @150 mm c/c
Material	
Concrete	M25
Reinforcement steel	Fe500

Uniform Force Method has been used to evaluate the forces on the gusset plate. [6,7] In this study, steel brace and gusset plate have been designed to remain elastic such that the capacity of concrete-anchor connections can be assessed along with the mode of failure. Servo-hydraulic actuator having 500 kN capacity and a stroke length of ±250 mm has been utilized to apply the monotonically increasing force.

Force-controlled test

A hollow circular steel brace having a cross-section of 165 mm and a thickness of 5 mm has been welded with gusset plates on both ends. The gusset plate is welded with an anchor plate, which is then bolted to the concrete surface as per Fig. 1.

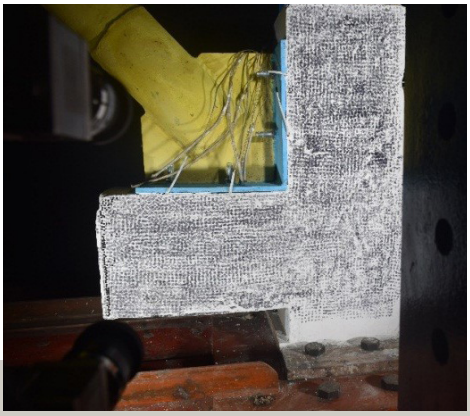

Fig. 1: Beam-column sub-assembly

The RC beam column sub-assembly connected to the steel brace has been tested under force-controlled mono-tonic pull-out protocol. The brace is connected at an angle of 45 degree with the joint. The force transfer between beam and column faces is equally distributed. The loading has been linearly increased at 10 kN intervals at 0.1 kN/sec till connection failure is observed.

RESULTS AND CONCLUSIONS

As expected, during the test, no yielding of brace and gusset plate has been observed. The diagonal cracks started developing in the beam-column joint at an axial force of 160 kN, as shown in Fig. 2. The concrete connection suffered a sudden brittle failure at an axial brace load of 184 kN as shown in Fig. 3. The failure was observed as concrete breakout mostly limited to cover of the beam and column face. The axial force vs displacement curve is seen in Fig. 4. Based on the test results the distribution of forces on each anchor face has been calculated to be 65 kN in tension and

Fig. 2: Diagonal crack at beam-column joint

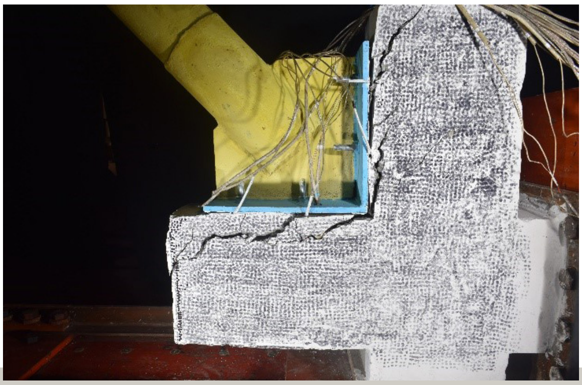

Fig. 3: Beam-column subassembly at the end of experiment

shear at failure. The equal value of tension and shear component is due to the missing RC frame action on the joint which only effectively reduced tension component on each face making shear force component governing in such case. [8] According to tension-shear interaction equation 1 as per ACI318-19, the maximum strength of the anchor group is restricted to 18 kN and 33 kN in tension and shear, respectively, with and without factor of safety.

$$\frac{N_{ua}}{\phi N_n} + \frac{V_{ua}}{\phi V_n} \le 1.2 \qquad 1$$

The difference between actual failure and expected failure is quite evident. It can be attributed to presence of reinforcement steel in the specimens. Post-installed HILTI anchors have shown to be a suitable choice for connection between steel brace and existing RC beam-column joint.

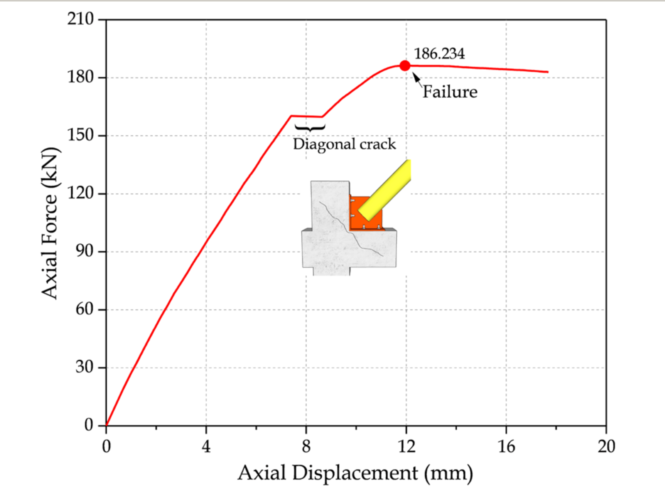

Fig. 4: Axial force vs displacement curve

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HANDBOOK ON SEISMIC RETROFIT OF BUILDINGS – A PRIMER

Amlan K. Sengupta
Professor
Indian Institute of Technology
Madras

INTRODUCTION

The Handbook on Seismic Retrofit of Buildings was brought out by the Central Public Works Department under the aegis of Indian Buildings Congress. [1] (Fig. 1)The intention of the Handbook was to present the material in a style that will be understood and appreciated by the people of diverse backgrounds involved in the design and construction of buildings.

The chapters are explained briefly.

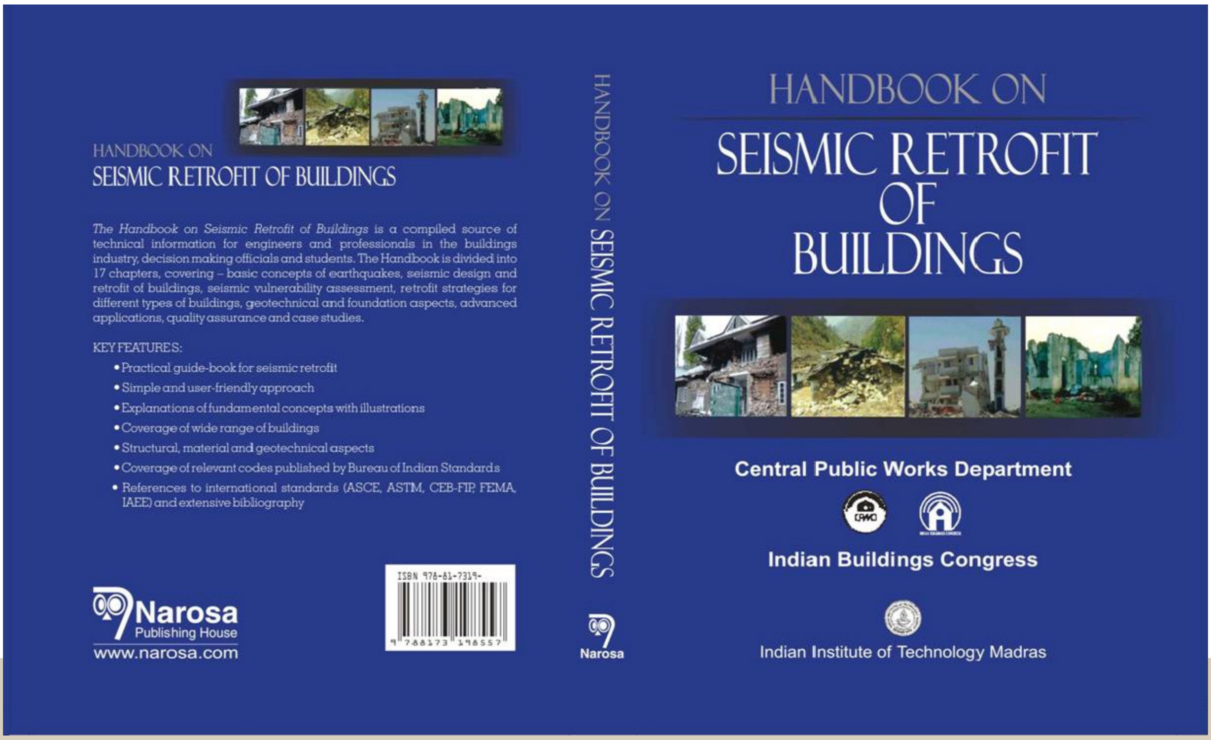


Fig.1: Cover of the Handbook on Seismic Retrofit of Buildings

Making buildings safe against earthquakes

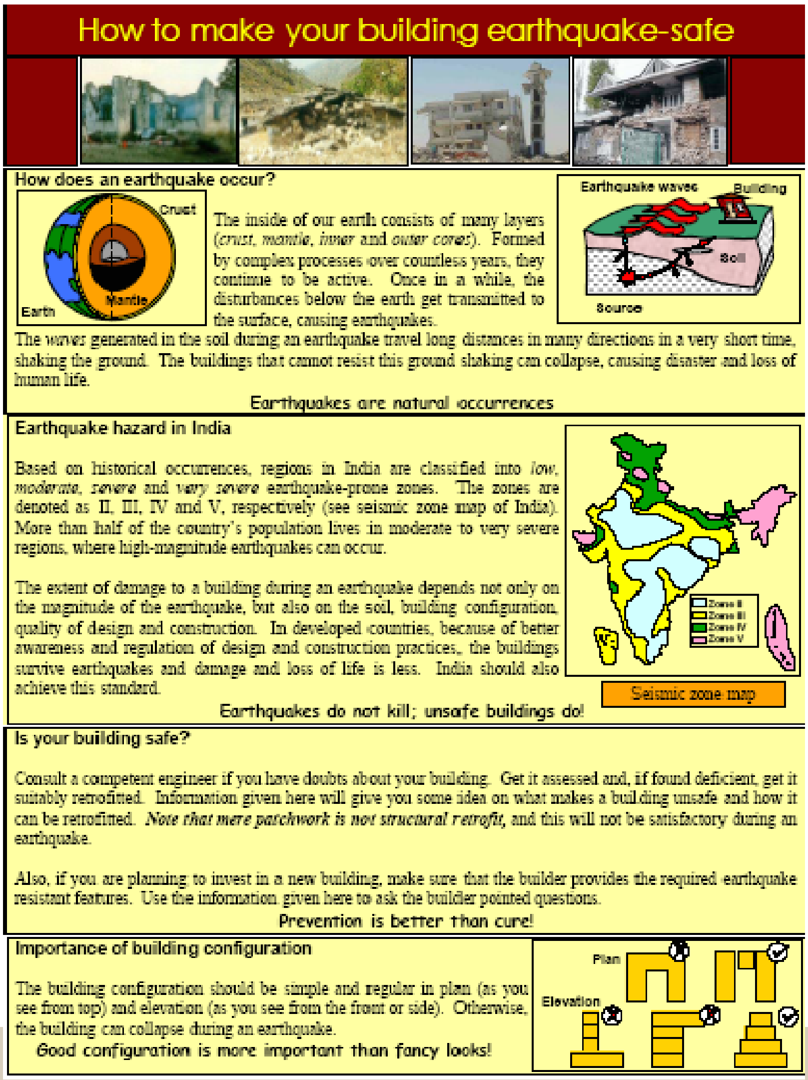
This is a standalone chapter that explains the concepts of seismic design and retrofit in a language suitable for a layperson. The chapter covers the common deficiencies, simple techniques of diagnosis of these deficiencies and suitable retrofit strategies for the major types of buildings in India. A 4-page handout has been included to generate awareness about the do's and don'ts of seismic design of buildings and the questions to be asked before buying a house. (Fig. 2)

Introduction and seismic analysis cum design

The first chapter starts with an explanation of the need of retrofit of buildings in India, with reference to the provisions of IS 1893.* [2]

(*The updated versions of the codes are provided in the reference list.)

The measures emphasised by the National Institute of Disaster Management are highlighted. The chapter explains the attributes of seismic design, goals, objectives and steps of seismic retrofit. The performance based objectives are mentioned. An option for considering reduced base shear for retrofit of older buildings is provided. There is a glossary of terms associated with seismic retrofit.


How to make your building earthquake-safe

How does an earthquake occur?

The inside of our earth consists of many layers (*crust, mantle, inner* and *outer cores*). Formed by complex processes over countless years, they continue to be active. Once in a while, the disturbances below the earth get transmitted to the surface, causing earthquakes.

The *waves* generated in the soil during an earthquake travel long distances in many directions in a very short time, shaking the ground. The buildings that cannot resist this ground shaking can collapse, causing disaster and loss of human life.

Earthquakes are natural occurrences

Earthquake hazard in India

Based on historical occurrences, regions in India are classified into *low, moderate, severe* and *very severe* earthquake-prone zones. The zones are denoted as II, III, IV and V, respectively (see seismic zone map of India). More than half of the country's population lives in moderate to very severe regions, where high-magnitude earthquakes can occur.

The extent of damage to a building during an earthquake depends not only on the magnitude of the earthquake, but also on the soil, building configuration, quality of design and construction. In developed countries, because of better awareness and regulation of design and construction practices, the buildings survive earthquakes and damage and loss of life is less. India should also achieve this standard.

Earthquakes do not kill; unsafe buildings do!

Is your building safe?

Consult a competent engineer if you have doubts about your building. Get it assessed and, if found deficient, get it suitably retrofitted. Information given here will give you some idea on what makes a building unsafe and how it can be retrofitted. *Note that mere patchwork is not structural retrofit,* and this will not be satisfactory during an earthquake.

Also, if you are planning to invest in a new building, make sure that the builder provides the required earthquake resistant features. Use the information given here to ask the builder pointed questions.

Prevention is better than cure!

Importance of building configuration

The building configuration should be simple and regular in plan (as you see from top) and elevation (as you see from the front or side). Otherwise, the building can collapse during an earthquake.

Good configuration is more important than fancy looks!

Fig. 2: First page of the 4-page handout

In the second chapter, first the fundamentals of earthquakes, its characterisation, seismic zone map, seismic micro-zonation and response spectrum are briefly explained. Next, the layout and configuration of buildings for seismic design and the different types of lateral load resisting systems are explained.

Rapid visual screening, data collection and preliminary evaluation

In India, the Rapid Visual Screening (RVS) method was introduced for masonry buildings in IS 13935. [3] The RVS data sheet identifies a building into a certain type based on seismic resistant features and provides an estimate of damage for the building based on the seismic zone. The data sheet and the background information are explained in this chapter.

To facilitate seismic evaluation of a building, it is necessary to collect relevant data of the building as much as possible. This step in a retrofit programme is referred to as Data Collection. The data tables were adopted from the Model Town and Country Planning Legislation, Zoning Regulations, Development Control, Building Regulation / Byelaws for Natural Hazards Zones of India. The required information includes building description, the seismic resistant features and miscellaneous data.

For a building identified for seismic evaluation, the preliminary evaluation involves a set of initial calculations to identify areas of potential weaknesses in the building. These calculations are called quick checks. The preliminary evaluation also checks the compliance with the provisions of the seismic design and detailing codes. [4]

Condition assessment of buildings

Condition assessment describes the process of assessing the actual condition of a structure in relation to its use. This chapter describes the techniques to assess the condition of the structure. An initial visual inspection of the structure can reveal useful information about areas that need a closer look. A number of investigative techniques are available to study the condition of the material in a structure. These include non-destructive tests, intrusive tests and load tests. The tests are briefly described and the associated codes are cited.

Repair and retrofit of non-engineered buildings

The non-engineered buildings refer to those, which are not formally designed, but built using traditional vernacular techniques.

Fig. 3a:
Introduction of bands and braces in a school building, Kashmir
(Courtesy: National Centre for People's Action in Disaster Preparedness, Ahmedabad)

The classification of non-engineered buildings as per the Vulnerability Atlas of India [5] is presented. This chapter provides the information on the available codes of practice, the preferred seismic resistant features of non-engineered buildings and the available repair materials and retrofit techniques. Horizontal bands and vertical reinforcement at key locations, proper size and location of the openings as recommended in IS 4326 [6] are emphasized.

Retrofit of masonry buildings

The masonry buildings refer to those with load bearing walls made of fired clay bricks, stone blocks or concrete masonry units without reinforcement. This category comprises a large sector of buildings in the urban areas. This chapter deals with evaluation, field and laboratory tests, and the methods of strengthening masonry buildings. The method of piers for seismic analysis is explained. The retrofit techniques are grouped under local and global techniques. The local retrofit techniques include strengthening of roof, upstairs floors and walls. The global retrofit techniques cover introduction of bands (Figs. 3a & 3b) and strengthening by post-tensioning. The actions for maintenance after undertaking retrofit are highlighted.

Retrofit of historical and heritage structures

Structural assessment and remedial interventions on structural systems of historical buildings require special considerations aimed at retaining the architectural integrity and historical authenticity. A vast majority of historical buildings in India is constituted of stone and brick masonry structures. Hence, the retrofitting techniques in this chapter are based on such structures. The techniques include strengthening of walls, arches, domes and towers.

The chapter also provides an insight into the internationally endorsed principles and recommendations of heritage conservation advocated by the ICOMOS (International Council on Monuments and Sites). The principles of archaeological reconstruction are introduced.

Structural analysis for seismic retrofit

This chapter covers the structural analysis of framed buildings. The analysis is a part of the detailed evaluation of an existing building. The steps involve developing a computational model of the building, applying the external forces, calculating the internal forces in the members of the building, calculating the deformations of the members and building, and finally interpreting the results. The analysis can be linear (elastic) or non-linear (inelastic or geometric non-linear), static or dynamic. The chapter discusses primarily the equivalent

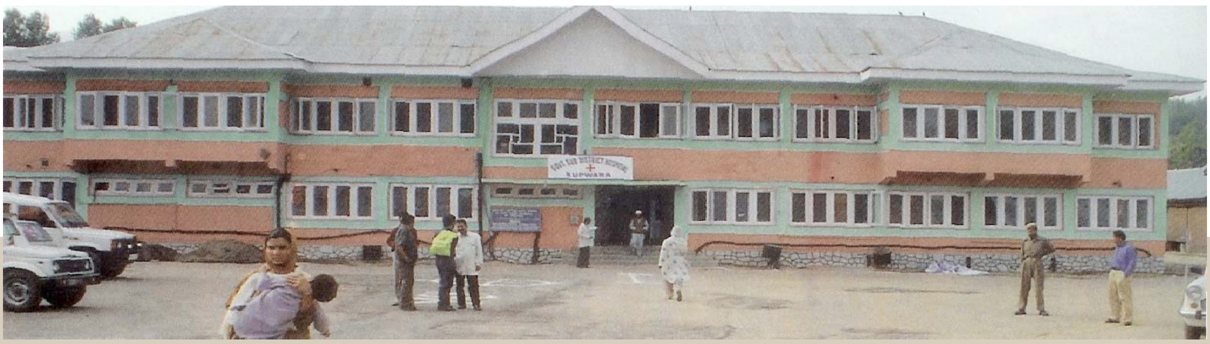


Fig. 3b: Civil Hospital at Kupwada, Kashmir
(Courtesy: Building Materials and Technology Promotion Council, New Delhi)

static analysis. The fundamentals of the response spectrum method, time-history analysis and the pushover analysis are elucidated.

Retrofit of reinforced concrete buildings

In this chapter, first the common deficiencies observed in reinforced concrete (RC) buildings for resisting earthquake forces are listed. Next, suitable strategies to retrofit the deficient buildings are explained and illustrated. The retrofit strategies are compared in terms of their general merits and demerits. The different retrofit strategies are grouped under global or local strategies. Addition of new walls, frames or braces, reduction of any irregularity or mass of the building are grouped under global retrofit strategies. The local retrofit strategies include concrete jacketing of columns (Fig. 4), beams, walls, footings or attaching steel plates to columns [7] or beams.

Fig. 4: Sharavati Hostel, IIT Madras
(Courtesy: Hitech Concrete Solutions, Chennai)

Retrofit of steel buildings

Structural steel is used in different types of single storeyed structures (such as industrial and storage facilities, railway sheds and aircraft hangars) and multi-storeyed buildings. The steel used in these structures may consist of hot rolled sections, cold rolled sections or sections fabricated from steel plates. This chapter discusses the different types of structural systems, the common deficiencies and the suitable retrofit strategies for both the single storeyed structures and multi-storeyed buildings. The uses of non-buckling braces, steel plate shear walls and self-centering post-tensioned connections are briefly explained.

Mitigation of geotechnical seismic hazards and retrofit of foundations

A proper understanding of the geotechnical hazards is necessary for comprehensive retrofit of buildings. This chapter discusses the types of site hazards, site characterisation, modelling of site effects and liquefaction. The ground improvement techniques and strengthening of unstable slopes are broadly presented.

The chapter on Retrofit of Foundations covers modelling of foundations in analysis of buildings, possible types of interventions for retrofitting foundations and methods of execution. The types of intervention include strengthening of rubble masonry foundation, enlarging the area of footing, use of micro-piles, underpinning with piles, strengthening of piles and base plates of steel columns. To execute the retrofit, it is necessary to provide adequate shoring and temporary supports.

Fig. 5: Strengthening of unstable slopes using gabions at Mangalore Refinery

Retrofit using fibre reinforced polymer composites

The constituent materials of fibre reinforced polymer (FRP) composites, the forms of FRP composites and the technique of bonding the laminates on concrete are described in this chapter. For strengthening masonry walls, the possible configurations of FRP laminates are illustrated. The use of FRP in retrofitting

RC beams is explained under strengthening for flexure and shear. The enhancement of shear strength of RC columns and strengthening of exposed beam-column joints are covered. The procedures for analysis of retrofitted members are explained.

Fig. 6: FRP wrapping with near surface mounted plates at Apollo Proton Therapy and Cancer Hospital, Chennai (Courtesy: Sanrachana Structural Strengthening Pvt. Ltd., Larsen & Toubro Construction)

Base isolation and energy dissipation

Conventional seismic design of buildings permits the reduction of design forces for the members below the values corresponding to elastic response. The intended inelastic deformations will cause significant damage of the non-structural elements such as infill walls, partitions and suspended ceilings. Because of these shortcomings, there has been research and development of devices that can reduce the seismic responses of buildings and bridges. The structural control devices can be grouped into four broad areas.

- Base isolation devices
- Passive energy dissipation devices
- Tuned devices
- Active and semi-active control devices

In this chapter, overviews of the first three types of devices are presented.

Fig. 7: Base isolation units placed in the right wing of a prototype building (Courtesy: Sajal K. Deb, Indian Institute of Technology Guwahati)

Quality assurance and control

The requirements of quality in building repair and rehabilitation projects are often not given the same attention as for new projects. This chapter discusses the steps to be taken to ensure that retrofit of structures are conducted in a manner that confirms to contractual and regulatory requirements. Organising for quality, work and material specifications and documentation are briefly described. A typical flow chart for quality control of retrofitting of columns is provided. In addition, temporary construction and safety issues are highlighted.

Retrofit case studies

Two case studies are provided: a heritage masonry building and a multi-storeyed RC building. The calculations for seismic retrofit are explained as per the steps explained in

Fig. 8: Finite element analysis of a retrofitted building

the Handbook. These include rapid visual screening, data collection, preliminary evaluation and detailed evaluation.

CONCLUDING REMARKS

The retrofitting of buildings and other structures for seismic forces has special challenges as compared to the design and construction of new buildings. The huge building stock poses challenge to the practicing professionals. They need easy-to-understand principles, tools to analyse a building, retrofit strategies that are practical and maintain the functional requirement of a building, and methods to estimate the cost of retrofit. The Handbook is an attempt to provide an adequately compiled source of technical information on retrofitting of buildings, for different groups of practicing professionals. The style of presentation and illustrations are intended to be user friendly. Duplication of codes has been avoided. The references list the readily available sources of supporting information.

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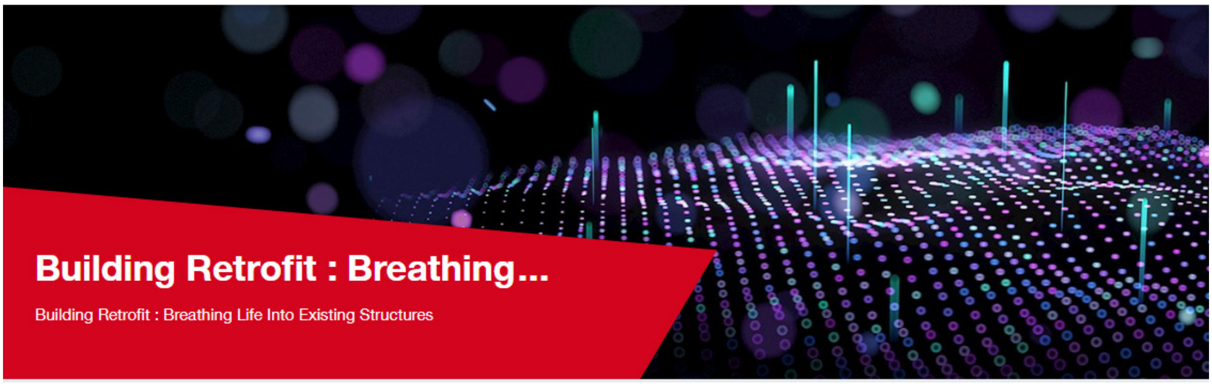
PAST WEBINAR - SEISMIC SAFETY OF NON-STRUCTURAL ELEMENTS



PAST WEBINAR -
BUILDING RETROFIT : BREATHING LIFE INTO EXISTING STRUCTURES

SEISMIC STRENGTHENING OF BRIDGES

Vinay Gupta
Director & CEO
Tandon Consultants Pvt. Ltd.

INTRODUCTION

Occurrence of earthquake is no more a rare eventuality. India has witnessed several major earthquakes, involving substantial loss of lives. To name a few, a major earthquake (Richter scale 8.5) occurred in Assam in 1897 wherein the reported death toll was 1500. It was repeated at the same place in 1950 with similar number of reported deaths. Similarly in 1934 major earthquake (Richter scale 8.4) occurred in Bihar-Nepal area claiming 14,000 lives. It was repeated in 1988 claiming about 1000 lives. The most recent major earthquake (Richter scale 8.0) in Bhuj claimed over 20,000 lives. By and far, major earthquakes have been observed to repeat in about 50 years in high earthquake prone areas.

Comparatively, a larger number of bridges have been affected by seismic activities in America and Japan than those in India. Latur earthquake in 1993 did wake up the authorities to survey the bridges in Maharashtra area, retrofit and rehabilitate those bridges. Golden Gate Suspension Bridge, San Fransisco has been another example of Earthquake Retrofitting. Technique of retrofitting is not unique or predefined. It has to be decided on case to case basis, depending upon the prevailing circumstances.

OBSERVED DAMAGES

Quite often, damage is noticed in and around the bearings due to stress concentration at these locations. Fig.1 shows an example of such damages even in a newly constructed bridge. Bearing has always been said to be a week link between massive superstructure and the substructure. Similarly Fig. 2 shows that the superstructure of another bridge pounded the dirt wall, due to excessive longitudinal movement.

Fig. 1: Damage at bearing level in new Surajbari Bridge

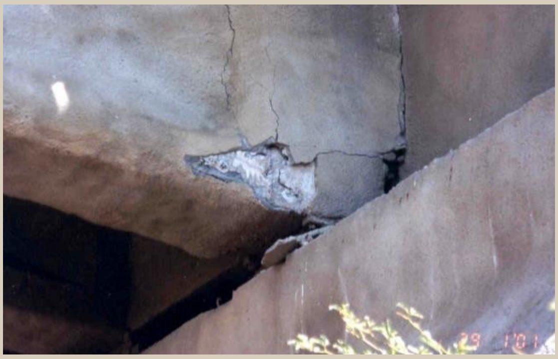


Fig. 2: Macchu Bridge superstructure pounded the dirt wall

Fig. 3 shows damage of short vertical cantilever attached to the pier cap provided to negotiate difference of depths of the two adjoining superstructures. This happens due to formation of plastic hinges and lack of dissipation of earthquake energy at these locations.

Fig. 3: Bridge between Surajbari and Bhachau

Similarly, Fig. 4 shows damages of L-shaped superstructure at the half joints provided to house the hinge bearing.

Fig. 4: Surajbari old bridge half joint in distress due to vertical and horizontal shaking

SEISMIC STRENGTHENING

Possible causes of deficiency in a bridge can be broadly the following:

- Inadequate Design
- Lack of Understanding by the Designer
- Inadequate Construction
- Deterioration of Material with Time
- Upgradation of Seismic Design Requirements
- Upgradation of Seismic Zones

Therefore, main requirements of the proposed strengthening are as follows:

- Should be Economically Feasible
- Should be Technically Viable
- Should Surmount Functional Constraints
- Should Reduce Seismic Demand
  - Reduce SILD and LL
  - Reduce Stiffness – Saw Cutting of Parapet
- Increase Dissipation of Seismic Energy
- Dampers
- Increase the Supply Strength
- Structural Strengthening

Seismic forces cause plastic hinge formation and overstressing at specified locations, such as pier- foundation junction, pier-superstructure junction in case of integral bridge, etc. For all such conditions, the pier cap can be confined to substantially enhance the performance during ultimate load conditions, see Figs. 5 and 6.

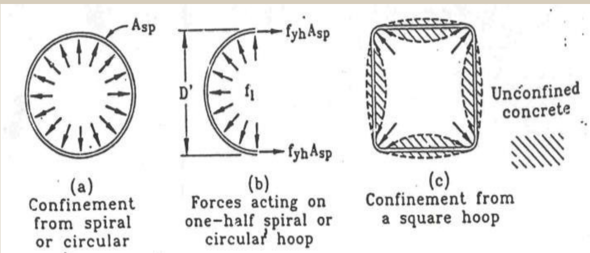


Fig. 5: Confinement of concrete by circular and square hoops

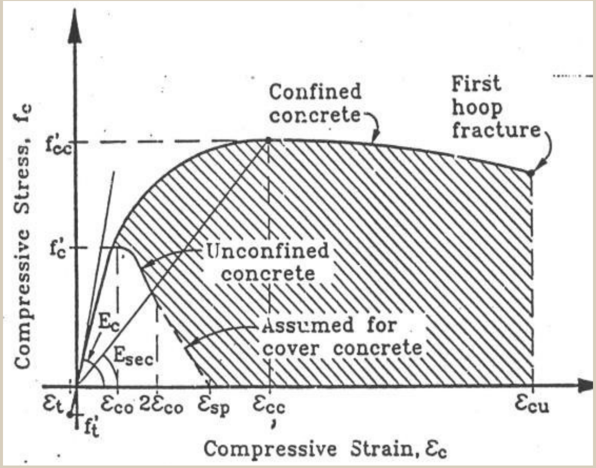


Fig. 6: Stress-strain model for concrete in compression

The Figs. 7 and 8 below depict detailing for strength enhancement through addition of steel and concrete respectively. The additional concrete of the pier needs to be adequately anchored to the corresponding foundation.

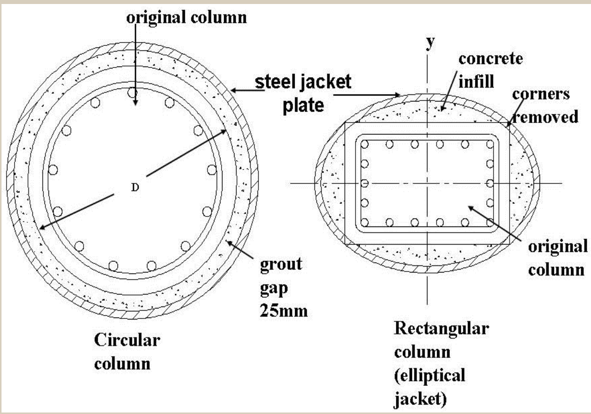


Fig. 7: Confinement of columns by steel jacketing

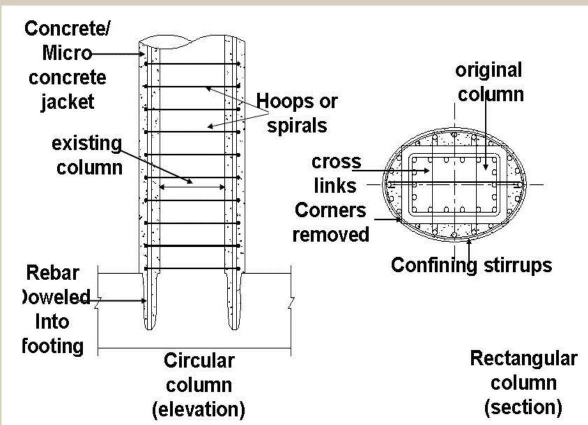


Fig. 8: Confinement of columns by concrete jacketing

Concrete portals are commonly connected to the superstructure either through bearings or integrally. In such cases, the seismic force carrying capacity of a portal can be enhanced as depicted in Figs. 9 and 10.

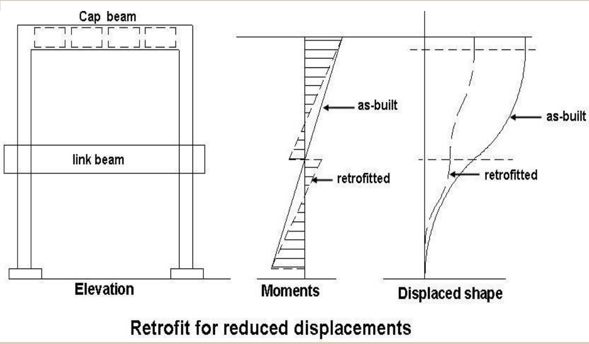


Fig. 9: Use of link beam to improve transverse seismic response of multi-column bents

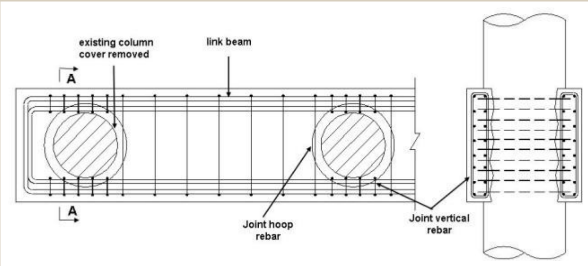


Fig. 10: Retrofit using link beams

In the seismic conditions, foundations need to be strengthened both for downward load and uplift. Fig. 11 depicts the use of additional piles to increase downward load capacity of pile foundation and the use of Passive Ground Anchors for prevention against uplift. Fig. 12 depicts increase of structural strength of foundation by additional concrete and addition of prestressing after drilling hole into the foundation and grouting it after the application of prestress.

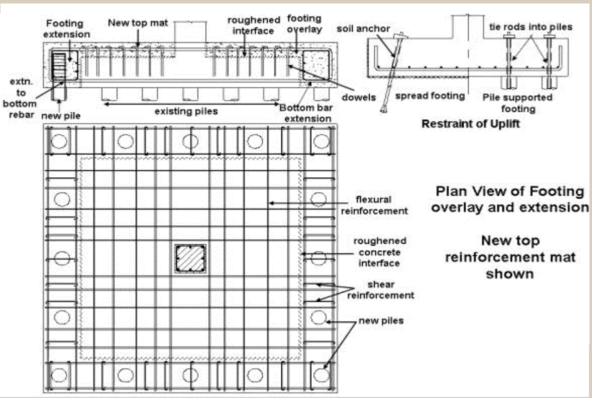


Fig. 11: Footing retrofit measures

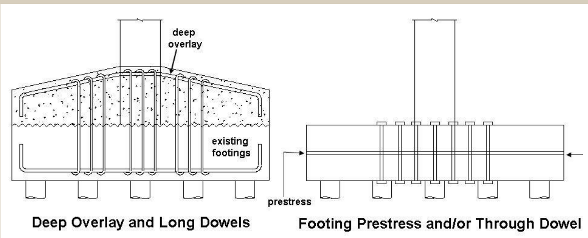


Fig. 12: Retrofit measures for joint shear stress deficiencies

Reinforcement couplers and rebar fasteners are very useful components for enhancing the strength of an existing structures. Existing reinforcement can be suitably extended by providing reinforcement couplers, see Fig 13. In case, new reinforcing bars have to be added, rebar fasteners can be provided by drilling a hole of specified diameter and depth in concrete and filling high strength resin before inserting reinforcing bar, see Fig. 14. This way full strength of the bar can be achieved.

Fig. 13: Reinforcement couplers

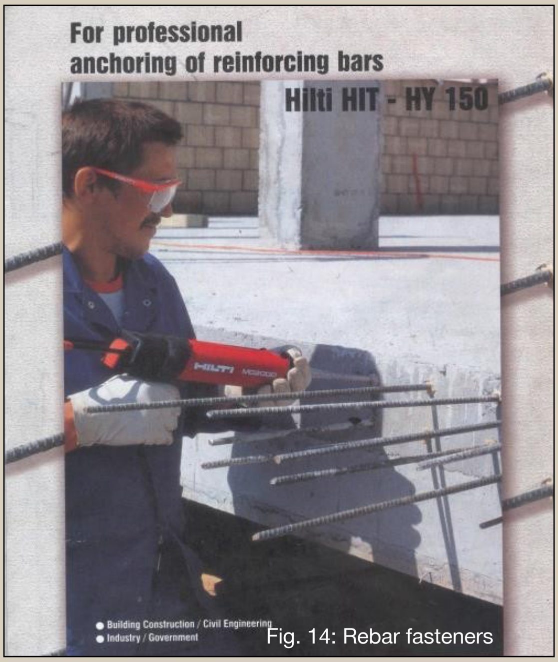


Fig. 14: Rebar fasteners

In case a well foundation has to be strengthened, it can be done in the manner depicted in Fig. 15. In case a masonry pier/abutment has to be increased in dimension, it can be done in the manner depicted in Fig. 16.

In many cases, wing walls are found to be bulged out due to seismic movement of the earthfill behind the wing wall. In such cases, solution lies in providing prestressing force to restore the wing wall as shown in Figs. 17 & 18.

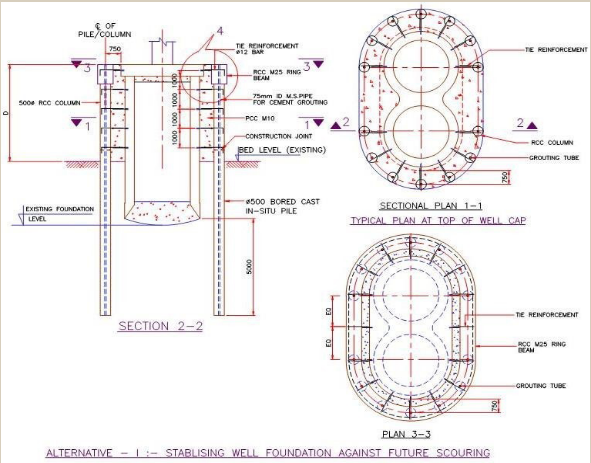


Fig. 15: Strengthening of well foundation

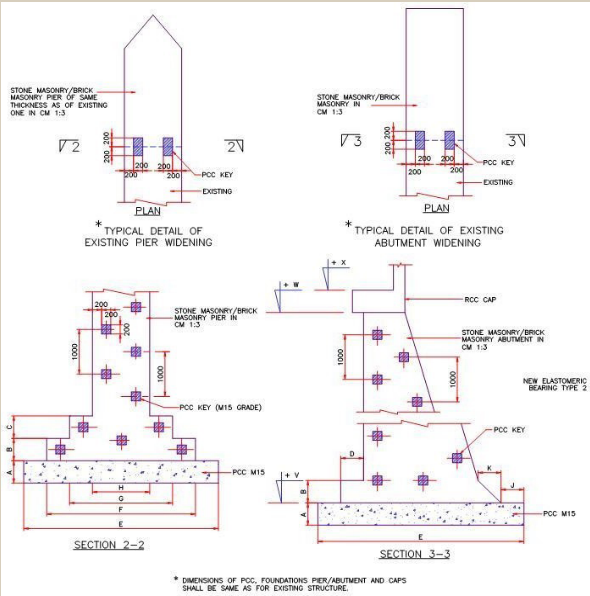


Fig. 16: Widening of masonary pier & abutment using shear keys

In these cases, the operation is performed in two parts, (one half road width at a time). After removing the road crust, a 300 mm dia CI pipe with coupling flanges is placed. Thereafter, RCC is added (along with necessary shear connectors) to increase the section of the wing wall and the size of its footing. Now, prestressing wire/strands encased in HDPE tube are inserted into the CI pipe and prestessed and subsequently grouted.

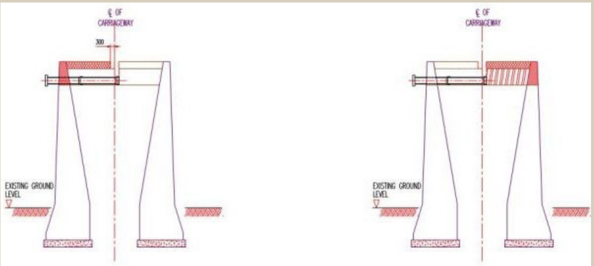


Fig. 17: Scheme for strengthening of moved wing wall

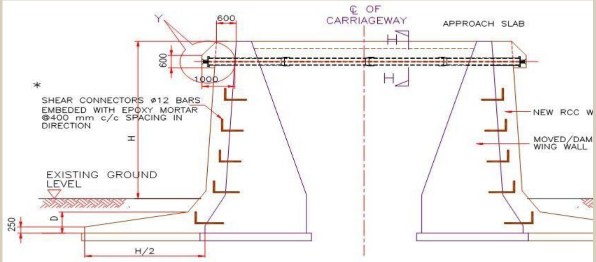


Fig. 18: Scheme for strengthening of moved wing wall

Seismic forces experienced by the bridge can be substantially reduced by addition of vertical concrete upstands from the pier/abutment cap and sandwitching flexible material, such as elastomer. Figs. 19 and 20 depict the system of such an arrangement.

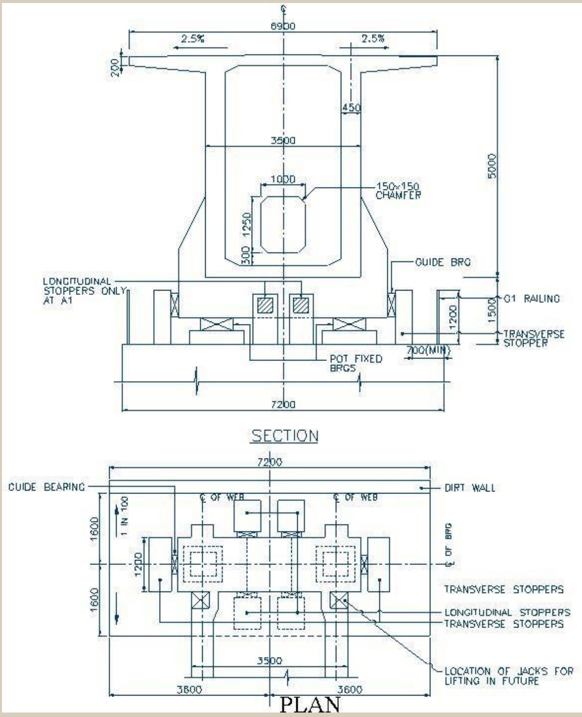


Fig. 19: Seismic restraint devices over abutement

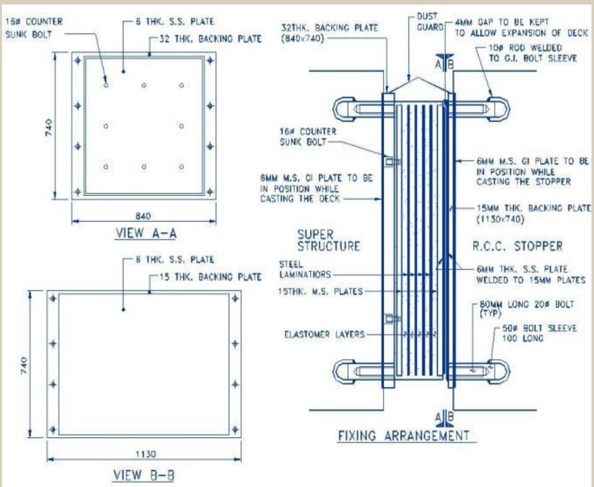


Fig. 20: Vertically positioned elastomeric bearings

In this arrangement the vertical elastomeric bearings need to be detailed in a specialized way, wherein, the mating surface between the fixed side and the moveable side is made into stainless steel, in order to reduce sliding friction. For anchoring purpose a mild steel plate vulcanized on the surface of the bearing, as shown in Fig. 20 is provided. Figs. 21 & 22 depict an isometric view and photograph of such concrete up stands that receive the vertical elastomeric bearings. The elastomer acts as isolator by substantially increasing time period of the structure, thereby reducing the seismic forces experienced by the structure.

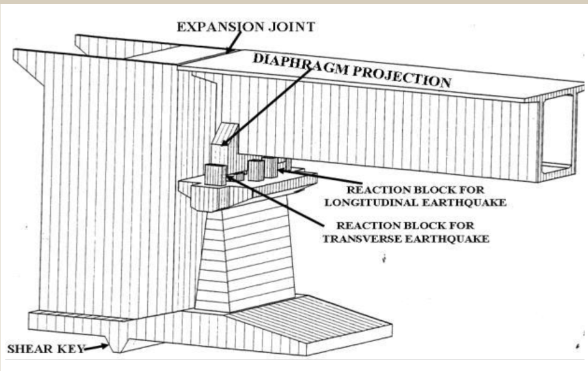


Fig. 21: Details at restrained bearing over abutment


Fig. 21: Details at restrained bearing over abutment

The other method of strength enhancement is to provide fiber wraps. Mainly there are Carbon Fiber Wraps and Glass Fiber Wraps. These fiber wraps exhibit low creep and elongation and compared to steel, they are thinner, lighter and have up to 10 times and tensile strength capacity. Since, these wraps have unidirectional tensile capacity, they have to be carefully provided in the direction, strength enhancement is desired. Incase both shear and flexural strengths are required, two layers of the wrap perpendicular to each other are provided, refer Figs. 23 and 24 for examples of fiber wrap application.

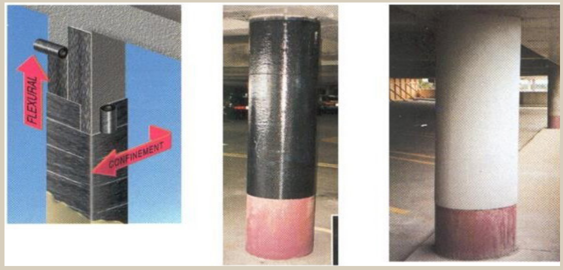


Fig. 23: Examples of fiber wrap system

High tensile carbon sheets can also be used as laminates. These laminates exhibits higher tensile strength compared to fiber wrap. The laminates are provided as discrete strips in the orientation of desired strength viz. shear or flexure, see Fig. 25 for illustration.

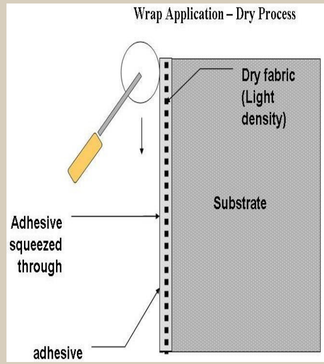


Fig. 24: Application of fiber wrap


Fig. 25: Carbon laminate

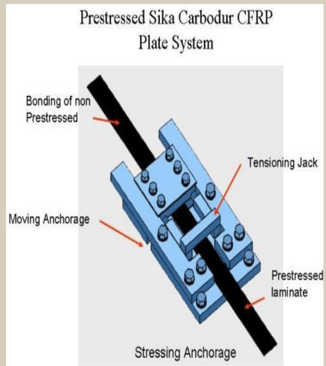


Fig. 26: Prestressed laminate

These laminates can also be prestessed as shown in Fig. 26.

CONCLUSION

Method of seismic strengthening of bridges is a case specific matter. Depending upon the requirements of a particular location, the system of strengthening of superstructure, substructure and/or foundations has to be decided. An attempt should be made to reduce seismic demand by providing seismic isolators/dampers or increasing flexibility of the structure, provided they do not impare efficiency and functionality of the bridge. Confinement of core of piers using concrete jacket or steel jacket is an effective method of strength enhancement. When reinforcement has to be added, reinforcement couplers and rebar fasteners turn out to be useful items of structure. All the bridge components need to be investigated for strength enhancement.

DESIGNED TO EFFECTIVELY WITHSTAND SHOCKWAVES, SABIHA GÖKÇEN INTERNATIONAL AIRPORT IS AN ANATOLIAN PRIDE

Istanbul that straddles Europe and Asia across the Bosphorus Strait; the commercial hub and largest city of the transcontinental country, Turkey boasts the remarkable, monumental and a wonder of the human mind – the Sabiha Gökçen International Airport. The airport was developed as a Greenfield project and named after the Turkey's first woman combat pilot.

It is one of two international airports serving the city, offering a whopping total area of more than 3,20,000 sq. m and is comprised of an integrated domestic and international terminal building, a hotel, a new VIP terminal and a multitude of other airport facilities.

With 28,285,578 passengers and 206,180 aircraft movements in 2015, Sabiha Gökçen International Airport is the third busiest single-runway airport in the world, after Mumbai and London Gatwick.

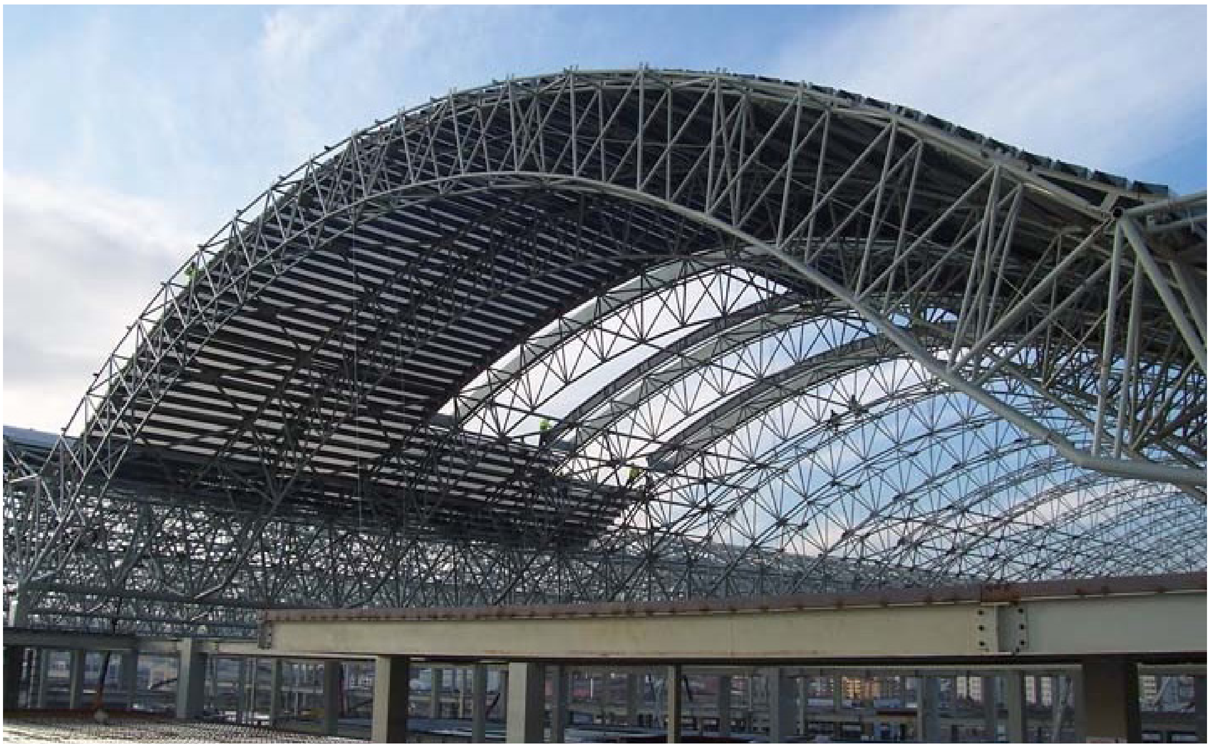
Since Istanbul is located at the confluence of 3 tectonic plates close to the North Anatolian Fault, which runs for 1,500 km between the African and Eurasian tectonic plates, it experiences large earthquakes because of its geographical positioning. The tragic 1999 Kocaeli earthquake killed 17,000, injured 43,000 and forced 250,000 people to relocate. An estimated property loss ranged from $3 to $6.5 billion, along with the overall economic loss to the country as the earthquake hit a heavily industrialized area of Turkey. This led to the adoption of more and more earthquake-resilient structures to minimize loss of lives and damage to assets.

The is credited to the fine sense of engineering of Arup's Istanbul and Los Angeles teams offices, who worked together to design and deliver the project in just 18 months – record time for a project of such scale and ambition.

STRUCTURAL SYSTEM

The new SGIA Terminal building is a steel structure with a plan dimension of 160 m by 272 m with a total building height of approximately 32.5 m. The building consists of four storeys above and a basement floor below the isolation plane.

> **“Sabiha Gökçen International Airport is the third busiest single-runway airport in the world, after Mumbai and London Gatwick.”**



The gravity system of the superstructure is composed of concrete filled steel decks, composite steel beams, and composite steel columns. The superstructure resists lateral loads by a system of steel moment frames through rigid horizontal diaphragms. The clear span length supported by the columns is 16 m in both directions.

All structural members, such as columns and beams, are built-up members. Plates were cut in appropriate shapes and were connected via welding in order to constitute the required structural sections. Floor rib beams are made of grade S235 steel plates and columns and main beams are made of grade S355 steel plates.

Rib beam layout orientations are changed in every main cell (16m x 16 m), so that all the main beams are loaded with the same gravity loads. The framing for the stairs and elevators below the isolation plane is suspended from and braced by the isolated super structure above. The concrete compressive strength is 35 MPa for composite columns.

The roof system consists of light steel space purlin systems running longitudinally and located at every 8 m and braced in the transverse direction. The purlin has a parabolic curve form with a depth of 12 m and 6 m placed evenly next to each other. They are pin-supported by the top of the columns at every 32 m and 48 m. Purlins consist of pipe members which are in grade S355. Considering the shape of the roof, unbalanced snow drift load was taken into consideration in the analysis.

“The roof system consists of light steel space purlin systems running longitudinally and located at every 8 m and braced in the transverse direction.”

SEISMIC DESIGN

As per the client’s requirements, two performance levels were defined for seismic analysis of the terminal building, numerated as follows:

- The building was designed for Operational Level. i.e. no structural and no non-structural damage for an earthquake hazard with a uniform 10% probability of exceedance in 50 years, which is equivalent to a hazard with a return period of 475 years. This earthquake hazard is commonly known as Design Basis Earthquake (DBE) or design earthquake in practice.

- The building was designed for Structural Immediate Occupancy for an earthquake hazard with a uniform 2% probability of exceedance in 50 years, which is equivalent to a hazard with a return period of 2475 years. This earthquake hazard is known as Maximum Considered Earthquake (MCE).

Contrary to the conventional seismic detailing which are generally adopted, base isolation was implemented to achieve the desired seismic performance.


Isolator-column-beam connection


Placement of a typical isolator

To determine the amount of movement it could withstand, Arup used real-time earthquake simulation modelling and LS-DYNA specialist software to test the building's integrity at 100th of second intervals. The results of 14 potential earthquake scenario tests showed that it could withstand an earthquake of magnitude 7.5-8.0, as measured on the Richter scale.

Triple friction pendulum devices were used to build the world's largest seismically isolated building. There are 300 triple-friction pendulum isolators that are distributed over the entire plan. The triple-friction pendulum bearings, with a conceptual period of 3 seconds and displacement limit of 345 mm, were selected owing to performance and cost. The effective damping provided by the isolators is 38% and 30% at DBE and MCE events, respectively.

> **Triple friction pendulum devices were used to build the world's largest seismically isolated building.**

Structure	The terminal comprises four storeys above and a basement floor below the isolation plane. It has a steel superstructure, with plan dimensions of 160 x 272 ^{m}, without floor joints and a total building height of approximately 32.5 m.
Area of Terminal	200,000 m^2
Passenger Capacity	22 million
Opening	31st October, 2009
Architect	Tekeli-Sisa Architecture Partnership
Master Planning, Structural Design, Seismic Simulation and Design	Arup
Triple Friction Pendulum Isolators	Earthquake Protection Systems, Vallejo, California
Simulation Software	LS-DYNA, developed by Livermore Software Technology Corporation

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