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DEVELOPMENT OF A HANDBOOK ON SEISMIC RETROFIT OF BUILDINGS IN INDIA

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ABSTRACT

The Department of Civil Engineering, Indian Institute of Technology Madras, received a project on developing a Handbook on seismic retrofit of buildings. The Handbook will contain seventeen chapters covering different aspects of seismic retrofit. The first chapter is a stand alone chapter that explains the concepts of seismic design and retrofit in a language suitable for the lay man. Besides the introductory chapters, there are chapters on evaluation and retrofit of various types of buildings. The types of buildings cover non-engineered, masonry, reinforced concrete, steel buildings and historical and heritage structures. The geotechnical seismic hazards and retrofit of foundations are placed as separate chapters. Retrofit using fibre reinforced polymer composites, energy dissipation and base isolation devices are introduced. A chapter on quality assurance and control is included. This paper presents the content of the Handbook and the issues relevant to retrofit of buildings.

Keywords: Buildings, masonry, reinforced concrete, retrofit, seismic.

INTRODUCTION

After the earthquake in Gujarat, in 2001, there has been a concerted effort to address the seismic vulnerability of existing buildings in India. The Department of Civil Engineering, Indian Institute of Technology Madras, received a project on developing a Handbook on seismic retrofit of buildings. This project is sponsored by the Central Public Works Department and is also under the aegis of Indian Building Congress. The intention of the Handbook is to present the material in a style that will be understood and appreciated by the people of diverse backgrounds involved in the design and construction of buildings. The professionals include engineers with four years of technical education, licentiate engineers with three years of technical education and construction personnel with some technical training. Each chapter of the Handbook is written by a faculty member of the Department and is reviewed by a faculty member from another institute or a practicing professional from a reputed organisation. This paper presents the content of the Handbook and the issues relevant to retrofit of buildings.

CONTENT OF THE HANDBOOK

The handbook is divided in to the following seventeen chapters.

- Seismic Retrofit Made Easy
- Introduction
- Introduction to Seismic Analysis and Design
- Rapid Visual Screening, Data Collection and Preliminary Evaluation

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- Condition Assessment of Buildings
- Retrofit of Non-engineered Buildings
- Retrofit of Masonry Buildings
- Historical and Heritage Structures
- Structural Analysis for Seismic Retrofit
- Retrofit of Reinforced Concrete Buildings
- Retrofit of Steel Buildings
- Geotechnical Seismic Hazards
- Retrofit of Foundations
- Retrofit using Fibre Reinforced Polymer Composites
- Energy Dissipation and Base Isolation
- Quality Assurance and Control
- Retrofit Case Studies

DESCRIPTION OF CHAPTERS

Seismic Retrofit Made Easy

This is a stand alone chapter that explains the concepts of seismic design and retrofit in a language suitable for the lay man. The chapter covers the common deficiencies, simple techniques of diagnosis of these deficiencies and suitable retrofit strategies for the major types of buildings in India. It is intended to publish this chapter in future as a separate booklet in the vernacular languages.

Introduction

The chapter starts with an explanation of the need of retrofit of buildings in India. The changes of the design base shear as per the revision of IS 1893 (*Criteria for Earthquake Resistant Design of Structures*) is shown in Figure 1. The values of seismic coefficient (the ratio of base shear to seismic weight) as per IS 1893: 1984 and IS 1893: 2002 are shown for the different seismic zones of India. It is apparent that there is a substantial increase in the seismic coefficient for each zone. Moreover, substantial areas of the country have been upgraded to higher seismic zones.

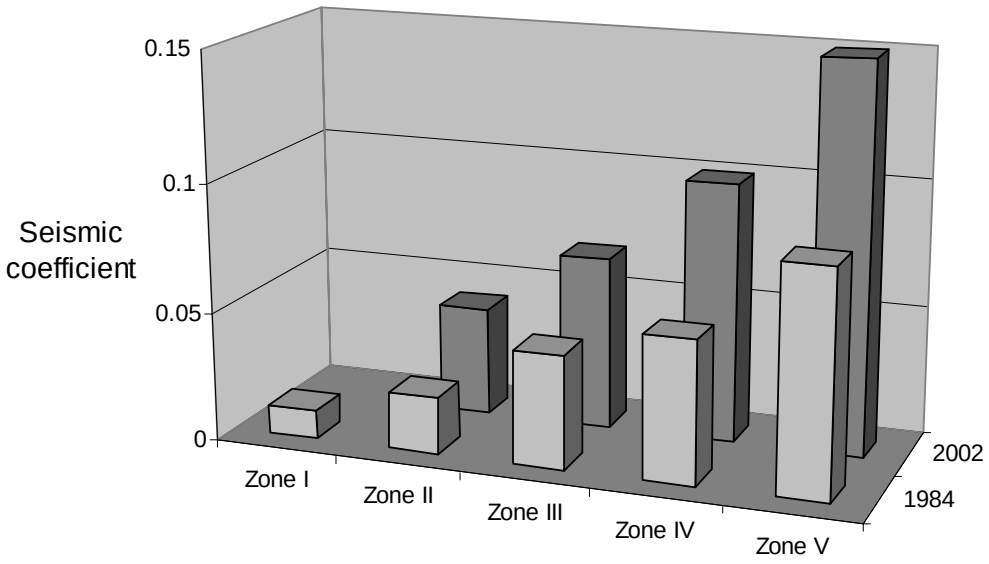

Figure 1. Variations of seismic coefficient as per IS 1893: 1984 and IS 1893: 2002

The chapter explains the attributes of seismic design, goals, objectives and steps of seismic retrofit. The performance based objectives as per FEMA 356 (2000) are mentioned but they not made mandatory. An option for considering reduced base shear for retrofit is provided.

Introduction to Seismic Analysis and Design

In this chapter, first the fundamentals of earthquakes including plate tectonics and characteristics of ground motion are briefly explained. Next, the principles of earthquake resistant design, the calculation of base shear, the response spectrum and the other main features of IS 1893: 2002 are explained.

Rapid Visual Screening, Data Collection and Preliminary Evaluation

An initial step in a seismic retrofit programme can be Rapid Visual Screening (RVS). In India, the RVS was introduced for masonry buildings in the recent draft of IS 13935, *Seismic Evaluation, Repair and Strengthening of Masonry Buildings – Guidelines*. The RVS procedures for reinforced concrete and steel buildings are drafted (Arya, 2003), but yet to be published. The RVS data sheet identifies a building into a certain type based on seismic resistant features and provides an estimate of damage for the building based on the seismic zone. Simple recommendations are provided for low-rise masonry buildings where further evaluation may not be possible due to lack of resources or trained professionals.

To facilitate seismic evaluation of a building, it is necessary to collect relevant data of the building as much as possible. This step in a retrofit programme is referred to as Data Collection. The data sheets were adopted from the *Model Town and Country Planning Legislation, Zoning Regulations, Development Control, Building Regulation/Byelaws for Natural Hazards Zones of India* (Draft version, 2004). The required information includes building description, the seismic resistant features, and miscellaneous data.

For a building identified for further seismic evaluation, the preliminary evaluation first involves a set of initial calculations to identify areas of potential weaknesses in the building. These calculations are called quick checks. The preliminary evaluation also checks the compliance with the provisions of the seismic design and detailing codes. The methodology from ASCE 31-03 (2003) was adopted in a simplified form.

Condition Assessment of Buildings

Condition assessment describes the process of assessing the actual condition of a structure in relation to its use. This chapter describes the techniques to assess the condition of the structure. An initial visual inspection of the structure can reveal useful information about areas that need a closer look. A number of investigative techniques are available to study the condition of the material in a structure. These include non-destructive tests, semi-destructive tests or even destructive tests, where the material is tested to failure without damaging the overall structure. The tests are briefly described and the associated codes are cited for further information.

Retrofit of Non-engineered Buildings

The non-engineered buildings refer to those, which are not formally designed, but built using traditional vernacular techniques. In India there is a huge stock of such houses in the country side. The houses are made of mud/brick/stone/concrete walls, wooden/bamboo/casuarina posts and thatch/tile/wooden/concrete roofs. This chapter provides the information on the available codes of practice, the preferred seismic resistant features of non-engineered buildings and the available repair materials and retrofit techniques.

The essential seismic resistant features aim to enhance the integrity of the building. The horizontal bands and vertical reinforcement at key locations, proper size and location of the openings in non-engineered masonry buildings as recommended in IS 4326: 1993 (*Earthquake Resistant Design and Construction of Buildings – Code of Practice*) are emphasized (Figure 2).

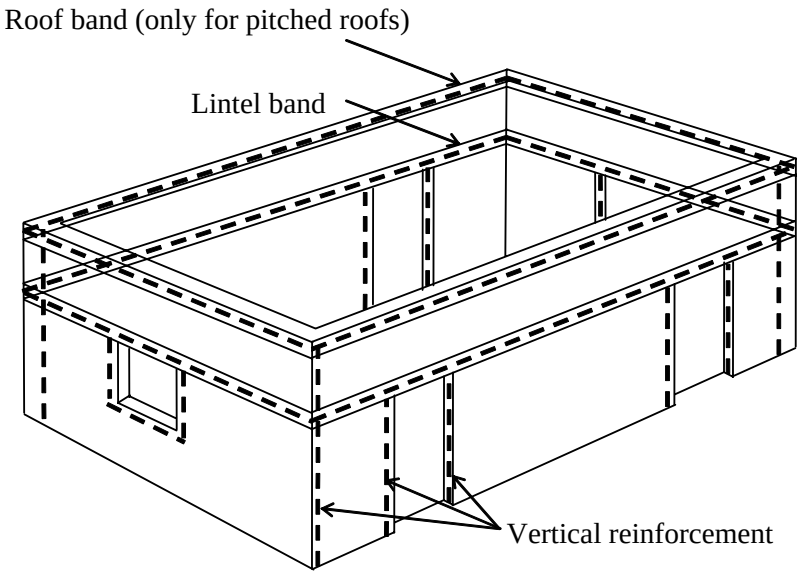

Figure 2. Horizontal bands and vertical reinforcement for a non-engineered masonry building

Retrofit of Masonry Buildings

The masonry buildings refer to those with load bearing walls made of fired clay bricks, stone blocks or concrete masonry units without reinforcement. This category comprises a large sector of buildings in the urban areas of India. This chapter deals with evaluation, field and laboratory tests, and the methods of strengthening masonry buildings. The method of piers for the analysis is explained.

The retrofit techniques are grouped under local and global techniques. The local retrofit techniques include strengthening of roof and walls. The global retrofit techniques cover introduction of joints, walls and braces and strengthening by post-tensioning. The actions for maintenance after undertaking retrofit are highlighted.

Historical and Heritage Structures

Seismic retrofit of historical and heritage structures is part of the complex, multidisciplinary science of conservation engineering. Structural assessment and remedial interventions on structural systems of historical buildings require special considerations aimed at retaining architectural integrity and historical authenticity. The techniques reported in this chapter are with reference to two categories of buildings: traditional buildings (residential clusters) within heritage areas of cities or towns and monumental structures such as royal palaces, victory towers and religious structures notable for their cultural, historical and architectural values. A vast majority of historical buildings in India is constituted of stone and brick masonry structures. Hence, the retrofitting techniques in this chapter are based on such structures. The chapter also provides an insight into the internationally endorsed principles and recommendations of heritage conservation advocated by the ICOMOS (International Council on Monuments and Sites).

Structural Analysis for Seismic Retrofit

This chapter covers the structural analysis of reinforced concrete or steel framed buildings. The analysis is a part of the detailed evaluation of an existing building. The steps involve developing a computational model of the building, applying the external forces, calculating the internal forces in the members of the building, calculating the deformations of the members and building, and finally interpreting the results.

The analysis can be linear or non-linear, elastic or inelastic, static or dynamic. The chapter discusses primarily the equivalent static analysis. The fundamentals of the response spectrum method, time-history analysis and the pushover analysis are elucidated. The important aspects of developing an appropriate computational model of a building are the modelling of the material properties, structural elements, boundary conditions, applied loads and finally the interpretation of the results. The knowledge factor is used to account for the missing information of the material properties of an existing building.

Retrofit of Reinforced Concrete Buildings

Reinforced concrete (RC) buildings include residential, dormitory, institutional, office, government, commercial and industrial buildings. Many multi-storeyed buildings have frames made of RC beams and columns which are intended to carry the vertical gravity loads as well as lateral earthquake forces. Some buildings have flat slab / flat plate and column system to carry the vertical loads and shear walls to carry the lateral loads. In this chapter, first the common deficiencies observed in RC buildings for resisting earthquake forces are listed. Next, the suitable strategies to retrofit the deficient buildings are explained and illustrated. Finally, the retrofit strategies are compared in terms of their general merits and demerits.

Figure 3 shows the plan of a typical multi-storeyed residential building. In many residential buildings, there are multiple dwelling units in one level. For each dwelling unit, to have windows in different directions and to maintain privacy, and to provide lift- and stair- wells, there are often large cut-outs in the floor slabs. This leads to diaphragm discontinuity.

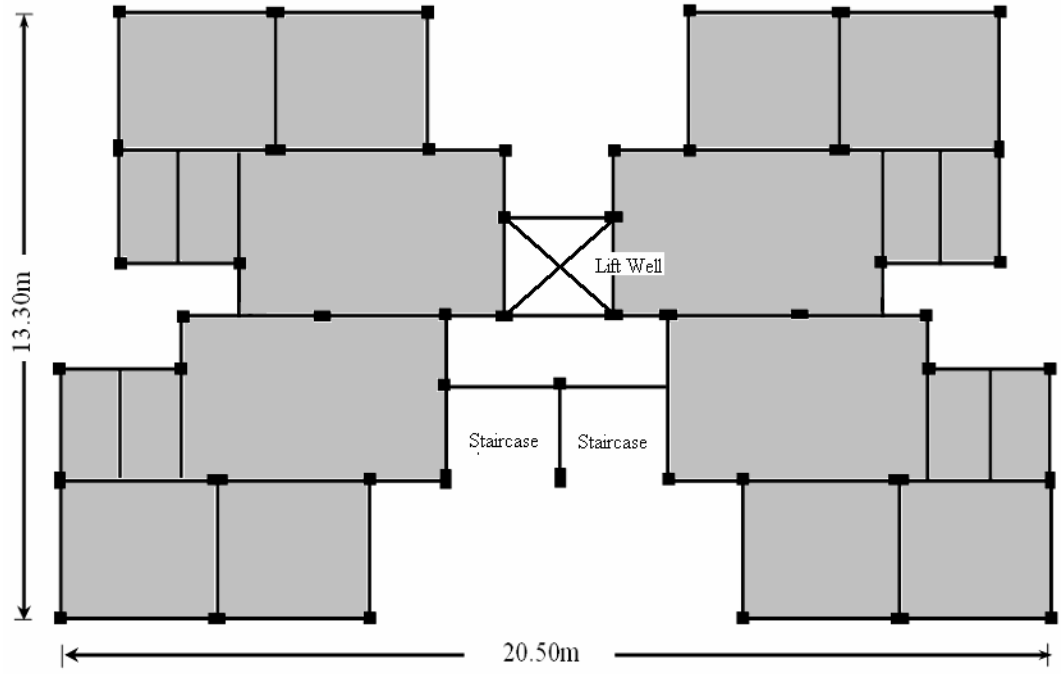

Figure 3. A typical building plan with diaphragm discontinuity and re-entrant corners

The different retrofit strategies are grouped under global or local strategies. Addition of new walls, frames or braces, reduction of any irregularity or mass of the building are grouped under global retrofit strategies. The local retrofit strategies include concrete jacketing or attaching steel plates to a column or a beam.

Retrofit of Steel Buildings

Structural steel is used in single storey structures such as industrial, storage, railway shed and aircraft hangar buildings. The steel used in these structures may consist of hot rolled sections, cold rolled sections or sections fabricated from steel plates. This chapter provides a brief description of different types of structural systems used in the above buildings and the methods to evaluate the inadequacies in such buildings. The common deficiencies encountered and the methods for retrofitting such buildings are discussed.

Geotechnical Seismic Hazards

A proper understanding of geotechnical earthquake engineering principles is necessary for rational retrofit design. Past earthquakes have shown that the effects of strong ground shaking are diverse, but can be broadly divided into two classes, depending on whether they lead to permanent ground displacements or not. This chapter discusses the seismic site characterization, response of site during earthquakes, evaluation of bearing capacity and settlement of foundation due to seismic loads, evaluation of liquefaction hazard and mitigation, evaluation of stiffness of foundation and seismic stability of soil retaining structures and slopes.

Retrofit of Foundations

The foundation related issues are condensed in this chapter. The chapter covers soil investigation, modelling of foundations in analysis and retrofit of foundations. The types of intervention include improvement of the ground, increasing the area of footing, micro-piling, underpinning with piles, and strengthening of rubble masonry foundation, piles and base plates of steel columns. To execute the retrofit, it is necessary to provide adequate shoring and temporary supports. The methods of shoring, temporary supports and underpinning are illustrated.

Retrofit using Fibre Reinforced Polymer Composites

The chapter discusses the constituent materials of fibre reinforced polymer (FRP) composites, the forms of FRP composites and the technique of bonding the laminates on concrete. The use of FRP in retrofitting RC beams is explained under strengthening for flexure and shear. For strengthening of masonry walls, the possible configurations of the FRP laminates are illustrated. The use of FRP in increasing the shear strength of a column, confinement of concrete and clamping at splice regions are covered. The procedures for analysis of retrofitted members are explained.

Energy Dissipation and Base Isolation

Conventional seismic design practice permits the reduction of forces for design below the elastic level on the premise that inelastic action in a suitably designed structure will provide that structure with significant energy dissipation potential and enable it to survive a severe earthquake without collapse. Inelastic behaviour while capable of dissipating substantial energy, also often results in significant damage to the structural member. The inter-storey drifts required to achieve significant hysteretic energy dissipation usually result in substantial damage to non-structural elements such as infill walls, partitions, doorways, and ceilings. As a response to the shortcomings, attention has been paid to the development of structural control devices, with particular emphasis on reduction of seismic response. By and large, structural control devices can be grouped into four broad areas.

1. Base isolation

2. Passive energy dissipation
3. Active control
4. Semi-active control

In this chapter, an overview of various base isolation systems and passive energy dissipation devices is presented.

Quality Assurance and Control

The requirements of quality in building repair and retrofitting projects are often not given the same attention as for new projects. Since many of these projects are of smaller scope and performed by contractor organizations that are small in size, formal systems of quality assurance and control are not followed. This chapter discusses the steps to be taken to ensure that retrofit of structures are conducted in a manner that confirms to contractual and regulatory requirements. The procedures describe how the quality assurance and control programme is designed to ensure a consistent and uniform control of the requirements.

The correct type of specification has to be used in order to ensure that quality product is delivered in the most economical way. Documentation constitutes a very important component of any quality plan. It is found that the documentation process is very weak in many projects in India. The various types of documents and document control are discussed. Temporary structures including scaffolding and formwork need to be properly designed and erected. The issues related to scaffolding, formwork and shoring are discussed. The safety of workers involved in the repair and retrofitting works is very important to improve quality and productivity in these projects. The safety issues and protection and life saving equipment are discussed.

CONCLUDING REMARKS

The retrofitting of buildings and other structures for seismic forces has special challenges as compared to the design and construction of new buildings. The following are a few questions that are raised during the selection of retrofit strategies.

- What should be the design base shear for retrofitting a building?
- How to analyse a building when the available information is limited?
- How to analyse a building which does not have a conventional lateral load resisting system?
- What is a cost effective and practical retrofit strategy?
- How to implement and ensure the effectiveness of a retrofit strategy?

The huge building stock poses challenge to the practicing professionals. They need easy to understand principles, tools to analyse a building, retrofit strategies that are practical and maintain the functional requirement of a building, and estimate of the cost of retrofit. Besides these they are confronted with non-technical issues such as consent from the owner, disruption, relocation of the tenants, losses in production, finance, profitability, availability of skilled work force.

The Handbook is an attempt to provide an adequately compiled and readily available source of technical information of retrofitting of buildings. The style of presentation is expected to be user friendly and targets to reach out to the different groups of the practicing professionals.

ACKNOWLEDGMENTS

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