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# Dynamic Analysis of Retrofitting Multi-Storey Reinforced Concrete Structure Using Jacketing and Steel Wrapping Techniques

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**Abstract:** Earthquakes are one of the most severe natural hazards that cause significant damage to structures, especially those not designed as per modern seismic codes. Many existing reinforced concrete (RC) buildings are vulnerable due to inadequate design, poor detailing, and lack of ductility. Therefore, strengthening and retrofitting of such structures has become essential to improve their seismic performance and ensure safety. The present study focuses on the dynamic analysis of a multi-storey reinforced concrete structure and its strengthening using steel jacketing technique. A G+9 storey RC building is modeled and analyzed using SAP2000 software. Two models are considered, namely the bare frame structure and the retrofitted structure with steel jacketing applied at critical regions such as beam-column joints. The analysis is carried out using linear time history analysis and nonlinear pushover analysis to evaluate the seismic behavior of both structures. The performance is assessed based on various parameters such as storey displacement, storey drift, base shear, time period, frequency, and plastic hinge formation. Real earthquake ground motion data such as Imperial Valley, Northridge, and Loma Prieta earthquakes are used to obtain realistic results. The results show that the retrofitted structure performs significantly better than the bare frame structure. The displacement and drift are reduced by approximately 20% to 40%, while the stiffness and load-carrying capacity are increased. The time period decreases and frequency increases after retrofitting, indicating improved dynamic characteristics. The formation of plastic hinges is also better controlled, enhancing the ductility and safety of the structure. Thus, the study concludes that steel jacketing is an effective and economical retrofitting technique for improving the seismic performance of existing RC structures. It enhances strength, stiffness, and stability, making the structure safer under earthquake loading conditions.

**Keywords:** Dynamic Analysis, Steel Jacketing, Retrofitting, Pushover Analysis, Time History Analysis, Seismic Performance, Reinforced Concrete Structure

## I. INTRODUCTION

Seismic design of structures is an important part of civil engineering, especially in countries like India where many regions fall under different seismic zones. The main objective of seismic design is to ensure that the structure can safely resist earthquake forces without collapse. This is achieved by providing a proper balance between strength and ductility. Strength refers to the ability of a structure to resist external loads without failure, while ductility refers to the ability of a structure to undergo large deformation without sudden collapse. In earthquake engineering, ductility is very important because it allows the structure to absorb and dissipate seismic energy. Even if some damage occurs, the structure should not collapse suddenly, which helps in saving lives. During frequent and low-intensity earthquakes, structures are expected to remain in the elastic range, meaning they return to their original shape after the load is removed and no permanent damage occurs. However, during moderate to severe earthquakes, the forces acting on the structure increase significantly, and the structure may enter the inelastic range, where permanent deformation takes place. At this stage, cracks may develop in beams and columns, and plastic hinges may form at critical locations such as beam-column joints. In earlier times, most structures were designed using equivalent static methods, where earthquake forces were considered as static loads.

Although this method is simple and easy to apply, it does not accurately represent the actual behavior of structures under real earthquake conditions. Earthquakes are dynamic in nature, meaning the loads vary with time, direction, and intensity. Therefore, modern design practices focus on dynamic analysis methods, such as time history analysis and response spectrum analysis, which provide a more realistic understanding of structural behavior.

## II. METHODOLOGY

### Building Geometry:

In the present study, a 3-dimensional (3D) structural model of a multi-storey reinforced concrete building is considered. The building consists of G+9 storeys and is modeled as a moment-resisting frame structure.

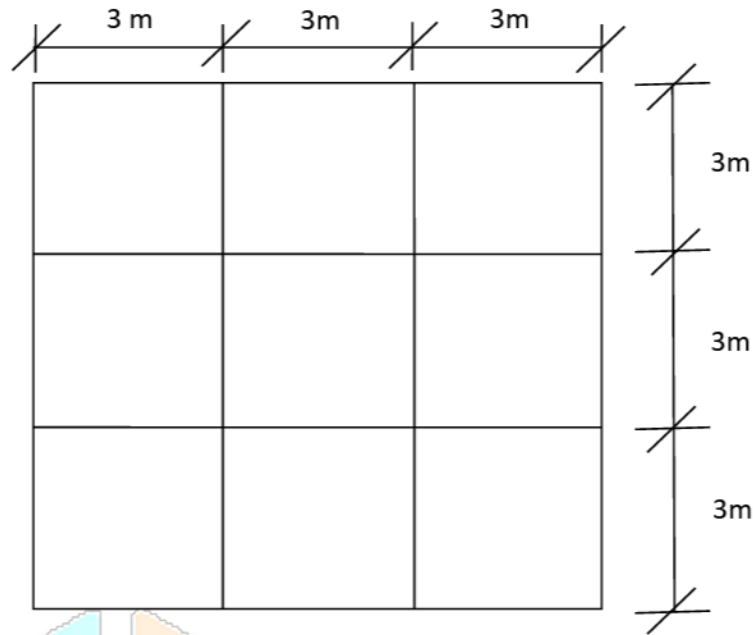
The foundation of the structure is assumed to be fixed.

**Table 3.1: General Description of Building**

Sr. No.	Parameter	Description
1	Number of Bays (X Direction)	3
2	Number of Bays (Y Direction)	3
3	Bay Width (X Direction)	3 m
4	Bay Width (Y Direction)	3 m
5	Storey Height	3 m
6	Live Load	3 kN/m <sup>2</sup>
7	Floor Finish	1 kN/m <sup>2</sup>
8	Concrete Grade	M20
9	Steel Grade	Fe415
10	Beam Size	250 mm × 250 mm
11	Column Size	300 mm × 300 mm

### Plan of Modeled Building:

The plan of the modeled building is an important part of the structural analysis, as it defines the arrangement of structural elements such as beams, columns, and bays in both directions. In the present study, a regular and symmetrical plan is considered for simplicity and better understanding of structural behavior under seismic loading. The building consists of 3 bays in both X and Y directions, with each bay having a uniform spacing of 3 meters, forming a grid pattern. This regular configuration helps in achieving uniform distribution of loads and avoids torsional irregularities during earthquake action. The plan layout represents a typical reinforced concrete moment-resisting frame structure, where columns are placed at the intersection of grid lines and beams connect these columns horizontally. The symmetry of the plan ensures that the center of mass and center of rigidity are closely aligned, which reduces the chances of uneven displacement and torsional effects. Such a regular plan is generally preferred in seismic design, as it performs better compared to irregular structures. The modeled plan is used as the base for developing the three-dimensional structural model in SAP2000, where all storeys are assumed to have the same layout. This simplifies the analysis and allows for clear comparison between the behavior of the bare frame structure and the retrofitted structure.



**Figure 3.1: Plan of Modeled Building**

### Steel Jacketing Modeling:

Steel jacketing modeling is one of the most important steps in this study, as it directly affects the improvement in seismic performance of the existing reinforced concrete (RC) structure. In the present work, steel jacketing is applied as a retrofitting technique to strengthen the deficient columns of the multi-storey building. The modeling of steel jacketing is carried out carefully based on design guidelines, assumptions, and analytical procedures to ensure that the behavior of the retrofitted structure is realistically represented.

In this study, the grade of steel used for jacketing is Fe250, which is commonly used for structural steel applications due to its adequate strength and ductility. Unlike full-length jacketing, the steel jacket is not provided over the entire height of the column, but it is applied only at critical regions, particularly at the potential plastic hinge locations near beam-column joints. These regions are most vulnerable during seismic loading, as they experience maximum bending moments and shear forces. By strengthening these zones, the overall performance of the structure can be significantly improved.

The primary purpose of steel jacketing is to provide confinement to the concrete core and increase the shear strength and ductility of the column. It is important to note that the steel jacket is designed in such a way that it mainly resists shear forces and confinement pressure, and does not significantly contribute to the bending strength of the column. This assumption is made to avoid overestimation of structural capacity and to ensure realistic modeling behavior.

The design of steel jacketing is based on the concept of equivalent confinement pressure, which ensures that the retrofitted column satisfies modern seismic design requirements. According to design procedures suggested by researchers such as Xiao and Wu, the confinement provided by the steel jacket should be equivalent to the confinement required by seismic design codes such as ACI 318.

The transverse reinforcement requirement for confinement is expressed as:

$$A_{sh} \geq 0.3 s h_c \frac{f'_c}{f_{yh}} \left( \frac{A_g}{A_{ch}} - 1 \right)$$

and

$$A_{sh} \geq 0.09 s h_c \frac{f'_c}{f_{yh}}$$

Where:

- $A_{sh}$  = area of transverse reinforcement
- $s$  = spacing of reinforcement
- $h_c$  = core dimension of column
- $f'_c$  = compressive strength of concrete

- $f_{yh}$  = yield strength of transverse steel
- $A_g$  = gross area
- $A_{ch}$  = confined core area

From these equations, an equivalent confinement pressure  $f_{eq}$  is defined as:

$$f_{eq} = \frac{A_{sh}f_{yh}}{sh_c}$$

This confinement pressure ensures that the column behaves in a ductile manner during seismic loading.

Further, for steel jacketing, the design assumes that the steel plate provides a uniform confinement pressure around the column. The design is based on a limit state condition where plastic hinges are formed at critical sections. The moment and axial force per unit width for the confinement element can be expressed as:

$$m = \frac{1}{16} h^2 f_{eq}$$

$$p = \frac{1}{2} h f_{eq}$$

These values are then used in accordance with design provisions such as AISC (1999) to determine the adequacy of the steel jacket.

For steel plate jacketing, the strength per unit width is given as:

$$m_n = \frac{t^2 f_{yj}}{4}$$

$$p_n = t f_{yj}$$

Where:

- $t$  = thickness of steel jacket
- $f_{yj}$  = yield strength of steel jacket

Using these expressions, the required thickness of the steel jacket can be calculated to ensure sufficient confinement and strength.

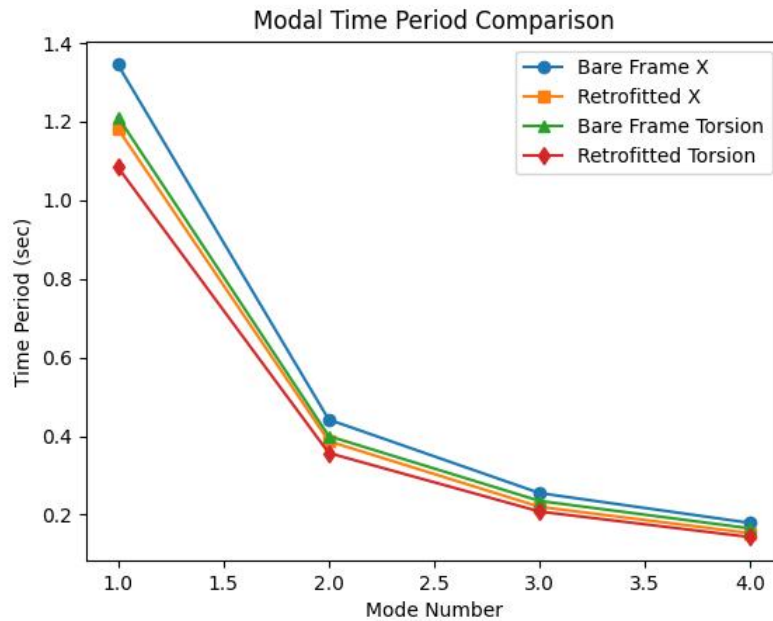
### III. RESULTS AND DISCUSSION

#### Modal Time Period and Frequency:

The modal time period of the structure is an important parameter that represents the vibration characteristics of the building. It depends on the mass and stiffness of the structure.

**Table 4.1: Modal Time Period of Bare Frame and Retrofitted Structure**

Direction	Mode No.	Bare Frame (sec)	Retrofitted (sec)
X	1	1.345	1.182
X	2	0.442	0.387
X	3	0.255	0.220
X	4	0.179	0.153
Y	1	1.345	1.182
Y	2	0.442	0.387
Y	3	0.255	0.220
Y	4	0.179	0.153
Torsion	1	1.212	1.084
Torsion	2	0.400	0.357
Torsion	3	0.235	0.208
Torsion	4	0.165	0.143



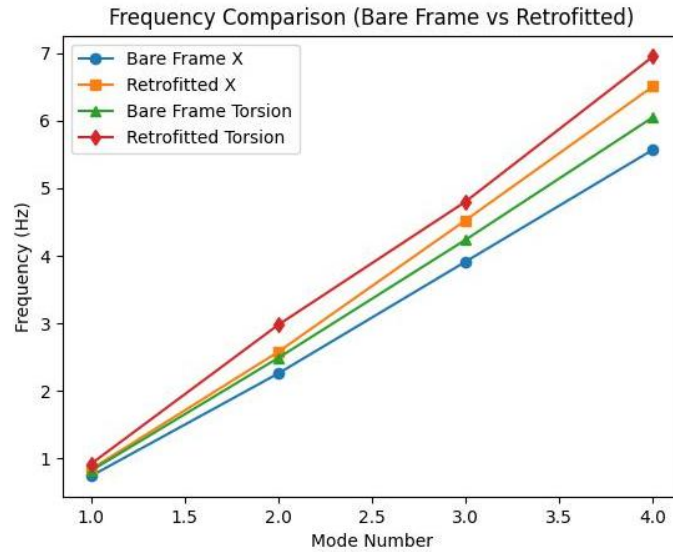
**Graph 4.1: Modal Time Period of Bare Frame and Retrofitted Structure**

**Observation:**

1. Time period is maximum in first mode and decreases with higher modes
2. Time period of retrofitted structure is less than bare frame
3. This indicates increase in stiffness due to steel jacketing
4. Similar values in X and Y direction show symmetry of structure

**Table 4.2: Frequency of Bare Frame and Retrofitted Structure**

Direction	Mode No.	Bare Frame (Hz)	Retrofitted (Hz)
X	1	0.743	0.845
X	2	2.260	2.579
X	3	3.914	4.526
X	4	5.570	6.506
Y	1	0.743	0.846
Y	2	2.260	2.580
Y	3	3.914	4.526
Y	4	5.570	6.508
Torsion	1	0.820	0.921
Torsion	2	2.490	2.979
Torsion	3	4.238	4.802
Torsion	4	6.050	6.947



Graph 4.2: Frequency of Bare Frame and Retrofitted Structure

**Observation:**

1. Frequency increases with mode number
2. Retrofitted structure has higher frequency
3. Indicates higher stiffness and lower deformation

**Mode Shapes:**

Mode shapes represent the deformation pattern of the structure during vibration.

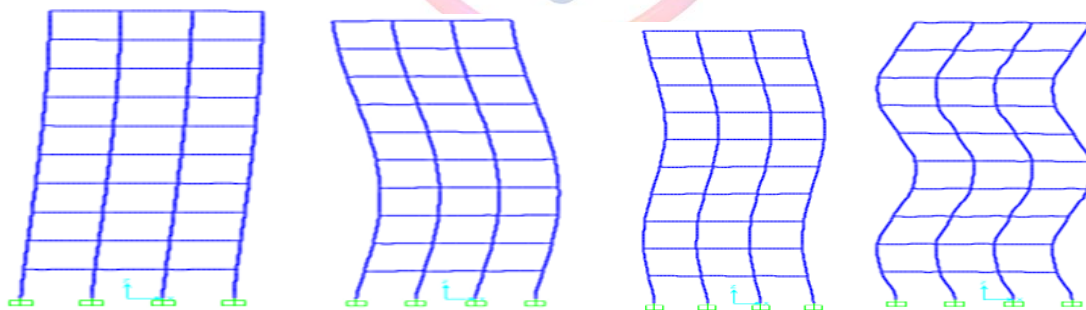


Fig 4.1: Mode Shapes of Building

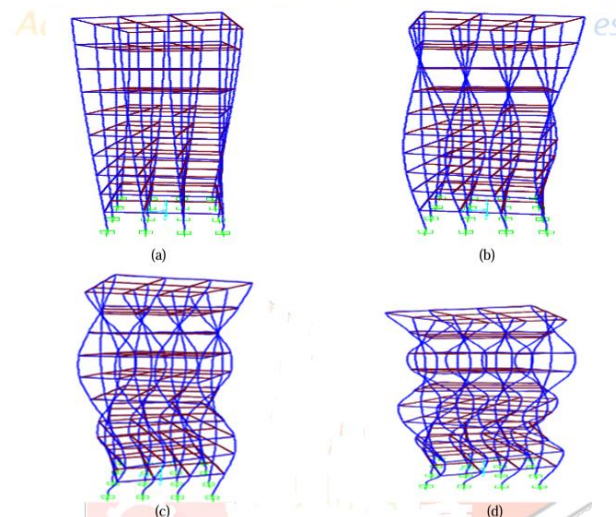


Figure 4.2: Picture (a) depicts first mode shape (b) depicts second mode shape (c) depicts third mode shape and (d) fourth mode shape in torsion

**Observation:**

1. Mode shapes in X and Y direction are similar
2. Indicates regular and symmetric structure
3. Torsional mode also observed in higher modes
4. Retrofitting does not change shape but improves performance

**Linear Time History Analysis:**

Linear Time History Analysis is one of the most advanced and realistic methods used in seismic analysis to evaluate the behavior of structures under earthquake loading. Unlike static or simplified dynamic methods, this analysis considers the actual variation of ground motion with time, which makes it highly accurate for understanding real structural response during earthquakes. In the present study, linear time history analysis is carried out for both the bare frame structure and the retrofitted structure (with steel jacketing) using SAP2000 software. The purpose of this analysis is to evaluate how the structure behaves under real earthquake ground motions and to compare the performance before and after retrofitting.

**Table 4.3: Storey Displacement for Bare Frame and Retrofitted Structure**

**(a) Imperial Valley Earthquake**

Storey No.	Bare Frame (mm)	Retrofitted (mm)
1	15	10
2	30	20
3	50	35
4	70	50
5	90	65
6	110	80
7	125	90
8	140	100
9	150	110
10	160	120

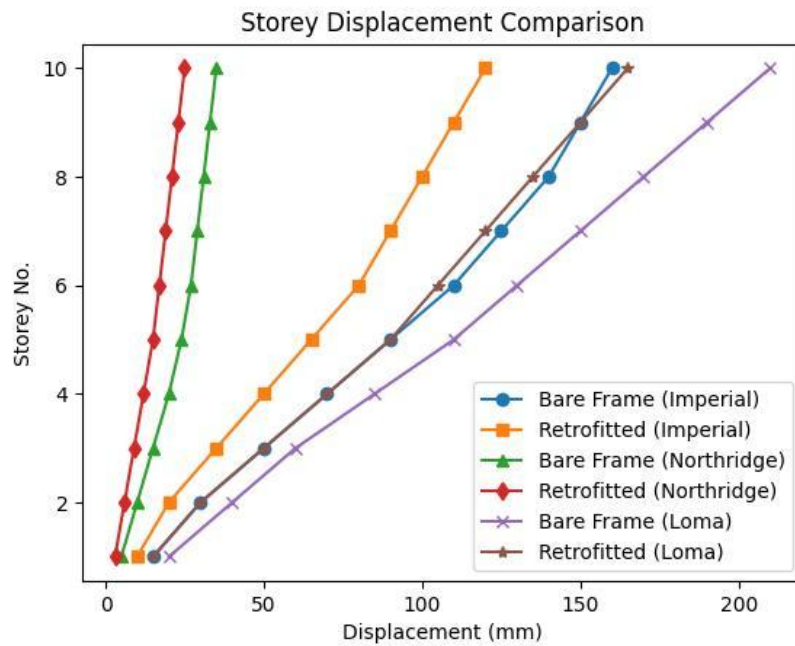
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**(b) Northridge Earthquake**

Storey No.	Bare Frame (mm)	Retrofitted (mm)
1	5	3
2	10	6
3	15	9
4	20	12
5	24	15
6	27	17
7	29	19
8	31	21
9	33	23
10	35	25

**(c) Loma Prieta Earthquake**

Storey No.	Bare Frame (mm)	Retrofitted (mm)
1	20	15
2	40	30
3	60	50
4	85	70
5	110	90
6	130	105
7	150	120
8	170	135
9	190	150
10	210	165



Graph 4.3: Storey Displacement for Bare Frame and Retrofitted Structure

Table 4.4: Storey Drift for Bare Frame and Retrofitted Structure

(a) Imperial Valley Earthquake

Storey No.	Bare Frame (mm)	Retrofitted (mm)
1	22	15
2	24	16
3	23	15
4	21	14
5	19	13
6	17	12
7	15	11
8	13	10
9	11	9
10	9	8

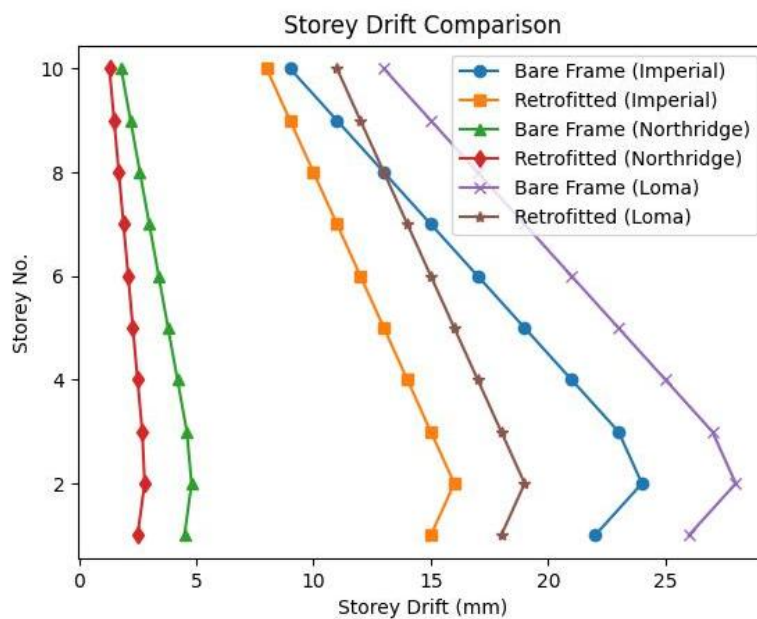
(b) Northridge Earthquake

Storey No.	Bare Frame (mm)	Retrofitted (mm)
1	4.5	2.5
2	4.8	2.8
3	4.6	2.7
4	4.2	2.5
5	3.8	2.3

6	3.4	2.1
7	3.0	1.9
8	2.6	1.7
9	2.2	1.5
10	1.8	1.3

(c) Loma Prieta Earthquake

Storey No.	Bare Frame (mm)	Retrofitted (mm)
1	26	18
2	28	19
3	27	18
4	25	17
5	23	16
6	21	15
7	19	14
8	17	13
9	15	12
10	13	11



Graph 4.4: Storey Drift for Bare Frame and Retrofitted Structure

## CONCLUSION

The present study focused on the dynamic analysis of a multi-storey reinforced concrete (RC) structure and its improvement using steel jacketing retrofitting technique. Based on the analysis results obtained from time history analysis and pushover analysis, the following conclusions are drawn:

- i. The bare frame structure shows higher displacement and drift, indicating lower stiffness and higher vulnerability to earthquake forces.
- ii. The retrofitted structure exhibits reduced displacement (20%–40%), showing significant improvement in structural stiffness due to steel jacketing.
- iii. The storey drift values are reduced in the retrofitted model and are within permissible limits, ensuring better safety of the structure.
- iv. The time period of the structure decreases after retrofitting, which indicates an increase in stiffness.
- v. The natural frequency increases in the retrofitted structure, confirming improved dynamic behavior.
- vi. The base shear increases after retrofitting, which shows that the structure can resist higher seismic forces.
- vii. The plastic hinge formation is controlled in retrofitted structure, especially at beam-column joints, leading to improved ductility and performance.
- viii. The steel jacketing technique provides effective confinement, enhancing shear strength and preventing brittle failure of columns.
- ix. The structure shows better performance under all earthquake cases (Imperial Valley, Northridge, and Loma Prieta).
- x. Among all cases, Loma Prieta earthquake produces maximum response, while Northridge shows minimum response.
- xi. The results confirm that steel jacketing is an effective and economical retrofitting method for improving seismic performance of existing structures.
- xii. Overall, the retrofitted building shows improved strength, stiffness, ductility, and stability, making it safer under earthquake loading.

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