Seismic Retrofitting methodologies for RC Buildings: A Review

Saif Usmani, *Student* , Prof Kuldeep Dabhekar, *Asst.Prof.*,Dept. of Civil Engineering,
G.H.Raisoni College of Engineering,Nagpur

Abstract-Seismic retrofitting is being increasingly regarded as a viable solution to ensure code compliance in under-designed buildings. Rehabilitation and retrofitting of buildings partially damaged due to earthquakes is done to increase their capacity in an event of earthquake. The methodology adopted depends upon the performance level desired. An attempt has been made in this paper to underline the various methodologies of seismic retrofitting for RC buildings.

I Introduction

Seismic retrofitting is largely adopted to strengthen existing under-designed buildings,the various solutions to achieve this include Local or global jacketing, Bracing or other energy dissipation devices ,along with base isolation techniques. A few studies also experiment with alloys in making sliding connections that facilitate energy dissipation.

II Related work

Hugo Rodrigues et al.(2018) The study analyses the vulnerability of school buildings through non-linear dynamic analysis ,wherein peak storey drifts are analysed to highlight the effect of presence of masonry infill walls on response of the buildings. The authors propose four methodologies for retrofitting the school buildings.

The first obvious solution is the introduction of Infill masonry walls,this strategy can tackle the problem of vertical irregularity of stiffness provided through infill walls in the original structure. However this will reduce the functionality of space, as addition of walls might disturb the intended floor plan.

The second feasible solution might be the strengthening of vertical members by Reinforced concrete jacketing.This method is effective as it leads to uniform distribution of stiffness throughout the building. However this employs skilled labour and special techniques which may not be available locally.The authors aim to increase the lateral stiffness of the building and ensure compliance with Eurocode 8.Third solution is the addition of steel braces,this method though uncommon in Nepal has high efficiency. Improper connections can lead to formation of torsion mechanisms or soft-storey mechanisms. All methods are validated using non-linear dynamic analysis, parameters like peak-storey drift ratios along with natural frequency are compared.

Though all methods were effective in increasing the strength of building, braces and jacketing were found to be the most effective.

Min Ho-Chey et al.(2013) investigate the response of added storey isolation system. The strategy involves addition of a few stories at the top of building which act as Tuned mass dampers (TMD).The model for 12 storey target model is evaluated for “12+2” & “12+4”retrofitted models.The 50th percentile responses for all floors are compared in three different suites i.e Low,medium & high. peak relative displacements, interstory drift ratios,story shear forces and total accelerations for all floors are calculated as control effectiveness indices to develop response envelopes.

The solution improves the seismic response of buildings,the results are found to be significantly favourable as far as improvement of response is concerned.

Cenghizan Durucan et al.(2010) has evaluated the suitability of a steel link bracing system in a RC building.The system is modelled through finite element analysis .Response spectra for seven earthquakes which are compatible with SRSS are used in analysis.The spectra for various buildings including school buildings ,office buildings and hospital buildings etc. are compared with average design spectra .Non-Linear time history and Non-linear static pushover analysis is employed to analyse the structure modelled in SAP2000.

Retrofitting design is done considering the performance levels of Immediate occupancy(IO),Life safety (LS) and Collapse prevention,the approach is iterative in nature,the rotation limits for members mentioned in FEMA 356 is considered.The performance in LS and CP performance levels is compared with the performance of buildings retrofitted in the conventional means. Story drift is the differentiating criteria for assessment in this study.

The shear link absorbs the energy similar to that of hysteretic dampers and improves seismic response of a building ,this method is superior with respect to conventional retrofitting namely cross bracing system.

Marco Valente et al. (2018) an under-designed RC frame is reviewed for design deficiencies through displacement based approach. Three retrofitting methodologies are then evaluated to improve the seismic response of building. Seismic performance of bare frame is evaluated using NLTH (Non-linear time history) and NLSP (Non-Linear Static Pushover) analysis.

First method is retrofitting through eccentric steel bracings incorporated within the weak stories. The base shear using eccentric steel bracings is about 1.5 times the bare frame. The Second method is retrofitting using infill wall, this method is used to provide structural stiffness to the structure. The peak base shear obtained is 1.65 times the bracing solution and four times greater than the base shear for bare frame. Another methodology proposed includes a combination of RC and FRP jacketing to strengthen the building, this is one of the most convenient methods. The peak base shear for this method is 1.25 times more than bare frame. Either one of these methods or a combination of all three can be employed to improve seismic response of building.

Mohammad Taghi Nikoukalam et al.(2015) this paper proposes the use of slotted bolt connection in elements where shear is encountered within a structure. The term Shear Slotted Bolt Connection (SSBC) is coined by the authors. The Connections are used in retrofitting of structure are developed as friction dampers similar to SBC (Slotted Blot Connection) and RSBC (Rotational Slotted Bolt Connection).These friction dampers are placed near the beams such that the input energy due to an earthquake is dissipated in a non-destructive way to give smooth hysteresis loops. The SSBC is discussed in detail within the paper to give an idea regarding its energy dissipation mechanism. The use is primarily limited to Moment resisting frames.The effect of incorporation of these friction dampers is studied through Finite element analysis of members.

Fabio Mazza et.al.(2015) a displacement based design methodology is underlined to proportion hysteretic damped braces. This proportioning is done in order to achieve a specific seismic intensity.The frame under investigation is vertically irregular which is modelled by changing the loading patterns of the first two floors.The brick masonry infill walls on the periphery are replaced by glass walls.Non-linear dynamic analyses is done for the frame in unbraced ,with infill walls and braced conditions is done to identify the most suitable solution. The test structure is a six-storey building built according to old Italian codes, the bracings are added to increase the seismic performance of the building as per FEMA 356.

KI Moon Hoon et al.(2017) a new method to design friction damping system is elaborated for retrofitting old mid and high-rise buildings.The Currently proposed methodology has a bracing and a friction damper.

The design methodology involves the evaluation of old building prior to application of any retrofitting methodology, the capacity and demand is evaluated using the provisions of ATC-40.The further step is the design of friction damping system for this deficiency in capacity and to make up for the remaining demand. The next involves the evaluation of such a frame after retrofitting ,using the pushover and time history analysis. The model building is designed using ASCE 7-10 for gravity loads only. The seismic performance prior to and after incorporation of friction damping system is compared. The roof displacement and response spectrum of original and retrofitted strucuture is compared.

Fabio Mazza et al.(2018) propose a study for evaluating the effectiveness of base-isolation techniques for seismic retrofitting of RC framed buildings.The study focusses on three conditions to compare and evaluate results,namely bare unretrofitted structure with non-structural moment infills, structure with non-uniform distribution of moment infills,structure with uniform distribution of structural moment infills.The normal and base-isolated models are compared for their seismic responses using Non-linera static analyses.The study discusses the suitability of base-isolation technique in improving the seismic response of buildings.

Y.Ribakov et al.(2018) perform a life cycle assessment of buildings retrofitted with stiff diaphragms or seismic isolation systems.Roof displacement time history analyses are performed on buildings retrofitted with stiff concrete diaphragms and seismic isolation columns.The results and performance levels of a particular building are co-relate in an attempt to perform an overall life-cycle assessment.The seismic performance gives an idea about the useful life-span of a building before it is rendered unfit for use.

G.E Thermou et al. (2012) propose a method to distribute the stiffness of building throughout the height in an effort to seismically upgrade (retrofit) the under-designed buildings.

The displacement profiles of different buildings is compared to decide on a target drift profile.The retrofit options were proportioned to achieve the target profile.

First of the many retrofit options includes addition of the reinforced concrete walls or infill walls. It is ideal for flat slab structures and reduce plan eccentricity, while controlling drift and act as boundary element for in-frame applications. Other issues concern provisions to secure safe transfer of inertial forces to the walls through floor diaphragms, struts, and collectors, the integration and connection of the wall into the existing frame buildings, and transfer of loads to the foundation. Added walls are typically designed and detailed following current code requirements for new structures.

The second alternative suggested by the study includes Reinforced concrete jacketing,this method ensures uniform distribution of stiffness,it eliminates the risk of joint shear failiure by encasing beam-column joints.

The third solution incorporates the use of masonry infill walls ,the method increases the stiffness and limits the displacement demands. Although in some cases it may be argued that the mass increase is greater and outweighs the benefit of reduced drift.

Every method is evaluated based on the changes in story drift ratios and were subjected to testing on a four storey model. Time-history and pushover analysis were used to effectively demonstrate the improvement in seismic response of the building.

G.E Thermou et al. (2007) propose the retrofitting of an under-designed RC frame to improve its seismic response.They aim for modification in deflected shape of structure to achieve a uniform distribution of drift.

Two retrofit methodologies are proposed to modify the deflected shape ,the existing frame is evaluated using response spectra.

There are two solutions to retrofit the frame being evaluated, first is the extensive retrofit solution, the second being lower bound solution. While the former uses jacketing of almost all lateral members, the lower bound solution jackets only a few critical stories .

Both the strategies were verified by pushover analysis ,where retrofitting evidently improves the performance of building.

The extensive retrofit solution is better suited for buildings built prior to the advent of specific codes for seismic design.

Nicola Impollonia et.al.(2018) investigate a strategy which involves non-linear viscous dampers between existing buildings and some reaction towers.The equations of coupled torsion seismic motion are derived mathematically from first principle. The method is implemented on an actual building in Mesina Italy.

Method is evaluated using time history analysis ,to underline the effect of increased stiffness on seismic performance.

IV. Summary

Different methodologies are suggested for seismic retrofitting of RC buildings. While most are concerned with redistriburion of stiffness, some employ energy dissipation through special connections and linkages. Due to practical considerations application of each method is limited by availability of techniques and labour. Global strategies reduce formation of localised failiure mechanisms, whereas local methods increase the capacity of specific elements to make the building perform better.

V. Conclusion

Seismic retrofitting is increasingly being sought as a viable option in the light of recent developments in codes. Modifying a building to make for its less capacity is a more feasible option as far as economic prospects are concerned in some cases technical as well.

VI.References

i)Hugo Rodrigues ,André Furtado ,Nelson Vila-Pouca · Humberto Varum, André R. Barbosa,International Journal of civil engineering,,Springer (2018).

ii)Innovative seismic retrofitting strategy of added stories isolation system, Min-Ho Chey , J. Geoffrey Chase, John B. Mander, Athol J. Carr,Springer (2013).

iii)Analytical study on seismic retrofitting of reinforced concrete buildings using steel braces with shear link, Cengizhan Durucan, Murat Dicleli, Journal of Engineering structures, Elsevier (2010).

iv)Design Methodology for Seismic Upgrading of Substandard Reinforced Concrete Structures, Georgia E. Thermou, Stavroula J. Pantazopolou,& AMR S. Elnashai,Journal of earthquake engineering,Taylor and francis (2007).

v)Global Interventions for Seismic Upgrading of Substandard RC Buildings, G. E. Thermou, S. J. Pantazopoulou, and A. S. Elnashai,ASCE (2012).

vii)Seismic performance of buildings retrofitted with nonlinear viscous dampers and adjacent reaction towers, Nicola Impollonia, Alessandro Palmeri,Wiley (2017).

viii)Alternative retrofitting strategies to prevent the failure of an underdesigned reinforced concrete frame, Marco Valente, Gabriele Milani, Engineering Failiure Analysis 89 271-289,Elsevier (2018).

Analytical Study of Moment-Resisting Frames Retrofitted with Shear Slotted Bolted Connection SeismicIsolation,Y.Ribakov,I.Halperin,S.Pushkar,AS CE (2015).

ix)Displacement-based seismic design of hysteretic damped braces For retrofitting in elevation irregular r.c. framed structures, FabioMazza, Mirko Mazza,Alfonso Vulcano, Soil Dynamics and Earthquake Engineering 115-124,Elsevier (2015).

x)Seismic retrofit design method using friction damping systems for old low- and mid-rise regular reinforced concrete buildings, Ki Hoon Moon , Sang Whan Han , Chang Seok Lee, Engineering Structures 105-117,Elsevier (2017).

xi)Base-isolation systems for the seismic retrofitting of RC framed buildings with soft-storey subjected to near-fault earthquakes, Fabio Mazza, Mirko Mazza, Alfonso Vulcano,Soil Dynamics and Earthquake Engineering,209-221,Elsevier (2018).

xii)Seismic Resistance and Sustainable Performance of Retrofitted Buildings by Adding Stiff Diaphragm