It is a known fact that the Globe is facing a threat of natural disasters from time to time. With particular records based on earthquake occurrence, the consequences are loss of human lives and destruction of properties, which ultimately affects the natural economy. The occurrence of an earthquake cannot be predicted and prevented but the preparedness of the structures to resist earthquake forces become more important. Keeping the view of constant revision of the seismic zones in India, lack of proper design and detailing of structures against earthquake. Initiatives are being taken by a number of agencies in country towards reduction of seismic risk in existing building. In the past few decades, significant research effort, work over, have been dedicated to retrofitting of existing building and number of research papers and reports have been published. Still, the subject is in development stages and standardization of practice is a distant goal. In this paper comprehensive review of methods and techniques used for seismic retrofitting of RC buildings are discussed briefly. Finally, general concluding remarks are made along with possible future direction of research.

Keywords: RC Building, Seismic zone, Earthquake, Retrofitting, Strengthening.

1. Introduction

A large number of existing buildings (Yogendra Singh, 2003) in India are severely deficient against earthquake forces and the number of such buildings is growing very rapidly. This has been highlighted in the past earthquake. Retrofitting of any existing building is a complex task and requires skill, retrofitting of RC buildings is particularly challenging due to complex behavior of the RC composite material. The behavior of the buildings during earthquake depends not only on the size of the members and amount of reinforcement, but to a great extent on the placing and detailing of the reinforcement. The construction practices in India result in severe construction defects, which make the task of retrofitting even more difficult.

There are three sources of deficiencies in a building, which have to be accounted for by the retrofitting engineer: (i) inadequate design and detailing, (ii) degradation of material with time and use, and (iii) damage due to earthquake or other catastrophe. The retrofit engineer is expected to estimate the deficiency resulting from all the three sources, suggest a retrofit scheme to make up for the deficiencies and demonstrate that the
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retrofitted structure will be able to safety resist the future earthquake forces expected during the lifetime of the structure. This paper presents a brief review of the available methods and techniques for retrofitting of RC building.

The report Applied Technology Council, (1996) highlights the nonlinear static pushover analysis. It is an efficient method for the performance evaluation of a structure subjected to seismic loads. The step by step procedure of the pushover analysis is to determine the capacity curve, capacity spectrum method and displacement coefficient method. By using these procedures this report is detailed with modeling aspects of the hinge behavior, acceptance criteria and locate the performance point. The present guidelines (Dr Durgesh C Rai., 2005) are intended to provide a systematic procedure for the seismic evaluation of buildings, which can be applied consistently to a rather wide range of buildings. This document also discusses some cost effective strengthening schemes for existing older buildings where identified as seismically deficient during the evaluation process.

The document (Dr Durgesh C Rai., 2005) highlights a higher degree of damage in a building is expected during an earthquake, if the seismic resistance of the building is inadequate. The decision to strengthen it before an earthquake occurs depends on the building’s seismic résistance. The structural system of deficient building should be adequately strengthened, in order to attain the desired level of seismic resistance. This publication (FEMA156, 1994) presents a methodology to estimate the costs of seismic rehabilitation projects at various locations in the United States. The above edition is based on a sample of almost 2,100 projects, with data collected by using a standard protocol, strict quality control verification, and a reliability rating. A sophisticated statistical methodology applied to this database yields cost estimates of increasing quality and reliability as more and more detailed information on the building inventory is used in the estimation process.

This handbook (FEMA172,1992) describes techniques that engineers can use to solve a variety of seismic rehabilitation problems in existing buildings, a broad spectrum of building types and building components (both structural and nonstructural). Techniques are illustrated with sketches, and the relative merits of the techniques are also discussed. This handbook and its supporting report (FEMA173, 1989), (FEMA174, 1989) documents information need to develop a seismic rehabilitation program and establish priorities for rehabilitation. Through the presentation of nationally applicable guidelines, it helps local jurisdictions to make informed decisions about rehabilitating seismically hazardous existing buildings, and it includes a review of the relevant technical and societal issues and a procedure to resolve the issues. This report (FEMA237, 1992) assists in the preparation of guidelines for the seismic rehabilitation of existing buildings. It identifies and analyses issues that might impact the preparation of the guidelines and offers alternative and recommended solutions to facilitate their development and implementation. It also discusses issues related to the scope, implementation, and format of the guidelines, as well as coordination efforts and legal, political, social, and economic aspects. Issues related to historic buildings, research and new technology, seismicity and mapping, and engineering philosophy and goals are also discussed. The report concludes with a presentation of issues related to the development of specific provisions for major
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structural and nonstructural elements. This document (FEMA308, 1999) consists of practical guidance for the repair, upgrade of earthquake damaged concrete and masonry wall buildings. Target audiences are design engineers, building owners, officials, insurance adjusters, and government agencies. The publication contains sections on performance based repair design, repair technologies, categories of repair, and nonstructural considerations. The last section includes repair guides, which provides outline specifications for typical repair procedures. This publication (FEMA315, 1998) discusses the mission, history, and results of FEMA are Existing Building Program (EBP) and provide four objectives and 25 tasks to be carried out through the EBP. The four objectives are:

1. Promote seismic rehabilitation and advance the implementation of previously developed materials
2. Monitor the use of and refine existing materials
3. Develop new seismic rehabilitation tools, and
4. Consider new program directions for the EBP. Estimated costs for the next ten to fifteen years and guidelines for plan implementation are also included.

These publications (FEMA395-399, 2003-04) describe administrators with information to assess the seismic vulnerability of school buildings, hospital building, office building, apartment building, retail building and to implement a program of incremental seismic rehabilitation. Increase in the number of seismically resistant buildings in all areas of identified earthquake risk.

2. Methods of Seismically Deficient Building

Existing buildings (Murty CVR, 2002) can become seismically deficient when (a) seismic design code requirements are upgraded since the design of these buildings with an older version of the code; (b) seismic design codes are deficient, (c) engineering knowledge makes advances rendering insufficient the previous understanding used in their design, and (d) designers lack understanding of the seismic behavior of structures. Indian buildings built over the past two decades are deficient because of items (b), (c), and (d) above.

3. Seismic Retrofitting of Deficient RC Buildings

Concept of pushover analysis (Sudhir K. Jain et al., 2002) that is becoming a popular tool in the profession for design of new buildings, seismic evaluation of existing buildings and developing appropriate strategy for seismic retrofitting of buildings. It is shown how this analytical technique can be useful in deciding seismic retrofitting strategy and techniques.

Pushover analysis of the structures (Lakshmanan D, 2006) using SAP 2000 evaluating the various repair strategies for use in the improvement of the seismic performance of RC structures are highlighted. The behaviors of repaired beams of beam column joints are discussed. It is observed that inherent deficiencies in the detailing of the beam-column joints get reflect even after repair, though the performance factors indicate significant
improvement. Two of the logical extensions show that the repair would not be as effective in these cases. The nonlinear static analysis of RC building (Shailesh Kr. Agrawal et al., 2003) is performed using pushover approach before and after retrofitting. The comparison of strength parameters and pushover curve indicates that there is increase in ductility. As regards to stiffness of the building, it is seen that it remains more or less same up to linear stage, while in nonlinear stage every point increase after retrofitting. The strength of the building is correlated with base shear, the net enhancement in strength after retrofitting. This paper (Abhijit Mukherjee et al., 2004) introduces a method of design of structural upgradation using FRC and discusses the design of enhancement of RCC elements with FRC, a strategy of upgradation of RCC frames and use of the developed strategy of upgradation for retrofitting of RCC frames based on Capacity Spectrum Method.

Evaluation (Richard N. White) procedures and retrofit strategies for existing reinforced concrete framed buildings are designed primarily for gravity loads. Selected evaluation and rehabilitation methods are reviewed, including portions of the 1996 NEHRP guidelines for seismic rehabilitation of buildings. New research results for predicting the behavior of masonry infilled frames are presented, and general research issues are suggested. The seismic evaluation and retrofitting procedures of reinforced concrete buildings (Seki M et al., 2007) within JICA technical cooperation project in Romania. The content of the paper covers i) an outline of the seismic evaluation; history and comparison of Romanian seismic design codes with the Japanese seismic evaluation guidelines, ii) an outline of the retrofitting techniques which are transferred from Japan to Romania and structural tests for retrofitting techniques employed in Romania and iii) retrofitting details that were used by JICA/NCSRR in the retrofitting design of two vulnerable buildings in Bucharest.

Case studies (Chandrasekaran S et al., 2003) are conducted in the 150 year old building Ganga Mahal located in Assi Ghat and Sanskrit University of Kashi. The buildings are mathematically modeled and analyzed for its structural behavior. The suggested measures of structural strengthening for these heritage structures are based on the understanding of the detailed studies conduct by the authors on the failure pattern of various structures during earthquakes in India. The typical (Suneja BP, 2003) features of seismic retrofitting strategy for historic monuments and the various structural control methods, effectiveness of control methods, as compared to the existing conventional techniques and the issues related with the adaptability of such innovative techniques are addressed. A case study (Ryanj Williams et al., 2009) is conducted to find the impact of a modest retrofit strategy applied to the identical buildings in Memphis and San Francisco. The probabilities of failure and generalized reliability indices are calculated for the retrofitted building in both locations and compared to the corresponding values for the original buildings. The results of the parametric analysis and case study are used to determine the effects of building location on retrofit feasibility.

The traditional methods of seismic retrofitting (Giusepe Oliveto et al., 2005) are reviewed and their weak points are identified. Modern methods and philosophies of seismic retrofitting, including base isolation and energy dissipation devices, are reviewed. The presentation is illustrated by case studies of actual buildings, where traditional and
innovative retrofitting methods are applied. An overview of analysis methodologies (Leo Panian et al., 1999) are used for a seismic rehabilitation of an historic high rise building is presented. The use, in the design process, of nonlinear soil structure interaction foundation analyses and three dimensional finite element analyses of the towers are highlighted. Finally, the impacts of the results of the analyses on the construction details are discussed.

4. Improvement of Existing RC Buildings

Three levels of improvement of existing RC frame buildings (Murty CVR, 2002) are possible, namely (a) repair, (b) restore, and (c) strengthen. The consequence of any prescribed method of the retrofitting are (a) adding brick masonry walls in all possible bays in ground storey, (b) jacketing of all RC columns in ground storey only, (c) adding steel diagonal braces in some bays in ground storey, and (d) infilling existing RC frame with RC structural walls in some bays in ground storey only. In all cases, foundation strengthening may be essential. On the seismic capacity of the building should be quantitatively evaluated its effectiveness from the points of view of strength, stiffness and ductility are shown in Figure [1.a, 1.b]. Sometimes, a retrofit scheme may have better performance than the damaged structure, but still may be poor; the retrofit scheme that assures at least a basic ductility is preferable to the others.

![Figure 1: a) Effect of retrofit Strategy on lateral strength, stiffness and ductility, b) Relative performance of different retrofit strategies. (Murty CVR, 2002)](image)

5. Methods of Seismic Retrofitting

This paper (Murty CVR, 2002) deals with two approaches a) simple approach, and b) state-of-the-art approach are presented for seismic retrofitting of existing RC frame buildings. For the retrofit of general RC frame buildings in India, it is technically and economically the best compromise to adopt the first approach because of the prevalent dismal practices of seismic structural design and construction in the country. And, in the
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retrofit of the critical structures and important structures, it is necessary to take up the state-of-the-art retrofit approach.

This paper (Kaustubh Dasgupta et al.,) concludes that to identify an efficient retrofitting method for existing open ground storey RC frame buildings. A two dimensional RC frame is designed with non-ductile. Detailing is subjected to nonlinear static pushover analysis. The RC frame is retrofitted by three methods. a) Concrete jacketing of columns in the ground storey, b) Brick masonry infill in the ground storey, and c) RC structural wall in the ground storey panel of all the methods studied the use of structural wall in the ground storey panel give the maximum strength and ductility.

The objective of this study (Ashutosh V Mahashabde et al., 2003) is to identify an efficient retrofitting method for reinforced concrete buildings. Two buildings: One open ground storey with infills and the other partial open ground storey with infills, which are damaged in the January 2001 Bhuj earthquake, are subjected to static pushover analysis with code specified design shear distribution. The observed failure modes conform to the actual structural damages sustain by the buildings during that earthquake. The selected methods of retrofitting are a) Jacketing of columns in the ground storey, b) Structural walls in the ground storey of some selective panels, and c) Structural walls for all the stories in some panels. These three basic schemes are used in combination for ascertaining an economical method giving the maximum strength and ductility. Of all the methods studied, the combination of column jacketing in ground storey and shear wall throughout the height of the building with selective strengthening of upper storey frame members, give the most economic and desirable performance.

The objective of this study (Ei-Sokkary H et al., 2009) is to investigate analytically the effectiveness of different rehabilitation patterns in upgrading the seismic performance of existing nonductile RC frame structures. The study investigates the performance of two RC frames (with different heights representing low and high rise buildings) with or without masonry infill when rehabilitated and subjected to three types of ground motion records. The ground motion records represent earthquakes with low, medium and high frequency contents. Three models are considered for the RC frames: bar frame, masonry infilled frame with soft infill and masonry infilled frame with stiff infill. Four rehabilitation patterns are studied namely; 1) introducing a RC shear wall, 2) using steel bracing, 3) using diagonal FRP strips (FRP bracings) in the case of masonry infilled frames, and 4) wrapping or partially wrapping the frame members (columns and beams) using FRP composites. Incremental dynamic analysis is conducted for the studied cases. The seismic performance enhancement of the studied frames is evaluated in terms of the maximum applied peak ground acceleration resisted by the frames, maximum inter storey drift ratio, maximum storey shear-to-weight ratio and energy dissipation capacity.

An efficient (Binici B et al., 2006) FRP retrofit scheme was developed, in which hallow clay brick infill walls are utilized as lateral load resisting elements. Based on failure modes and measured deformation limits obtained from a large database of experiments, a diagonal compression-strut and tension-tie model are developed. The model is verified with a number of reinforced concrete frame test results with and without upgrades. The
characteristics of various intervention techniques (Jong – Wha Bai, 2003), (Helen Santhi M et al., 2003) are discussed and the relationship between retrofit and structural characteristics are also described. In addition, several case study structures for which retrofit techniques have been applied are presented. This paper (Zou XK et al., 2007) presents an optimization technique for the performance based seismic FRP retrofit design of RC building frames. The thickness of FRP jackets used for confinement of columns are taken as the design variables, and minimizing the volume and hence the material cost of the FRP jackets are the design objective in the optimization procedure. The pushover drift is expressed explicitly in terms of the FRP sizing variables using the principle of virtual work and the Taylor series approximation. The Optimality Criteria (OC) approach is employed for finding the solution of the nonlinear seismic drift design problem. A numerical example is presented and discussed to demonstrate the effectiveness of the proposed procedure. Performance based seismic evaluation of building models (Savitha V Athani et al., 2009) namely: bare frame, soft storey, retrofitted building with unreinforced masonry infill and increased stiffness of columns and different locations in open ground storey for G+2, G+5, G+8. Storey’s located in seismic zone III. The buildings are designed by gravity loads which are analyzed by equivalent static method using ETAB and nonlinear version 9 software. The recent (K.G.Bhatia, 2003) Indian earthquake has clearly demonstrated that maximum suffering during earthquake disaster is bore by common man. Seismic evaluation of majority of such construction, though essential, appears to be infeasible. Whereas desired safety can still be expected and achieved for engineered constructions, its assurance for nonengineered construction draws a big question mark? The paper dwells upon the real life situation and the likely impact of the post earthquake scenario on the society.

The present paper (Amar Prakash et al., 2003) deals with the seismic retrofitting of an existing fourteen storied RC building frame located in seismic zone IV. The study includes seismic evaluation and retrofitting of RC framed building, by using steel bracing and infill masonry walls. The seismic performance of two retrofitting techniques such as steel bracing (V, diamond and cross pattern) and infill walls are relatively compared. Among three patterns of steel bracing, cross pattern shows better performance than V and diamond bracing patterns. The structural analysis (Dr. Meher Prasad A et al.,) is performed using a suitable computer analysis program. 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. First deficiencies observed in existing RC buildings for resisting earthquake identified. It is essential to identify the deficiencies in a building before undertaking retrofit. Identification of the deficiencies is also expected to create awareness for future construction. The material for each building (Dr Santhakumar AR et al.,) is presented under the following topics; rapid visual screening, data collection, preliminary evaluation, detailed evaluation and retrofit.

6. Conclusion

Many guidelines are reviewed regarding seismic rehabilitation of school, office, hospital and apartment buildings. Some of the researchers discussed the various seismic
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retrofitting and strengthening methods for existing building. The following methods are carried out by most of the researchers which are concrete jacketing of columns of ground floor, brick masonry infill in the ground floor, X and V bracing, shear wall, FRP of beams and columns. All these topics require further research, and it is essential for seismic retrofitting of reinforced concrete structures.

7. References


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