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INFLUENCE OF THE RETROFITTING TECHNIQUE ON THE SEISMIC RESPONSE OF REINFORCED CONCRETE STRUCTURES

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ABSTRACT

In this paper, a numerical investigation has been carried out in order to compare the seismic behavior of an existing non-ductile reinforced concrete (RC) structure under different retrofitting schemes (RC-Jacketing, Steel-Bracing and Steel-cage technique) and the same structure designed according to the Algerian seismic code, RPA 2003, in order to establish the most effective and economic retrofit solution. The construction details for the existing building are typical of constructions prior to the seismic guidelines of 1980.The frame structure is evaluated using both a nonlinear static (push-over) analysis to estimate the inelastic strength and deformation capacities and nonlinear dynamic time-history analyses under a set of different ground motions for comparison purposes. The results indicate that retrofitting with RC-Jacketing yields good performance in terms of ductility resistance capacities, the Steel-Bracing system resistance is increased but may collapse for great PGA of ground motions. , and the Steel-cage system has a large resistance but low ductility compared to the other retrofitting techniques.

Keywords: Retrofitting; pushover analysis; RC-jacketing; steel-cage; RC-jacketing; nonlinear dynamic.

1. INTRODUCTION

Old type structures are characterized by insufficient reinforcement detailing (lack of stirrups for ensuring a certain ductility level, indirect supports, insufficient anchorages of element), non-uniform distribution of stiffness or mass along the height of the building, insufficient foundation system, poor quality of materials, and various other surcharge such as *t*he change of use and corrosion. The result of these systematic deficiencies of the existing buildings is the decreased level of seismic protection, the increased seismic vulnerability and the

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extensive damage expected in future seismic excitations.

The experience gained from field observation and back-analysis led to the improvement of the level of knowledge and the evaluation of seismic codes. Repair and retrofitting of concrete structures have been attracting the attention of researchers over the last two decades.

The various repair/retrofit options available today include crack injection, shortcreting, steel jacketing, steel plate bonding, CFRP/GFRP jacketing, RC jacketing, addition of new structural elements (braces, walls, etc.), incorporation of passive energy dissipating devices, and provision of base isolation. Retrofitting can be at the system level or at the local level. Introduction of additional shear wall, braces, base isolation etc., to enhance the performance of a structure belong to the former category, while repair of a beam or column element using various jacketing techniques, such as jacketing using micro-concrete, steel, carbon fiber reinforced plastics (CFRP) and glass fiber reinforced plastics (GFRP) essentially fall under the category of local retrofitting. Repair and retrofit techniques can be used for enhancing the stiffness, the strength, and/or the ductility.

In this paper, we tried to compare three types of the most known retrofitting techniques (RC-Jacketing, Steel-Bracing and Steel-cage technique) in order to assess the most efficient retrofitting system using nonlinear procedures such as nonlinear static (pushover) analysis and nonlinear dynamic (time history) analysis.

2. DESCRIPTION OF THE DIFFERENT RETROFITTING POCEDURE

2.1 Steel-cage technique

The application of metallic jackets in RC columns aims to the increase the shear strength, the strengthening of the lap-splicing region and ductility capacity [1]. The steel jacketing option involves the total encasement of the column with thin steel plates placed at a small distance from the column surface, with the ensuing gap filled with non-shrink grout [2, 3].

For strengthening the reinforced concrete column in building, Pedro A used the steel caging [4], because it is now a common practice in many countries through the world. Based on the results of experimental end finite element models to analysis the influence that various parameters (size of the angles, the yield stress of the steel of the cage, the compressive strength of the concrete in the column, the size of the strips, the friction between the layer of mortar and the steel of the cage) can have on the behavior of the strengthened column axially loaded. The results of this study are that the numerical models were verified from the experimental results, and all of these parameters increased the confinement of concrete, ultimate load, the confinements of concrete are affected by the size of steel angle. When increased the yield stress of the steel the ultimate load on the strengthened column increases.

2.2 Rc jacketing

Reinforced Concrete (RC) jacketing is one of the most commonly applied methods for the habilitation of concrete members. Jacketing is considered to be a global intervention method if longitudinal reinforcement placed in the jacket passes through holes drilled in the slab and new concrete is placed in the beam-column joint. However, if the longitudinal reinforcement stops at the floor level then RC jacketing is considered as a member intervention technique. The main advantage of the RC jacketing technique is the uniformly distributed lateral load capacity throughout the structure there by avoiding concentrations of lateral load resistance, which occur when only a few shear walls are added [5].

In order to strengthen concrete columns with concrete jackets, Konstantinos et al. [6] are investigation three alternative method of jacketing and results are compared with results. The column were tested It has been demonstrated that the behavior of elements can be significantly improved by strengthening; even when the jacket is constructed with no treatment at the interface. In this study a significant reduction in the ductility and dissipated energy capacity can be expected, when compared between the strengthening procedures. The failure mechanism and the observed crack patterns are influenced by the strengthening method, the placing concrete jackets around columns considerably increases the strength and stiffness.

2.3 Steel bracing

Steel bracing can be a very effective method for global strengthening of buildings. Some of the advantages are the ability to accommodate openings, the minimal added weight to the structure and in the case of external steel systems minimum disruption to the function of the building and its occupants. Alternative configurations of bracing systems may be used in selected bays of a reinforced concrete frame to provide a significant increase in horizontal capacity of the structure. Concentric steel bracing systems have been investigated for the rehabilitation of non-ductile buildings by many researchers [7, 8, 9, 10].

For improve of seismic performance of existing reinforced concrete building, Hendramawat et al. [11] used the steel bracing. Three methods of seismic evolution are employed in this study, the nonlinear static Pushover as described in FEMA 356 and FEMA 440 and dynamic time history analysis. The results indicate that the target displacements are reduced by 16%-55% in pushover analysis and the story drift are within the limit criteria in dynamic time history analysis if the proposed steel bracing are used.

The study by Massumin et al. [12] used the interaction between bracing system and moment resisting frame in braced RC frames, used frames are designed based on old traditional codes, but one of them is strengthened with steel X-barcing. Both the results with experimental and ANSYS software, under cyclic static loading are performed. The results show considerable interaction effects between two systems in enhancement of seismic characteristics of compound system, especially on increasing of energy damping.

For a more efficient balance between whole-life costs and in-service performance, Di Sarno et al. [13] used of special metals such as stainless steels (SSs) for structural applications in building systems provides possibilities. The comparison between of SSs for seismic retrofitting of framed structures, either braced (CBFs) or moment resisting (MRFs) frames, for multi-story CBFs and MRFs. The results of both inelastic static (pushovers) and dynamic (response history) analyses demonstrate that systems retrofitted with SSs exhibit enhanced plastic deformations and excellent energy absorbing capacity. The augmented strain hardening of SS is beneficial in preventing local buckling in steel members in both MRFs and CBFs.

3. NUMERICAL TOOL AND MODELING STRATEGIES

The numerical analyses developed and described in this paper with different nonlinear source were performed using the computer program SAP2000. The program includes models for representation of the behavior of spatial frames under static or dynamic loading, considering both material and geometric nonlinearities. With the software, six types of analyses can be performed, namely modal analysis, static analysis, dynamic and static time-history analysis, conventional pushover.

The software allows for the use of element with lumped-plasticity (with fixed length, so called plastic-hinge), Nonlinear analysis of RC structures using concentrated plastic with fiber hinge option in SAP2000 [21, 22, 23]. The fiber hinge computes a moment-curvature relation in any bending direction for varying level of axial load throughout a static or dynamic analysis (Fig. 1). This interaction between biaxial moment and axial force, and the distribution of inelastic action throughout the section is obtained automatically by assigning particular stress-strain (σ-ε) relationships to individual discretized fibers in the cross section. The stress s-strain relationships correspond to unconfined concrete, confined concrete, and longitudinal steel reinforcement.

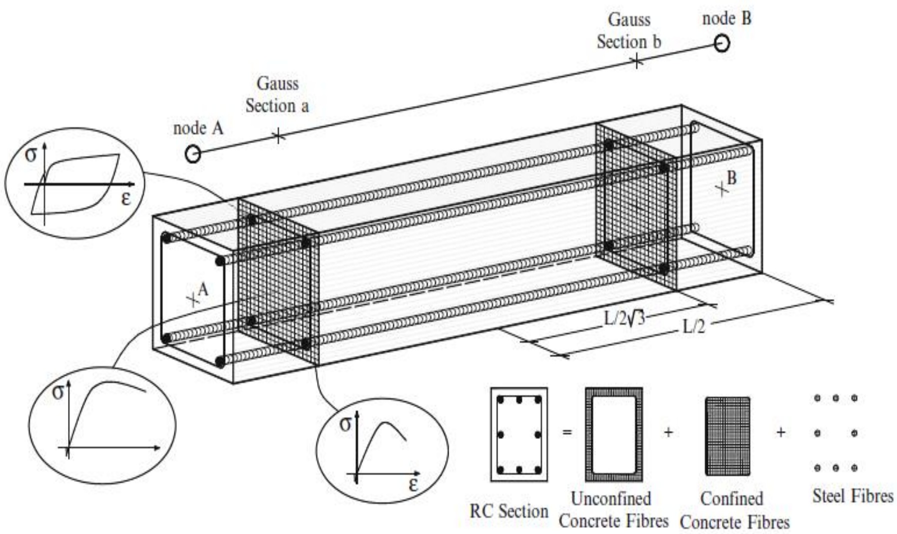


Figure 1. Discretization of typical reinforced concrete cross-section

The fiber hinge model is lumped plasticity model with a characteristic length L_p, assigned to an elastic element at a specific point (Fig. 2). The use of this model can be extended to model analysis, nonlinear static (pushover), and nonlinear time history analysis with direct integration. The fiber model can represent the loss of stiffness caused by concrete cracking, yielding of reinforcing steel due to flexural yielding, and strain hardening. Is successful in representing degradation and softening after yielding; however pinching and bond slip are not included in the present model. Shear and torsion behavior of the cross section are represented elastically.

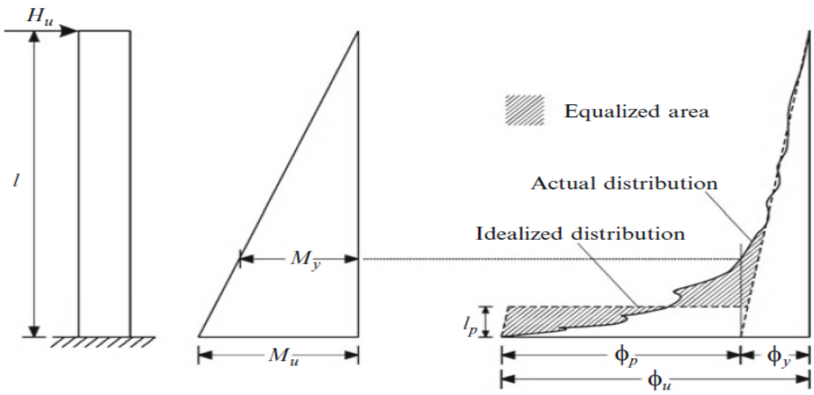


Figure 2. Equivalent column and the definition of the equivalent plastic hinge length based on the idealized curvature distribution

In the lumped plasticity approach, a rigid plastic hinge could be defined for every degree of freedom. For a comprehensive nonlinear analysis, consideration of the shear failure in members is necessary. However, some past studies [9, 10, 11,12], have reported that even for under-designed RC buildings, possessing inadequate transverse reinforcement, the shear demand is significantly lower than the shear capacity in both beams and columns and that no shear failure would occur. Therefore, in this study, only inelastic flexural behavior of structural elements was considered through concentrated. Rigid plastic hinges at the ends which are susceptible to inelastic behavior. The nonlinear structural analysis program SAP2000 was chosen for this work [13]. The plastic hinge length is determined using Equation 1, which considers the axial load ratio (P/P_0), span-depth ratio (L/h), and reinforcement ratio (A_s/A_g)[24].

$$\frac{l_p}{h} = \left[0.3\frac{p}{p_0} + 3\frac{A_s}{A_g} - 0.1\right]\frac{L}{h} + 0.25 \geq 0.25 \tag{1}$$

Were Ag is the section area of reinforcement, L is the length of the column, h is column depth, P is the axial load, and P_0 $(= 0.85f_c'(A_g - A_s) + f_yA_s)$ is the nominal axial load capacity.

4. DESCRIPTION OF FRAME MODELS

Five stories RC building have been used in this study, Fig. 3. The slabs were represented in the structural model of the building using their weight in the gravity load case and as concentered masses at all joint, the bay lengths are 4m and the height is 3m. The building was designed without seismic design criteria, and is located in high seismicity region with a peak ground acceleration of 0.32g. The dimension of the beam (30x30) and of the columns (30x30), the reinforcement details are shown in Table1.

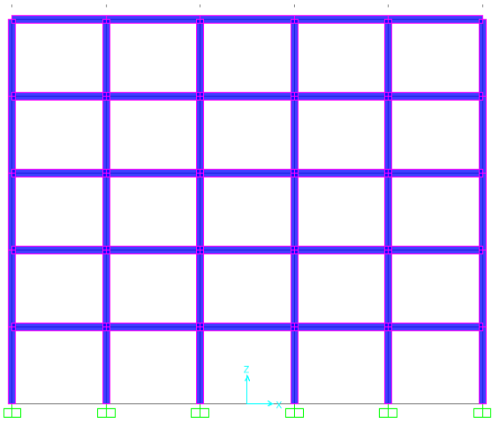
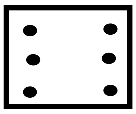
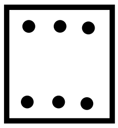
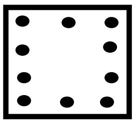
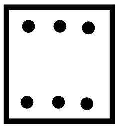


Figure 3. Structural models

Table 1: Reinforcement's details

	Details of columns	Details of beams
Stru-Old	30X30  3T12 3T12	30X30  3T12 3T12
Stru-RPA	40X40  10T14	35X30  3T16 3T16

5. PUSHOVER RESULTS OF THE ORIGINAL AND DESIGN WITH RPA FRAME

Butts of reinforcement of the structure is to increase the capacity of resistance has shearing and the ductility of the old structure until to the capacity of new the structure calculating by Code RPA [14], to wait this butts in has to start with an analysis nonlinear static to know esteem between the two capacity of the structure (old and new), and follows from there choose the type of reinforcement. The Fig. 4 represents comparison between two curve of capacity of the structure old and new in remark that the Shear force of structure new is larger with 55%, and the ductility is larger 58%.

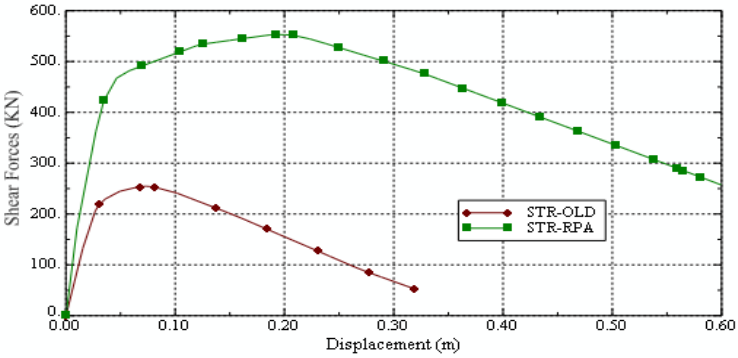


Figure 4: curve of capacity for Old end RPA structural

6. PUSHOVER RESULTS FOR DIFFERENT SYSTEM OF RETROFITTING

6.1 Steel– bracing

To reinforce the structures with bracing system, it is necessary to have study the influence dimensions of profiles and the position of each system on the capacity of the structure Fig. 5 (resistance and ductility), the Fig. 6 to present the influence of the increase in the number of bracing in each floor on the curve of capacity, to have some that each time to increase in the number of the bracing, the curve of capacity it is increased, the increase in the 1st bracing is of 40% of the capacity of the old structure, and has the last floor with a value of 80%, but ductility it to influence in the opposite path.

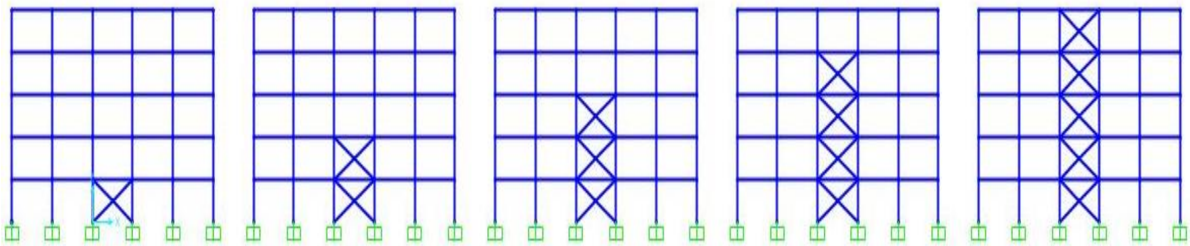


Figure 5. Positions each system of bracing

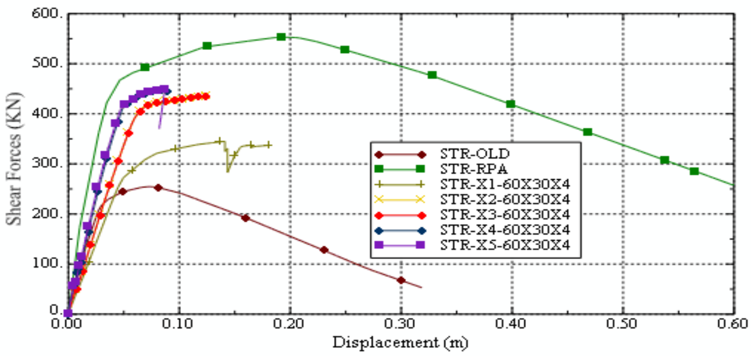


Figure 6. Curve of capacity for each positions each system of bracing

The Fig 7. to present the influence of the dimensioning of profiles, almost all dimensioning to give the same capacity to shearing but the ductility it increased up to 50%.

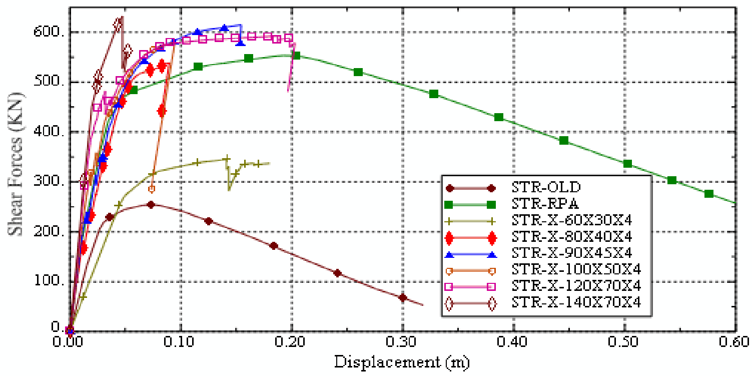


Figure 7. Influence dimensioning of bracing system

6.2 Rc-jacketing

The Fig. 8 presents the influence of the change thickness of Rc-jacketing on the curve of capacity, with reserved the diameter of reinforcement, the increase thickness given an increase in the capacity of to the shear forces and ductility.

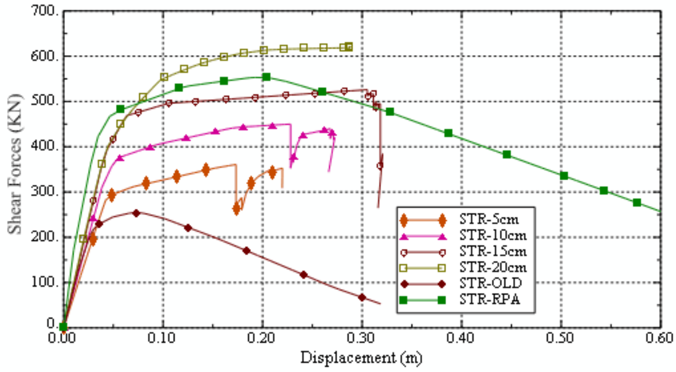


Figure 8. Influence the thickness of Rc-jacketing

In the Figs. 9 and 10 in reserved the thickness and changed the diameter of reinforced, notices of it that the increase in the diameter of steel it is followed an increase in the shear force and the ductility. Until has awaits diameter T12 (1.13 cm^2) and the T14 (1.53 cm^2) increase and very weak.

6.3 Steel-cage technique

The Fig. 11 to present curve of capacity of the different dimensionnement of corner, when increased in type of corner, to have an increase in the sear force of it, but ductility it increases in a weak way, until both last type it is almost coincide.

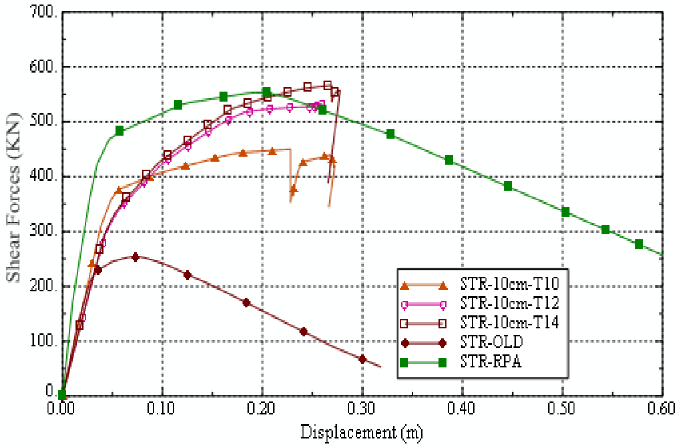


Figure 9. Influence of changed the diameter of reinforced for 10 cm Rc-jacketing

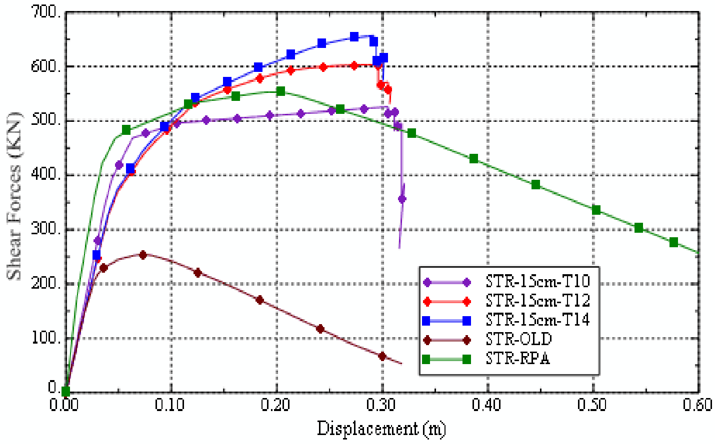


Figure 10. Influence of changed the diameter. of reinforced for 10 cm Rc-jacketing

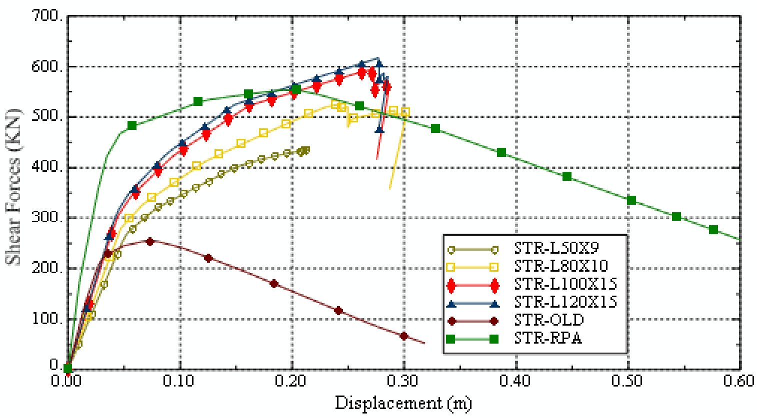


Figure 11. Influence the dimensioning of corner

The Fig. 12 has present the best dimensions and system for check of retrofitting, for reinforcement with bracing system of section 120x70x4, it is given an increase of 70% of the shear force and 4 of ductility; the system of rc-jacketing (15 cm-T10) given a 504 kN of shear force with good a ductility of 6, and 600 kN of the shear force and weak ductility for the system of reinforcement with steel-cage technique (L100x15).

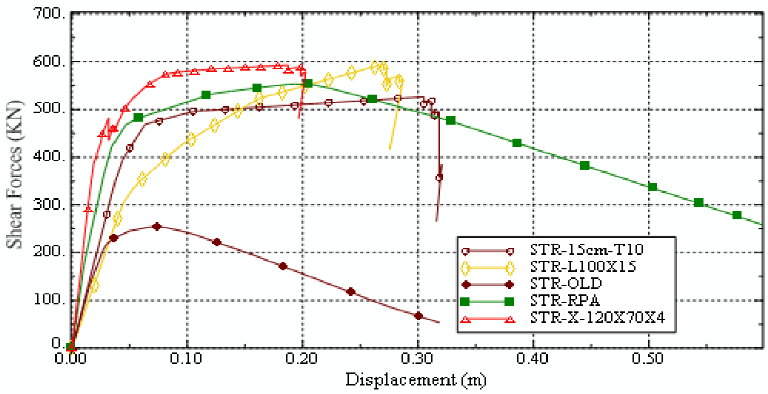


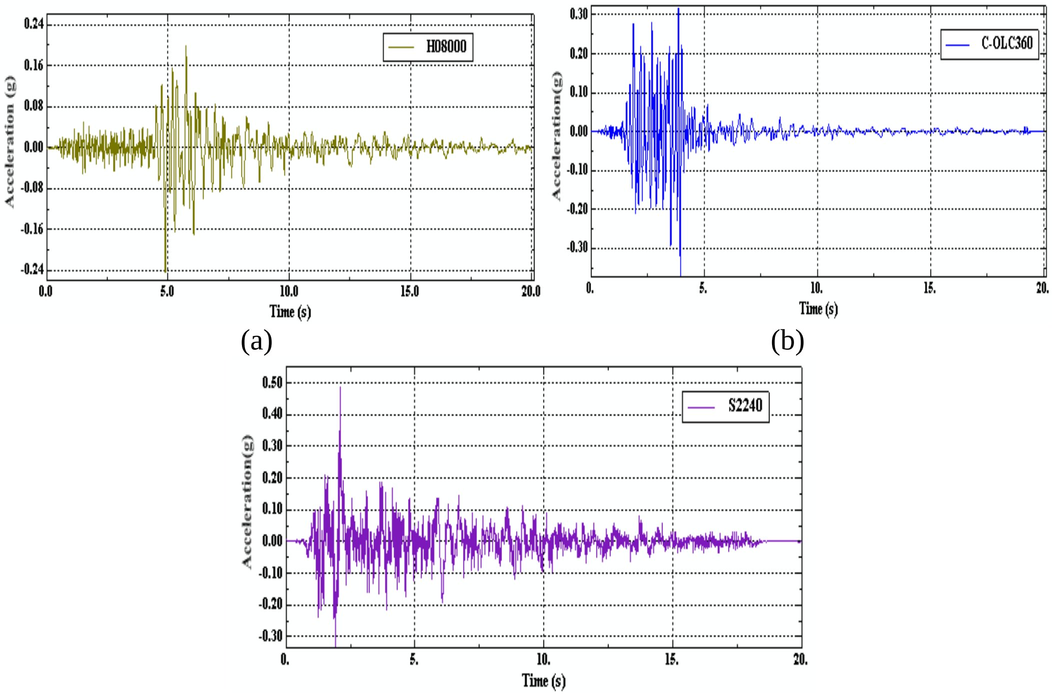
Figure 12. Best dimensions and system for different type of retrofitting

7. NONLINEIAR TIME HISTORY ANALYSES RESULTS

Due to the limitation of the response spectrum analysis procedure to approximate the dynamic nonlinear response of a complex structure, nonlinear time-history analysis is strongly recommended instead. Nonlinear time history analysis accounts for the nonlinearities or strongly degradation of different elements of the structure, as well as the load pattern or ground motion intensity and characteristics used during nonlinear dynamic analysis. Nonlinear time history analysis also allows determining the effect of added energy-dissipation devices in structural systems.

The main disadvantage of the time history analysis method is high computational and analytical effort required and the large amount of output information produced. During the analysis, the capacity of the main structure components is evaluated as a function of time, based on the nonlinear behavior determined for the element and materials.

The most general approach for the solution of the dynamic response of structural systems is the direct numerical integration of the dynamic equilibrium equation at a discrete point in time (SAP 200). The accelerograms used in this investigation are the horizontal components of the San Jacinto Soboba, Oil City and Nahanni, Canada records, Fig. 13.The duration of the earthquake used in this analysis was primarily limited to the first fifteen seconds of the earthquake. The peak ground acceleration of the horizontal component of SAN JACINTO SOBOBA is 0.24 g, that of OIL CITY is 0.37g and that of Nahanni, Canada is 0.5 g (Fig. 13).



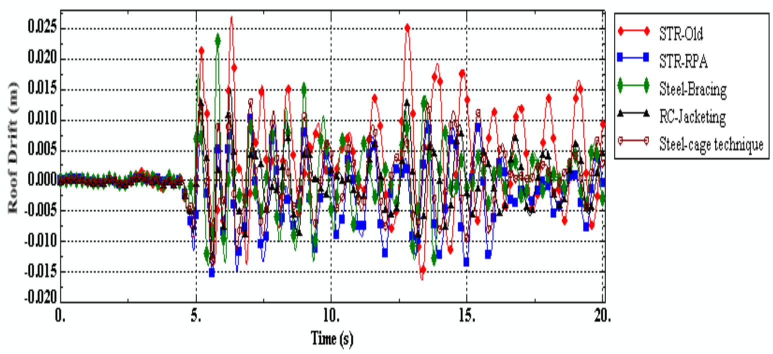
(a) (b)

(c)

Figure 13. Earthquake records a- san jacinto soboba, b- oil city c- Nahanni, Canada

8. MAXIMUM INTER-STOREY DRIFT

The peak inter-story drift profiles at top displacement of structure obtained from NTH analyses of the buildings subjected to the three sets of ground motions (i.e. 0.25g, .37b, 0.5g) are presented in Figs.14 (a,b) ,15 (a,b) ,16 (a,b).



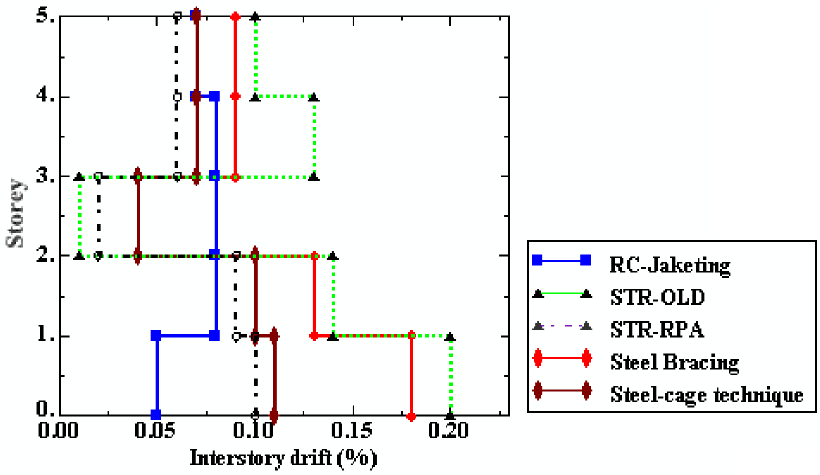
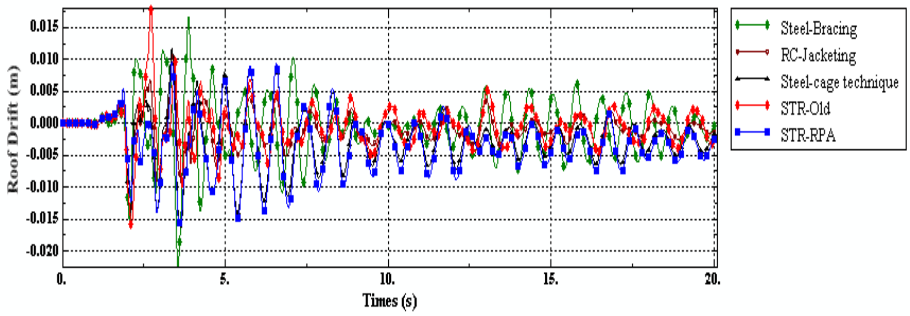


Figure 14. (a) Top displacement time histories and (b) interstory drift ratio for time



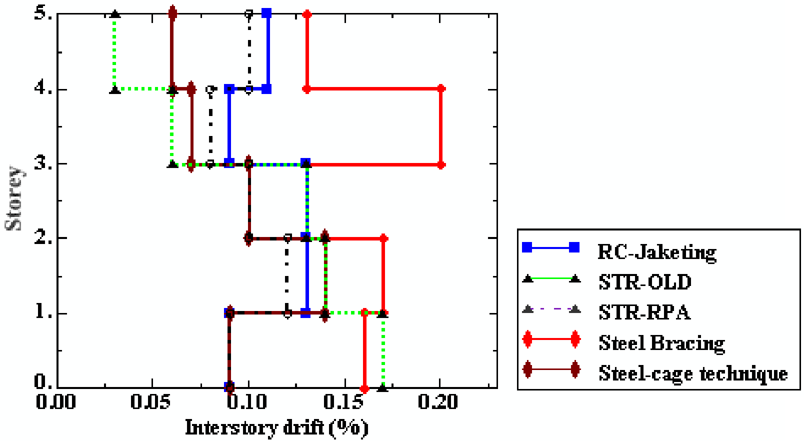


Figure. 15 (a) Top displacement time histories and (b) interstory drift ratio

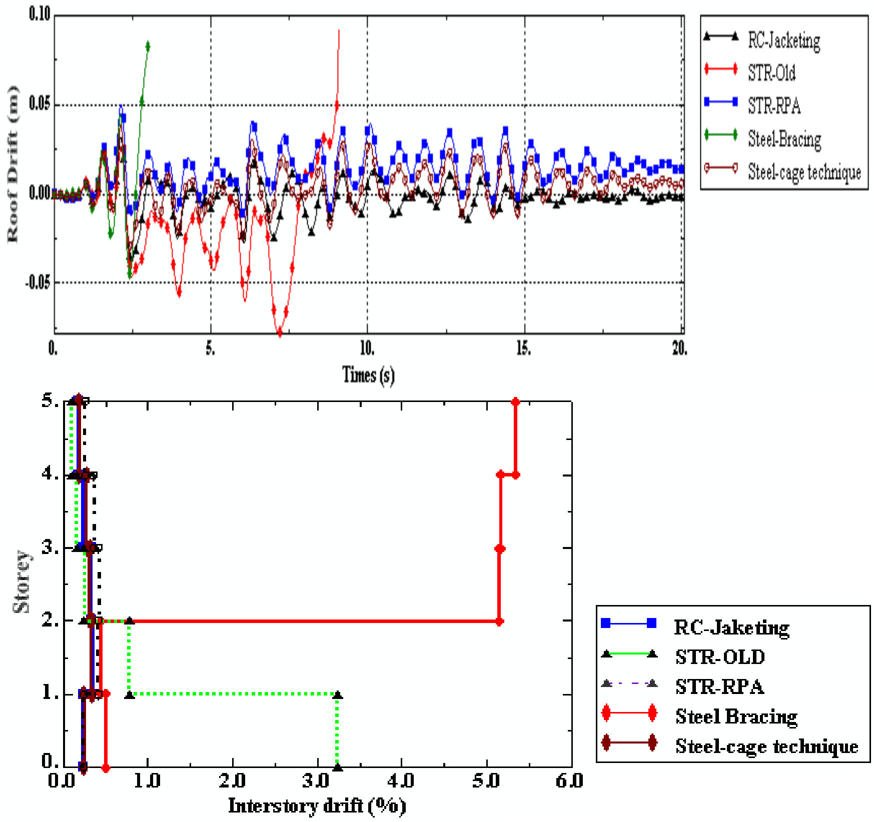


Figure: 16 (a) Top displacement time histories and (b) interstory drift ratio

The alternative intervention increased the stiffness of the structure and reduced the maximum interstorey drift at all levels with respect to the bare structure in retrofitting by RC Jacketing, steel-cage technique and increased in ductility for bracing system. The reinforcement by Rc Jacketing and steel-cage technique reduced interstory drift by 50%, and the last type of Bracing reduced interstory drift by 17% for PGA 0.25, 0.37and collapse in PGA 0.5.

9. CONCLUSION

The seismic performance of an under-designed R/C structure and different strategies for the seismic retrofitting were studied and compared by nonlinear dynamic time-history analyses and simplified assessment procedures based on nonlinear static pushover analyses. The retrofitting design strategy was aimed at reducing the interstory drift component of the seismic response and at improving the global ductility of the structure. The retrofitting strategy R/C jacketing and steel cage technique based on increased the strength and stiffness columns proved to be an effective retrofitting strategy for lower and higher seismic actions. For strategy based on bracing system, the analysis with nonlinear static pushover analyses given a good estimation in the shear force and ductility but this estimation is not satisfied in the analysis by time history To the failed the bracing and concentration of retrofitting in Heart of the structure.

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