

SEISMIC ASSESSMENT AND FORTIFICATION ESSENTIALS (SAFE)

A Guide To Seismic Retrofitting



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FOREWORD

by

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It is a great honour for me to contribute this foreword to the Seismic Retrofitting Guidebook.

As a researcher and educator in earthquake engineering, I have had the privilege of working with many talented students and researchers from India over the years. At my laboratory in Japan, I have supervised numerous Indian graduate students whose academic excellence, dedication, and creativity have consistently impressed me.

My connection with India has also been strengthened through professional activities. As the Chair of the International Committee of the Japan Society of Seismic Isolation, I had the opportunity to visit India and organize technical seminars on seismic engineering and seismic isolation technologies. During these visits, I was deeply impressed by the warm hospitality extended by our Indian colleagues and by the enthusiasm of engineers, researchers, and students who actively participated in technical discussions.

Both Japan and India face serious earthquake hazards. Japan's experience has demonstrated that seismic retrofitting of existing buildings is one of the most effective measures for reducing earthquake losses. The lessons learned from major earthquakes, including the 1995 Great Hanshin-Awaji Earthquake and the 2011 Great East Japan Earthquake, have led to continuous improvements in seismic assessment, retrofit technologies, design standards, and public policies.

An important lesson from Japan is that seismic retrofitting is not solely an engineering challenge. Its successful implementation requires collaboration among governments, researchers, engineers, building owners, and local communities. Sustainable progress can only be achieved through the integration of scientific knowledge, practical technologies, education, and public awareness.

In this context, this handbook is both timely and valuable. It provides practical guidance and technical knowledge that can support engineers, practitioners, policymakers, and stakeholders involved in improving the seismic safety of existing buildings. I sincerely hope that this handbook will serve as a useful reference for professionals throughout India and will further strengthen collaboration between India and Japan in the field of earthquake engineering and disaster risk reduction. By sharing knowledge and experiences across national boundaries, we can work together toward a safer and more resilient future.

MESSAGE FROM ADVISORY BOARD

"India's rapidly growing and ageing building stock presents a significant challenge in ensuring seismic safety and resilience. The safe guidebook is a timely and valuable initiative that bridges the gap between codal provisions and practical field implementation. By providing a structured framework for assessment, condition evaluation, and retrofitting of vulnerable structures, it empowers engineers, owners, and authorities to make informed decisions. The emphasis on practical strengthening techniques, quality execution, and risk mitigation is particularly relevant for the Indian context. I commend seismic academy for developing this comprehensive guide, which will contribute meaningfully towards safer, more resilient, and sustainable built environments. I am confident that this guidebook will serve as an important reference for practitioners and stakeholders involved in seismic safety and structural rehabilitation "



Mr. Alok Bhowmick
Managing Director
B&S Engineering Consultants Pvt. Ltd.

"I congratulate the authors who painstakingly prepared this draft which is a treasure and covers a reasonably good ground on a subject which is vast. The document attempts to present in a concise and practical way the state of the practice of our current understanding of building failures due to earthquakes. It serves the purpose & objective of the academy by giving background information about current standards and future directions, by stimulating focus on the earthquake problem, extending knowledge concerning earthquakes, and giving ideas and reassurance to those faced with the task of building a safer future for the public and to save lives"

"It gives me immense pleasure to present this guidebook, "Seismic Assessment and Fortification Essentials (SAFE) – A Guide to Seismic Retrofitting," a timely and significant contribution towards enhancing seismic resilience of our built environment.

India's growing urbanization, coupled with the presence of a vast portfolio of existing buildings constructed prior to the adoption of modern seismic design provisions, accentuates the urgent need for systematic assessment, strengthening, and risk reduction measures. Understanding from past earthquakes across the world has repeatedly revealed that the greatest losses occur not because of the hazard itself, but because of the vulnerability of existing buildings. In this context, seismic retrofitting emerges as one of the most effective and sustainable strategies for safeguarding lives, infrastructure, and economic assets. This guidebook provides a comprehensive yet practical framework covering assessment, condition evaluation, retrofitting strategies, and structural audit requirements. By integrating current Indian standards with globally accepted engineering practices, it serves as a valuable reference for engineers, architects, policymakers, academicians, building owners, and disaster management professionals.

I praise the Seismic Academy for its vision and commitment in developing this important publication. I am confident that this guidebook will contribute significantly towards promoting a culture of safety, preparedness, and resilience, while supporting the nation's collective efforts to build earthquake-resistant and disaster-resilient communities"



Dr S M Ali
Director General
Solar Energy Society of India

"With India's ageing building stock, seismic safety is increasingly important. The SAFE Guidebook provides practical guidance on assessment and retrofitting, making it a valuable resource for creating safer and more resilient structures"



Dr. Harshavardhan Subbarao
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ABOUT THE GUIDELINE

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The Seismic Assessment and Fortification Essentials (SAFE) guideline is a practical guidebook developed to address the growing need for improving the seismic safety and resilience of existing building structures. It provides a structured and easy-to-follow framework for assessing, evaluating, and strengthening buildings that may be vulnerable to earthquake effects.

The guideline bridges the gap between theoretical codal provisions and real-world implementation by providing guidance to apply codal provisions through systematic procedures, checklists, and actionable recommendations. It covers the lifecycle of seismic risk management from rapid post-earthquake assessment and preliminary screening to detailed engineering evaluation and the design of suitable retrofitting strategies. The guidebook also integrates the requisites of structural audit, emphasizing periodic inspection, condition assessment, and timely intervention as essential components of structural safety. It aligns with regulatory provisions requiring regular audits and outlines how audit findings must translate into repair, strengthening, or retrofitting actions, ensuring continued safety and serviceability of structures. It also establishes a clear flow from assessment to retrofit decision-making.

A key focus of the guideline is the strengthening of existing structures through both member-level and global-level interventions, including techniques such as jacketing, bracing, addition of shear walls, base isolation, and energy dissipation systems. It also emphasizes condition assessment, structural analysis, and the importance of quality execution to ensure that retrofit measures achieve the intended performance.

The guideline places significant emphasis on local (member-level) retrofitting strategies, which are often the most practical and cost-effective solutions for strengthening deficient structural elements. Techniques such as reinforced concrete jacketing, steel jacketing, and shear strengthening using post-installed systems which are critical in retrofit applications for ensuring proper load transfer and composite action between new and existing structural components and FRP wrapping are explained with clarity, along with execution checks to ensure quality and performance. These methods aim to enhance strength, ductility, and detailing of individual members without major alterations to the overall structural system.

Recognizing the Indian context, the guideline highlights challenges such as non-engineered construction, aging building stock, and implementation gaps, while aligning its recommendations with relevant Indian Standards. It also outlines the roles of engineers, authorities, contractors, and building owners in ensuring effective seismic safety practices.

Overall, the SAFE guideline aims to shift the approach from reactive repairs to proactive risk mitigation, supporting safer, more resilient, and sustainable built environments through practical and implementable retrofitting solutions.

1. Introduction

The durability and safety of any structure depend on good construction practices and proper maintenance throughout its life. During construction, careful planning, use of proper methods, and following standards help ensure long-term performance. After the structure is in use, its condition must be maintained through regular inspections, routine maintenance, and timely repairs or strengthening measures such as rehabilitation or retrofitting. This overall approach helps prevent early damage or failure and ensures the structure remains safe, functional, and cost-effective throughout its life.

Structural deterioration arises from a combination of interconnected factors. Changes in usage, often involving higher or different loading conditions, can impose stresses that exceed the original design capacity. Deficiencies in design or construction such as poor workmanship, material weaknesses, or errors in analysis can further compromise structural performance. Over time, updates in building codes and design standards may render older structures non-compliant, making upgrades necessary to meet current safety requirements.

In hazard-prone regions, particularly those susceptible to earthquakes, blasts, or fire, retrofitting becomes essential to improve resilience. A lack of regular inspection and maintenance accelerates deterioration, allowing minor issues to develop into serious problems. Additionally, structural configurations with irregular shapes or discontinuities can lead to stress concentrations, reducing stability. Inadequate detailing of reinforcement or connections can also affect durability and performance.

Continuous exposure to environmental conditions, accidental impacts, and material aging gradually weakens the structure. This highlights the importance of proactive monitoring, regular maintenance, and timely interventions to preserve structural integrity and ensure long-term safety.

Retrofitting plays a critical role in advancing Disaster Risk Reduction (DRR), climate resilience, and overall urban safety by directly addressing the vulnerabilities of existing building stock. In the context of DRR, retrofitting reduces the likelihood of structural failure during earthquakes, thereby minimizing loss of life, economic disruption, and post-disaster recovery costs. It shifts the approach from reactive response to proactive risk mitigation.

From a climate resilience perspective, retrofitting aligns with sustainability goals by extending the life of existing structures, reducing the need for demolition and new construction, and lowering associated carbon emissions. It also enhances

the ability of buildings to withstand multiple hazards including extreme weather events making cities more adaptive in the face of climate change.

In terms of urban safety, retrofitting strengthens critical infrastructure and densely populated housing, improving structural reliability, service continuity, and public confidence. When integrated with policy, planning, and community participation, it contributes to creating cities that are not only safer during disasters but also more resilient, sustainable, and prepared for future risks.

This guidebook offers a step-by-step framework for strengthening of structures against earthquakes - from rapid safety assessments to detailed damage evaluation and implementing effective retrofitting strategies. It also highlights the coordinated roles of engineers, government agencies, building owners, contractors, and communities in ensuring effective design, policy enforcement, quality execution, and long-term resilience. This guidebook helps turn codes into simple, practical actions that people can follow on site. It provides easy checklists, clear steps, and ready-to-use details so engineers and contractors know exactly what to do. This makes it easier to apply code requirements correctly and consistently in real construction and retrofitting work.

2. Seismic vulnerability and retrofitting needs in India

India is located in a seismically active zone with nearly 59% of its land area vulnerable to moderate or severe seismic activity. The Himalayan belt and the northeast experience frequent high magnitude tremors, while other regions such as the Kutch in Gujarat, parts of Delhi NCR, and the Andaman & Nicobar Islands also fall in high-hazard seismic zones. Rapid urbanization, high population density, and widespread non engineered construction amplify the potential impact, as many buildings are neither designed nor retrofitted to withstand strong ground shaking. Soft soil conditions in certain cities further increase the risk of ground motion amplification and liquefaction. Combined with limited public awareness and inconsistent enforcement of seismic safety codes, these factors make India particularly vulnerable to devastating losses in life, infrastructure, and economy in the event of major earthquakes.

The 2001 Bhuj earthquake in Gujarat exposed the severe vulnerability of built infrastructure, with over a million buildings damaged or destroyed. The widespread failures were primarily due to poorly designed and non-engineered buildings, inadequate detailing of reinforcement, inferior materials, and non-compliance with seismic design standards. Structural irregularities and lack of quality control during construction further aggravated the damage, leading to catastrophic collapses even in relatively modern buildings. This disaster clearly

demonstrated that the absence of seismic considerations in both design and construction can have devastating consequences. It underscored the urgent need for systematic seismic assessment and retrofitting of existing structures, especially those not originally designed to resist earthquake forces. The lessons from Bhuj reinforced the importance of adopting earthquake-resistant practices, seismic assessment and strengthening vulnerable buildings to improve resilience and reduce future risks.

Retrofitting in India has been lagged not due to lack of codes, but largely due to implementation gaps and systemic constraints. The challenge is less technical and more institutional, economic, and socio-cultural. Some key barriers of large-scale retrofitting in India include:

- Weak enforcement of codes
- Huge stock of non-engineered and old buildings
- Low awareness and risk perception
- Technical and execution challenges
- Regulatory and institutional gaps
- Urban realities
- Fragmented codal guidance (historically)

India's seismic vulnerability is strongly linked to the composition and age of its existing building stock. More than 70% of buildings are masonry constructions, a large proportion of which are unreinforced masonry (URM) with inherently poor seismic performance due to low tensile strength and ductility. In addition, non-engineered or informally constructed buildings constitute nearly 70-80% of the total stock, reflecting limited professional design input and weak compliance with seismic provisions. A significant share of reinforced concrete (RC) buildings was constructed prior to the revision of IS 1893 in 2002 and is therefore typically lacking ductile detailing and seismic design considerations, implying that around 60-70% of the urban stock remains non-compliant with modern codes. Compounding this, nearly 59% of India's landmass lies in earthquake-prone zones, encompassing regions that house roughly 80% of the population, thereby placing a substantial portion of this vulnerable stock at direct seismic risk. Together, these factors highlight that the majority of India's buildings particularly non-engineered masonry and pre-code RC structures require urgent evaluation and retrofitting to enhance seismic resilience.

3. Codes and Standards landscape

India has a comprehensive and technically robust framework for building codes and standards, reflecting contemporary engineering knowhow and aligning with international best practices. Over the past several decades, significant progress in earthquake engineering has driven continuous updates to the nation's seismic standards. Since the publication of the first Indian seismic code (IS 1893) in 1962, it has since been revised in 1966, 1970, 1975, 1984, 2002 and 2016. The other relevant standards pertaining to the seismic design and retrofitting of structures include the following Table 3.1.

Table 3.1: Relevant Indian Standards for design, detailing, assessment and strengthening of structures against earthquake

Standards	Description
IS 1893	Criteria for Earthquake Resistant Design of Structures
IS 13920	Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice
IS 18168	Earthquake Resistant Design and Detailing of Steel Buildings — Code of Practice
IS 17848	Confined Masonry for Earthquake Resistance Code of Practice
IS 4326	Earthquake Resistant Design and Construction of Buildings- Code of Practice
IS 13827	Improving Earthquake Resistance of Earthen Buildings- Guidelines
IS 13828	Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines
IS 13935	Seismic Evaluation, Repair and Strengthening of Masonry Buildings – Guidelines
IS 15988	Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings – Guidelines
IS 18289	Post-Earthquake Safety Assessment of Buildings – Guidelines

A major revision of India's earthquake standards is underway (Table 3.3), which will bring important improvements in earthquake-resistant design developed over the past two decades. The updated provisions are expected to enhance design accuracy, performance expectations, and safety margins, marking a clear shift towards more robust, modern, and globally aligned seismic practices. IS 1893 part 1:2025 introduces a paradigm shift in seismic design by replacing the traditional zone-factor approach with probabilistic seismic hazard assessment, revising the seismic zonation map, strengthening geotechnical and soil-structure interaction provisions, enhancing response-history analysis requirements, and introducing dedicated provisions for non-structural elements. The code separates general seismic criteria from building-specific requirements and moves Indian seismic design practice toward a more performance-based and internationally aligned framework. The revised hazard framework in IS 1893 part 1:2025 is expected to increase seismic design demands for many existing structures, particularly in regions where the updated probabilistic hazard assessment indicates higher ground motions than those considered under previous editions. A brief on the proposed or upcoming changes in draft IS 1893 part 1:2025 regarding earthquake design criteria for structures has been shown in Table 3.2.

Table 3.2: Proposed / upcoming revisions in IS 1893 part 1:2025

Topic	IS 1893 part 1:2016	Draft IS 1893 part 1:2025
Seismic Hazard Philosophy	Deterministic seismic zoning	Probabilistic Earthquake Hazard Assessment (PEHA/PSHA)
Code Structure	General + buildings combined	General provisions separated from building provisions (Part 5)
Seismic Zones	Zones II-V	Revised seismic zonation with finer hazard classification and proposed additional zone VI
Design Basis	Zone factor (Z) approach	Hazard-based acceleration values linked to return periods
Importance Factor	Importance factor (I)	Return-period-based design hazard levels

Topic	IS 1893 part 1:2016	Draft IS 1893 part 1:2025
Response Spectrum	Traditional design spectrum	Uniform hazard response spectrum with expanded spectral definitions
Soil Classification	Broad soil categories	Greater reliance on shear-wave velocity and site characterization
Soil-Structure Interaction (SSI)	Limited guidance	Explicit SSI provisions and soil flexibility effects
Liquefaction	Existing procedures	Revised liquefaction assessment methodology
Ground Motions	Limited guidance	Suites of near-fault and far-fault records for response-history analysis
Non-Structural Components	Minimal provisions	Dedicated provisions for architectural elements and utilities

Enhanced provisions for site effects, liquefaction, soil-structure interaction, and performance assessment may reveal deficiencies in structures designed to earlier codes. Consequently, a larger inventory of existing buildings, bridges, industrial facilities, and lifeline infrastructure may require detailed seismic evaluation and, where necessary, strengthening or retrofit interventions to achieve the desired level of safety, resilience, and post-earthquake functionality.

The revised framework of major standards by Bureau of Indian Standards is presented in Table 3.3.

Table 3.3: Revised framework of Indian Standards (proposed) for design and detailing of structures against earthquake

Standard		IS 1893	IS 13920	IS 13935
Part	Title	Design Earthquake Hazard and Criteria for Earthquake-Resistant Design of Structures	Earthquake-Resistant Design and Detailing of Structures	Assessment and Retrofit of Structures for Earthquake Safety
1	General Provisions	✓	✓	✓
2	Liquid Retaining Tanks	✓	✓	✓
3	Bridges & Retaining Walls	✓	✓	✓
4	Industrial & Stack-Like Structures	✓	✓	✓
5	Buildings	✓	✓	✓
6	Base-Isolated Buildings	✓	✓	✓
7	Pipelines	✓	✓	✓
8	Dams and embankments	✓	✓	✓
9	Coastal structures	✓	✓	✓
10	Steel towers	✓	✓	✓
11	Tunnels	✓	✓	✓

The application of seismic codes in retrofitting is inherently multi-layered, as different standards govern different building typologies and stages of intervention from initial assessment to final strengthening. Unlike new design, retrofitting requires a combination of evaluation guidelines, material-specific provisions, and

overarching seismic criteria, making it essential to clearly map code applicability for effective and consistent implementation.

The matrix in Table 3.4 highlights that seismic retrofitting in India is governed by a combination of type-specific codes (RC, masonry, steel) and stage-specific guidelines (assessment, repair, strengthening), with IS 1893 [1] providing the overarching seismic design basis.

Table 3.4: Code applicability matrix (Building type × Retrofit stage × Governing IS code)

Building Type	Retrofit Stage	Governing Indian standard (s)
All building types	Seismic hazard definition and design basis	IS 1893 (Part 1 – General)
RC buildings	Evaluation (rapid / detailed)	IS 15988
	Retrofitting design and strengthening	IS 15988 + IS 13920 (ductile detailing)
	New additions / alterations	IS 1893 + IS 13920
Masonry buildings (URM / confined / low-strength)	Rapid assessment	IS 13935
	Detailed evaluation and repair	IS 13935
	Strengthening / retrofitting	IS 4326, IS 13828, IS 13935
	Confined masonry systems	IS 17848
Earthen buildings	Strengthening / improvement	IS 13827
Steel buildings	Evaluation and retrofit design	IS 18168 + IS 1893

Building Type	Retrofit Stage	Governing Indian standard (s)
	Detailing and strengthening	IS 18168 + IS 800
Mixed / non-engineered buildings	Vulnerability reduction and basic strengthening	IS 4326 + IS 13828
Post-earthquake damaged buildings (all types)	Rapid safety assessment	IS 18289
	Repair and retrofitting strategy	IS 13935 / IS 15988 (depending on type)

Despite such comprehensive regulatory framework, gaps persist due to inconsistent enforcement, uneven implementation across states, limited awareness among stakeholders, inadequate training for enforcement agencies, and the prevalence of non-engineered construction in both urban and rural areas. These factors collectively weaken the intended safety net, leaving many structures vulnerable in the event of earthquakes.

Comprehensive but evolving: The codes cover design, detailing, and retrofitting, but provisions for existing buildings and practical retrofitting are still developing compared to new design codes.

Periodic revisions: Major codes (e.g., IS 1893 [1], IS 13920 [2]) have been updated post major earthquakes (especially post-2001 Bhuj), reflecting improved understanding.

Strong technical base: Indian codes are aligned with global practices and research, offering robust engineering guidance.

Implementation gap: Despite availability, enforcement and compliance remain inconsistent, especially in informal and private construction sectors.

Limited penetration for retrofitting: While IS 15988 exists, awareness and use in practice are still limited, particularly outside critical infrastructure projects.

Some additional grey areas identified as follows:

- Neither IS 15988 [3] nor IS 13935 [4] clearly prescribe how to consistently link assessed capacity to IS 1893 [1] design demand

- Engineers often rely on judgement to decide target performance levels (life safety, collapse prevention, etc.)
- No clear codal definition for acceptable post-retrofit performance levels and return periods / hazard levels for retrofitted buildings
- Whether full ductile detailing compliance is mandatory or partial in retrofit situations is often unclear
- Lack of codal provisions for integrated retrofit strategies for hybrid construction (RC frame + masonry infill, informal construction)
- Lack of knowledge on integration of non-structural elements
- Lack of clarity in risk-based prioritization and phased retrofitting strategies at city scale

4. Post-earthquake assessment of structures

IS 18289:2023 “Post Earthquake Safety Assessment of Buildings” [5] establishes a structured framework to determine a building’s suitability for continued occupancy after an earthquake, supporting authorities, engineers, and first responders in making timely, evidence-based decisions during post disaster situations. It outlines two levels of assessment: a Rapid Visual Survey (RVS) for quick, on-site classification of buildings into safe, restricted, or unsafe categories, and a Detailed Assessment for structures showing significant distress for retrofit design. The guideline emphasises on consistency, speed, and safety in post disaster inspections, encouraging the use of modern tools like drones to reduce risk to inspectors and accelerate data collection. By standardising assessment criteria, IS 18289 helps authorities prioritise repairs, retrofits, or demolitions, preventing premature re-occupancy of unsafe buildings and reducing the likelihood of secondary disasters.

The standard specifies parameters such as structural integrity, foundation stability, architectural vulnerabilities, and non-structural hazards, ensuring that decisions are based on both visible damage and underlying weaknesses. It also introduces a colour coded tagging system- green for safe, yellow for restricted use, and red for unsafe to guide immediate occupancy decisions (Table 4.1). The guidelines apply to a wide range of common building types, including residential, educational (schools, colleges, institutes, universities), healthcare facilities, police and fire stations, food and civil supply centres, transport hubs, power and communication infrastructure, disaster management facilities, business and mercantile premises, and governance buildings.

Table 4.1: Rapid Visual Screening with tagging to evaluate condition of structures

Tag	Damage	Typical Condition	Action
 Green	Minor	Non-structural cracks, no structural damage	Safe to use
 Yellow	Moderate	Cracks in members, localized damage	Restricted use, repair needed
 Red	Severe	Major cracks, deformation, partial collapse	Unsafe, evacuate

However, during Rapid Visual Screening (RVS), common misjudgements can occur, such as overlooking foundation distress, misinterpretation of masked damage due to infill walls or finishes, and underestimation of hidden structural deficiencies. Since tagging decisions directly affect public safety, engineers must take full responsibility and use careful judgment, proper interpretation, and follow established guidelines.

A format for post-earthquake assessment of existing structures is provided in IS 18289 [5].

A clear transition from emergency assessment to retrofit design is essential to ensure continuity and reliability in decision-making. After rapid tagging and preliminary evaluation, buildings classified as Yellow or Red must undergo a detailed engineering assessment, including material testing, structural analysis, and identification of deficiencies. At this stage, responsibility shifts from emergency safety judgment to systematic design, where retrofit strategies are developed based on codal requirements, data reliability, and performance objectives. This handover ensures that initial visual decisions are validated, refined, and translated into technically sound and accountable retrofit solutions.

5. Assessment of existing structures (not designed as per existing standards)

Existing buildings that are not originally designed in accordance with the principles and requirements of current seismic standards shall be subjected to a formal assessment.

The process begins with a preliminary evaluation, which involves a broad appraisal of the building's physical condition, structural integrity, and load carrying capacity, supported by simple calculations. If the preliminary evaluation indicates that the building's strength, overall stability, and integrity are satisfactory for given seismic demand, no further action is required. If deficiencies are identified, and unless specifically exempted, a detailed evaluation must be undertaken.

The preliminary evaluation is a rapid screening procedure intended to establish the actual structural layout, identify characteristics that may influence seismic vulnerability and estimate potential earthquake risk using conservative parameters. This method is primarily based on observed damage patterns from past earthquakes, supplemented by simple analytical checks, and is used to determine whether a building should proceed to detailed evaluation.

Under preliminary evaluation a site inspection by the design professional is mandatory to verify existing building data, collect additional information, and assess the condition of the structure and its components. These should include general information (e.g., number of storeys, plan dimensions, year of construction), structural system (e.g., description of vertical and lateral load resisting systems, diaphragm connections, basement and foundation systems), building type and soil classification, occupancy (building use and nature of occupancy), neighbouring structures (potential for pounding or falling hazards), general condition (material deterioration, past earthquake damage, alterations or additions affecting seismic performance), architectural features (elements influencing seismic behaviour, especially masonry infill wall locations), geological and foundation conditions (liquefaction susceptibility, slope failure potential, surface fault rupture risk) and special construction anomalies.

A detailed evaluation comprises of numerical checks on the stability and integrity of the entire structure, as well as the strength of individual members. Conventional design calculations for these checks shall be performed using modified demands and strengths in accordance with applicable codes. Conventional design calculations for such checks are typically carried out using modified demands and reduced strengths as per applicable codes. However, this conventional approach may underestimate the actual capacity of existing structures, particularly where material behaviour, redundancy, and reserve strength are not fully captured. Therefore, the adoption of higher levels of analysis and improved approximation

methods is encouraged to achieve a more realistic assessment of structural performance and to avoid over conservative or deficient retrofit decisions.

For buildings without drawings or with unauthorized modifications, assessment must rely on detailed field investigation and conservative assumptions, with retrofit strategies designed to account for unknowns and altered load paths.

A screening threshold is a set of predefined criteria used to determine whether a structure requires advanced analysis or can be assessed using simplified methods. Not all buildings require detailed nonlinear analysis, especially during preliminary assessment or retrofit planning. Screening thresholds can be used to identify cases where simpler linear or empirical methods are adequate, and it reserves advanced analysis for critical or complex conditions.

A building shall be classified as acceptable for continued use without mandatory seismic strengthening if it satisfies both configuration related checks and strength-related checks. Compliance with geometric and structural configuration requirements that influence seismic performance include continuity of load path, redundancy, plan and vertical geometry, weak storey/ soft storey, vertical irregularities, mass irregularity, torsional irregularity, proximity to adjacent buildings, short columns, intermediate levels (proper integration of mezzanines, lofts, or sub floors into the lateral load resisting system).

Compliance with global level stress limits for primary structural elements under seismic demand, include reinforced concrete (RC) frame columns in accordance with IS 456 [6] and IS 13920 [2], RC shear walls (with shear stress within code-defined limits for in plane and out of plane actions), RC masonry infill walls and moment resisting frames.

It is important to clearly distinguish between evaluation for immediate safety and evaluation for strengthening, as they differ in purpose, depth, and outcomes (Table 5.1):

Table 5.1: Evaluation for safety vs Evaluation for strengthening

Aspect	Evaluation for Safety	Evaluation for Strengthening
Objective	Determination of the building if safe for occupancy	Determine how to upgrade capacity to meet required performance

Aspect	Evaluation for Safety	Evaluation for Strengthening
Stage	Emergency / rapid assessment (post-earthquake or initial screening)	Detailed engineering assessment (pre-retrofit design)
Approach	Visual inspection, rapid screening (RVS), limited testing	Detailed analysis, NDT + destructive tests, modeling
Focus	Identification of immediate hazards (collapse risk, instability)	Identification of deficiencies in strength, stiffness, ductility
Output	Tagging (Green / Yellow / Red), occupancy decision	Retrofit strategy, design calculations, intervention scheme
Data requirement	Minimal, quick judgement-based	Comprehensive, data-driven with verification
Timeframe	Immediate / short-term	Medium to long-term (design and execution)

Common deficiencies such as soft storeys, floating columns, slab discontinuities, and ponding introduce irregular load paths and stress concentrations and make existing Indian buildings highly vulnerable to seismic damage.

6. Condition assessment of structures – a prerequisite for defining retrofit strategy

The primary objective of condition assessment is to ensure the safety of the structure and its occupants, while maintaining its intended functionality. Structural deterioration can significantly reduce the ability to withstand loads, increase the risk of failure or collapse. Regular assessments help in early identification of such vulnerabilities, timely interventions to prevent damage, enhance safety, and address serviceability concerns such as excessive vibrations or deflections. After the preliminary screening, the structure designated for strengthening to satisfy enhanced performance criteria shall undergo a comprehensive condition

assessment. This process involves determination of in situ material properties, residual strength, and other governing parameters essential for defining an optimum retrofitting strategy. The field evaluation is executed through a suite of non-destructive and partial destructive test protocols, conforming to the applicable provisions of IS 516 (Part 1 to Part 5).

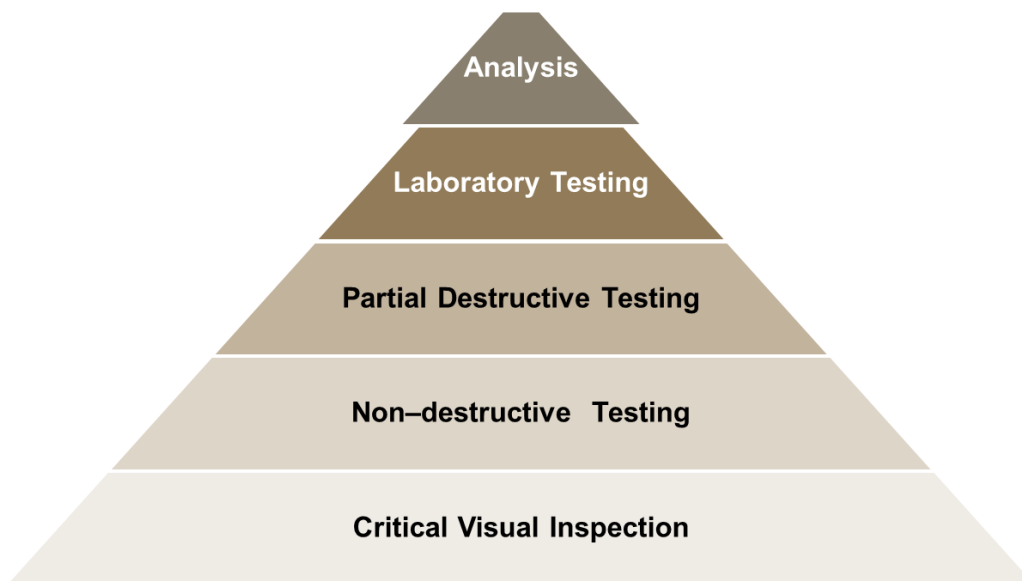


Fig. 6.1: The condition assessment pyramid

Different tools provide different types of information (Fig. 6.1):

- **Visual inspection:** Provides a qualitative overview of the structure's surface condition.
- **NDT methods:** Offer qualitative data on the in-situ properties of materials and the presence of hidden defects.
- **Laboratory testing:** Provides detailed information about the material composition, strength, and deterioration mechanisms.

Combining these tools creates a synergistic effect. The information from one method complements and validates the information from others, leading to a more comprehensive and reliable understanding of the structure's condition. Visual inspection might reveal cracking, which can then be investigated further using NDT to determine the extent and depth of the cracks and laboratory testing to understand the cause of the cracking. NDT might indicate a potential problem area, which can then be confirmed and characterized by core sampling and laboratory analysis. Non-destructive testing (NDT) results should be interpreted as indicative measures of in-situ condition rather than definitive design values.

Therefore, NDT findings must be correlated with engineering judgment, calibration data, and supplementary investigations, and should not be used directly as substitutes for characteristic material properties in design. The commonly used NDTs are as follows,

- **Rebound Hammer Test (Schmidt Hammer)** - to estimate surface hardness as an indirect measure of compressive strength
- **Ultrasonic Pulse Velocity (UPV) Test** - to evaluate uniformity, detect cracks/voids, and estimate quality
- **Cover Meter / Rebar Locator** - to locate reinforcement bars and measure concrete cover depth.
- **Half Cell Potential Test** - to assess the likelihood of reinforcement corrosion
- **Windsor Probe / Penetration Resistance Test** - to estimate compressive strength by measuring penetration depth of a steel probe driven into concrete
- **Ground Penetrating Radar (GPR)** - to map reinforcement layout, detect voids, and locate embedded utilities
- **Impact Echo Test** - to detect delamination, voids, and thickness variations
- **Radiographic Testing (X ray / Gamma Ray)** – to detect internal voids, honeycombing, and reinforcement placement

Effective NDT interpretation depends on a well-planned sampling strategy, adequate test density, and careful consideration of reliability. Tests should cover representative locations across the structure, as insufficient or uneven sampling can miss critical defects. Moreover, inherent variability in NDT results means findings must be interpreted cautiously, with proper correlation and engineering judgment to ensure reliable conclusions.

The common partially destructive testing methods are as follows:

- **Concrete Core Test:** to determine compressive strength, density, and durability by drilling cores
- **Pull-off / Bond Strength Test:** to evaluate surface tensile strength and bond quality of overlays/repairs

- **Penetration Resistance Test (e.g., Windsor probe):** to estimate the in-situ compressive strength and quality of concrete, particularly in existing structures.

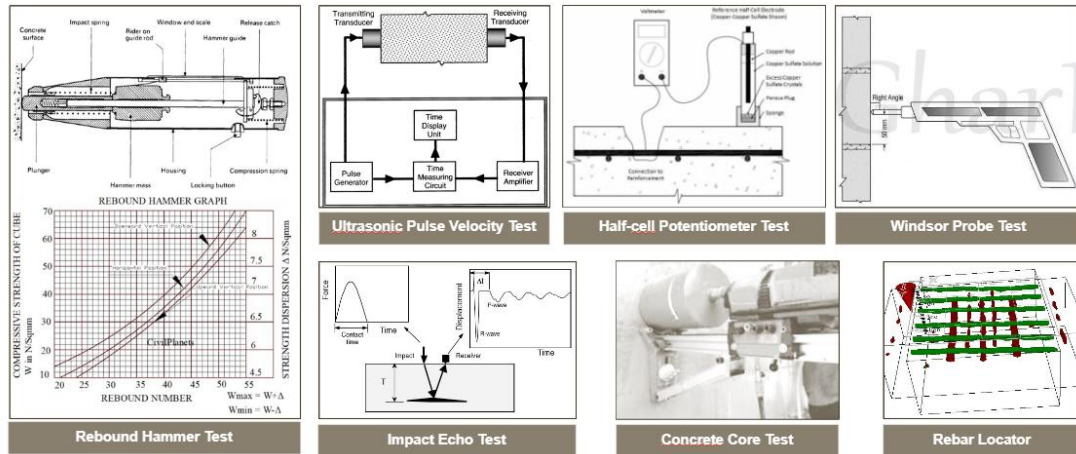


Fig. 6.2: Non-destructive, partially destructive tests

The knowledge factor represents the level of uncertainty in the available information regarding the structural configuration and the current condition of materials and components of an existing building. It links uncertainty to design by reducing assumed structural capacity as confidence in data decreases, thereby ensuring progressively conservative retrofit decisions for lower knowledge levels. Though IS 15988 [3] does not explicitly mention or correlate retrofitting strategy to knowledge factor, a guideline on retrofitting considerations has been presented in below table.

Table 6.1: Guideline on retrofitting approaches based on knowledge factor

Range	Description (IS 15988)	Data confidence	Implication on design values	Recommended retrofitting approach
1.00	Complete documentation + testing	Very High	Use actual measured properties	Highly optimized, localized retrofit (member strengthening, minimal intervention)
0.90 - 0.80	Good documentation, limited / no testing, minor deterioration	High	Slightly reduced confidence; near-design values	Targeted strengthening with some conservatism (jacketing, wrapping, joint strengthening)
0.70	Incomplete documents or extensive testing compensating gaps	Moderate	Use reduced material properties	System-level retrofit (combine member strengthening + addition of shear walls / bracing)
0.60	Incomplete data + limited testing + high variability	Low	Use conservative lower-bound values	Robust retrofit required with redundancy (global strengthening, significant additions)
0.50	Very Less knowledge of structure	Very Low	Assume worst-case properties and detailing	Highly conservative/global intervention (new lateral systems, major strengthening, possible partial reconstruction)

Recent advances in sensing technologies and Structural Health Monitoring (SHM) systems have enabled continuous monitoring of structural performance and real-

time assessment of damage. In earthquake-prone regions, sensor-based monitoring offers significant potential for rapid post-earthquake damage assessment,

Sensor-based Structural Health Monitoring (SHM) systems enable rapid post-earthquake damage assessment by providing real-time measurements of structural response. Changes in vibration characteristics, strain, displacement, or tilt can be used to identify damage, allow engineers and authorities to quickly evaluate structural safety, prioritize inspections, and support emergency response and recovery efforts.

7. Structural analysis and evaluation

Once the preliminary screening is done, a competent structural engineer shall undertake a comprehensive structural analysis to quantify the residual strength of the structure and identify deficiencies relative to current codal design demands. In this process, the engineer may refer to IS 18299: Structural Design and Proof Checking Consultancy Services for Structures – Requirements [7]. While several advanced standards exist for design and construction, the frameworks for structural audit and retrofitting remain limited in availability and scope. However, the Bureau of Indian Standards (BIS) is actively working toward developing and strengthening these provisions.

The engineer shall develop structural models that reflect the actual geometry, material properties, and boundary conditions of the structure and perform detailed analysis to evaluate the ultimate and service load capacities of structural members. The engineer shall identify overstressed elements, detailing deficiencies, and potential failure mechanisms. The engineer shall carry out seismic vulnerability assessment in accordance with IS 1893 [1], using advanced methods such as nonlinear static (pushover) or nonlinear dynamic (time-history) analysis. Linear analysis is appropriate for routine assessment of regular and lightly damaged structures, while nonlinear analysis is required for irregular, heavily damaged, or performance-critical buildings where realistic behaviour and failure mechanisms must be explicitly captured. The assessment shall evaluate member-level and global structural capacity, inter-storey drift, and likely failure modes. The engineer shall compile the findings into a comprehensive diagnostic report, including analytical results, material property data, identified deficiencies, numerical outputs, and supporting photographic or schematic documentation of the structural condition.

While advanced software can perform sophisticated linear or nonlinear analyses, the accuracy of results depends fundamentally on assumptions, input data, and

modelling choices made by the engineer. It is important to note that while nonlinear static (pushover) analysis is a powerful tool, its results must be interpreted with caution, particularly for irregular buildings. Pushover analysis is based on simplified load patterns and assumptions of force redistribution, which may not adequately capture complex behaviour such as torsion, higher mode effects, or load path discontinuities commonly present in irregular structures. Engineers must apply critical judgement, validate assumptions, interpret results cautiously, and cross-check findings with physical behaviour and field observations, which ensures that the analysis reflects realistic structural performance rather than merely computational precision.

Based on the assessment findings, the structural engineer shall develop a retrofit strategy in compliance with relevant Indian Standards and, where required, applicable international standards. The engineer shall design the retrofit measures to achieve the target performance level and satisfy codal requirements, including appropriate load combinations and detailing provisions. In doing so, the engineer shall select suitable retrofitting techniques by considering the severity of structural deficiencies, material characteristics, desired performance objectives, site constraints, and cost implications.

For seismic retrofit projects, independent peer review and proof checking are strongly recommended to enhance reliability and accountability. Given the uncertainties in existing structures such as incomplete data, material variability, and modelling assumptions, a second-level technical review helps validate analysis methods, assumptions, and design decisions.

Some of the commonly adopted retrofitting techniques include reinforced concrete jacketing, steel plate jacketing, addition of shear walls, addition of seismic bracing, external post tensioning, use of energy dissipating devices, fibre reinforced polymer (FRP) confinement, etc. The structural engineer should produce detailed construction documentation, including reinforcement detailing, material specifications, quality control requirements, and method statement for each strengthening intervention.

8. Strategies for strengthening of concrete structures against earthquake

Seismic strengthening measures are implemented when existing structures do not meet required performance under earthquake demands. These measures can be broadly classified into member-level interventions, which focus on strengthening deficient structural elements, and global-level interventions, which

address irregularities in strength, stiffness, and mass distribution. The selection of an appropriate strengthening approach depends on the identified deficiencies, desired performance objectives, and applicable codal requirements.

Global retrofitting methods focus on modifying the structural system to improve overall seismic behaviour, ensuring better load distribution, reduced irregularities, and enhanced resilience.

Local-level retrofitting focuses on strengthening individual structural elements without significantly altering the overall structural system. These methods aim to enhance strength, ductility, and detailing of deficient members (Fig. 8.1).

A significant proportion of earthquake-induced structural damage arises from geotechnical failures such as liquefaction, seismic settlement, lateral spreading, slope instability, and soil amplification. These phenomena can compromise foundation support and alter seismic demands on structures, leading to excessive deformation, loss of stability, or collapse even when the superstructure itself satisfies seismic design requirements. Geotechnical assessment forms a key component of earthquake safety evaluation by addressing site-specific hazards such as liquefaction, seismic settlement, slope instability, and soil-structure interaction. Where deficiencies are identified, ground improvement and foundation strengthening measures may be required to ensure the effectiveness of structural retrofit strategies and enhance overall seismic resilience. Deficiencies identified during the assessment may necessitate geotechnical strengthening measures such as ground improvement, soil densification, grouting, stone columns, deep soil mixing, installation of additional foundations or piles, and stabilization of slopes and retaining systems. Addressing geotechnical vulnerabilities not only enhances foundation performance during earthquakes but also improves the overall effectiveness of structural retrofit interventions and contributes to increased safety, resilience, and post-earthquake functionality.

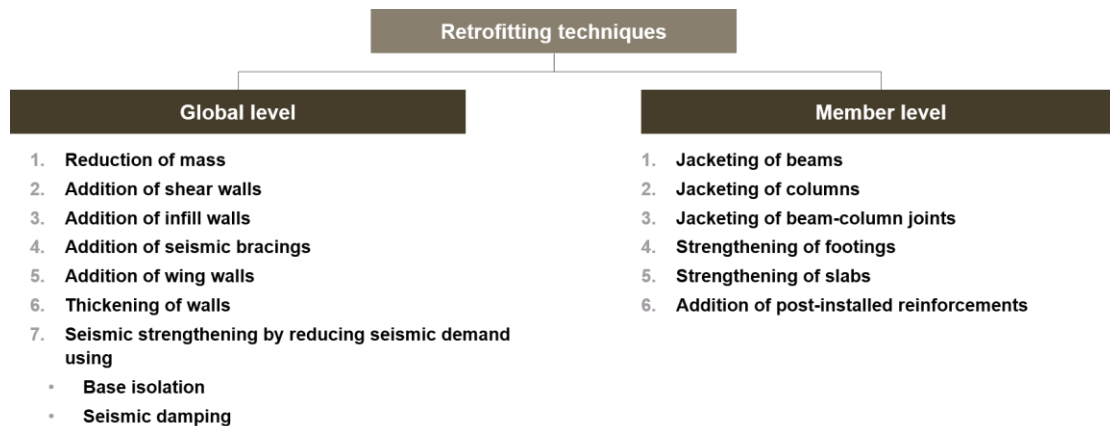


Fig. 8.1: Global and local level retrofitting techniques

8.1 Member level strengthening strategies

8.1.1 Concrete jacketing

In concrete jacketing, an existing beam, column or footing is encased with additional concrete and reinforcement to enhance its axial, flexural, shear, and ductility capacities. Depending on site constraints and performance objectives, jacketing may be applied on three sides or on all four sides, the latter being preferred for comprehensive strengthening that includes joint confinement. While three-sided jackets can improve vertical load bearing capacity, their effectiveness under seismic lateral loads is limited due to inadequate joint strengthening.

Key design requirements include:

- ✓ ensuring full composite action between existing and new concrete,
- ✓ proper anchorage of longitudinal and transverse reinforcement,
- ✓ adequate confinement detailing, and
- ✓ extension of jackets through slabs where flexural continuity is necessary.

The minimum specification of concrete jacketing shall be in accordance with the provisions of IS 15988 [3]. An example of concrete jacketing for columns has been shown in Fig. 8.2.

For effective load transfer, post-installed rebar connections are used to embed longitudinal bars into the existing concrete. Additionally, shear connectors are provided to ensure the monolithic behaviour between the existing concrete and the concrete overlay. Utmost attention must be provided to ensure the connections are designed as per relevant standards. In absence of local standards, reference may be made to international standards like EN 1992 [8], EOTA TR 069 [9] and EOTA TR 066 [10]. These connections should be essentially designed for performance under seismic conditions.

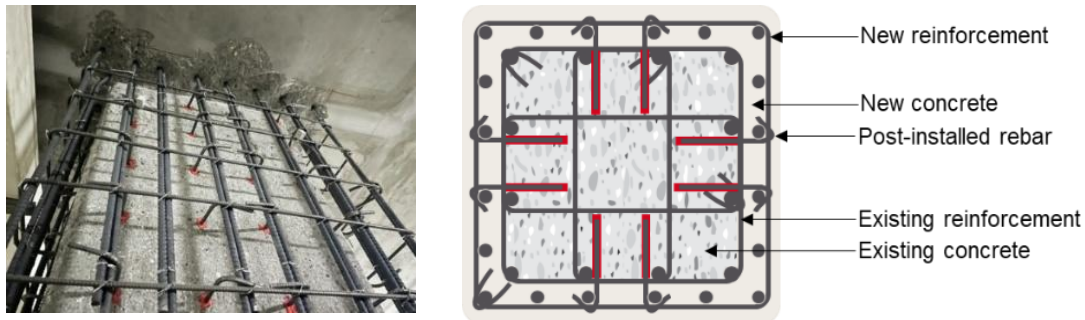


Fig. 8.2: RC jacketing of columns

Proper interface preparation, provision of shear connectors, compatibility considerations, and checks on foundation capacity for column jacketing are essential to ensure effective composite action and reliable seismic performance. The impact of increased stiffness and mass on global structural response shall also be evaluated, and jacketing should be complemented with system-level interventions where required. Special attention shall be given to execution quality, as poor workmanship can significantly compromise the effectiveness of jacketing. Anchorage failures, due to insufficient embedment length or improper installation of dowels, may prevent proper force transfer between old and new concrete. Additionally, inadequate curing can result in reduced strength, increased shrinkage cracking, and poor bond characteristics. Therefore, strict quality control during construction, including inspection of reinforcement placement, anchorage details, and curing practices, is essential to ensure the intended performance of the retrofit.

8.1.2 Steel jacketing

Steel jacketing strengthens a concrete member by wrapping it with steel plates. A small gap between the steel and the concrete is provided and is filled with high-strength, non-shrink grout to achieve full composite action.

The steel jacket provides additional confinement, increases member stiffness, and improves ductility under seismic or other extreme loading conditions. During design, the steel thickness and yield strength are selected to achieve the required confinement pressure. Proper anchorage at the ends is provided to transfer axial and shear forces and splices and welds are carefully design to maintain continuity of the steel shell.

The effectiveness of steel jacketing (Fig. 8.3) depends on achieving a uniform and reliable bond between the steel jacket and the existing concrete surface. This is

typically achieved through the use of post-installed anchoring or welded systems, which ensure that the steel jacket act compositely with the concrete core under axial and lateral loads. The design of post-installed anchorage in concrete shall be carried out in accordance with IS 1946 Part 2 [11] and the anchors shall be checked for adequacy for seismic design requirement. Preventing de-bonding at the interface is essential to achieve the intended enhancement in flexural and shear resistance.



Fig. 8.3: Steel plate jacking of columns

The performance of this system depends heavily on execution. Poor workmanship such as misalignment, inadequate welding, or gaps in the jacket can reduce effectiveness. Anchors must be properly designed and installed; anchorage failures can prevent load transfer and compromise the retrofit. Proper curing of the grout is also essential insufficient or uneven curing can lead to weak bonding and loss of composite action.

8.1.3 Shear Strengthening of beams and slabs using post-installed reinforcements

A novel shear strengthening approach (Fig. 8.4) employs post installed chemical anchors without baseplate confinement to enhance the shear capacity of structural members, delivering a high performance, value engineered connection that is straightforward to execute. This shear strengthening method uses epoxy mortar with threaded rods and a filling set of nuts and washers to create a high-performance connection. Installed much like an adhesive anchor, it involves drilling to a set embedment depth, cleaning the boreholes, injecting epoxy, and inserting the rods. Once cured, the filling set is tightened to a specified torque,

ensuring reliable load transfer. The solution is granted a national general construction technique permit (aBG) Z-15.5-383 by DIBt and uses the provisions for Design assisted by testing contained in Annex D of EN 1990 [12]. The resistance model used is fully aligned with the design requirements of DIN EN 1992-1-1/NA [13]. The necessary checks follow principles of DIN EN 1992-1-1/NA [13].

One of the most common failure mechanisms which are observed in structures is the one which happens due to punching shear effect. It occurs when a concentrated load from column causes “punched through” in slabs or foundations. This is a localized shear stress that develops around the perimeter of a column or load-bearing element where it connects to a slab or foundation. The similar technology with post-installed systems is used for strengthening concrete member (flat slab, foundation etc.) against punching shear failure. The installation and design methods are same as for shear strengthening technique as explained in earlier section.

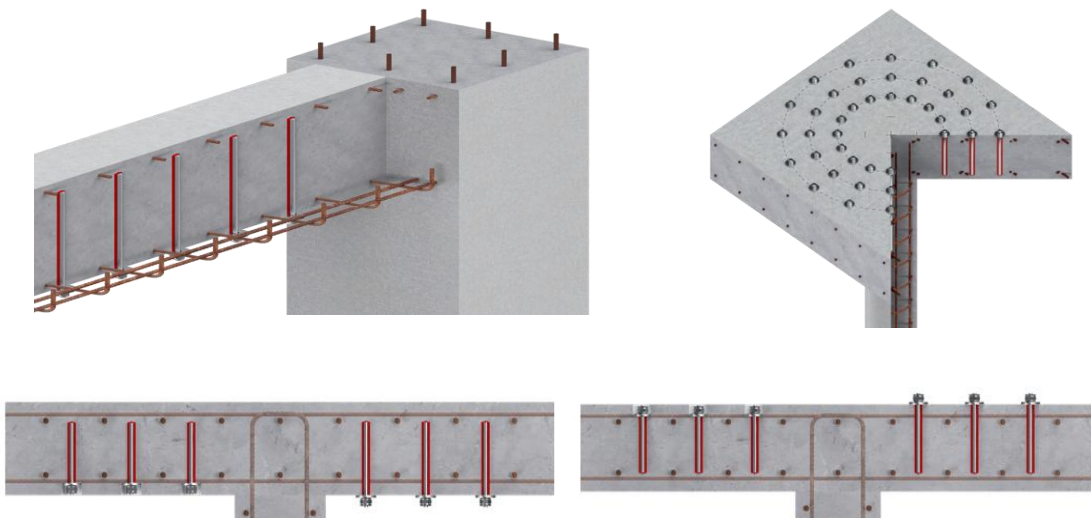


Fig. 8.4: Shear and punching shear strengthening of beams, slabs with post-installed reinforcements

8.1.4 FRP wrapping

FRP (Fibre-Reinforced Polymer) wrapping (Fig. 8.5) involves application of continuous sheets or laminates typically made of carbon, glass, or hybrid fibres bonded to the surface of a column using structural resin. When wrapped around the member, the FRP forms a confining jacket that enhances the behaviour of the concrete core.

This confinement increases compressive strength, improves deformability, and enhances ductility, making FRP an effective solution, particularly for improving shear capacity and overall seismic performance.

However, the effectiveness of FRP systems is highly dependent on proper installation and bonding. Poor workmanship such as improper surface preparation, uneven resin application, or inadequate fibre alignment can significantly reduce performance. Bonding issues are particularly critical; insufficient adhesion between the FRP and concrete can lead to premature debonding, prevent the jacket from mobilizing confinement.



Fig. 8.5: FRP wrapping of beam-column joint

8.1.5 Checklist for member level strengthening

RC jacketing:

Table 8.1: Checklist for RC jacking at site

Parameters	Yes/No	Remarks
Unsound concrete removed and surface roughened	☐	
Surface cleaned (dust / oil-free)	☐	
Saturated surface dry condition achieved before concreting	☐	
Dowels / connectors installed properly	☐	
Reinforcement as per design (Longitudinal bars + stirrups)	☐	
Anchor length and lap length correct	☐	
Formwork tight (no leakage)	☐	
Proper micro concrete grade used	☐	
Adequate compaction (no honeycombing)	☐	
Curing done properly	☐	

Steel plate jacketing:
Table 8.2: Checklist for Steel plate jacketing at site

Parameters	Yes/No	Remarks
Concrete surface prepared and cleaned	☐	
Steel plate thickness as per design	☐	
Proper alignment (no gaps / misalignment)	☐	
Continuous welding done	☐	
Weld quality checked	☐	
Adequate end anchorage provided	☐	
Bolts/anchors installed correctly	☐	
Full grout filling ensured (pressure grouting)	☐	
No voids in grout	☐	
Corrosion protection applied	☐	

FRP wrapping:

Table 8.3: Checklist for FRP wrapping at site

Parameters	Yes/No	Remarks
Surface grinding and edge rounding done	☐	
Surface clean, dry, and crack-free	☐	
Primer applied uniformly	☐	
Fibre orientation as per design	☐	
Proper resin saturation	☐	
Overlap length maintained	☐	
No wrinkles / air bubbles	☐	
Proper bonding (no de-bonded areas)	☐	
Adequate curing conditions maintained	☐	
Protective coating applied (if required)	☐	

8.2 Mitigation of plan irregularities

When seismic deficiencies arise from irregularities in strength, stiffness, and mass, interventions must address the structural system as a whole. Such irregularities (vertical and plan) can significantly affect seismic performance.

- Vertical irregularities such as weak or soft storeys can be addressed through the introduction of RC shear walls, infill walls or steel braced frames within the deficient storey to restore stiffness and load path continuity.
- Plan irregularities can be mitigated by providing shear walls or braced frames placed strategically to balance stiffness and reduce eccentricity.

- Building with highly irregular plan geometries may be divided into independent dynamic units using seismic separation gaps (movement joints). The width of such gaps should comply with codal provisions to prevent pounding under maximum considered earthquake (MCE) displacements.

8.3 Global level strengthening strategies

In structures when multiple critical members or components exhibit inadequate strength and ductility, a suitable approach is to enhance the overall lateral stiffness and strength of the structure to reduce global displacement demands. The incorporation of braced frames or shear walls is an effective method in this regard. Such intervention may, however, increase force demands on other structural elements, necessitating their subsequent strengthening (member level).

Seismic isolation and supplemental damping are advanced and rapidly developing strategies for enhancing the seismic performance of structures. Base isolation functions by decoupling the superstructure from ground motion, thereby significantly reducing the seismic demand on structural elements. Energy dissipation systems (e.g. fluid viscous dampers, viscoelastic dampers and tuned mass dampers) reduce overall structural displacements by absorbing and dissipating seismic energy, in addition to reduction in seismic base shear.

8.3.1 Increasing strength and stiffness

Global stiffness and strength can be improved by introducing new lateral or longitudinal-load resisting elements, redistributing forces more effectively within the structure.

8.3.1.1 Addition of shear walls

Reinforced concrete or steel shear walls are introduced to enhance the overall lateral stiffness and strength of frame structures. They help reduce inter-storey drift, improve the distribution of seismic forces, and minimize torsional effects. In bridge structures, abutment walls and diaphragm walls perform a comparable role. These walls act as primary lateral force resisting elements that resist lateral forces. They help limit damage to gravity load-carrying members and improve energy dissipation during cyclic loading. The position, thickness, and reinforcement of the shear wall should be decided based on structural analysis and performance goals. This ensures the upgrade not only increases strength but also improves ductility and post-yield stability. It is also important to plan construction sequence properly, provide adequate connections with beams and

slabs, and ensure the new wall and existing frame deform together. This helps the structure behave as a single unit and satisfy seismic design requirements.

This requires the reinforcement bars to be embedded into the existing concrete structures as post-installed rebar connections. Utmost attention must be provided to ensure the connections are designed as per relevant standards (e.g., EN 1992 [8] and EOTA TR 069 [9]). These connections should be essentially designed for performance under seismic conditions.

When adding new shear walls to an existing frame, it is important to carefully check how loads will flow, ensure stiffness compatibility, and verify that the foundation can support the additional demands. This helps avoid torsion problems or excessive stress in nearby members (Fig. 8.6).

It is also important to clearly demonstrate the effectiveness of the retrofit by preparing before-and-after stiffness distribution diagrams and analytical results. These illustrations help in visualizing how the structural behavior changes after the introduction of shear walls. They show improvements in lateral stiffness, reduction in drift concentrations, and better distribution of forces across the structural system. Such comparisons are valuable not only for design validation but also for communication with stakeholders and regulatory approvals.

Careful attention should be given to architectural and functional aspects. Adding shear walls can change how space is used, affect movement inside the building, obstruct doors or windows, and alter the appearance. In occupied buildings, construction can disturb daily activities, so work may need to be done in phases, with temporary supports or shifting of services. Planning ahead helps reduce these issues, for example, by placing walls in less important areas or aligning them with existing partitions.

Good coordination between structural and architectural teams is important. This ensures the retrofit not only improves structural safety but also maintains the building functionality and occupants comfort.

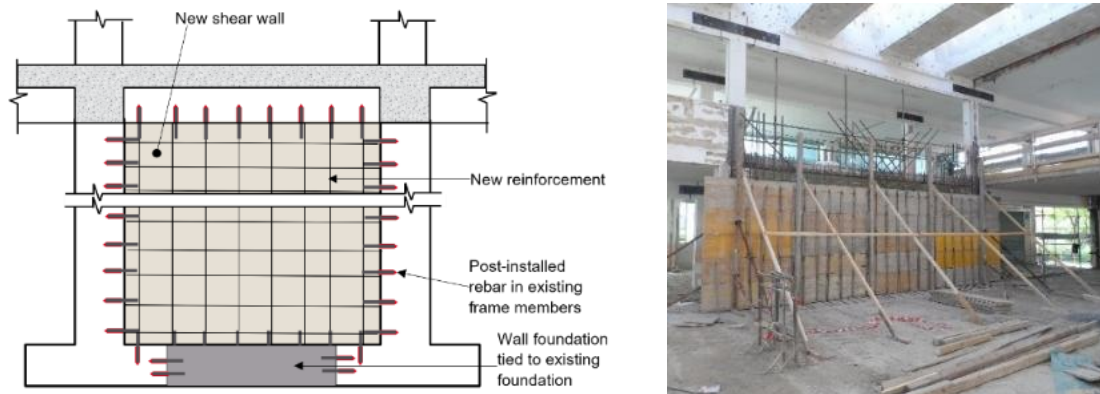


Fig. 8.6: Addition of new shear wall and shear wall in construction

8.3.1.2 Addition of braces

Addition of steel braces is a common method to improve the lateral load resistance of existing structures. Braces, usually arranged in diagonal, X, V, or K patterns, increase the structure's stiffness and strength and help in dissipating forces from earthquakes. While their lateral stiffness and strength are generally lower than those of RC shear walls, braced frames impose significantly less additional mass, thereby limiting increases in seismic inertial demand in accordance with IS 1893 Part 1 [1] response spectrum principles. Effective integration into an existing RC frame requires rigorous connection design, as substantial axial and shear forces must be transferred between the bracing system and the primary structure.

When integrating braces into an existing frame, gusset plates, post-installed anchors, or welded connections are used to ensure proper force transfer. The design of post-installed anchorage in concrete shall be carried out in accordance with IS 1946 Part 2 [11] and the anchors shall be checked for adequacy for seismic design requirement.

Fig. 8.7 shows an example of a concrete building strengthened with an externally added braced frame.



Fig. 8.7: Building strengthened with external braced frame

8.3.2 Base Isolation systems

Seismic base isolation is a disaster mitigation and retrofitting strategy that reduces earthquake induced demands on a structure by decoupling the superstructure from ground motion through flexible isolation devices. By introducing isolators such as laminated elastomeric bearings, lead rubber bearings, or friction pendulum systems at a designated isolation interface (e.g., between columns and foundations, at plinth level in buildings, refer to Fig. 8.8), the fundamental period of the structure is lengthened. This is attributed to increased flexibility of the building through an increased time period which reduces seismic base shear and acceleration transmitted to the superstructure. This technology enhances safety, durability, and seismic resilience, and in new construction, particularly mid-rise buildings and medium span bridges, can enable reductions in member sizes, reinforcement quantities, and foundation demands due to lower design seismic forces. For retrofitting, base isolation can be a viable solution from both a design and execution perspective, provided that structural detailing, load path continuity, and site conditions permit practical installation. IS 1893 Part 6 [14] gives conceptual guidelines on base isolation technology. Design and detailing of base isolation- International standard EN 15129 [15] for anti-seismic devices including base isolation and damping and FEMA 356/547 for retrofit applications, ensuring performance objectives are met under both Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) levels. The entire structure is analysed

with the stiffness of isolators and the elastic (laminated elastomeric isolators) / nonlinear properties of isolators (lead rubber isolators, friction-based isolators, high damping rubber isolators etc.). Using base isolation technology, the uniqueness and aesthetics on the original heritage structure is maintained intact even after its seismic retrofitting for improved performance during the earthquakes. In order to implement the base isolation as a retrofit scheme, evaluation of an existing structure's dynamic properties using ambient or forced vibration tests is essential for designing base isolation systems. These results guide numerical studies, which help determine the optimal location of isolators and the most suitable type of isolation system for effective performance [16].

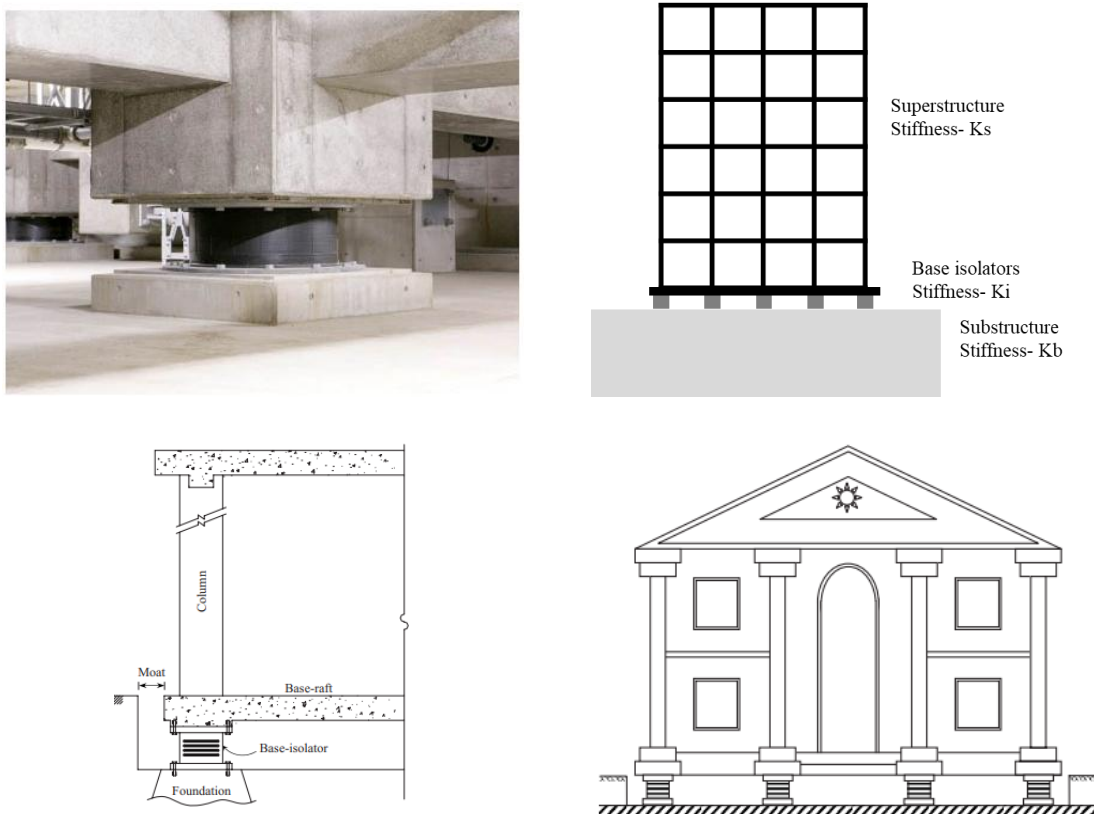


Fig. 8.8: Base Isolation system in buildings

8.3.3 Supplemental damping systems

Seismic dampers are supplemental energy dissipation devices incorporated into structural systems to enhance effective damping and reduce seismic demand. During earthquake excitation, these devices dissipate a portion of the input kinetic energy, primarily by converting it into heat through mechanisms such as viscous fluid motion, frictional sliding, metallic yielding, or tuned mass interaction, thereby

reducing the dynamic response of the structure. The resulting increase in equivalent damping ratio leads to a reduction in design seismic base shear. Dampers may be configured in various forms, including diagonal bracing elements between columns and foundations, horizontal link elements at supports, or integrated within braced frames, depending on performance objectives and architectural constraints (Fig. 8.9). For retrofitting, dampers offer an effective means of improving seismic performance with minimal alteration to the primary load bearing system, provided that detailing, load path continuity, and site conditions permit their installation.

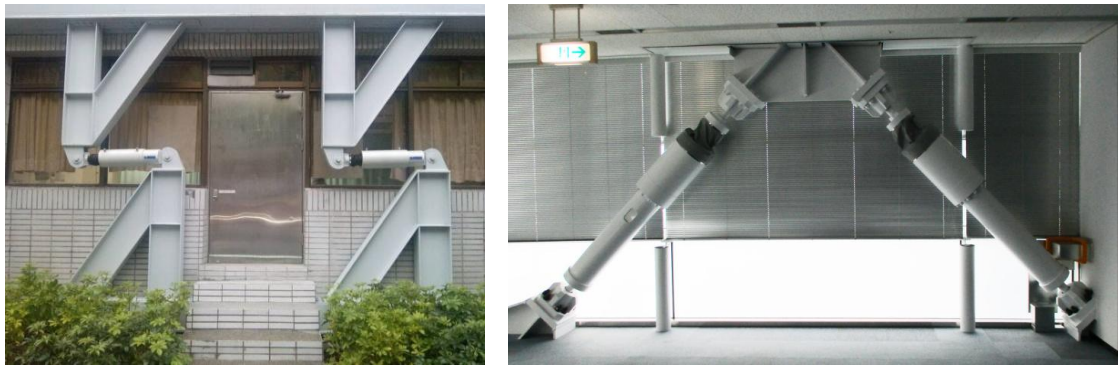


Fig. 8.9: Seismic dampers in buildings

9. Post-installed connections against seismic loading

Structural and non-structural connections including retrofitting or strengthening applications both need to be designed to withstand seismic force for seismic zone moderate to high (zone III and above). While structural applications obviously require seismic design for safety and sustainability of structure situated in seismic prone, damage of non-structural connections can also lead to significant damage, safety, economy and emergency services etc.

9.1 Post-installed anchors in seismic loading

Post-installed anchors are integral part of retrofitting applications; whether any local level retrofitting (steel jacketing or any steel-to-concrete connections) or global level retrofitting (connections of bracing, supplemental dampers, base isolators etc. to existing concrete structure). Anchors under seismic loading are usually subjected to cyclic loading with significant amplitude and base material is supposed to be cracked beyond the serviceability limit state (i.e. > 0.3 mm) due to the potential significant deformations. These conditions must be considered in the prequalification and design of anchors. The ground accelerations induce deformations in a structure and the transfer of seismic actions to anchors

connecting structural and non-structural elements. This results in high-rate cyclic loading and cracks of changing width (Fig. 9.1).

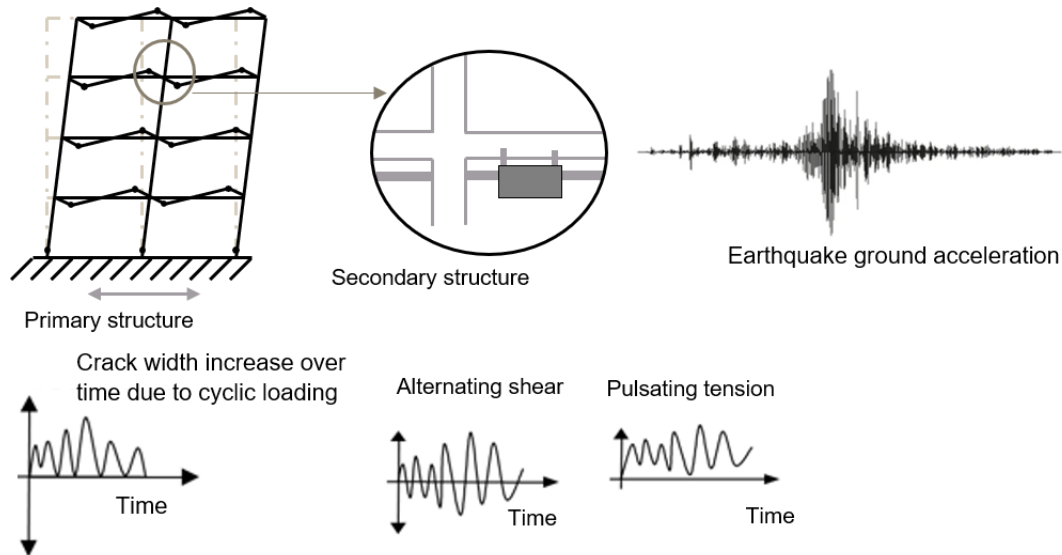


Fig. 9.1: Seismic acceleration induce deformation and results in cyclic loading in connections with larger and progressive crack width

In case of seismic cyclic loading the crack primarily generates at beam-column joint due to high shear loading. Post-installed connections experience larger crack width which widens over time due to cyclic loading. Moreover, there is a chance that the connections fall at the plastic hinge zone in the concrete structure (Fig. 9.2). According to national and international guidelines, post-installed connections are not allowed to design and install at plastic hinge locations as the larger crack and plastic hinge formation will affect the interlocking, keying or bonding between post-installed connections and concrete. In that case anchors will lose its performance drastically.

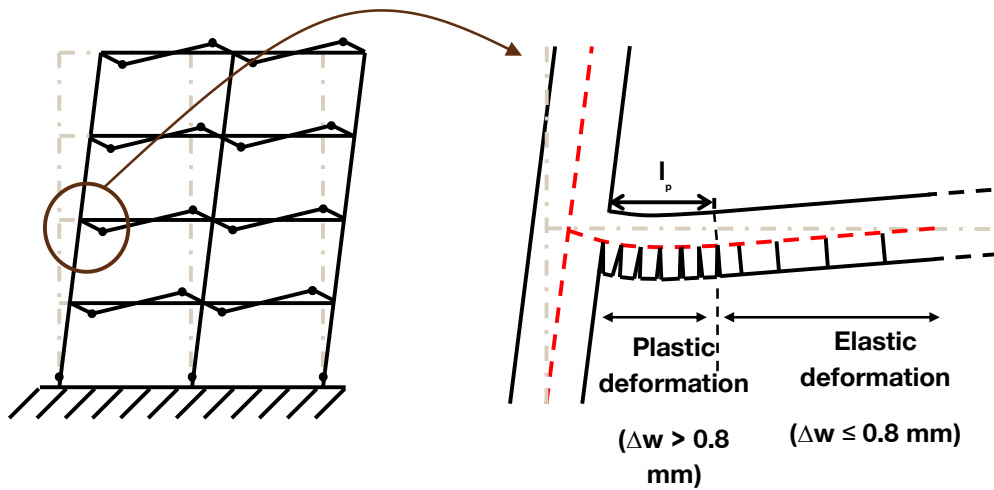


Fig. 9.2: Plastic and elastic zones in concrete members

The Indian standard for design and assessment of post-installed anchors IS 1946 [11] includes the design and assessment of anchors for a max crack width Δw of 0.8 mm in seismic condition. In plastic zone the crack width will likely exceed the limit of $\Delta w = 0.8$ mm, for which the anchors are assessed.

The crack width can reduce the performance of anchors around 30% to 70% for static and seismic loading. Fig. 9.3 shows the drop in resistance from uncracked to cracked concrete for static loading. Even the resistance varies from smaller to larger crack width for which seismic assessment is recommended to verify the performance of anchors.

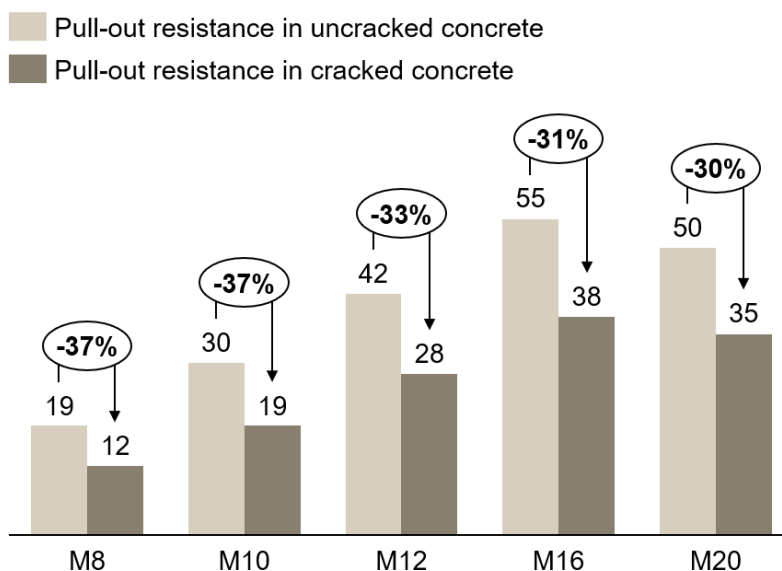


Fig. 9.3: Resistance reduction for crack width of 0.3 mm (static loading)

Fig. 9.4 shows the comparison of resistance between static loading (crack width ≤ 0.3 mm) and seismic loading (crack width ≤ 0.8 mm).

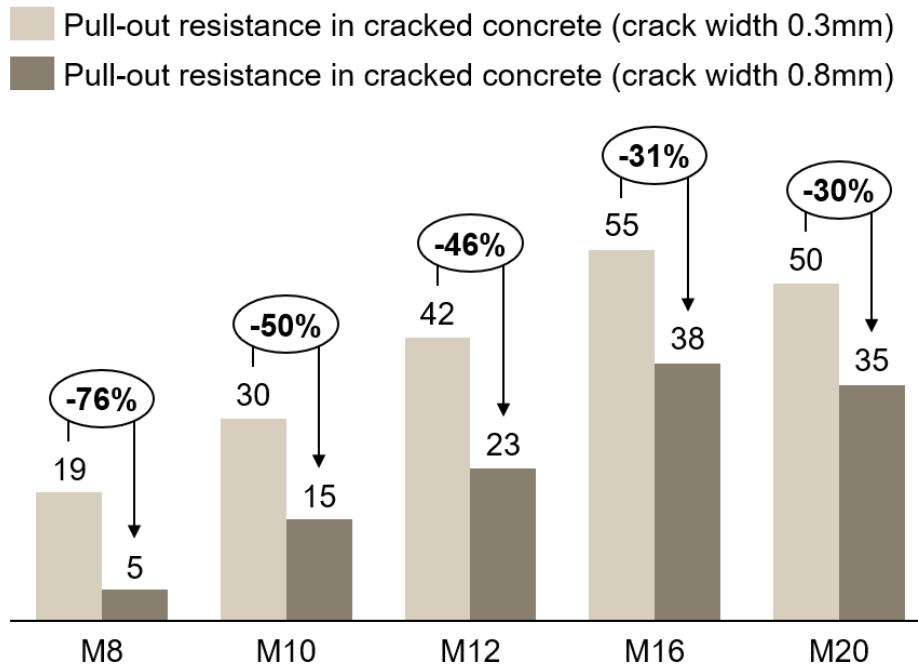


Fig. 9.4: Resistance reduction for crack width of > 0.3 mm (seismic loading)

9.2 Design and assessment guidelines for post-installed anchors in seismic

The Indian standard for the design of post-installed anchors, IS 1946 part 2 [11] mentions that seismic design is recommended for any post-installed anchors for seismic zone III and above which represents the moderate to high seismic zone as per IS 1893 part 1 [1]. The seismic design is governed by actual resistance derived from qualification and assessment as per IS 1946 part 3 [17] (adhesive anchors) and part 4 [18] (mechanical anchors) along with reduction factors for seismic.

- Factor to consider the influence of seismic actions and associated cracking large crack widths uneven tension stiffness of anchors in a group due to random crack distribution. It can vary from 0.75 to 1 depending on type of anchor and whether the application includes single or group of anchors
- Reduction factor to consider inertia effect due to clearance of hole between anchor and baseplate, 0.5 for with hole clearance and 1.0 for without any hole clearance

Displacement limitation of anchors under tensile and shear loads at damage limitation state (DLS) is also recommended to be considered in design to ensure the anchors remain operational after earthquake.

- To meet requirements regarding e.g., functionality and assumed support conditions are considered fulfilled
- When assuming a rigid support in the analysis the designer shall establish the limiting displacement compatible to the requirement for the structural behaviour.
(In a number of cases, the acceptable displacement associated with a rigid support condition is considered to be in the range of 3 mm)
- If deformations (displacements or rotations) are relevant for the design of the connection (such as, for example, on secondary seismic members or façade elements) it shall be demonstrated that these deformations can be accommodated by the anchors
- If anchors and attached elements shall be operational after an earthquake, the relevant displacements have to be taken into account

The design resistance is reduced linearly to account the limiting displacements with respect to actual displacement of anchors. The expected rotations are also derived from displacement and spacing between anchors.

Design of post-installed anchors are done using two concepts considering that fasteners are non-dissipative elements, and they are not able to dissipate energy by means of ductile hysteretic behaviour and that they do not contribute to the overall ductile behaviour of the structure.

Capacity design: This design concept is followed to

- protect against brittle failure of connections by a controlled and predictable failure mechanism during a seismic event
- resist maximum load that can be transferred by the attached structural steel element or baseplate at its ductile yield point including strain hardening and material overstrength effects

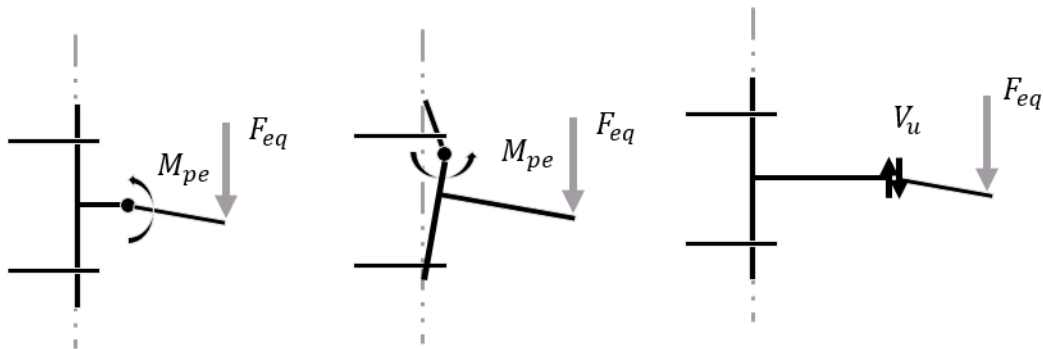


Fig. 9.5: Capacity design: yielding of baseplate and connections

Elastic design: This design concept is followed to

- design structures to remain elastic during the seismic event
- ensure structures can withstand the seismic action without experiencing significant damage or collapse using linear elastic behaviour

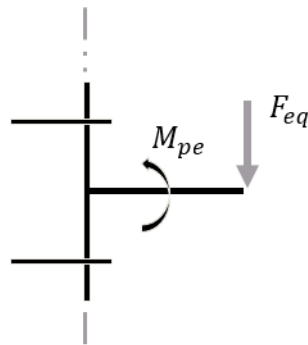


Fig. 9.6: Elastic design: yielding of baseplate and connections

The qualification and testing criteria is defined in IS 1946 part 3 [17] for adhesive anchor based on EAD 330499 and IS 1946 part 4 [18] for mechanical anchors based on EAD 330232.

Table 9.1: Qualification and Testing of anchors for seismic

Description	Crack width [mm]
Reference test - tension	0.8
Reference test - shear	0.8

Description	Crack width [mm]
Pulsating tension load	0.5 ($\leq 0.5 \cdot N/N_{\max}$) 0,8 ($> 0.5 \cdot N/N_{\max}$)
Alternating shear load	0.8
Cyclic crack opening with constant tension load	0.1 – 0.8

IS 1946 part 2 [11] recommends design of non-structural connections for seismic loading for structures situated in zone III and above. While structural applications obviously require seismic design for safety and sustainability of structure situated in seismic prone, failure of non-structural connections can also lead to significant damage, safety, economy and emergency services etc. Extensive research shows that the costliest repairs in most commercial buildings caused by a seismic event are found in non-structural systems, such as mechanical or electrical supports or utilities fastening. Many non-structural installations must be designed properly to meet safety requirements.

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Cost breakdown for different structural systems

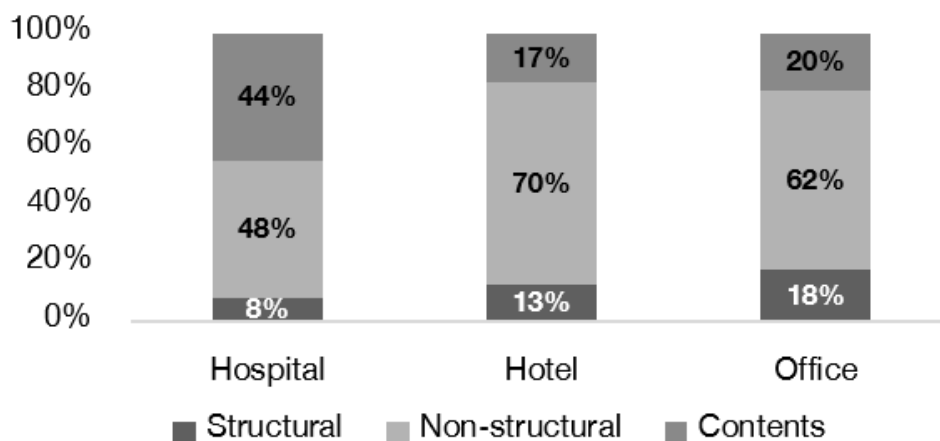


Fig. 9.7: Loss assessment of structural, non-structural components

The failure of non-structural connections can lead to serious injuries, damage to assets and production downtime (Fig. 9.8).



Fig. 9.8: Asset damage, production downtime for failure of non-structural connections

Post-installed anchors used for retrofitting applications where seismic load is important to consider in design of structures; anchors also need to be designed for the relevant reduced resistance derived from assessment for cyclic loading and larger crack width during seismic.

9.3 Post-installed rebars in seismic loading

Post-installed rebars are commonly used as connection between existing and new concrete members for strengthening applications. Lap splices are one of the preferred way to ensure a monolithic connection. Post-installed rebars play an important role for extension of any existing concrete members; column, beam, wall, slab etc. this splice connection is established when post-installed rebar is parallel to cast-in rebars of existing concrete elements. This type of splice (Fig. 9.9) is a non-contact splice since post-installed rebar installation involves drilling inside existing concrete without damaging the cast-in rebar. The primary load transfer is via local compression struts formed between the two rebars.

The lap splice length requirements for post-installed rebars subjected to seismic actions may be designed using the same provisions applicable to cast-in reinforcement under static loading conditions according to Eurocode 8 [19]. For post-installed rebars the suitability of the mortar to resist seismic (cyclic) loading must be checked in seismic assessments under various influencing parameters and values of design bond strength. These requirements are mainly motivated by the need to avoid a possible bond failure, which is obviously a non-desirable failure mechanism when large deformations are expected under cyclic seismic loading (e.g., plastic mechanism). All the other coefficient values and design calculations for seismic remain the same as for static loading.



a) Slab extension

b) Column extension

Fig. 9.9: Concrete to concrete lap splice connections

End anchorage connections (Fig. 9.10) are a category of post-installed rebar applications that usually enable the connection of members perpendicular to existing ones. This application is required when a lap splice with cast-in bars present in the existing member is not possible.



a) Beam to column

b) Column to slab/corbel

Fig. 9.10: Concrete to concrete end anchorage connections

For post-installed rebars the suitability of the mortar to resist seismic (cyclic) loading is checked in seismic assessments under various influencing parameters and values of design bond strength. The failure modes, yielding of rebar, concrete cone break-out, bond splitting are calculated based on the assumption related to the applicable crack width ranging between 0.3 mm and 0.8 mm. Smaller crack width can be expected to occur in members predominantly loaded in

compression. On the other hand, larger crack width should be assumed for members that might deform significantly (i.e., high ductility).

EN 1992-1-1 [8] includes the scope of design of post-installed rebar in lap splice connections and EOTA TR 069 [9] includes the scope of design for end anchorages against seismic loading. When properly designed and qualified, post-installed rebars can achieve performance comparable to cast-in reinforcement under seismic actions. Therefore, modern seismic design provisions generally aim to ensure that steel yielding governs before bond failure, enabling the connection to develop the required ductility and energy dissipation capacity of the structural system.

Repeated seismic load reversals can progressively reduce the bond strength between the adhesive, rebar, and surrounding concrete, leading to increased slip and reduced stiffness. Post-installed rebars crossing these cracks must maintain load transfer capability despite crack movements. Only systems specifically qualified through seismic testing and assessment (e.g., ETA according to the relevant seismic qualification procedures EAD 330087 [19], EAD 332402 [20], EAD 332347 [21]) should be used for structural applications in seismic regions. The bond strength degradation of post-installed bars subjected to cyclic loading is more severe compared to that observed for equivalent cast-in bars.

9.4 Post-installed shear friction connections in seismic loading

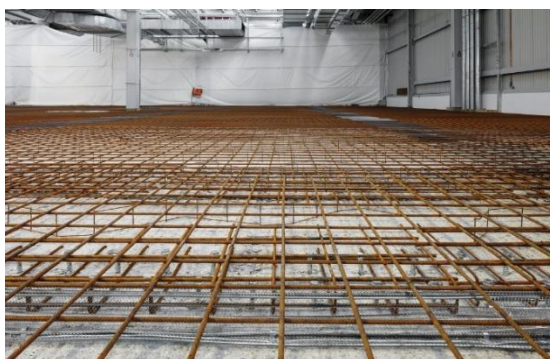
The interface shear transfer between concrete elements cast at different times must be verified. Conventional shear-friction models for reinforced concrete members cast at different times, as incorporated in state-of-the-art standards such as EN 1992-1-1 [8], primarily address situations where longitudinal shear stresses develop at the interface due to the addition of a new concrete layer, such as in wall strengthening or slab overlay applications. In such cases, interface shear resistance is provided through a combination of adhesion and aggregate interlock, together with friction mobilized by rebars acting as shear dowels. However, for these dowel bars to develop their full yielding capacity, adequate anchorage lengths are required, which may necessitate relatively thick concrete sections.

More recently, EOTA published the TR 066 [10] “Design and Requirements for construction works of post-installed shear connection for two concrete layers” to provide solutions for thin overlays, as commonly required for strengthening of reinforced concrete elements using special shear connectors. The seismic forces required to be transferred through an interface depend on the repair/strengthening application.

Verification of the resistances for the various failure modes shall be carried out for required seismic performance category in accordance with EN 1992-1-1 [8], depending on the design assumptions and intended application. The assessment shall consider the governing failure mechanisms, including:

- Steel yielding of the connectors.
- Concrete-related failure modes under tension loading in both the existing and overlay concrete, including concrete cone failure, splitting failure, pull-out failure, and blowout failure.
- Additional capacity design verifications, as required by the selected design approach, such as checks to prevent collapse of the existing concrete member following failure of the overlay, verification of connector anchorage in the existing concrete, and other application-specific detailing requirements.

Under seismic loading, post-installed shear-friction connections (Fig. 9.11) may experience degradation of adhesion, aggregate interlock, and frictional resistance due to repeated load reversals and crack movements. Consequently, a greater proportion of interface shear is transferred through the post-installed rebars acting as dowels, increasing demands on their anchorage and cyclic performance. Seismic design should therefore ensure adequate connector anchorage, prevent brittle concrete-related failures, and promote ductile steel yielding to maintain composite action and reliable shear transfer between concrete elements cast at different times.



a) Slab overlays



b) Wall overlays

Fig. 9.11: Shear-friction connections

9.5 Design and assessment guidelines for post-installed rebars in seismic

For seismic applications, the qualification philosophy of the three EADs is different because they address different failure mechanisms.

Table 9.2: Qualification and testing of post-installed rebars in seismic

EAD	Product/ Application	Seismic Qualification	Main Seismic Tests
EAD 330087	Post-installed rebar connections with mortar	Verify that the bond behavior remains equivalent to cast-in reinforcement under earthquake actions	Cyclic tension loading, cyclic crack opening/closing tests, determination of seismic bond efficiency factor
EAD 332402	Post-installed rebars with improved bond-splitting behaviour (EOTA TR 069)	Verify performance of moment-resisting and ductile connections under seismic actions	Cyclic bond-splitting tests, cyclic pull-out tests, cracked concrete tests, increased crack-width tests, determination of seismic resistance parameters for steel yielding, concrete cone and bond-splitting failures
EAD 332347	Concrete overlay shear connectors	Verify reliable shear transfer between existing and new concrete during earthquakes	Cyclic shear loading, reversed loading cycles, determination of seismic cyclic loading factor

With proper qualification, assessment and design, post-installed rebars can be made earthquake resistant and further leads to avoid any failure of structures and connections during earthquake.

10. Seismic strengthening of masonry structures

Masonry structures are highly vulnerable during seismic events due to number of reasons such as low tensile strength, brittle behaviour, heavy mass and poor

connections. The common failure modes include out-of-plane wall collapse, diagonal shear cracks, and separation at wall intersections.

The primary objective of seismic strengthening is to enhance the earthquake resistance of a damaged building during the repair process, ensuring greater safety in future seismic events. This process may include several key interventions –

1. **Enhancing lateral strength** in one or both directions by increasing the cross-sectional area of columns and walls, or by adding new structural elements such as additional walls and columns.
2. **Improving structural integrity** by establishing effective connections among load-resisting components. This ensures that inertia forces generated during seismic vibrations are properly transferred to elements capable of resisting them. Critical connections include those between roofs or floors and walls, between intersecting walls, and between walls and foundations.
3. **Eliminating structural weaknesses** or features that cause stress concentrations. Examples include irregular distribution of load-resisting members, sudden changes in stiffness between floors, large mass concentrations, and oversized wall openings lacking adequate edge reinforcement.
4. **Preventing brittle failure modes** by ensuring appropriate reinforcement and secure connections among structural members, thereby promoting ductile behavior under seismic loads.

Different types of masonry construction are discussed in Table 10.1.

Table 10.1: Different types of masonry construction

Category	URM (Unreinforced Masonry)	RM (Reinforced Masonry)	CM (Confined Masonry)
			
Basic Definition	Masonry with no reinforcement	Masonry with embedded steel reinforcement	Masonry confined by RC tie-columns and beams
Structural Concept	Load carried only by masonry	Composite action of masonry + reinforcement	Masonry panel confined by RC elements
Construction Method	Simple brick/block construction	Reinforcement provided within masonry + bands	Masonry built first, then RC columns & beams cast
Reinforcement Type	None	Vertical bars + RC bands	RC tie-columns + bond beams
Seismic Features	None	Partial seismic features	Full seismic-resistant system
Key Elements	Only brick masonry	Corner rebars + lintel band	Tie-columns + tie-beams + bond beams
Load Transfer Mechanism	Brittle masonry action	Reinforced masonry action	Confinement + box action
Integrity of Structure	Poor	Moderate	Excellent
Crack pattern	Early diagonal + horizontal cracks	Cracks controlled near bands	Distributed cracks + confined behavior
Failure Mode	Sudden collapse	Progressive cracking	Controlled failure (flexure + shear)
Seismic Performance	Very poor	Moderate	Excellent
Strengthening techniques	Corner vertical bars + MS lintel band	Wire mesh + plaster + grouting	Confinement itself

The commonly employed techniques for retrofitting of masonry structures include the following

Local Strengthening Techniques (Wall-level)

1. **Center Core Technique** (vertical steel bar is inserted into drilled holes in walls and grouted to bond with masonry – this improves vertical load transfer and ductility)
2. **Ferrocement Jacketing** (wire mesh + cement mortar applied to wall surfaces which increases shear strength and confinement)
3. **FRP Wrapping** (fibre sheets bonded with epoxy enhances tensile and shear capacity - minimal weight addition, good for heritage buildings)
4. **Grouting and Repointing** (injecting cementitious grout into cracks and voids, which improves mortar bond between bricks and restores integrity without major structural changes)

Global Structural Strengthening

1. **Diaphragm Strengthening** (strengthening floors and roofs to act as rigid diaphragms to ensure lateral loads are transferred to shear walls)

Hybrid / System-Level Strengthening

1. **Steel Bracing Systems** (diagonal steel braces added to frames provides lateral stiffness and energy dissipation - often used in combination with wall strengthening)

Indian earthquake damage studies highlight repeated causes of failure and success, which guide the following practical Do's and Don'ts for masonry structures in Table 10.2.

Table 10.2: Do's and Don'ts as per Indian Earthquake damage evidence

Do's	Dont's
Provide horizontal bands (lintel, roof, plinth)	Do not construct plain URM in seismic zones
Use corner and junction reinforcement	Do not rely only on crack stitching

Do's	Dont's
Ensure good wall-roof connection	Avoid poor wall-roof bonding (causes sliding)
Strengthen openings with bands	Avoid large unreinforced openings
Maintain symmetrical layout	Avoid irregular building shapes
Use good quality mortar and bonding	Do not use weak mortar/bricks
Prefer confined masonry construction	Avoid lack of load path continuity
Ensure box action of structure	Do not ignore out-of-plane wall stability

In the Indian context, a vast majority of buildings (>85%) are non-engineered URM, built with low construction cost, using local materials, and due to informal housing sector dominance. Seismic safety needs to focus on simple, replicable, and low-cost interventions rather than complex structural upgrades.

Techniques such as horizontal bands, ferrocement overlays, vertical reinforcement, and improved connections significantly enhance structural integrity and enable box action, thereby transforming brittle failure modes into more ductile and predictable behaviour.

Transitioning toward confined masonry construction for new buildings and incremental retrofitting of existing URM stock offers the most practical and scalable solution for reducing earthquake risk in India.

These guidelines emphasize that proper reinforcement, connectivity, and structural integrity are essential to prevent brittle failures observed in Indian earthquakes.

It also shows that simple, low-cost measures (bands, mesh, grouting, vertical reinforcement) are far more effective and scalable for housing safety in earthquakes than complex or purely repair-based methods [19].

11. Requisites of structural audit

According to the National Building Construction Standards (NBCS 2026 [20]), all buildings must undergo periodic structural evaluations. The building owner is responsible for initiating a structural audit or inspection by a registered or empanelled expert structural engineer. This should first be conducted in the tenth

year following the issuance of the occupancy certificate, and subsequently every five years. The findings from each audit must be submitted to the relevant authority for official recordkeeping.

If a building shows any signs of structural problems such as visible cracks, damage, or other indications of distress, the owner is required to arrange for an inspection right away, without waiting for the regular or scheduled inspection timeline. Such issues must be treated as urgent to ensure safety and prevent further deterioration.

In cases where the building is taller than 50 meters or falls under the category of special structures, the evaluation becomes more stringent. These types of buildings must be inspected only by a qualified expert structural engineer who has the necessary expertise and experience to assess complex structural systems accurately.

If the structural audit recommends any measures to ensure the safety and stability of the building, the owner must complete these actions within the deadline set by the authority in order to retain occupancy rights. This may include carrying out repairs, restoration, strengthening, or retrofitting works as advised in the audit report. If the owner does not take the required action within the given timeframe, the authority or an agency appointed by it has the right to carry out the necessary work and recover the cost from the owner.

After the inspection and completion of all required corrective measures, the authority or its approved expert will issue a certificate confirming that the building complies with the required standards. However, if the inspection identifies any deficiencies, violations, or structural weaknesses, the authority will direct the owner to fix these issues within six months. Failure to do so within this period will result in the building being officially declared unsafe or unfit for occupancy.

While the typical inspection cycle ranges from three to five years, it must not exceed five years under any circumstances.

Similar requirement has been captured in “**Uttar Pradesh Building Construction and Development Byelaws 2025**” - Byelaws for Urban Development Authorities.

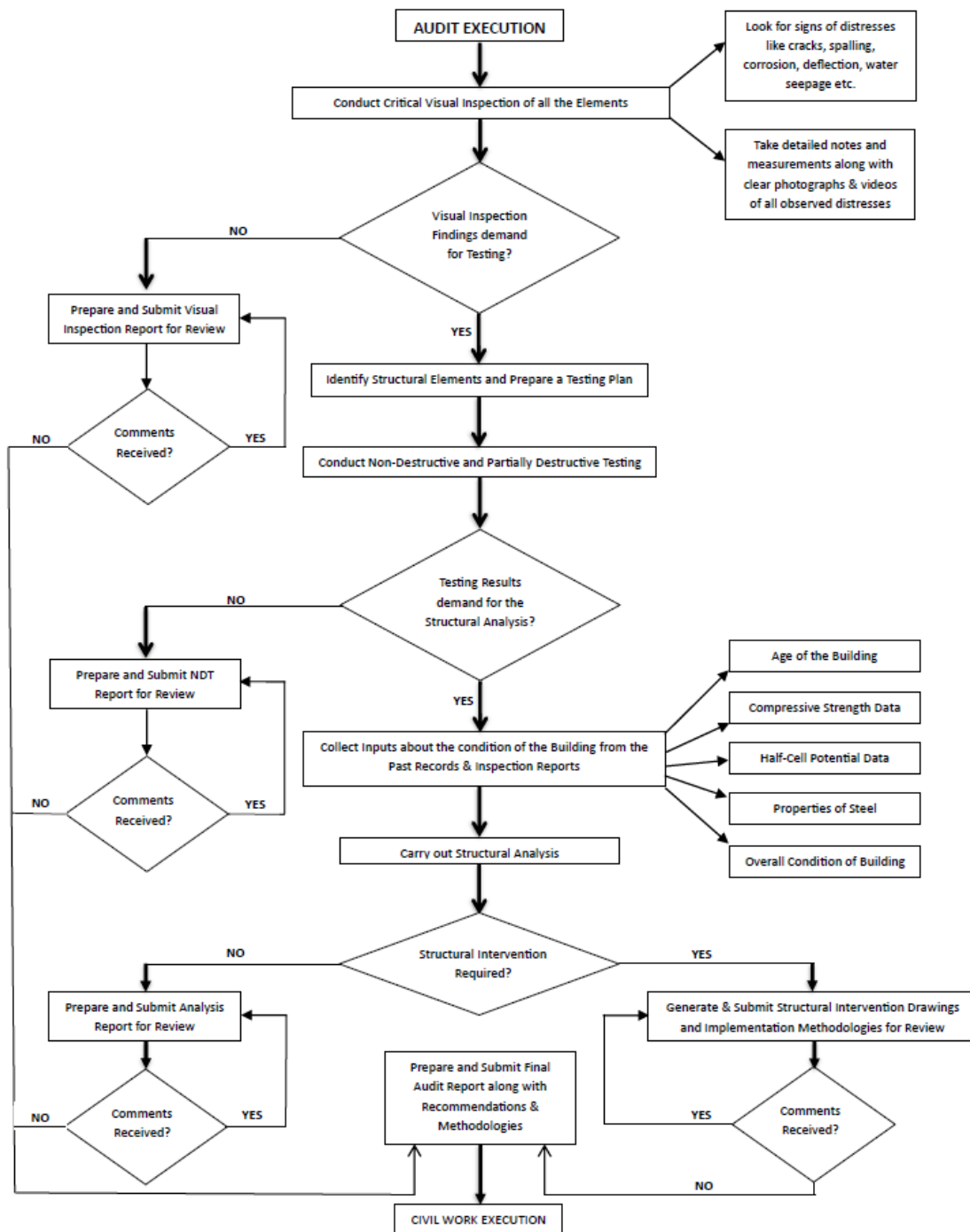
As per Model Bye-law No. 77 applicable to co-operative housing societies, conducting a structural audit is mandatory for residential buildings that are 15 years or older.

- For buildings **aged 15 to 30 years**, a structural audit must be conducted **every five years**.

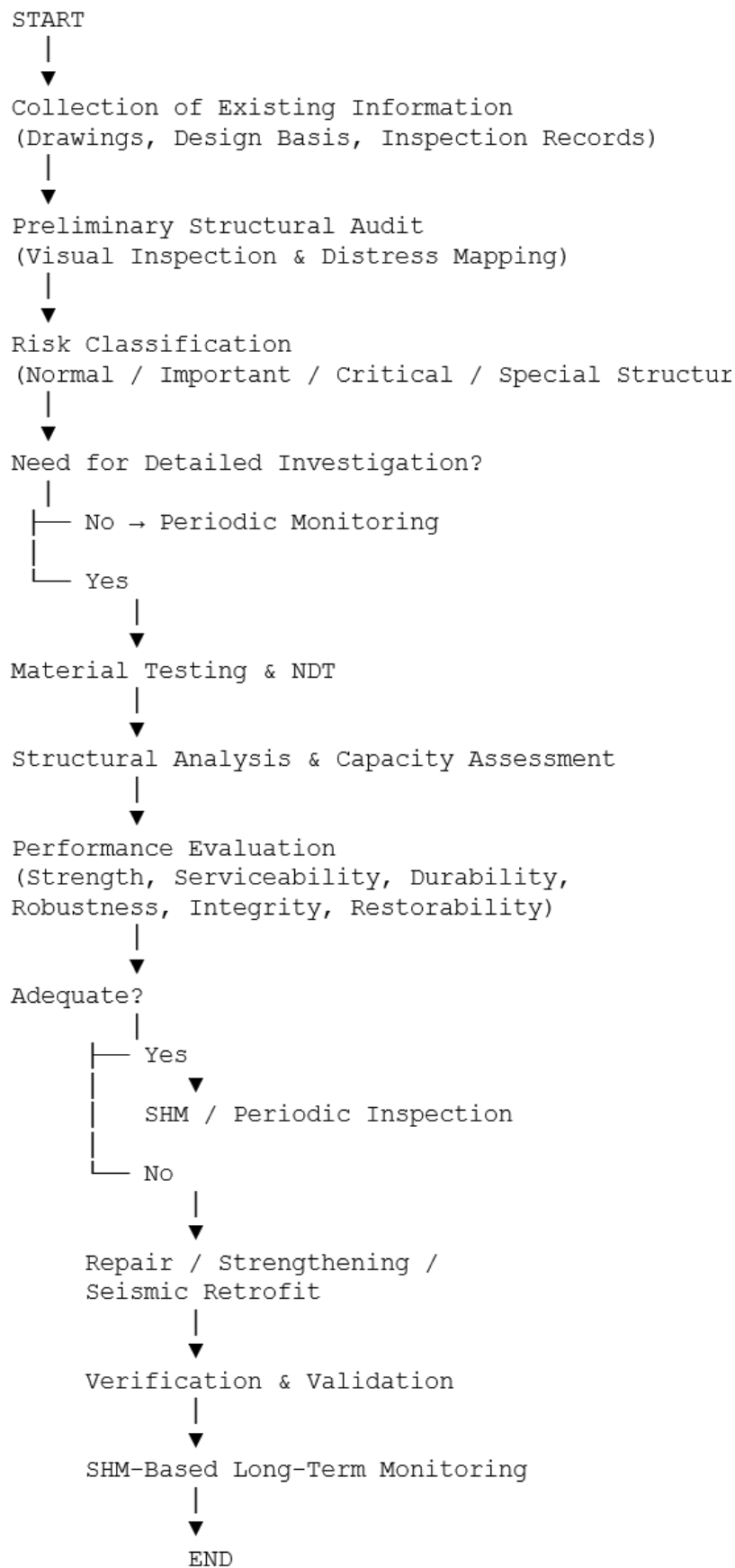
- For buildings **older than 30 years**, the audit frequency increases to **once every three years**.

In addition to age-based requirements, a structural audit should also be undertaken if visible cracks appear on the frame or surface of a newly constructed building. Such cracks may indicate construction defects or uneven load distribution on structural elements like columns, which could compromise the building's stability.

The Mumbai Municipal Corporation (BMC) has mandated that all buildings exceeding 30 years of age must undergo a structural audit and submit the corresponding report to the local ward office at regular intervals. Non-compliance with this requirement may lead to legal proceedings, particularly if the building is deemed hazardous to its occupants or the general public.



The upcoming BIS standards are expected to follow a risk-based, performance-oriented approach involving preliminary inspection, detailed assessment, material testing, structural analysis, and performance evaluation. The findings will guide repair, strengthening, retrofit, or monitoring measures, with Structural Health Monitoring (SHM) envisaged for critical structures to support lifecycle safety and resilience.



A structural audit should not be treated as just a formality, but as an important risk-management tool to ensure safety, extend the building's life, and avoid failures. After the audit, the findings should be clearly communicated to the owner or management, and the recommended actions must be carried out. Responsibilities should be well defined: the owner is responsible for taking action, the structural engineer provides technical assessment and guidance, and the authority ensures compliance. All audit reports, repair work, and future inspections should be properly recorded for ongoing monitoring of the building's condition.

12. Conclusion and way forward

Seismic retrofitting is important because it helps make old buildings safer during earthquakes by strengthening weak areas and reducing the risk of collapse. Many structures are built incrementally, sometimes without proper engineering input, and may not fully comply with seismic codes. Retrofitting helps strengthen these vulnerable buildings by improving key elements like walls, connections, and materials, reducing the risk of collapse and protecting lives. It protects lives, reduces damage, and improves how buildings perform during seismic events. As cities continue to grow and earthquake risks remain, retrofitting should be seen as an essential safety measure, not just a technical task. A proactive approach supported by regular structural audits and proper adherence to building codes can help communities stay prepared and minimize losses.

To move forward, coordinated action is essential. Policymakers should create simple, enforceable guidelines and provide financial incentives to encourage retrofitting, especially for older and high-risk buildings. Urban local bodies must strengthen enforcement, simplify approval processes, and spread awareness among building owners and resident societies. Practicing engineers should adopt practical, cost-effective retrofit solutions suited to Indian site conditions and actively guide owners on risk reduction. Academic institutions should focus on hands-on training, research, and capacity building in seismic safety to address real-world challenges. Together, these efforts can make Indian cities safer and more resilient to earthquakes.

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