2. LITERATURE REVIEW

2.1 General

This chapter of the thesis presents the effectiveness of seismic evaluation and retrofit strategy of reinforced concrete buildings, and also derived a methodology for evaluation of the seismic design parameters. Effort has been made to highlight the importance of seismic design parameters and a brief review of previous studies on seismic evaluation and retrofit of infilled masonry reinforced concrete structures under seismic load is presented in this section before outlining the objectives of the thesis work.

2.2 Literature review

In this study, the literature review is divided into two categories, *viz.*, (1) seismic design parameters, and (2) seismic evaluation & retrofit strategies.

2.2.1 Seismic design parameters

Response reduction factor (R-factor) is the most important seismic design parameter which is utilized for the seismic design purpose. The response reduction factor (R-factor) of reinforced concrete buildings for steel X and knee-braced system evaluated by Maheri and Akbari (2003). The different models have been analyzed by using Drain-2DX software. The results observed that the knee braced frame system is more appropriate than X-braced frame system for R-factor of structures. The response reduction factor and ductility factor of different four-storied reinforced concrete two dimensional frames evaluated by Tamboli *et al.* (2015). Five different models, *viz.*, bare frame, RC bracing central bay, RC bracing alternate bay, Shear wall at center bay, Shear wall at alternate bay have studied. The modeling study is carried out in SAP-2000 software and analyzed by using nonlinear static pushover analysis. The results observed that, the response reduction factor of RC frame with bracing or Shear wall at alternate bays increased by 1.77 and 1.99 times as compared to RC frame with bracing or Shear wall at central bay frames respectively.

Whittaker *et al.* (1999) have studied the seismic response modification factor of structure is based on purely engineering judgment. An experimental research data is used to develop the understanding of the seismic response of concentrically and eccentrically steel braced system and proposed a new draft formulation for the response modification factor. The R-value determined experimentally for the concentrically braced dual system and the eccentrically braced dual system were 4.5 and 6 respectively. These values were observed comparatively smaller according to Uniform Building Code (1997). Recent studies (ATC 1995) support a new formulation for R-value, where in, R-factor is expressed as the product of three factors such as a strength factor; ductility factor; and redundancy factor. The proposed formulation does not specifically address the effects of plan and vertical irregularity in framing systems. The results concluded that, the reserve strength of building system varies with building type, building height, seismic zone, etc. Izadinia *et al.* (2012) studied the response modification factor of steel moment-resisting frames having 3, 9 and 20 stories adopted from SAC steel project by different pushover analysis methods. In this study, a conventional and adaptive pushover analysis has been adopted. The conventional pushover analysis does not account the higher mode effects and member stiffness changes. The seismic parameters, *viz.*, ductility based reduction factor, overstrength factor, and response modification factor have been obtained from the adaptive and conventional pushover analysis. The results concluded that, the major difference in the response modification factor for conventional and adaptive pushover analysis was about 16% obtained. Also it is to be noted that the adaptive pushover analysis is more appropriate than conventional pushover analysis. The response reduction factor of irregular RC frames was computed by Brahmavrathan and

Arunkumar (2016). In this study, three types of reinforced concrete structures having equal number of bays, but different number of storeys are considered. The static pushover analysis of the three stepped RC building models was carried out by using SAP 2000 software. The results observed that, the actual values of R-factor for stepped RC buildings are lesser than the values recommended by BIS code. The value of R decreases as the storey of building increases. Due to vertical irregularity, R-value decreases significantly so there is need to consider the irregularity in BIS code and ductility factor actually depends on the optimum percentage of steel reinforcement. Nishanth *et al.* (2017) worked on the evaluation of response reduction factor for two dimensional ordinary and special moment resisting frames. In this study, five RC frames having 4, 7, 10, 13, and 16 stories are analyzed by using nonlinear static pushover analysis in SAP 2000 software and evaluated the effect of the zone, height of structures on the seismic parameters, *viz.*, response reduction factor, overstrength factor, ductility factor, etc. The results concluded that the R-factor depends on overstrength and ductility reduction factor and it decreases suddenly as the seismic zone increases. The overstrength factor generally varies based on the seismic zone and time period of structures. The ductile frames give the better performance as compared to non-ductile frames.

Chaulagain *et al.* (2014) studied the evaluation of response reduction factor of twelve existing irregular RC buildings (bare frame) in Kathmandu valley. The nonlinear static pushover analysis is carried out in different models. The results concluded that the R-factor is sensitive to both geometrical configuration and material strength. The calculated R-values for different buildings are less than the values recommended by the IS 1893 (Part-1): 2002 code. The R-value is highly dependent on “column to beam capacity ratio”. The response reduction factor of reinforced concrete buildings was evaluated by Goud and Pradeep Kumar (2014). In this study, five storey building is designed for all seismic zones along with ductile and non-ductile detailing design provision. All the buildings are analyzed with nonlinear static pushover analysis in SAP 2000 software. The authors concluded that, the R-value given by the IS 1893 (Part-1): 2002 code is on conservative side. The response modification factors of nine RC frames designed with different geometric configurations as per the Egyptian code studied by Abou-Elfath and Elhout (2018). The buildings have different bay spans as well as different storey heights. The nonlinear static pushover analysis was performed in DRAIN-2DX software. The results noticed that, the R-factor is sensitive to the number and height of stories. The R-factor reduces as the height of the frame increases. The computed R values are lesser than the given values of 'R' by Egyptian code.

Saleemuddin and More (2015) studied the effects of response reduction factor on the seismic behavior of the reinforced concrete building. The nonlinear static pushover analysis was carried out in the ETABs software to find out the capacity curve for different values of R ranging between 2-7. The seismic parameters, *viz.*, design base shear, lateral displacement, interstorey drift, stiffness, etc. evaluated based on different value of 'R'. The results concluded that the effect of the R-value is more impactful on the ductility of RC structure. The higher the R-value, the higher will be the nonlinear behavior of a structure. Motiani *et al.* (2018) worked on the calculation of the response modification factor of RC buildings by using pushover analysis. In this study, 4, 8, and 12 storey RC buildings have designed as per the IS 456: (2000) code. The results observed that the value of 'R' given by IS 1893 Part-1:2002 is improperly estimated. The actual value of R is lesser than the values given by BIS code because of irregularity in structure, torsional effect, poor workmanship, etc. The overstrength factor and force reduction factor of multistoried reinforced concrete buildings evaluated by Elnashai and Mwafy (2002). In this study twelve RC buildings analyzed by using ADAPTIC program. The building height variation, different moment resisting systems, vertical irregularity, etc. have been considered for the detailed study. The results concluded that the ultimate capacity of the structure by using triangular load pattern is on the conservative side.

Mapari and Ghugal (2018) studied the seismic performance of multi-storey RC buildings. In this study, the R-factor has been evaluated using the FEMA P695 methodology. The nonlinear static pushover analysis has been carried out in SAP-2000 software. The effect of infill is also considered in the frame while modeling. The results concluded that the calculated R-values for RC-infilled frames are slightly higher than the value recommended by the IS:1893 Part-1:(2002) code. The stiffness of frame is enhanced by introducing the infill in the frame. The ductility of the special moment resisting frames (SMRF) is higher than the ordinary moment resisting frames (OMRF). The seismic evaluation of five storey existing RC building with and without infill was studied by Alguhane *et al.* (2015). In this study four different frames, *viz.*, bare frame, frame with infill-field test, frame with infill-ASCE 41, soft storey frame-ASCE 41 were analyzed by using pushover analysis in SAP 2000 software. The response modification factor is evaluated from capacity design spectra. The results concluded that the response modification factor of the bare frame does not fulfill the requirement of SBC-301 (Saudi Building Code) however, by incorporating infills in the frames the response modification factor and overstrength factor were increased and satisfied with code values. Haque *et al.* (2015) studied the overstrength factor and force reduction factor of industrial rack clad buildings (RCB). In this study 4, 6, 8, 10 storey RCB frames were modeled for the calculation of force reduction factor. These all RCB frames were analyzed by using pushover and incremental dynamic time history analysis. The results observed that the overstrength and force reduction factor decreases as the height of the structure increases.

Uang (1991) studied the response reduction factor (R) and displacement amplification factor (C_d) of building. These both factors depend on structural overstrength factor and ductility factor. As per the study, it is very difficult to predict the values of ‘R’ and ‘C_d’ for building systems. National Earthquake Hazards Reduction Program (NEHRP) provided the ‘R’ and ‘C_d’ values for the different structural system. The results observed that the R-factor is the function of the overstrength and ductility factor. The effect of damping is generally counted in ductility reduction factor. The values of ‘R’ and ‘C_d’ are not consistent with various structural systems according to NEHRP. The response reduction factor of 2D RC frames for two different types of infill i.e., semi-interlocked masonry (SIM) and unreinforced masonry (URM) with and without opening in the infill was studied by Shendkar and Pradeep Kumar (2018). A nonlinear static pushover analysis was carried out for different frames in SeismoStruct software. In this study “double strut nonlinear cyclic model” was used for the infill panel. The results concluded that the R-factor decreases effectively by considering opening in the infill. The response reduction factor is higher in the SIM panel frame as compared to the URM panel frame due to shear sliding mechanism of SIM panel.

2.2.2 Seismic evaluation & retrofit strategies

Seismic evaluation & retrofit of structure is one of the challenging tasks and has a wide scope in earthquake prone areas. Many researchers did work on this area as:

Varum *et al.* (2013) worked on seismic evaluation and retrofit of existing RC buildings in Kathmandu. In this study, four different three-storey RC frame structures were analyzed by using static pushover analysis and dynamic time history analysis. The results observed that the RC jacketing is a more predominant method to get the good seismic performance of structures. The failure mechanism of RC columns is highly dependent on the load path, ductility, and energy dissipation capacity of the columns. The seismic response of RC buildings with different design system was studied by Chaulagain *et al.* (2013). In this study, three storey RC buildings were analyzed by using nonlinear static pushover analysis and time history analysis. The results concluded that the structure according to modified Nepal building code and well designed structures shown a better performance with low inter-storey drift as compared to current construction practice structure. A sudden change in the inter-storey drift was observed in the current construction practice and national building code structures due to inadequate design and detailing. Kaushik *et al.* (2008) worked on the analytical modeling of masonry infills in RC building. In the present study, several analytical models for infills were studied, *viz.*, the single strut model, three strut model, and finite element model. The comparative study was carried out for different analytical models of masonry infills using experimental results. The results observed that the three strut model was found to be more accurate as compared to the single strut model.

The seismic vulnerability and retrofitting scheme for low and mid rise reinforced concrete buildings was studied by Adhikari *et al.* (2018). Nine residential buildings were studied by using different nonlinear analysis, *viz.*, static pushover with uniform loading, static pushover with triangular loading, static adaptive pushover analysis and dynamic time history analysis. The vulnerability of building was checked based on the maximum inter-storey drift ratio and compared with the standard drift limit (VISION-2000). All vulnerable buildings were retrofitted with the column jacketing method. The results observed that the column jacketing method enhances the seismic performance of the buildings, and it is an effective method to reduce the vulnerability of buildings. Rodrigues *et al.* (2018) worked on the seismic evaluation of school building in Nepal. In the present study, the school building is modeled for seismic assessment and retrofitting purposes. This building is analyzed by different nonlinear analysis methods, *viz.*, adaptive pushover analysis, pushover analysis with triangular and uniform loading pattern, and dynamic time history analysis. The vulnerability of the building has been checked based on peak inter-storey drift. This peak ISD (Inter-storey Drift) was calculated for each storey of the building and compared with the standard ISD limit, i.e., HRC scale (Homogenized Reinforced Concrete Scale). The different retrofitting solutions, *viz.*, the addition of infills, RC jacketing of all columns, addition of steel braces adopted to vulnerable building. The results concluded that the RC jacketing of all columns is a more efficient retrofitting solution to reduce the vulnerability of the building as compared to other methods. The seismic assessment of existing buildings with and without retrofit strategies was studied by Dumaru *et al.* (2018). In this study, the four existing buildings were selected. The incremental dynamic analysis was performed for the seismic vulnerability assessment of all existing buildings. The vulnerability assessment of all buildings has been carried out based on the peak inter-storey drift (ISD). The different retrofitting strategies were used, *viz.*, jacketing, bracing, shear wall, etc. to reduce the vulnerability of buildings and compared the performance of buildings with and without retrofit. The results observed that a steel bracing was more effective method to enhance the seismic performance of the buildings. Dumaru *et al*. (2016) studied the seismic assessment of bare frame buildings in Nepal. Two experimental tests, *viz.*, Schmidt hammer test and ambient vibration test were performed by using accelerometers to get the information of characteristic strength of structural members, and the frequency of the building respectively. Nonlinear static pushover analysis was performed to get the lateral capacity of the structure. The infills have been also considered in the bare frame to get the actual performance of the structure. Ultimately, the results concluded that the infill model has four times maximum strength as compared to the bare frame because infill increases the strength, stiffness. The seismic assessment and retrofitting of an existing building in India was studied by Sengupta *et al.* (2004). In this study, four storey building was considered to be located in a zone-III. FEMA 178 was used for the preliminary evaluation purpose after that the detailed analysis was done by using the linear static method and the response spectrum method in SAP-2000 software. There were two retrofit schemes proposed, i.e., jacketing of the ground storey column, plinth beam, and addition of infill walls at ground storey. The results observed that the absence of the plinth beam at ground level makes a vulnerable structure. Varsha *et al.* (2018) studied seismic retrofitting of an existing building. In this study functionality of four storey building changed from residential to commercial due to that reason load on the building increased. The linear static analysis was adopted to check the deficiency in different members of the building. The results concluded that the retrofitting technique increases the axial load and moment carrying capacity of structural members. Gunay *et al.* (2004) worked on the comparative evaluation of performance based seismic assessment procedures. In this study, two buildings were taken for the seismic evaluation, from Dinar and Ceyhan. Four storey building was damaged after Dinar earthquake and eight storey building was moderately damaged after Ceyhan earthquake. The nonlinear static and nonlinear dynamic analyses were used for evaluation purposes. A shear wall was used for the strengthening purposes. The results concluded that a nonlinear static method is equally successful as a nonlinear dynamic method in predicting the performance.

The assessment of existing building in Pakistan was studied by Mohammad *et al.* (2012). An existing building was assessed through a different tier (screening test) process and was analyzed in the ETABs software for detailed analysis. During the screening phase weak storey, soft storey, torsion irregularity, etc. was observed. The results observed that the building was designed adequately, but it requires the removal of partial-height of masonry walls because it produces a short column effect at ground storey and results into the vulnerable building.

The seismic evaluation and retrofit of damaged structures studied by Sadrmomtazi *et al.* (2019). In this study, three storey building was evaluated in Iran. Preliminary evaluation was conducted by taking some tests, *viz.*, rebound hammer test, rebar locator, etc. The modeling of the building and analysis was done by using static pushover analysis to check the performance ratio. Retrofitting was done by incorporating the shear wall in the building. After retrofitting the performance point of the building is less as compared to before retrofitting. The results observed that some construction mistakes occurred such as stirrup spacing, bending of reinforcement, covers, etc. Therefore, it is essential to monitor the building construction for safety purposes.

Vielma *et al.* (2013) evaluated the low-rise RC buildings as per the Venezuelan code. In this study, quadrant method was used for rapid evaluation of buildings. The quadrant method is based on two parameters, *viz.*, design base shear and threshold damage limit state based on the Venezuelan codal provisions. This quadrant method is useful to check the need for retrofitting structures based on the performance point. Ghobarah (2004) studied the drift limits associated with different damage levels. Analytical and experimental data were used to evaluate the correlation between the drift and damage to various structural elements. An appropriate drift limit is required for the performance based design of structures to achieve the economy & safety. For the analytical study, nonlinear dynamic, nonlinear static systems were used for the design of RC-walls and moment resisting frames. The results concluded that the available drift limits were found on the conservative side for ductile structures and non-conservative for non-ductile structures. Ghobarah (2000) studied on the seismic assessment of reinforced concrete existing structures. The common weaknesses in the structural system were due to inadequate column shear capacity, inadequate joint shear resistance, vertical & horizontal irregularities, non-ductile detailing, etc. The different damage indices were used to compute the damage potential of existing structures. The results concluded that the pushover analysis is a simple and efficient approach for the evaluation of existing structures. The seismic evaluation & retrofit of existing multi-storeyed buildings was studied by Menon *et al.* (2004). In this study, the vulnerability of engineered and non-engineered buildings was discussed and also, the three stages of evaluation, *viz.*, rapid screening, preliminary evaluation & detailed evaluation methods discussed in detail. A field survey was conducted on some existing buildings in Guwahati, Mumbai, and Chennai. The two residential open ground storey buildings were presented in this study. Rebar detailing was not complete in the available structural drawings. So it was assumed that the buildings did not comply with the ductile detailing requirements of IS 13920:1993. There were two retrofit schemes adopted as the first one is addition of infills at ground level to enhance stiffness and strength, and the second is addition of infills at symmetrical positions and all ground columns were RC-jacketed. The results concluded that the combination of local & global retrofit methods is more effective. Farghaly *et al.* (2014) worked on the different retrofitting techniques in old reinforced concrete buildings. In this study, four different structures were studied as (1) Ground + 4 floors, (2) Ground + 5 floors, (3) Ground + 4 floors, (4) Bedroom + 10 floors with different functional use. Similarly, the different retrofitting techniques were used as (1) Jacketing of columns, (2) steel bracings, (3) steel angle at the corner of columns, (4) RC wall to improve the better seismic performance. The results concluded that the RC wall is an effective retrofitting technique as compared to other techniques. The application of bracings is a more effective method for tall structures, and RC wall distributed on a staggered manner is an alternative rehabilitation technique for medium-rise building. El-Betar (2016) studied the seismic vulnerability of two existing RC buildings in Egypt. The two case studies were selected for the seismic evaluation purpose as (1) old school building, (2) new school building. The results concluded that the priority of evaluation should be given for the old and non-engineered buildings in high seismic regions. The old school building shows more vulnerable under high seismic load.

Tesfamariam *et al.* (2008) worked on the seismic risk assessment of RC buildings using fuzzy rule based (FRB) modeling. In this study, walk down survey was handled through a fuzzy set theory. The results concluded that the vulnerability assessment is based on building type, vertical & plan irregularity, year of construction, construction quality, etc. Riza *et al.* (2020) worked on the seismic assessment of RC buildings designed by local practice. Six storey RC building was studied to check the seismic performance by using pushover analysis in SAP-2000 software. The results concluded that the pushover analysis is simple method to evaluate the nonlinear behavior of structure. The seismic evaluation and retrofit of the existing hospital building was studied by Hassaballa *et al.* (2014).The hospital building was studied for two different load cases viz., (1) DL+LL+WL, (2) DL+LL+SL. The building was designed based on Egyptian society for earthquake engineering. The results concluded that the seismic load effect is more significant than wind load. The capacity curve parameters for Indian RC-infilled buildings were evaluated by Haldar *et al.* (2012). The parametric study was carried out for low rise, mid-rise and high rise buildings. The nonlinear static pushover analysis was performed in SAP-2000. These parameters were implemented in the seismic risk assessment tool 'SeisVARA'. The authors concluded that the seismic risk assessment tool “SeisVARA” is the best option to identify the vulnerability of structure. Murty *et al.* (2012) worked on a methodology for documenting housing typologies in moderate and severe seismic zones. This study represents the pilot study on different housing typologies. Field trips were conducted in seven locations of moderate and severe seismic zones. The present method was based on the seismic safety index and performance rating value. In safety assessment there were two critical factors: (1) life threatening factors, (2) economic loss inducing factors. The results concluded that the safety of a house depends on the life threatening factors and economic loss inducing factors. The house owner will learn to prioritize the factors that cause an economic setback.

Gautam *et al.* (2016) worked on the structural and construction deficiencies of Nepalese buildings. In this study RC buildings, masonry buildings and adobe houses was surveyed and also significantly observed the major cause of failures, foundation problems, liquefaction associated damages, local settlement related damages. At the end the results concluded that there is a need of significant guidelines for the future construction practice to improve the seismic performance.

Pradeep Kumar *et al.* (2014) worked on the earthquake safety of houses in India. The parameters, *viz.*, vulnerability, exposure, and hazard play an important role to evaluate the risk index of houses. The information on housing density in districts of India, housing with roof and wall material collected based on the census of India (1991, 2001 & 2011). At the end the results concluded that earthquake disaster mitigation activities should be implemented to reduce the seismic risk index of structure. The simplified methods for seismic assessment of existing buildings were studied by Tehranizadeh *et al.* (2016). The present study focused on verifying the results of the simplified methods given by New Zealand guideline (NZSEE) and ASCE 41-06 code in the assessment of existing buildings. The results concluded that simple lateral mechanism analysis is effective because its results are compatible with the nonlinear dynamic analysis.

2.3 Research gaps & current status

Research gaps

As per the study of existing literature review, in the current construction practice, the seismic evaluation & retrofit of reinforced concrete buildings are not being carried out based on the nonlinear methods. Also in the evaluation part masonry infills are not being considered in the RC frame. The BIS code does not give the response reduction factor (R-factor) for RC frame with masonry infill by incorporating the irregularities. Seismic evaluation & retrofit of RC structures based on the material strain limit of concrete and steel are not present in the existing literature review. A quick structural assessment procedure through nonlinear analysis is not available currently.

Current status

Based on the existing gaps, in the present study the seismic evaluation and retrofit of existing RC structures from severe earthquake prone area (Koyna-Warna region) are done based on the newly developed "Quadrants assessment method" and "Material strain limit approach". The "Quadrants assessment method" is the global and quick approach to check the need of retrofit the structures and the "Material strain limit approach" is the local and precise way for the detailed assessment of the structure. Seismic design parameters play an important role in seismic evaluation & retrofit of the structure. The Seismic design parameters, *viz.*, ductility, overstrength factor, and response reduction factor, etc. are evaluated for the existing RC-infilled structures and compared with the BIS (IS 1893 Part-1:2016) code.

2.4 Objectives

1. To conduct the rapid visual screening of existing reinforced concrete buildings through Earthquake Disaster Risk Index (EDRI) Method in severe earthquake prone area (Koyna-warna region, Maharashtra) and select all vulnerable reinforced concrete buildings through EDRI Method.
2. To model the vulnerable reinforced concrete buildings with masonry infills from field study in SeismoStruct software.

3. To determine the seismic parameters, *viz.*, peak base shear, ductility, overstrength factor, response reduction factor, performance point, etc. and compare the evaluated response reduction factor (R-factor) with the values recommended by the BIS code (IS 1893 Part-1:2016).
4. To evaluate the vulnerable structures by using adaptive pushover analysis and apply the newly proposed "Quadrants assessment method" to check the need of intervention/retrofit the structures.
5. To evaluate the vulnerable structures which are located in IInd, IIIrd & IVth quadrant by using the newly proposed material strain limit approach for the identification of deficient members and adopt the possible retrofitting techniques to all deficient members of the structures
6. To compare the seismic performance of reinforced concrete structures before and after the retrofit.