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RETROFITTING OF REINFORCED CONCRETE FRAMES USING STEEL BRACINGS

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ABSTRACT

There has been an increase in the occurrence of the natural disasters globally, in the recent past. Earthquakes are leading among these in terms of loss of life, property and extensive damages to structures. As such, seismic retrofitting has evolved as a subject of modern context and engineering importance.Column jacketing is one of the most common methods practiced as a part of seismic retrofitting strategies. Different materials are in use for strengthening the columns and among them RCC, Steel and FRP are more popular. The choice of any of these three materials has so far been notional and is left most of the times to the discretion of practicing engineers and execution teams, giving priority to the availability of the materials and skills of field force. However, much depends on the actual interaction of these materials with the existing materials of columns, which is often ignored in the design offices while modelling the structures. RC framed buildings of five to ten storeys are most commonly found in all the seismic zones, in Indian scenario. Therefore, there is a strong need to look into the lapses and ignorances in modelling the retrofitting aspects such as column strengthening, in these types of buildings. Realising this need, a eleven (G+10) storeyed reinforced concrete framed building is taken up as a case study in the present work. The building is assumed to be originally in a location in zone 2 which is upgraded to zone 3, requiring retrofitting of columns. Three alternative materials are tried for column strengthening viz., RCC, Steel and FRP. For each of these one model is tried; which is closer to the actual practice. Response spectrum method of analysis is adopted using ETABS software. Results indicate that FRP jacketing is more effective in increasing strength and deformation capacity of the retrofitted columns

1. INTRODUCTION

1.1 GENERAL

There is a global consensus that natural disasters are occurring more frequently in the recent times. This may be majorly due to our inability to control the hazards from causing colossal damages to structures, properties and life. Earthquakes are the most dreadful among the natural disasters due to their high degree of un-creditability and capability of causing potential damages. It is estimated that around 500000 earthquakes occur in each year, that are detectable with current instrumentation. The number of seismic stations has also increased from about 350 in 1931 to many thousands as in today.

As per the United States Geological Survey (USGS) report, their have been an average of 18 major earthquakes(of magnitude 7 to 7.9) and one great earthquake(8.0 or greater)every year, since 1900.With the rapid growth of mega cities such as Mexico, Tokyo and Teheran, in the areas of high seismic risk, seismologists are worried that a single earthquake may claim the life's of up to 3 million people, besides ruining many structures.

A major portion of peninsular India is hit by natural disasters among which 58% is prone to earthquakes. Himaliyan region, Indogigantic planes are also more vulnerable to earthquakes.

Indian subcontinent has suffered some of the greatest earthquakes in the world with magnitude exceeding 8.0. For instance, in a short span of about 50 years, four such earthquakes occurred: Assam earthquake of 1897 (magnitude 8.7) (Oldham, 1899), Kangra earthquake of 1905 (magnitude 8.6) (Middlemiss, 1910), Bihar-Nepal earthquake of 1934 (magnitude 8.4) (GSI, 1939), and the Assam-Tibet earthquake of 1950 (magnitude 8.7) (CBG, 1953). The most tragic earthquakes of last 50 years in India are, the Latur earthquake (which caused about 8000 deaths) and the Bhuj earthquake of 2001(about 25000 deaths) . While the former caused an intensive damage to masonry buildings in many rural areas, the latter struck in a widespread area causing extensive damage to many RC framed buildings besides grounding many villages to debris.

1.2 RC FRAMED BUILDINGS

RC framed buildings are the most commonly found in Indian scenario, constituting to a major percentage among the total buildings in the country. This may be due to the ease in construction and vertical expansion of such buildings, in addition to the superior seismic performance as compared to the masonry buildings. Even in the rural parts of India, RC construction is clearly on the rise due to the increased awareness and access to raw materials.

However, these RC buildings are also suffering extensive damages during earthquakes in India, raising concern over their safety and the safety of the incumbents as well. Poor workmanship (defective concreting and wrong detailing) is identified as the main reason of failure of RC buildings during earthquakes in India. A review of various damage patterns of RC buildings during past few earthquakes is made here under.

1.2.1 Damages to RC Framed Buildings in past earthquakes

Reinforced concrete buildings have been damaged on a very large scale in Bhuj earthquake of January 26, 2001. These buildings have been damaged due to various reasons. Identifying a single cause of damage to buildings is not possible. There are combinations of reasons, which are responsible for multiple damages. It is difficult to classify the damage, and even more difficult to relate it in quantitative manner. This is because of the dynamic character of the seismic action and the inelastic response of the structures. In spite of all the weaknesses in the structure, either due to code

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imperfections or error in analysis and design, the configuration system of the structure and proportioning and detailing of structure elements play a vital role in the catastrophe. It has been observed that the causes of damage in Bhuj earthquake are more or less similar to those observed in other past earthquakes (Cassaro and Romero, 1986;EERI,1990,1993, 2000). The principal causes of damage to buildings are soft storeys, floating columns, mass irregularities, poor quality of material and faulty construction practices, inconsistent seismic performance, soil and foundation effect, pounding of adjacent structures and inadequate ductile detailing in structural components. These have been described in detail subsequently.

Building construction of this type (without any seismic features) suffered significant damage during Koyna (1967) and Killari (1993) earthquakes. Some damage was also observed during Jabalpur (1997) earthquake. The main damage patterns consisted of shear cracks in walls, mainly starting from corners of openings.-Vertical cracks at wall corners-Partial out of plane collapse of walls due to concatenation of cracks.-Partial caving-in of roofs due to collapse of supporting walls.-Shifting of roof from wall due to torsional motion of roof slab. This type of construction was also severely affected by the 2001 Bhuj earthquake (M 7.6). In the epicentral region, several buildings of this type suffered total collapse of the walls resulting in depth and injury to large number of people. The overall performance was dependent on the type of roof system: buildings with lightweight roof suffered relatively less damage while buildings with RCC roofs suffered much greater damage. (Source: IIT Powai 2001) Importance and effectiveness of seismic provisions, in particular RC lintel and roof bands (bond beams) was confirmed both in the 1993 Killari earthquake and in the 2001 Bhuj earthquake. Buildings with seismic provisions performed substantially better and did not suffer collapse, whereas similar construction without any seismic provisions was severely affected by the earthquake.

Figure 1.1: Damage patterns of RC-framed buildings

1.3 SEISMIC RETROFITTING

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STRATEGIES
Definition

Retrofit strategy refers to options of increasing the strength, stiffness, and ductility of the elements or the building as a whole.

A retrofit strategy is a technical option for improving the strength and other attributes of resistance of a building or a member to seismic forces. The retrofit strategies can be classified under global and local strategies. A global retrofit strategy targets the performance of the entire building under lateral loads. A local retrofit strategy targets the seismic resistance of a member, without significantly affecting the overall resistance of the building. The grouping of the retrofit strategies into local and global are generally not be mutually exclusive. For example, when a local retrofit strategy is used repeatedly it affects the global seismic resistance of the building. It may be necessary to combine both local and global retrofit strategies under a feasible and economical retrofit scheme.

The objectives of seismic retrofitting as per IS 13935:1993 [4] are as follows

1. Increasing the lateral strength and stiffness of the building.
2. Increasing the ductility and enhancing the energy dissipation capacity.
3. Giving unity to the structure.
4. Eliminating sources of weakness or those that produce concentration of stresses.
5. Enhancement of redundancy in the number of lateral load resisting elements.
6. The retrofit scheme should be cost effective.
7. Each retrofit strategy should consistently achieve the performance objective.

1.3.1 BUILDING DEFICIENCIES

The following two sections highlight some common deficiencies observed in multi-storeyed RC buildings in India. The building deficiencies can be broadly classified as:

1.3.2 LOCAL DEFICIENCIES AND GLOBAL DEFICIENCIES.

1.3.2.1 LOCAL DEFICIENCIES

Local deficiencies lead to the failure of individual elements of the building. The observed deficiencies of the elements are summarized below.

- Columns

a. Inadequate shear capacity.
b. Lack of confinement of column core. Lack of 135º hooks, with adequate hook length.
c. Faculty location of splice just above the floor, with inadequate tension splice length.
d. Inadequate capacity of corner columns under biaxial seismic loads.
e. Existence of short and stiff columns.

- Beams and Beam-to-Column Joints

a. Shear reinforcement not adequate for flexural capacity.
b. Inadequate anchorage of bottom rebar.
c. Inadequate plastic hinge rotation capability due to lack of confinement.

- Slab-to-Column Connections

a. Absence of drag and chord reinforcement.

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b. Inadequate reinforcement at the slab-to-beam connections.

- Structural Walls

a. Lack of adequate boundary elements.
b. Inadequate reinforcement at the slab-to-wall or beam-to-wall connections.

- Unreinforced Masonry Walls

a. Lack of out-of -plane bending capacity.
b. Precast elements
c. a. Lack of tie reinforcement.

- Deficient Construction

a. Frequent volume batching.
b. Additional water for workability.
c. Inadequate compaction and curing of concrete.
d. Top 100 to 200 mm of column cast separately, leading to deficient plastic hinge region.
e. Inadequate side face cover, leading to rebar corrosion.
f. Poor quality control.

1.3.2.2 GLOBAL DEFICIENCIES

Global deficiencies can broadly be classified as plan irregularities and vertical irregularities, as per the code. The items left out are listed under miscellaneous deficiencies. Some of the observed irregularities are as follows.

- Plan Irregularities

a. Torsional irregularity due to plan symmetry and eccentric mass from water tank.
b. Frequent re-entrant corners.
c. Diaphragm discontinuity due to large openings or staggered floors, along with the absence of collector elements.
d. Out-of-plane offset for columns along perimeter.
e. Nonparallel lateral load resisting systems (not observed in the building studied).

- Vertical Irregularities

a. Stiffness irregularity, soft storey due to open ground storey.
b. Mass irregularity (not observed in the building studied).
c. Vertical geometric irregularity from set-back towers.
d. In-plane discontinuity for columns along the perimeter of the building.
e. Weak storey due to open ground storey.

The miscellaneous deficiencies that were observed are as follows.

- Deficiencies in Analysis

a. Buildings designed as only gravity load resisting system.
b. Neglecting the effect of infill walls.
c. Inadequate geotechnical data to consider near source effects.
d. Neglecting the P-Δ effect.

- Lack of integral action of the lateral load resisting elements
- The building performance is degraded due to the absence of tying of the lateral load resisting elements. The beams are not framed into the elevator core walls and spandrel beams between the perimeter columns are missing.

- Failure of stair slab

If the stair slab is simply supported without adequate bearing length, a collapse of the slab closes the escape route for the residents.

- Pounding of buildings

  Another poor design concept is not providing adequate spacing between adjacent buildings or seismic joints between segments of a building.

1.3.3 REASONS THAT MAY LEAD TO RETROFITTING:

1. Building which are designed considering gravity loads only.

2. Development activities in the field of Earthquake Resistant Design (EQRD) of buildings and other structures result into change in design concepts.

3. Lack of timely revisions of codes of practice and standards.

4. Lack of revisions in seismic zone map of country.

5. In cases of alterations in buildings in high seismic activity zone i.e. increase in loading class, increase in number of story etc.

6. In cases of deterioration of Earthquake (EQ) forces resistant level of building e.g. decrease in strength of construction material due to decay in structure, damage caused by fire, and settlement of foundations.

7. The quality of construction actually achieved may be lower than what was originally planned.

8. Lack of understanding by the designer.

9. Improper planning and mass distribution on floors.

1.4 RETROFIT STRATEGIES :

Retrofit strategies that are viable for the type of buildings considered, are grouped under local and global strategies.

1.4.1 LOCAL RETROFIT STRATEGIES

Local retrofit strategies include local strengthening of beams, columns, slabs, beam-to-column or slab-to column joints, walls and foundations. Local strengthening allows one or more under-strength elements or connections to resist the strength demands predicted by the analysis, without affecting the overall response of the structure. This scheme tends to be the most economical alternative when only a few of the building's elements are deficient. The local retrofit strategies are grouped according to the elements.

Column Strengthening

Column strengthening techniques include the following.

a. Concrete jacketing

b. Steel jacketing

c. Fibre reinforced polymer sheet wrapping

Concrete Jacketing

This method increases both strength and ductility of the columns. But, the composite deformation of the existing and the new concrete requires adequate dowelling to the existing column. Also, the additional longitudinal bars need to be anchored to the foundation and should be continuous through the slab. Frequently, these considerations are ignored.

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Steel Jacketing

Steel jacketing refers to encasing the column with steel plates and filling the gap with non-shrink grout. It is a very effective method to remedy deficiencies such as inadequate shear strength and inadequate splices of longitudinal bars at critical locations. But, it may be costly and its fire resistance has to be addressed.

Fibre Reinforced Polymer Sheet Wrapping

The use of Fibre Reinforced Polymer (FRP) sheets is becoming popular in India. FRP sheets are thin, light and flexible enough to be inserted behind service ducts, thus facilitating installation. In retrofitting of a column there is no significant increase in the size. The main drawbacks of FRP are high cost, brittle behavior and fire resistance.

Beam Strengthening

i. Addition of Concrete : There are some disadvantages in this traditional retrofit strategy. First, addition of concrete increases the size and weight of the beam. Second, the new concrete requires proper bonding to the existing concrete. Third, the effects of drying shrinkage must be considered as it induces tensile stresses in the new concrete. Instead of regular concrete, fibre reinforced concrete can be used for retrofit.
ii. Steel Plating : Gluing mild steel plates to beams is often used to improve the beam flexural and shear performances. The addition of steel plate is simple and rapid to apply, does not reduce the storey clear height significantly and can be applied while the structure is in use. Glued plates are of course prone to premature debonding.
iii. FRP Wrapping : Like steel plates, FRP laminates are attached to beams to increase their flexural and shear capacities. The amount of FRP attached to the soffit should be limited to retain the ductile flexural failure mode.
iv. Use of FRP bars : FRP bars can be attached to the web of a beam for shear strengthening. FRP bars can be used as tendons for external prestressing.
v. Beam–To-Column Joint Strengthening :

The different methods of strengthening are as follows.

vi. Concrete Jacketing : The joint can be strengthened by placing ties through drilled holes in the beam But the placement of such ties is difficult.
vii. Concrete Fillet : the use of a concrete fillet at the joint to shift the potential hinge region away from the column face to the end of the fillet.
viii. Steel Jacketing : Steel jacketing helps in transferring moments and acquiring ductility through confinement of the concrete and proposed the use of corrugated steel jackets. Steel plating is simpler as compared to steel jacketing, where plates in the form of brackets are

attached to the soffits of beams and sides of the column.

ix. FRP Jacketing : The studies have shown that the retrofitted specimens exhibit better efficiency in terms of strength, energy dissipation, lesser rate of stiffness degradation and ductility levels.

x. Wall Strengthening : A concrete shear wall can be strengthened by adding new concrete with adequate boundary elements. For the composite action, dowels need to be provided between the existing and new concrete. Steel braces or strips, FRP or steel sheets, external prestressing or reinforced grouted core can be employed for strengthening unreinforced masonary walls.

xi. Foundation Strengthening : Foundation strengthening is done by strengthening the footing as well as the soil (FEMA 356).

1.4.2 GLOBAL RETROFIT STRATEGIES

Global retrofit strategies aim to stiffen the building, by providing additional lateral load resisting

elements, or to reduce the irregularities or mass.

Structural Stiffening

Addition of Infill Walls : The addition of masonry infill wall is a viable option for the buildings, with open ground storeys, addressed in the project. Of course masonry infill walls increase strength and stiffness of the building, but do not enhance the ductility. Infill walls with reinforced concrete masonry units can act as shear walls. For cast-in-place RC infill walls, the significant parameter that defines the lateral strength of the frame is the presence of dowels between a wall and the bounding frame. The use of modular precast panels involves minimal on-site casting and modest handling equipment. Connections between the panels and the frame are critical. Use of infill steel panels is an alternative to bracing system.

Addition of Shear Walls

New shear walls can be added to control drift. Critical design issues involved in the addition of shear walls are as follows.

a Transfer of floor diaphragm shears into the new wall through dowels.

b Adding new collector and drag members to the diaphragm.

c Reactions of the new wall on existing foundations.

Addition of Steel Braces

A steel bracing system can be designed to provide stiffness, strength, ductility, energy dissipation, or any combination of these. Connection between the braces and the existing frame is the most important aspect in this strategy. The uses of prestressed tendons and unbonded braces have been proposed by some investigators to avoid the problems associated with the failure of connections and buckling of the braces, respectively.

Reduction of Irregularities

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Torsional irregularities can be corrected by the addition of frames or shear walls. Eccentric masses can be relocated. Seismic joints can be created to transform an irregular building into multiple regular structures. Partial demolition can also be an effective measure, although this may have significant impact on the utility of the building. Discontinuous components such as columns can be extended beyond the zone of discontinuity. As mentioned earlier, walls or braces can alleviate the deficiency of soft and weak storey.

Mass Reduction

Reduction of mass results in reduction of the lateral force demand, and therefore, can be used in specific cases in lieu of structural strengthening.

1.4.3 RETROFIT PROVISIONS IN THE INTERNATIONAL EXISTING BUILDING CODE

The International Code Council published the first edition of the International Existing Building Code (IEBC) in February 2003. It contains five appendix chapters with seismic retrofit provisions for vulnerable building types common to many communities in North America. These chapters include simple-to-apply, cost-effective, compliance-based and prescriptive provisions for improving the earthquake resistance of:
1) Unreinforced masonry bearing wall buildings;
2) Single-story tilt-up, reinforced concrete or masonry wall buildings with flexible roofs;
3) Single-unit wood frame dwellings with poorly braced or anchored walls below the first floor;
4) Multi-unit wood frame residential buildings with soft stories or open fronts;
5) Non-ductile concrete frame buildings.

It is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. The retrofit techniques are also applicable for other natural hazards such as tropical cyclones, tornadoes, and severe winds from thunderstorms.

1.5. COLUMN JACKETING

Out of the various structure elements in building , columns are more vulnerable to seismic damages and could prove to be disasters if unattended. Column jacketing is the most popular and commonly adopted technique for strengthening the existing columns.

Figure 1.2: Concrete Jacketing of Column

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Figure 1.3: Steel jacketing of column

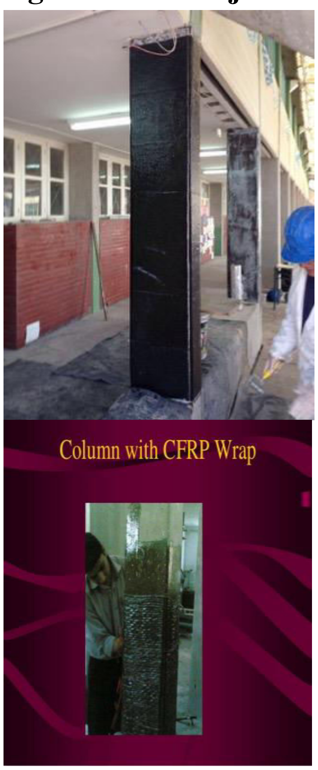

Figure 1.4: Carbon Fibre Reinforced Column

1.5.1. Materials used for jacketing

The most common materials used for jacketing the column are RCC, Steel and FRP. Each of these materials have their own advantages and disadvantages**.** For example, RCC is cheaper but less strong and hence greater sectional area is required to strengthen the column. Steel is much stronger but costlier. It is also more suceptiable for corrosion. FRP on the other hand provides great flexural rigidity for the column besides giving the advantage of protecting the reinforcing steel from corrosion. When judiciously used, it can become a viable solution. However, there are many unresolved issues in the understanding and implementation of this retrofitting stratagies.

1.6 FIELD PRACTICES AND UNRESOLVED ISSUES

Quite often the retrofitting strategy for an a existing building consists of strengthening the existing structure elements by either extending the sections on one side or by jacketing. In either case the new section has to be joined with the old sections, requiring proper modelling of the interaction at the interfaces by the designer. It is observed that this aspect is mostly ignored by the designers while the effectiveness of a retrofitting strategy such as column jacketing Further, the choice of the material for retrofitting is mostly decided based on its availability, skill of the labour in using it and such other factors rather than based on the behaviour of the materials used, their interaction and effectiveness in performing. Therefore, it is felt that there is strong need to investigate in to these unresolved issues and quantify the effects.

1.7 STATEMENT OF THE PROBLEM

Realising this need, a detailed numerical investigation is taken up in this work on a eleven (G+10) storied RC framed building, for seismic zone-3.The effectiveness of 3 types of column jacketing viz., RCC, STEEL and FRP, in contributing for better seismic performance of the building is checked in terms of bending moments, axial forces developed in the columns in various locations of the building. For each material, one model is tried which is closer to the field practice where the jacket is given connections with the existing column in the form of shear connectors, welds etc.

1.8 OBJECTIVES OF THE WORK

My research project aims at doing seismic evaluation of G+10 structure and suggesting how to retrofit the failing members, using RCC, Steel and FRP jacketing.

1. Analyse the seismic performance of the structure according to the design generated by ETABS
2. Check whether the suggested level of jacketing satisfies all the required limits of design and is feasible or not.
3. To compare the effectiveness of three types of column jacketing viz.,RCC, Steel and FRP.

1.9 SCOPE OF THE WORK

The scope of the work is confine to the study of response of a eleven (G+10) storied RC framed building when retrofitted with three types of column jacketing (RCC, Steel and FRP). Both element response and total structure response are studied for seismic zone-3.

1.10 ORGANISATION OF THE DISSERTATION REPORT

This report consists of five chapters. Chapter-1 introduces the background of the problem with emphasis on the need for proper the modelling of a most commonly adopted seismic retrofitting strategy i.e., column jacketing. Chapte-2 reviews the inferences of the research works by various people relevant to the topic. Chapter-3 describes the theory and practice of column jacketing procedures in RC framed buildings. Chapter-4 provides the details of numerical study made while the results obtained are presented and discussed in chapter-5. Conclusions are discussed in the Chapter-6.

2. RELATED WORK:

2.1 GENERAL

Seismic retrofitting is an age old subject and appears to have started in the year 1976.This chapter present a detailed review of the origin of seismic retrofitting, most common work of researcher on RC framed buildings, behavior of retrofitted RC buildings and a few latest works on the related topic.

2.2 METHODS OF SEISMIC RETROFITTING

Gnana sekaran Kaliyaperumal (2009) have worked on Seismic retrofit of columns in buildings for flexure using concrete jacket. Their present study has investigated the effect of jacketing on the flexural strength and performance of columns. First, slant shear tests were conducted to study the interface between the old and new concrete. Second, column specimens were tested to study the strength. Third, beam-column-joint sub-assemblage specimens were tested to study the ductility (or energy absorption) and energy dissipation. Analytical investigations were carried out to predict the experimental results. A lamellar approach and a simplified method of analysis were used for the prediction of the axial load versus moment interaction curves and moment versus curvature curves for the retrofitted columns. An incremental nonlinear analysis was adopted to predict the lateral load versus displacement behaviour for a retrofitted sub-assemblage specimen. Guidelines for the retrofitting of columns by concrete jacketing are provided. His studies revealed the following are the conclusions from the present study: The self-compacting concrete was found to be suitable for use in the concrete jacket. The retrofitted specimens did not show any visible delamination between the existing concrete and the concrete in the jacket. The roughening of the surface of the existing concrete by motorized wire brush was found to be satisfactory for the type of tests conducted. The moment capacities of the retrofitted column specimens were substantially more than those of the existing columns. This increase in capacities could be predicted by analysis. The retrofitted beam-column-joint sub-assemblage specimens showed substantial increase in lateral strength, ductility (i.e., energy absorption) and energy dissipation. The degradations in strength and stiffness of the retrofitted sub-assemblage specimen tested under cyclic loading were limited. A lamellar analysis considering the two grades of concrete in a retrofitted section, and the effect of confinement on the stress versus strain curve for concrete under compression, provides a good prediction of the strength and the moment versus curvature behavior of the section. However, a simplified analysis considering the lower grade of concrete for the whole section and using the code specified stress versus strain curve for the concrete under compression can give a conservative value of the strength alone. It cannot correctly predict ductility in the moment versus curvature behavior of the section. The prediction of the lateral load versus displacement behavior of a sub-assemblage in a building by the 11 pushover analysis using bilinear (up to the peak) moment versus rotation curve for a plastic hinge is approximate, especially in the pre-yield region. The incremental nonlinear analysis, with varying flexural stiffness for the hinge members (included to model the spread plasticity) and incorporating friction of the bearings, showed substantially better prediction of the lateral load versus displacement behavior of the retrofitted sub-assemblage specimen as compared to the pushover analysis. The tension stiffening effect of cracked concrete may be considered for improved predictions in the pre-yield region. Regarding the retrofitting of columns for flexure, tests can be conducted on larger-scale specimens with reduced increase in area after jacketing to study the improvements in strength and performance. The scheme of concrete jacketing selected in the present study needs to be qualified under a fast cyclic loading. This study can be extended to the exterior or corner columns by testing the corresponding sub assemblage specimens. Three-dimensional frames with jacketed columns can also be tested under the monotonic or cyclic lateral loads, or under a base excitation by using a shake table.

Shri.Pravin B. Waghmare (2011) have worked on materials and jacketing technique for Retrofitting of structures. Their studies revealed that Seismic protection of buildings is a need-based concept aimed to improve the performance of any structure under future earthquakes. Earthquakes of varying magnitude have occurred in the recent past in India, causing extensive damage to life and property. Some recently developed materials and techniques can play vital role in structural repairs, seismic strengthening and retrofitting of existing buildings, whether damaged or undamaged. The primary concern of a structural engineer is to successfully restore the structures as quickly as possible. Selection of right materials, techniques and procedures to be employed for the repair of a given structures have been a major challenges. Innovative techniques of the structural repairs have many advantages over the conventional techniques. Some guidelines regarding selection of materials for repair work such as steel, fiber reinforced polymer, has been discussed in the present paper. The selection of materials and techniques to be used depend on many aspects that may be viewed from different prospectives i. e. requirement and availability of financial resources, applicability and suitability of materials for the repair of damaged structures. Use of standard and innovative repair materials, appropriate technology, workmanship, and quality control during implementation are the key factors for successful repair, strengthening and restoration of damaged structures. The main objective of jacketing is to increase the seismic capacity of the moment resisting framed structures. In almost every case, the columns as well .as beams of the existing structure have been jacketed. In comparison to the jacketing of reinforced concrete columns, jacketing of reinforced concrete beams with slabs is difficult yielding good confinement because slab causes hindrance in the jacket. In structures with waffle slab, the increase in stiffness obtained by jacketing columns and some of the ribs, have improved the efficiency of structures. In some cases, foundation grids are strengthened and stiffened by jacketing their beams. An increase in strength, stiffness and ductility or a combination of them can be obtained. Jacketing serves to improve the lateral strength and ductility by confinement of compression concrete. It should be noted that retrofitting of a few members with jacketing or some other enclosing techniques might not be effective enough to improve the overall behaviour of the structure, if the remaining members are not ductile.

3. SEISMIC RETROFITTING OF RC COLUMNS

3.1 GENERAL

Given the structural retrofitting needs of various elements of a building, one can easily say that the strengthening needs of columns are very important when compared to other elements such as beams, walls and slabs. Adopting an appropriate seismic retrofitting strategy for columns will go a long way in protecting the life span of a structure. Understanding and comparing various methods of seismic retrofitting of columns helps in taking a right decision. This chapter presents a detailed report on various method of column jacketing.

3.2 DECISION FOR RETROFITTING:

It is not merely poor quality of materials and damage of structural elements serves as the reasons to retrofit a building. Change of the building's function, change of environmental conditions, and change of valid building codes could also be the reasons for retrofitting. Retrofitting must be conducted by experts from each field. In most retrofitting process, an engineer plays the main role. An engineer must assess and analyse the structural capacity. An engineer must also design and suggest the best retrofitting techniques to strengthen the structural deficiencies. The role of the novice is restricted to identify the possibility of insufficiency of the building capacity.

3.2.1 Factors Considered For Retrofitting

Some factors that should be considered in order to decide whether to retrofit or not are:

a) Technical aspect:

The technical aspects include the testing of materials and structural analysis. These measures are important to understand the condition of the structures related to the recent building codes.

b) Importance of building:

Each building is built for its own purpose. Some old buildings have extra values, such as historical values, that will strongly affect the final decision.

c) Availability of adequate technology:

Some of retrofitting techniques need a "modern" technology to implement it. A decision of retrofitting must consider whether the region provides such technology.

d) Skilled workmanship to implement the proposed measures:

Some of retrofitting techniques need unusual construction method to implement it. A skilled Workmanship must be provided to implement the proposed measures.

e) **Duration of works**:

Some of retrofitting works will consume less time to finish it, but others take more time to complete. Hence, it is important to take into the consideration the duration of works.

f) Cost intervention:

Cost benefit analysis must be conducted before the decision is made.

3.2.2 Cost-Benefit of Retrofitting:

Cost-Benefit analysis is sometimes conducted to determine whether retrofit or rebuild the building is more feasible. Most studies imply that retrofitting of an existing structure is more feasible than to build a new building. Retrofitting is a also a favourable approach to strengthen the building capacity to the external loads, e.g. earthquake

3.3 METHODS OF JACKETING

There are various retrofitting techniques available for strengthening the building components to with stand the extra loads. They are

a) Concrete jacketing
b) Steel jacketing
c) FRP Composites
d) Bonding of steel plates to slabs
e) Fixing of I-Beams for the slabs
f) Widening of the footing size
g) Adding of extra reinforcement mesh based on the design (Footing)
h) Increasing the depth of slab by extra reinforcement, e.t.c.,

a) Concrete Jacketing

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Concrete jacketing involves addition of a layer of concrete, longitudinal bars and closely spaced ties. The jacket increases both the flexural strength and shear strength of the column. Increase inductility has been observed. If the thickness of the jacket is small there is no appreciable increase in stiffness. Circular jackets of ferro-cement have been found to be effective in enhancing the ductility. The disadvantage of concrete jacketing is the increase in the size of the column. The placement of ties at the beam-column joints is difficult, if not impossible. Drilling holes in the existing beams damages the concrete, especially if the concrete is of poor quality. Although there are disadvantages, the use of concrete jacket is relatively cheap. It is important to note that with the increase in flexural capacity, the shear demand (based on flexural capacity) also increases.

The additional ties are provided to meet the shear demand.

The minimum specifications for the concrete jacket are as follows:

i).The strengths of the new materials must be equal to or greater than those of the existing column. The compressive strength of concrete in the jacket should be at least 5 MPa greater than that of the existing concrete.

ii). For columns where extra longitudinal bars are not required for additional flexural capacity, a minimum of 12 mm diameter bars in the four corners and ties of 8 mm diameter should be provided.

iii).The minimum thickness of the jacket should be 100 mm.

iv). The minimum diameter of the ties should be 8 mm and should not be less than ⅓ of the diameter of the longitudinal bars. The angle of bent of the end of the ties should be 135º.

v) The centre-to-centre spacing of the ties should not exceed 200 mm. Preferably, the spacing should not exceed the thickness of the jacket. Close to the beam-column joints, for a height of ¼the clear height of the column, the spacing should not exceed 100 mm.

The figure 3.1 and 3.2 shows standards cross section of reinforced concrete jacket and profile of shear connectors between original column and jacket reinforcement respectively.

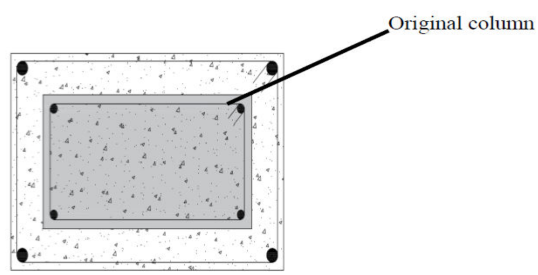

Fig 3.1: Standard cross-section of reinforced concrete jacket

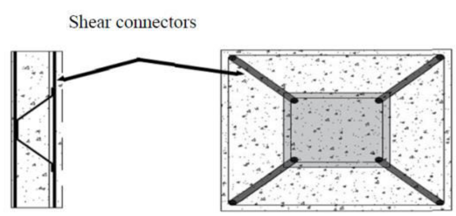

Fig 3.2: Profile of shear connectors between original column and jacket reinforcement

b) Steel Jacketing

Steel jacketing refers to encasing the column with steel plates and filling the gap with non-shrink grout. The jacket is effective to remedy inadequate shear strength and provide passive confinement to the column. Lateral confining pressure is induced in the concrete as it expands laterally. Since the plates cannot be anchored to the foundation and made continuous through the floor slab, steel jacketing is not used for enhancement of flexural strength. Also, the steel jacket is not designed to carry any axial load. If the shear capacity needs to be enhanced, the jacket is provided throughout the height of the column. A gap of about 25 to 50 mm is provided at the ends of the jacket so that the jacket does not carry any axial load. For enhancing the confinement of concrete and deformation capacity in the potential plastic hinge regions, the jacket is provided at the top and bottom of the column. Of course there is no significant increase in the stiffness of a jacketed column. Steel jacketing is also used to strengthen the region of faulty splicing of longitudinal bars. As a temporary measure after an earthquake, a steel jacket can be placed before an engineered scheme is implemented.

Steel jackets common retrofit method for columns, and are used frequently. In their most basic form, a steel jacket can be comprised of only wrapping steel plates around a column. Under different scenarios, steel jackets may also include adhesives between the jacket and the column, concrete or grout to fill in gaps between a larger jacket and the column, anchor bolts to facilitate the connections, and end stiffeners to move the plastic-hinge. Some of the primary considerations for these methods are the plastic-hinge behavior, interface preparation, connections within the jacket, sizing of the jacket, the cross-section or shape used, and various loading cases.

c) Fiber Reinforced Polymer Sheet Wrapping

Fiber-reinforced polymer (FRP) has desirable physical properties like high tensile strength to weight ratio and corrosion resistance. FRP sheets are thin, light and flexible enough to be inserted behind pipes and other service ducts, thus facilitating installation. In retrofitting acolumn with FRP sheets, there is increase in ductility due to confinement without noticeable increase in the size. The main drawbacks of FRP are the high cost, brittle behavior and inadequate fire resistance.

3.4 RE-ANALYSIS OF RETROFITTED STRUCTURE

The Retrofitting of a structure involves the following measures:

a) Increasing its strength and/or stiffness

b) Increasing its ductility

c) Reducing the seismic forces.

Normally a building which after being evaluated for its seismic capacity against the damages is judged for its necessity of seismic retrofitting or otherwise In case the building requires seismic retrofitting, appropriate strategies for retrofitting will be worked out and proposals are made for proper retrofitting measures. In order to check the adequacy of such measures the building is modeled and analysed duly incorporating the proposed retrofitting strategies. This process is called ‘Re-Analysis’.

4. NUMERICAL STUDY

4.1 ETABS SOFTWARE:

ETABS is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. ETABS 2016 features an intuitive and

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powerful graphical interface coupled with unmatched modeling, analytical, design, and detailing procedures, all integrated using a common database. Although quick and easy for simple structures, ETABS can also handle the largest and most complex building models, including a wide range of nonlinear behaviors necessary for performance based design, making it the tool of choice for structural engineers in the building industry.

Dating back more than 40 years to the original development of ETABS, the predecessor of ETABS, it was clearly recognized that buildings constituted a very special class of structures.

Early releases of ETABS provided input, output and numerical solution techniques that took into consideration the characteristics unique to building type structures, providing a tool that offered significant savings in time and increased accuracy over general purpose programs. As computers and computer interfaces evolved, ETABS added computationally complex analytical options such as dynamic nonlinear behavior, and powerful CAD-like drawing tools in a graphical and object-based interface. Although ETABS 2016 looks radically different from its predecessors of 40 years ago, its mission remains the same: to provide the profession with the most efficient and comprehensive software for the analysis and design of buildings.

To that end, the current release follows the same philosophical approach put forward by the original programs, namely:

- Most buildings are of straightforward geometry with horizontal beams and vertical columns. Although any building configuration is possible with ETABS, in most cases, a simple grid system defined by horizontal floors and vertical column lines can establish building geometry with minimal effort.
- Many of the floor levels in buildings are similar. This commonality can be used to dramatically reduce modelling and design time.
- The input and output conventions used correspond to common building terminology with ETABS, the models are defined logically floor-by-floor, column-by-column, bay-by-bay and wall-by-wall and not as a stream of non-descript nodes and elements as in general purpose programs. Thus the structural definition is simple, concise and meaningful.
- In most buildings, the dimensions of the members are large in relation to the bay widths and story heights. Those dimensions have a significant effect on the stiffness of the frame. ETABS corrects for such effects in the formulation of the member stiffness, unlike most general-purpose programs that work on centerline-to-centerline dimensions.
- The results produced by the programs should be in a form directly usable by the engineer.

4.2 MODELS CONSIDERED

All together five models are considered in

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the present work. The details are as follows,

- Normal RCC column (400mmX400mm).

MODEL-1: Normal RCC column (400mmX400mm) upgraded zone-3.

MODEL-2: Retrofitted model with RC jacketing modelled closer to field practice (400mmX400mm existing column with a RC jacket of 100mm all-round).

MODEL-3: Retrofitted model with steel jacketing closer to field practice

MODEL-4: Retrofitted model with FRP jacketing closer to field practice.

4.3 PARAMETERS VARIED

Three types of column jacketing were considered viz., RCC, Steel and FRP. For each of these three, two models are used. One similar to that normally adopted in design offices. The other is closer to the field practice, duly considering the connection between the old and new portions of the column

4.4 RESPONSES STUDIED

For each model the response of the columns is observed in various locations and at various floors. Response of columns were increased in terms of Bending moment(M) and Axial forces(P).At the same time the response of entire building in terms of top storey displacement, drifts and lateral loads on each floor.

4.5 DETAILS OF THE BUILDING CHOSEN:

Keeping in view the most commonly constructed buildings, an RC framed building with eleven (G+10) storeys is chosen for study, with the following details.

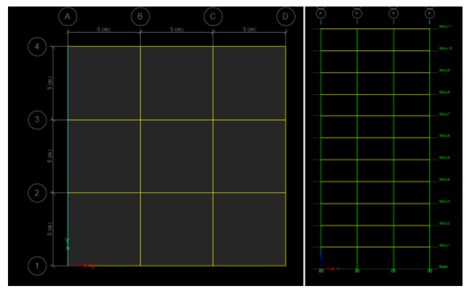

Fig.4.1: PLAN and ELEVATION of Building.

4.5.1 Building Details

- Type of frame :Ordinary RC moment resisting frame fixed at the base
- Seismic zone : III
- Number of storeys :11
- Floor height :3 m
- Depth of Slab :125 mm
- Spacing between frames :3m along both directions
- Live load on floor level :3 kN/m^2
- Live load on roof level :1.5 kN/m^2
- Floor finish :1.0 kN/m^2
- Terrace water proofing :1.5 kN/m^2

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- Materials :M 20 concrete, Fe 415 steel and Brick infill
- Thickness of infill wall :230mm (Exterior walls)
- Thickness of infill wall :150 mm (Interior walls)
- Density of concrete :25 kN/m^3
- Density of infill :20 kN/m^3
- Type of soil :Rocky
- Response spectra :As per IS 1893(Part1):2002
- Damping of structure :5 %

  **Live load on floor level and roof level are taken from IS-875 (Part-) considered RC framed buildings as residential usage

4.5.2 Member and Material Properties

Dimensions of the beams and columns are determined on the basis of trial and error process in analysis of ETABS by considering nominal sizes for beams and columns and safe sizes are as show in the table below.

	Beam (m)	Column (m)
G+10	0.23x0.400	0.4x0.4

Material properties of the building are like M20 grade of concrete, FE415 steel and 13800 N/mm2 of modulus of elasticity of brick masonry in the buildings.

4.5.3 Load calculations

In ETABS we need not calculate the self weight of frame members. This will automatically include the self-weight of structural members in the analysis based on present specific weights given in function of the material type.

Dead Load:

Floor finish : 1.5kN/m^2

Internal wall load : 2.7x0.15x20 = 8.1KN/m

External wall load : 2.7x0.23x20 =12.42KN/m

Parapet Wall : 1x0.15x20= 3KN/m

Live load:

For typical floors : 3kN/m^2

For top floor : 1.5kN/m^2

Load Combination:

In this Project 13 Load Combinations are considered.

- 1.5(D.L+L.L)
- 1.2(D.L+L.L+EQX)
- 1.2(D.L+L.L+EQZ)
- 1.2(D.L+L.L-EQX)
- 1.2(D.L+L.L-EQZ)
- 1.5(D.L+EQX)
- 1.5(D.L+EQZ)
- 1.5(D.L-EQX)
- 1.5(D.L-EQZ)
- 0.9D.L+1.5EQX
- 0.9D.L+1.5EQZ
- 0.9D.L-1.5EQX
- 0.9D.L-1.5EQZ

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Seismic Zone – III, Zone factor, Z – 0.24, Importance factor, I - 1.00, Response reduction factor, R- 3.00. The load cases considered in the seismic analysis are as per IS 1893 – 2002. Bay width in x-direction – 5m Bay width in y-direction – 5m.

	Table 4.1- Load Patterns			
Name		**Type**	**Self Weight Multiplier**	**Auto**
				Load
Dead		Dead	1	
Live		Live	0	
WALL		Super imposed Dead	0	
LOAD				
FLOOR		Super imposed Dead	0	
FINISH				
EQ-X		Seismic	0	IS1893
				2002
EQ-Y		Seismic	0	IS1893
				2002

IS1893 2002 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQ-X according to IS1893 2002, as calculated by ETABS

From IS Code $V_B = A_h W$

Where $A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$

Ta=0.09H/√D

Ta =0.76

$\frac{S_a}{g}$ **= 2.5**

Z = 0.16 for Zone III

R= 3

I = 1

Calculated Base Shear

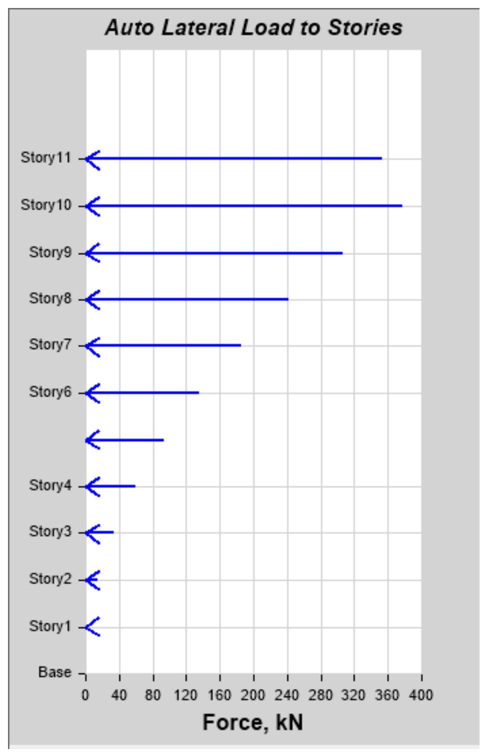

Figure4.2: Lateral load on stories.

Functions

Response Spectrum Functions

Table 4.2 - Response Spectrum Function - IS 1893:2002

Na me		**Peri od**	**Accel erat**		**Dam pin**	**Z**	**Soi l**

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		sec	ion		g		Type
ISRS		0	0.24		5	0.16	II
ISRS		0.1	0.6				
ISRS		0.55	0.6				
ISRS		0.8	0.408				
ISRS		1	0.3264				
ISRS		1.2	0.272				
ISRS		1.4	0.233143				
ISRS		1.6	0.204				
ISRS		1.8	0.181333				
ISRS		2	0.1632				
ISRS		2.5	0.13056				
ISRS		3	0.1088				
ISRS		3.5	0.093257				
ISRS		4	0.0816				
ISRS		4.5	0.0816				
ISRS		5	0.0816				
ISRS		5.5	0.0816				
ISRS		6	0.0816				
ISRS		6.5	0.0816				
ISRS		7	0.0816				
ISRS		7.5	0.0816				
ISRS		8	0.0816				
ISRS		8.5	0.0816				
ISRS		9	0.0816				
ISRS		9.5	0.0816				
ISRS		10	0.0816				

Load Cases

Table 4.3- Load Cases - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
WALL LOAD	Linear Static
FLOOR FINISH	Linear Static
EQ-X	Linear Static
EQ-Y	Linear Static
RS-X	Response Spectrum
RS-Y	Response Spectrum

]

4.6 STEPBY STEP PROCEDURE IN ETABS

Modelling and Analysis:

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Step-1

Open the ETABS Program

1) Open the ETABS program.
2) Check the units of the model in the drop-down box in the lower right-hand corner of the ETABS window, click drop-down box to set units to kN-m
3) Click the File menu > New model command.
4) Set the options according to IS codes below figure shows the model initialization

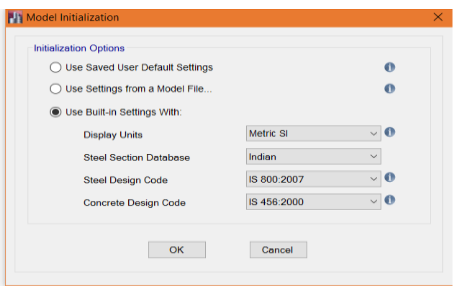
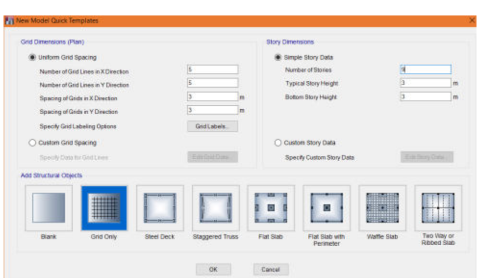


Figure4.3: Model Initialization

Step-2

Model the required Building of moment Resisting RC Frame by entering Grid data and storey data as per Model to be generated.



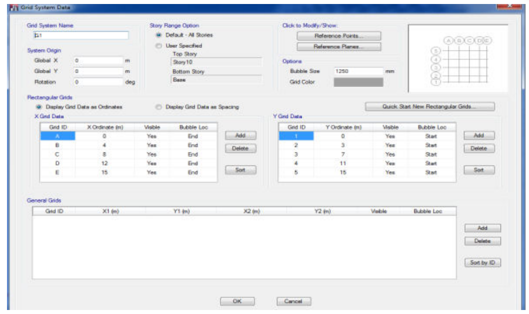
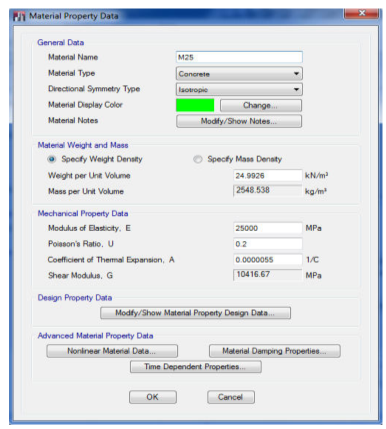


Figure 4.4: Edit grid data and Story data

Step-3

Defining the material Properties M25 and Rebar material property Fe415 as shown below



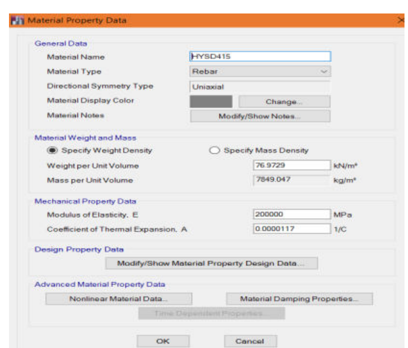


Figure4.5: Defining Material Properties

Step-4

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Define Beam, Column and Slab sections using Define > Frame section/Slab Section

Define Beam sizes and Column sizes and used two options Reinforcement checked or designed. Below figure shows the defining of beam and column sections.

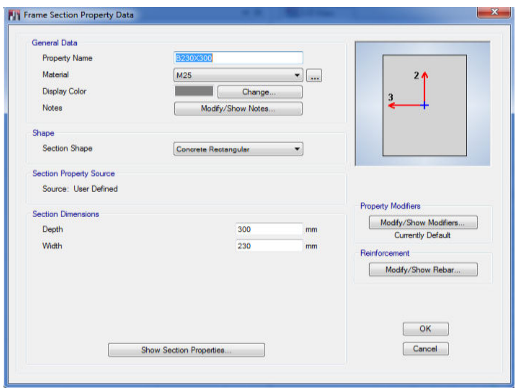

Figure 4.6: Defining Beam Section

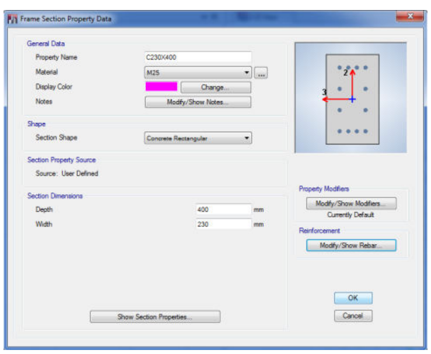

Figure 4.7: Defining Column Section

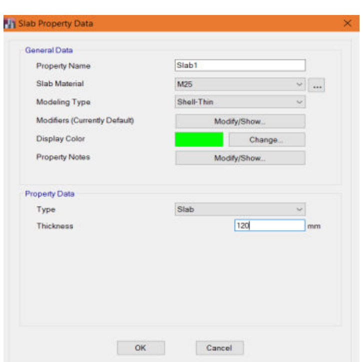

Figure 4.8: Defining Slab Section S120 in meters

Assigning Member Sections

Step 5

After defining the frame sections, you need to assign them through many ways, one of the easy method is to draw the beam and column sections on the grid lines in plan vie

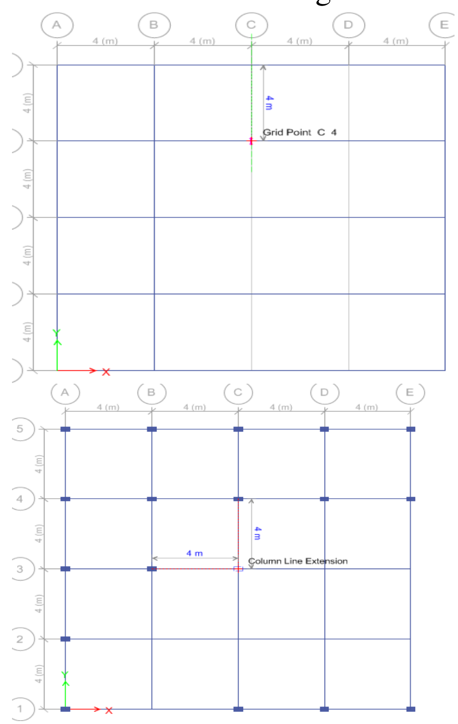

Figure 4.9: Assigning beam and column sections

Assigning Loads

Step 6

Define load combinations by selecting Add Default Design combo> Concrete Frame Design as shown in the below figure.

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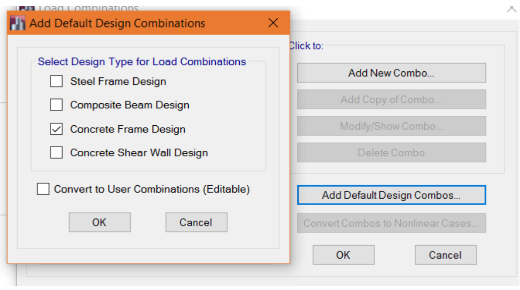

Figure 4.10: Defining Load Combination

Step 7 Assigning loads

Dead and Live Loads are assigned on to the frame and area sections as given in the data.

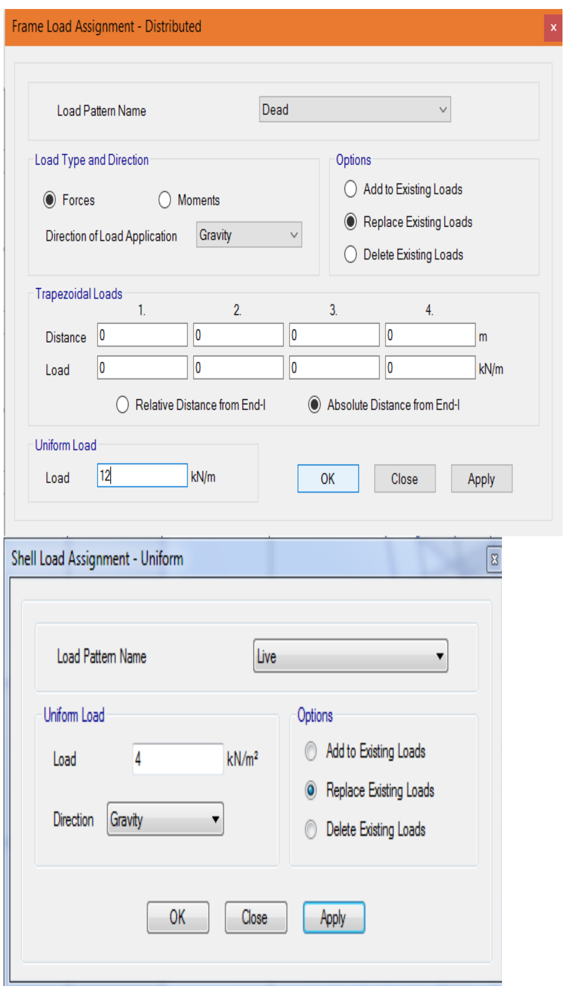

Figure 4.11: Defining distributed Loads

Step 8

For assigning Supports as Fixed Support, select Nodes then click on assign tool bar joints Restraints (support), click Fixed Support.

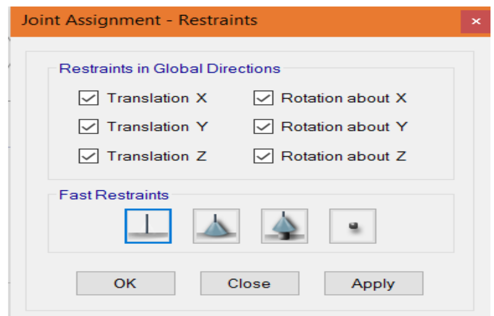

Figure 4.12: Assigning Fixed supports

Step 9: Defining mass source factors 1 for dead load as specified in clause 7.3.1Table 8 of IS 1893: 2002 Part I, percentage of imposed load as 0.25.

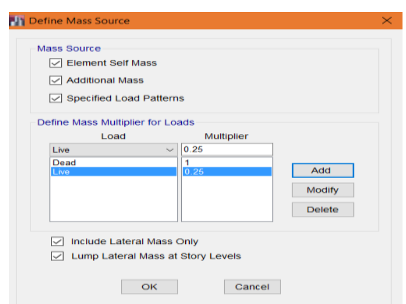

Figure 4.13: Defining Mass source

Step10: Setting up Floor Diaphragms

>Select the whole structure > From the **Assign** menu select **joint diaphragms** > Assign **D1** to the selected joints

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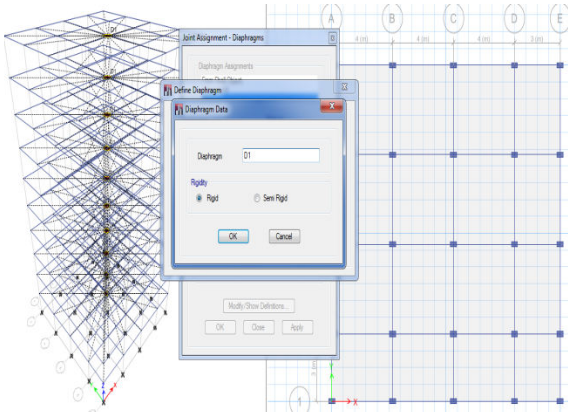


Figure 4.14: Defining Diaphragm action

Step 11: Select all beams and Slabs > Assign > Insertion point> select 8 (top centre)

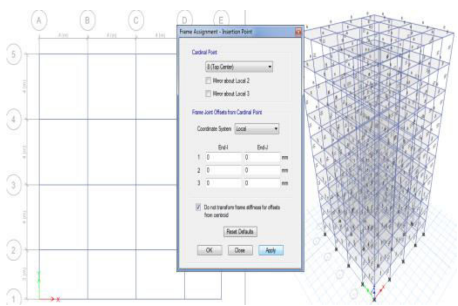


Figure 4.15: Insertion point

Step 12: Select whole structure > Concrete frame design> Framing Type > Ordinary

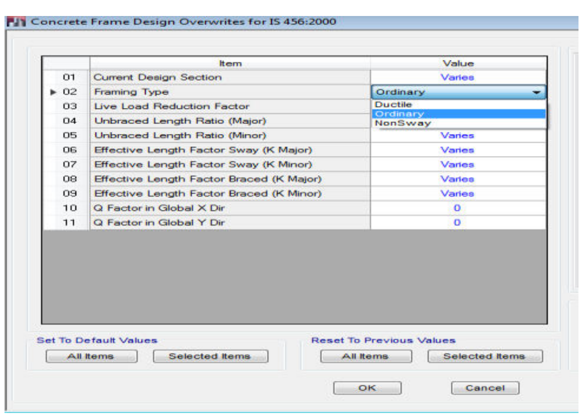
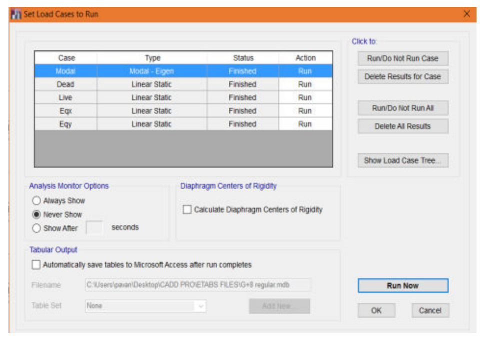


Figure 4.16: Assigning Framing Type

Step 13: Run Analysis.

Once the data has been entered, save your model and **Run the Analysis**



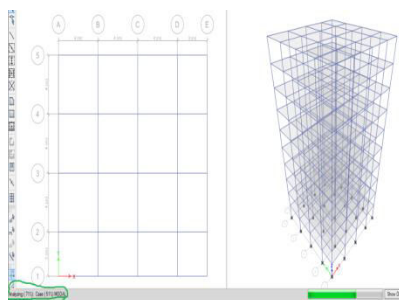


Figure 4.17: Run Analysis

- After this we need to click on concrete frame design

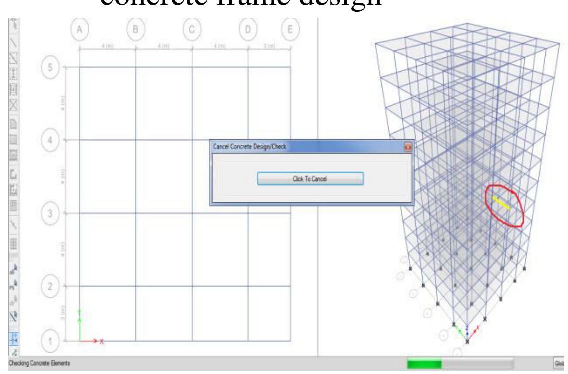


Figure 4.18: Concrete frame design

Step-14

To view results

- Firstly make sure that the , all the frame members should pass and then

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check the rebar% of beams and columns as per IS: 456-2000

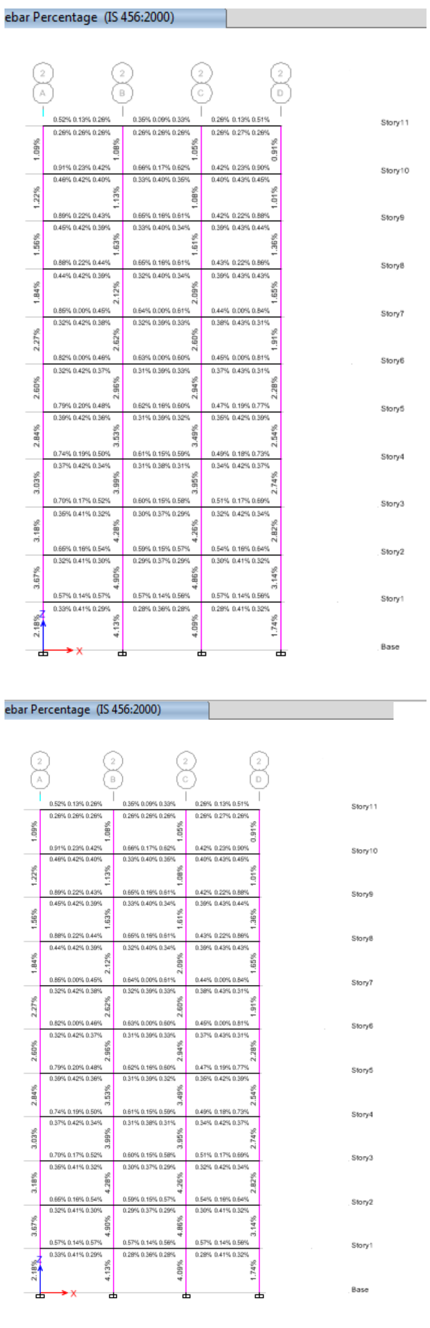

Figure 4.19: Rebar % in Columns

- To view member forces(bending moments and shear forces) on a step-by-step basis, select Display frame forces > select which ever force and load combination is necessary

4.7 CONSIDERED REROFITTED MODELS

In the normal RCC column model in which the columns of ground storey failed and indicated the requirement for retrofitting.

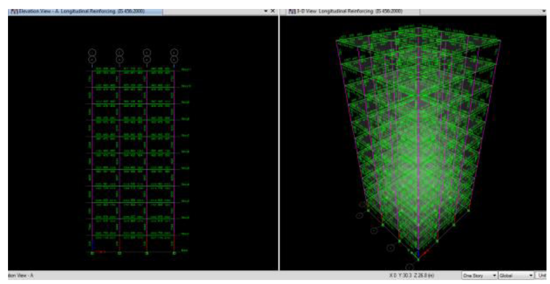

Figure 4.20: Columns failure at Ground storey

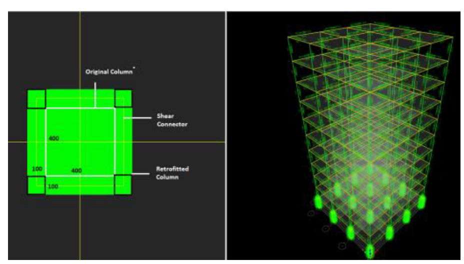

Figure 4.21: Concrete Jacketing for column

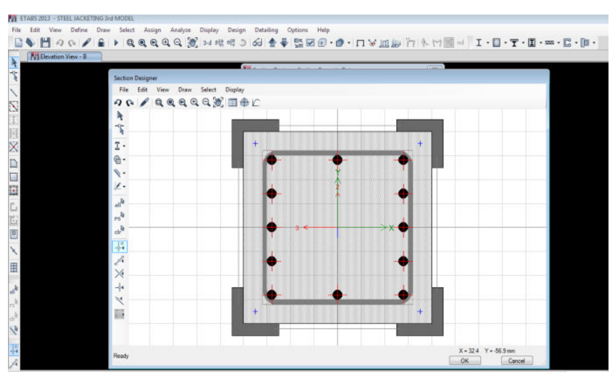

Figure 4.22: Steel Jacketing for column

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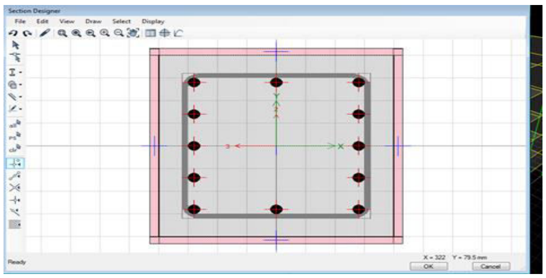

Figure 4.23: FRP Jacketing for column

5. RESULTS AND DISCUSIONS
5.1 GENERAL

Based on the results obtained from the response spectrum analysis of a six(G+10) storey RC framed building, trends in the responses of columns are observed for three types of column jacketing and are presented here term of bending moments(mx and my),shears and axial forces. Besides this the response of the total building in terms of top storey displacements, Inter-storey Drifts and lateral loads on to stories is observed and presented.

5.2 RESPONSES IN COLUMNS

5.2.1 COMPARISION OF BENDING MOMENTS AND AXIAL FORCES

(a) BENDING MOMENTS (Mx):

Table 5.1: Bending Moments MX

S.No	Normal RCC structure	Model 1 (KN-m)	Model 2 (kN-m)	Model 3 (kN-m)	Model 4 (kN-m)
1	252.6	498.98	582.7	600	428
2	125.3	223.61	304.7	370	356
3	153.01	188	214.2	190	212
4	112.4	162.5	260	200	124
5	100.7	127	230	251	300

(b) BENDING MOMENTS (My):

Table 5.2: Bending Moments MY

S.No	Normal RCC structure	Model 1 (kN-m)	Model 2 (kN-m)	Model 3 (kN-m)	Model 4 (kN-m)
1	15.07	28.25	32.5	25.7	33.6
2	5.3	12.79	17.3	19	15.6
3	10.2	16.78	18	15.6	21.3
4	3.2	9.84	5	7.53	13.152
5	1.26	4.2	6.2	6	2.3

(c) AXIAL FORCES

Table 5.3: Axial Forces FX

S.N	Normal	Model 1 (kN)	Model 2	Model 3	Model 4

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2581-4575

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o	RCC structure		(kN)	(kN)	(kN)
1	423	603	1933	1688	2892.7
2	321	545	869	955	1857
3	225	300	566	423	1582.2
4	174	201	365	382	978
5	168	277	545	605	625

From the above table when upgraded RCC (model 1) is compared with the normal RCC structure, increase in moments and axial forces was observed. Therefore we can say that size of existing columns is not sufficient to take the loads, hence accordingly column sizes are increased to make the structure safe

5.2.2 COMPARISION OF TIME PERIOD

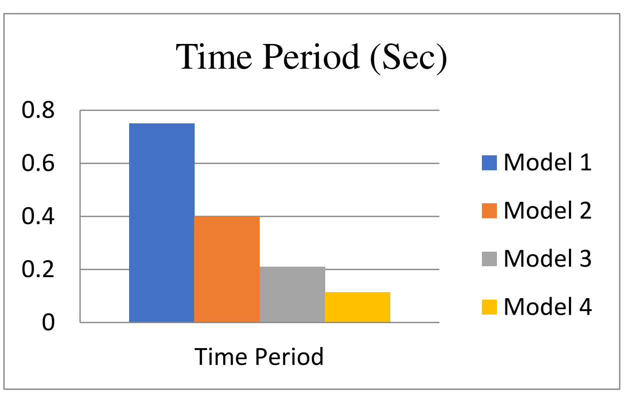

Figure 5.1: Time period comparison

In the normal RCC column model in which the columns of ground storey failed and indicated the requirement for retrofitting, the structure was showing greater time period (0.75) while the same got reduced for retrofitted models.

In all, an comparision of models for Concrete, Steel and FRP jacketing, it is observed that the time period of the structure greatly varied in FRP jacketing.

5.2.3 COMPARISON OF LATERAL LOADS ON EACH STORY

Table 5.4: Comparison of lateral loads in each storey

Story	Model 1 (kN)	Model 2 (kN)	Model 3 (kN)	Model 4 (kN)
0	0	0	0	0
1	3.7741	3.9746	4.3528	3.9497
2	15.0964	15.7671	17.4112	15.7986
3	33.967	35.4699	39.1752	35.547
4	60.3858	63.0684	69.6449	63.1946
5	94.3528	98.5443	108.8201	98.7416
6	135.868	141.7755	156.701	142.1878
7	184.9314	192.9723	213.2874	193.5334
8	241.5431	252.0454	278.5795	252.7784
9	305.7029	318.995	352.5771	319.9226

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10	353.411	364.821	388.2804	394.9662
11	377.2647	393.8334	435.353	441.2833

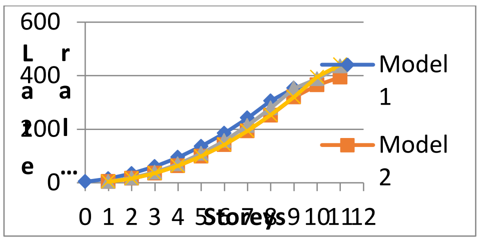

Figure 5.2: Storey vs Lateral loads on each storey

From the above results it has been observed that there is an increase in lateral loads on to the structure for model 3 (Steel jacketing). This is because of the increase in mass of the structure in steel jacketing structure when compared to RCC.

5.2.4 COMPARISION OF DISPLACEMENTS

Table 5.5: Comparison of displacements

Storey	Model 1 (mm)	Model 2 (mm)	Model 3 (mm)	Model 4 (mm)
0	0	0	0	0
1	7.1	3.8	4.8	3.9
2	24.1	16.7	15	12.5
3	46	37	27.4	22.8
4	72.3	60.8	40.5	32.8
5	98.7	85.8	53.5	41.1
6	124.6	110.4	65.9	46.9
7	148.9	133.4	77.3	50.2
8	170.7	153.9	87.3	51.9
9	189.6	171.3	95.6	52.9
10	205.2	185.3	101.9	53.5
11	218.2	196.5	106.3	53.8

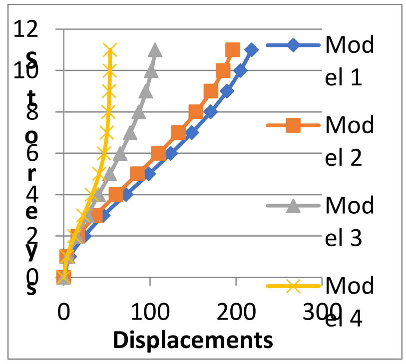

Figure 5.3: Storey vs Displacements

From the above graphs, it was observed that, the displacement is drastically reduced in FRP Jacketing (Model 4) and Steel Jacketing (Model 3) models when compared to normal RCC structure (Model 1). Hence significant effect of RCC, Steel and FRP was observed.

5.2.5 COMPARISION OF INTERSTOREY DRIFTS RATIO

Table 5.6: Comparison of drifts ratio

Storey	Model 1	Model 2	Model 3	Model 4
0	0	0	0	0
1	0.001494	0.003915	0.002362	0.001308
2	0.0021	0.004302	0.005673	0.00287
3	0.002753	0.006756	0.007554	0.003423
4	0.003334	0.007936	0.0085	0.003327
5	0.0038	0.008329	0.008803	0.002777
6	0.004138	0.008191	0.008635	0.00194

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7	0.004336	0.007666	0.008102	0.001089
8	0.004364	0.006841	0.007287	0.000579
9	0.004131	0.005804	0.00628	0.000319
10	0.003401	0.004682	0.005216	0.000189
11	0.001594	0.003709	0.004319	0.000129

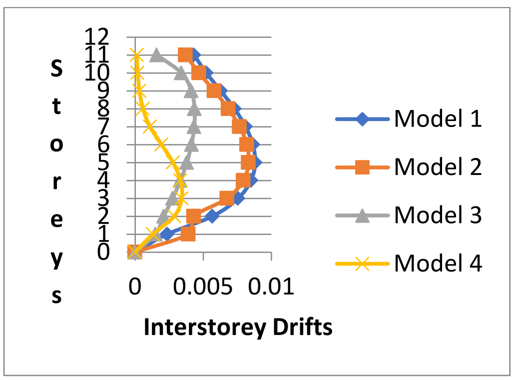

Figure 5.4: Storey vs Inter storey Drifts ratio

From the above graphs, it was observed that, decrease in inter-storey drifts was observed in Model 2, Model 3 and Model 4. Hence we can say that retrofitting has enhanced the performance of normal RCC structure.

6. CONCLUSIONS

Some of the important conclusions of the present study are presented here.

Increase in moments and axial forces were observed in Model 1 (structure which is upgraded to Zone 3). Therefore we can say that size of existing columns is not sufficient to take the loads, hence accordingly column sizes are increased to make the structure safe.

It has been observed that the entire jacketing models has less time period than normal RCC structure, but the least time period was found in FRP, from which we can say that FRP jacketing model is more stiffer than RCC and steel jacketing.

From the displacements and drifts ratio graphs, it was observed that, the displacement and drifts ratio is drastically reduced in FRP Jacketing (Model 4) and Steel Jacketing (Model 3) models when compared to normal RCC structure (Model 1). Hence significant effect of RCC, Steel and FRP jacketing was observed.

Therefore RCC, Steel and FRP jacketing models has better performance. Hence we can conclude that FRP jacketing is more effective in increasing both strength and deformation capacity of the retrofitted columns.

6.1 FUTURE SCOPE:

As the influence of modeling could be seen prominently in this work, the work can be extended further by

(i) Varying the retrofitting strategy(local/global)

(ii) (ii) Varying the number of connectors and their spacing, between the existing and new materials used.

(iii) (iii) Considering the interaction between existing and new structures used as a part of retrofitting, using appropriate modelling techniques and sophisticated software.

7. REFERENCES:

1. Niroomandi A, Maheri A, Maheri,

MR, Mahini SS, (2010). Seismic performance of ordinary RC frames retrofitted at joints by FRP sheets, Engineering Structures,32(8):2326-2336.

2. Massumi1 and A.A. Tasnimi(2008). Strengthening of low ductile reinforced concrete frames using steel x-bracings with different details, World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.
3. Maheri M R, Akbari R, (2003). Seismic behaviour factor, R, for steel X-braced and knee-braced RC buildings, Engineering Structures, 25:1505-1513.
4. American Society of Civil Engineering (ASCE), Prestandard and commentary for the seismic rehabilitation of buildings (2000). Prepared for the Federal Emergency Management Agency, FEMA 356.
5. Masri, A.C., and Goel, S.C. (1996). Seismic Design and Testing of an RC Slab-Column Frame Strengthened by Steel Bracing. Earthquake Spectra, 12:4, 645-666.
6. Maheri, M.R., and Sahebi, A. (1995). Experimental Investigations of Steel-Braced Reinforced Concrete Frames. Proceedings of 2nd International Conference on Seismology and Earthquake Engineering, Vol. 1, Tehran, IRAN, 775-784.
7. Pauley T, Priestley MJN, (1992). Seismic design of reinforced concrete and masonry buildings, John Wiley & Sons, Inc.
8. Hand book on Seismic Retrofit of Buildings (2007), Central Public works department and Indian Building Congres, IIT Madras.
9. sultan erdemligünaslan ijiset - international journal of innovative science, engineering & technology, vol. 1 issue 9, november 2014.
10. ATC, Seismic evaluation and retrofit of concrete buildings (1996). ATC-40, Applied Technology Council, Redwood city.
11. Shri. pravin b. waghmare ,international journal of advanced engineering research and studies,december, 2011/15-19 materials and jacketing technique for retrofitting of structures .
12. Agarwal, P. and Shrikande, M.(2006), "Earthquake Resistant Design of Structures", Prentice-Hall of India Private Limited, New Delhi, India.
13. IS 456:2000, "Plain and Reinforced Concrete - Code of Practice", Bureau of Indian Standards, New Delhi, 2000.
14. IS 1893-2016**,** Criteria For Earthquake Resistant Design of Structures (Part-1), Bureau of Indian Standards, New Delhi, 2002.

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www.csiamerica.com