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# Seismic Evaluation and Retrofit of A RC Frame Structure

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**ABSTRACT:** Recent earthquakes in India show that not only non-engineered but also engineered buildings in our country are susceptible even to moderate earthquakes. Indian Standard IS 1893 is revised in 2002. A number of buildings those were designed as per the previous code may not comply with the present code. Therefore evaluating seismic performance of a building and proposing suitable retrofit measure is an important area of study in this context. In the present study an attempt has been made to evaluate an existing building located in Guwahati (seismic zone V) using equivalent static analysis. Indian Standard IS-1893:2002 (Part-1) is followed for the equivalent static analysis procedure. Building is modeled in commercial software STAAD Pro. Seismic force demand for each individual member is calculated for the design base shear as required by IS-1893:2002. Corresponding member capacity is calculated as per Indian Standard IS456:2000. Deficient members are identified through demand-to-capacity ratio. A number of beams and column elements in the first floor of the present building are found to be deficient that needs retrofitting. A local retrofitting strategy is adopted to upgrade the capacity of the deficient members. This study shows that steel jacketing is an efficient way to retrofit RC members to improve flexure as well as shear capacity.

**KEYWORDS:** Reinforced concrete, seismic, retrofit, Response Spectrum Method, Equivalent Static Method

## I. INTRODUCTION

### 1.1 SEISMIC EVALUATION METHODS

- Preliminary investigation
- Detailed evaluation

#### 1.1.1 Preliminary investigation:

The preliminary evaluation is a quick procedure to establish actual structural layout and assess its characteristics that can affect its seismic vulnerability. It is an approximate method based on conservative parameters to identify the potential earthquake risk of a building and can be used for screening of buildings for detailed evaluation. It also helps the design engineers to get acquainted with the building, its potential deficiencies and behavior. A site visit is done as a part of preliminary investigation in order to familiarize with the building and take note of the ground conditions which are not reported in the drawings.

#### 1.1.2 Detailed evaluation methods:

- Equivalent static method
- Response spectrum method

##### 1.1.2.1 Response spectrum method:

Response spectrum analysis is a procedure for computing the statistical maximum response of a structure to a base excitation. Each of the vibration modes that are considered may be assumed to respond independently as a single-degree-of-freedom system. Design codes specify responsespectra which determine the base acceleration applied to each mode according to its period (the number of seconds required for a cycle of vibration).

Response spectrum analysis produces a set of results for each earthquake load case which is really in the nature of an envelope. It is apparent from the calculation, that all results will be absolute values - they are all positive. Each value represents the maximum absolute value of displacement, moment, shear, etc. that is likely to occur during the event which corresponds to the input response spectrum.

#### 1.1.2.2 Equivalent static method:

The equivalent static method is the simplest method of analysis because the forces depend on the code based fundamental period of structures with some empirical modifiers. The design base shear is to be computed as whole, then it is distributed along the height of the building based on some simple formulae appropriate for buildings with regular distribution of mass and stiffness. The design lateral force obtained at each floor shall then be distributed to individual lateral load resisting elements depending upon the floor diaphragm action.

## II. LITERATURE REVIEW

There are three key concepts in seismic design that were fully developed by researchers and engineers.

**First**, earthquake ground motions generate inertial loads that rapidly change with time. Thus, it is common that calculations include a term labeled with a unit of time (usually seconds) and these terms include periods of vibration or their inverse, frequencies; accelerations and velocities. In many other structural engineering problems such as calculations of gravity loads, no unit of time is used.

#### (Benjamin & Cornell, 1970):

**Second**, due to the large uncertainty associated with the forces and structural responses, probabilistic analysis is central to earthquake engineering (Benjamin & Cornell, 1970). The earthquake occurrence time, its magnitude, rupture surface features and dynamic response behavior of the structure cannot be predicted with certainty. Methods of probability and statistics are required to include these uncertainties and their effects on the structural performance evaluation and design.

#### (Newmark & Veletsos, 1960):

**The third** fundamental earthquake engineering concept that distinguishes this field is that the earthquake loading can be so severe that the materials must often be designed to behave inelastically. Within the domain of Hooke's Law, stress is proportional to strain, but beyond that point, behavior becomes complex. Most of the analytical and experimental work investigating inelastic behavior began approximately in the 1960s (Newmark & Veletsos, 1960).

#### (Paulay & Priestley, 1992):

Shear wall buildings are a popular choice for reinforced concrete buildings in many earthquake zone countries, like USA, Canada, Chile and New Zealand. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and non-structural elements. Properly designed and detailed buildings with shear walls have shown very good performance in past earthquakes. In many cases the "failure" mode of adequately reinforced concrete walls in severe earthquakes has been the formation of horizontal or diagonal cracks which are easily repaired after the earthquake (Paulay & Priestley, 1992).

#### (Symans, et al., 2002):

The flow of forces in a timber and a steel braced frame of the same layout are essentially the same under earthquake loads in the elastic range. However, the mode of behavior and seismic design philosophy in timber and steel braced frame can be quite different in the inelastic range. Because wood does not have well defined yield points like steel has. The splitting, crushing, and breaking of a piece of wood in the range defined as inelastic does not conform to a classic definition of ductility (Symans, et al., 2002).

#### (Moehle et al., 2012):

Walls should be well distributed within the building plan providing resistance to story shears in each principal direction and also they should be positioned such that their center of resistance is close to the center of mass to avoid induced torsion. Walls located near the perimeter may be preferred because they maximize torsional resistance. Furthermore, good connections between diaphragms and structural walls are essential to the seismic force path. Selection of special

reinforced concrete shear walls as primary seismic force-resisting elements is influenced by considerations of seismic performance, functionality, constructability, and cost. For low-to mid-rise buildings, shear walls typically are more cost effective than other systems such as concrete moment frames (Moehle et al., 2012).

### III. PROPOSED METHODOLOGY

#### 3.1 About the building:

##### 1. Building description:

Building type: Reinforced concrete frame  
Usage: Residential apartment  
Location: Nagpur, Maharashtra  
Year of construction: 1999  
Number of stories: Open ground + 4  
Plan dimensions: 25.2 m X 13.95 m  
Building height: 15 m

##### 1.2 Grade of Materials:

Concrete: M 15  
Reinforcing Steel: Fe 415

#### 3.2 Modeling in Staad Pro:

I adopted a scientific approach to modeling in STAAD. In my approach I did not use any shortcut commands and worked only through the Staad editor. The most important part of modeling was the nomenclature of nodes, beams and columns. A proper nomenclature of nodes, beams and columns is very important as it gives you the exact idea where that member is located in the entire structure and has an added advantage while debugging. The nodes were named by giving their x, z co-ordinates a specific number and the y coordinate (along the height) was according to the floor number.

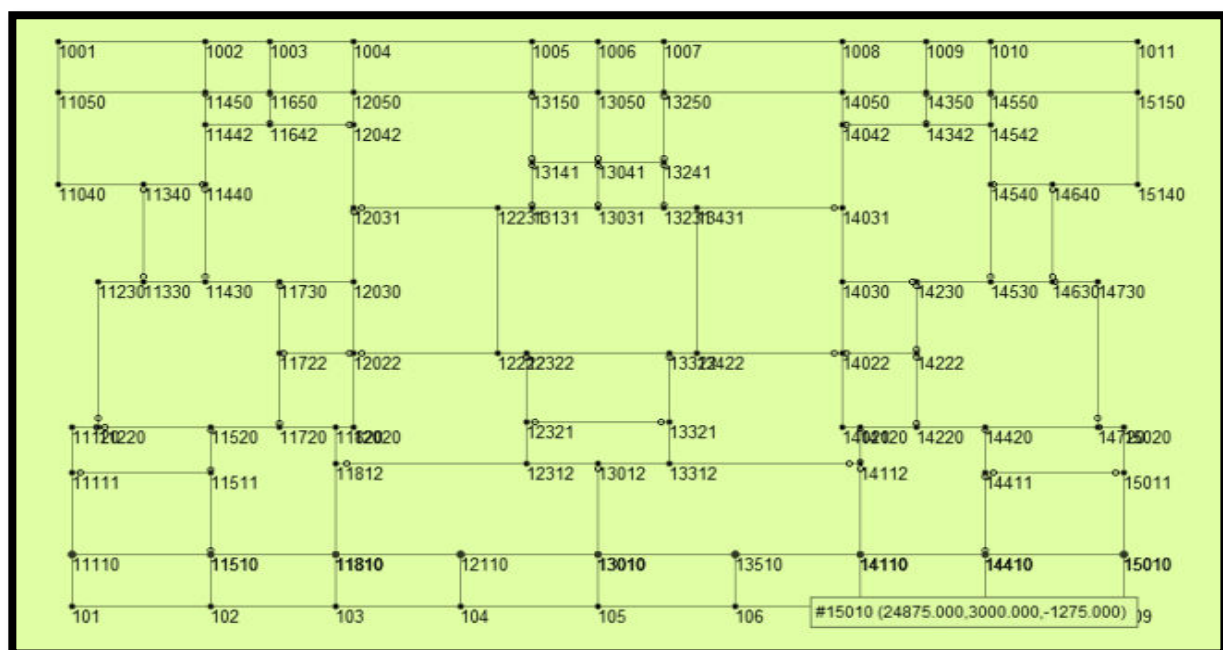


Figure 1: Highlighting all nodes of same z level ( 10) of level 1 (1)

Table 1: showing process of nomenclature of nodes in X direction

| X in metre | Allotted no. | X in metre | Allotted no. |
|------------|--------------|------------|--------------|
| 0          | 10           | 24.875     | 50           |
| 0.325      | 11           | 25.2       | 51           |
| 0.925      | 12           | 3.55       | 15           |
| 3.425      | 14           | 21.65      | 44           |
| 6.475      | 18           | 9.4        | 21           |
| 6.9        | 20           | 15.8       | 35           |
| 10.275     | 22           | 5.1625     | 17           |
| 10.925     | 23           | 20.0375    | 42           |
| 12.6       | 30           | 23.225     | 46           |
| 14.275     | 33           | 1.975      | 13           |
| 14.925     | 34           | 11.075     | 31           |
| 18.3       | 40           | 14.125     | 32           |
| 18.725     | 41           | 4.925      | 16           |
| 21.775     | 45           | 20.275     | 43           |
| 24.275     | 47           |            |              |



Table 2: showing process of nomenclature of nodes in Z direction

| Z in metre | Alloted no. |
|------------|-------------|
| -1.275     | 10          |
| -3.525     | 12          |
| -4.4       | 20          |
| -6.225     | 22          |
| -8         | 30          |
| -9.825     | 31          |
| -10.4      | 40          |
| -11.875    | 42          |
| -12.675    | 50          |
| -3.275     | 11          |
| -4.525     | 21          |
| -10.9375   | 41          |

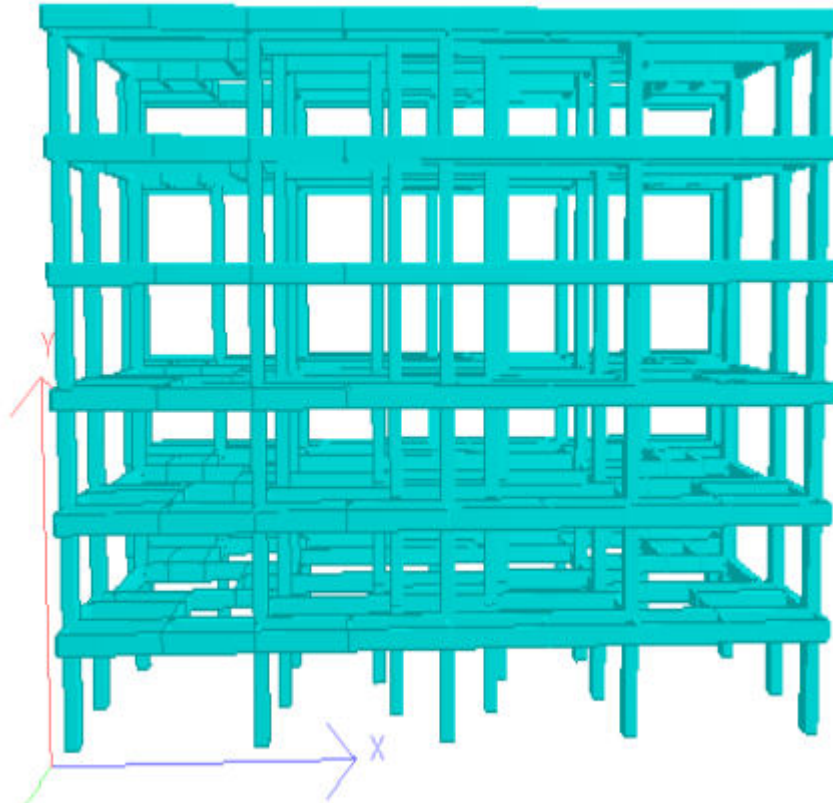


Figure 2: Whole building with member properties applied to all the members

### 3.3 Loading:

- Dead load: Includes self-weight of all members + Brick Load + Floor load from slabs Brick load due to 2.4 m high brick wall and 250 mm thick and of 2 T/m<sup>3</sup> density =  $2.4 \times 0.25 \times 2 = 1.2$  T per udl

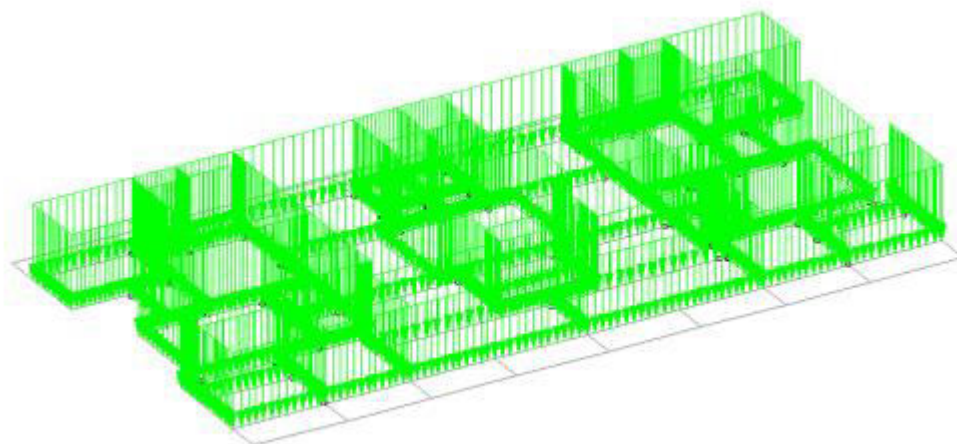


Figure 3: Showing application of brick load

- Floor load due to Slab: Considering 150 mm thickness of slabs and 2.5 T/m<sup>3</sup> density of concrete =  $.15 \times 2.5 \times 1 = 0.375$  T per m

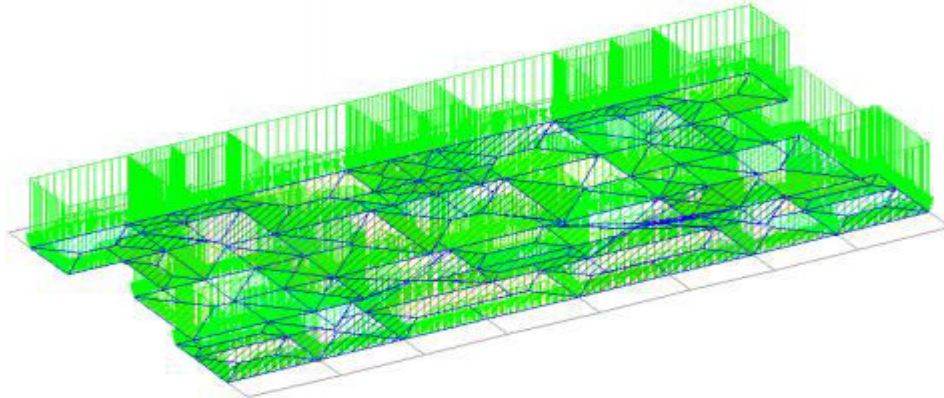


Figure 4: Showing application of dead load (brick load + slab load)

- Live load: Taking maximum live load for residential building as per IS 875 (part 2) = 0.3 T/m<sup>2</sup>

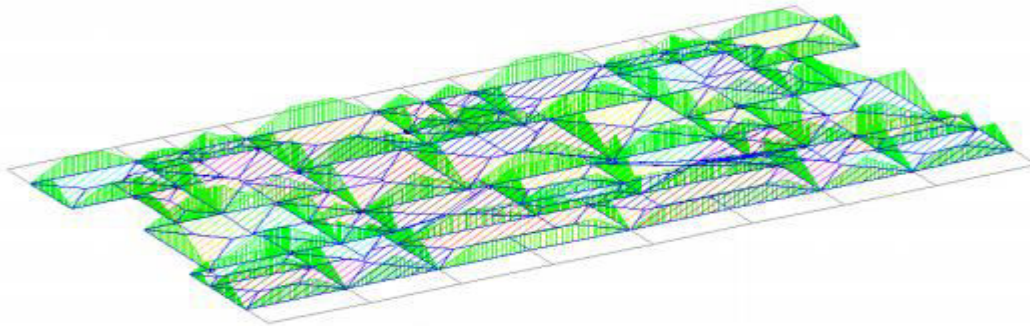


Figure 5: Showing application of live load

- Seismic load: The design seismic base shear was calculated as per IS 1893:2002 (part 1) for equivalent static procedure.

Table 3: Seismic weight calculation

| Weight Calculation                                             |              |                               |            |             |            |                          |                             |                |
|----------------------------------------------------------------|--------------|-------------------------------|------------|-------------|------------|--------------------------|-----------------------------|----------------|
| sl no.                                                         | category     | no.                           | length (m) | breadth (m) | height (m) | volume (m <sup>3</sup> ) | density (T/m <sup>3</sup> ) | weight (T)     |
| 1                                                              | columns      | 28                            | 0.5        | 0.4         | 3          | 0.6                      | 2.5                         | 42             |
| 2                                                              | beams        | 110                           | 0.5        | 0.25*       | 0.5        | 0.0625                   | 2.5                         | 18             |
| 3                                                              | slab         | -                             | 24.55      | 11.4        | 0.15       | ~42.0                    | 2.5                         | 81             |
| 4                                                              | brick load   | -                             | 212.58     | 0.2         | 2.4        | 102.03                   | 2                           | 205            |
| 5                                                              | imposed load | taking 25% of total live load |            |             |            |                          |                             | 26.27          |
| seismic wt for all floors except roof                          |              |                               |            |             |            |                          | =                           | 372.27 Tonnes  |
| seismic wt. for roof                                           |              |                               |            |             |            |                          | =                           | 222.50 Tonnes  |
| total seismic weight                                           |              |                               |            |             |            |                          | =                           | 2083.85 Tonnes |
| 0.25* is taken as an average                                   |              |                               |            |             |            |                          |                             |                |
| ~slab volume is reduced by bricks and effective value is 32.38 |              |                               |            |             |            |                          |                             |                |

Table 4: Calculation of base shear

| calculation of base shear |                         |           |                                                    |
|---------------------------|-------------------------|-----------|----------------------------------------------------|
| factors                   | formula                 | value     | remarks                                            |
| Z                         |                         | 0.36      | zone V value from Table 2 of IS 1893:2002          |
| I                         |                         | 1         | residential building value from Table 6 of IS 1893 |
| R                         |                         | 3         | from Table 7 of IS 1893:2002                       |
| T                         | $0.075(h)^{0.75}$       | 0.655     | $h = 18$ m from foundation                         |
| Sa/g                      | $Sa/g = 1.36/T$         | 2.075     |                                                    |
| Ah                        | $Ah = Z * I * Sa / 2Rg$ | 0.125     | Ah = design horizontal seismic coefficient         |
| W                         |                         | 2083.85 T | Total Seismic wt. of Building                      |
| Vb                        | $Vb = Ah W$             | 259.44 T  | Design Base Shear                                  |

Table 5: Distribution of base shear along vertical direction

| Calculation of Seismic force<br>per storey in X direction |             | V <sub>b</sub> per storey                |
|-----------------------------------------------------------|-------------|------------------------------------------|
| Floor                                                     | $W_i h_i^2$ | $W_i h_i^2 / \sum W_i h_i^2$ (in Tonnes) |
| 1 <sup>st</sup>                                           | 13401.8     | 18.87                                    |
| 2 <sup>nd</sup>                                           | 30154.0     | 42.45                                    |
| 3 <sup>rd</sup>                                           | 53607.0     | 75.47                                    |
| 4 <sup>th</sup>                                           | 83761.0     | 117.93                                   |
| Roof                                                      | 72090.0     | 101.50                                   |

Table 6: Distribution of base shear per node in X and Z directions for each floor

| Seismic forces per node (T) |                       |                       |
|-----------------------------|-----------------------|-----------------------|
| Floor                       | X direction (5 nodes) | Z direction (9 nodes) |
| 1 <sup>st</sup>             | 3.77                  | 2.10                  |
| 2 <sup>nd</sup>             | 8.49                  | 4.72                  |
| 3 <sup>rd</sup>             | 15.09                 | 8.39                  |
| 4 <sup>th</sup>             | 23.59                 | 13.10                 |
| Roof                        | 20.30                 | 11.28                 |

• Load combinations applied

Table 7: Load combinations as per IS 1893:2002 (part 1)

|               |
|---------------|
| 1.5 (DL+LL)   |
| 1.2(DL+LL±EL) |
| 1.5(DL±EL)    |
| 0.9DL ± 1.5EL |

### 3.4 Local retrofitting methods

From the results obtained above for this building, it is clear that the members will fail under the applied load combinations as per IS 1893:2002 (part 1) and we have to provide retrofitting in the building. The scope of my study is limited to local retrofitting measures.

Retrofit of columns:

Retrofit methods of columns include:

- Concrete jacketing
- Steel jacketing
- Fibre reinforced polymer wrapping

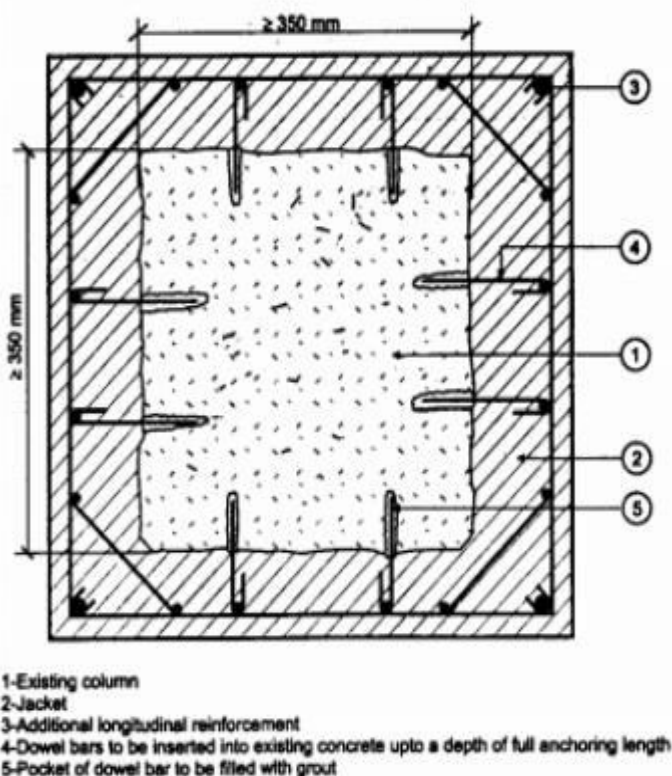


Figure 6: Concrete jacketing

Retrofit of beams:

Beams can be strengthened by:

- Concrete jacketing
- Steel plating
- Use of FRP bars
- External prestressing

In this structure we can use concrete jacketing as well as steel plating. The scope of my study is limited to retrofitting of beams by steel plating. In steel plating, steel plates are glued to beams to improve their flexural and shear capacities. It increases the strength and stiffness of the beams and reduces the crack width.

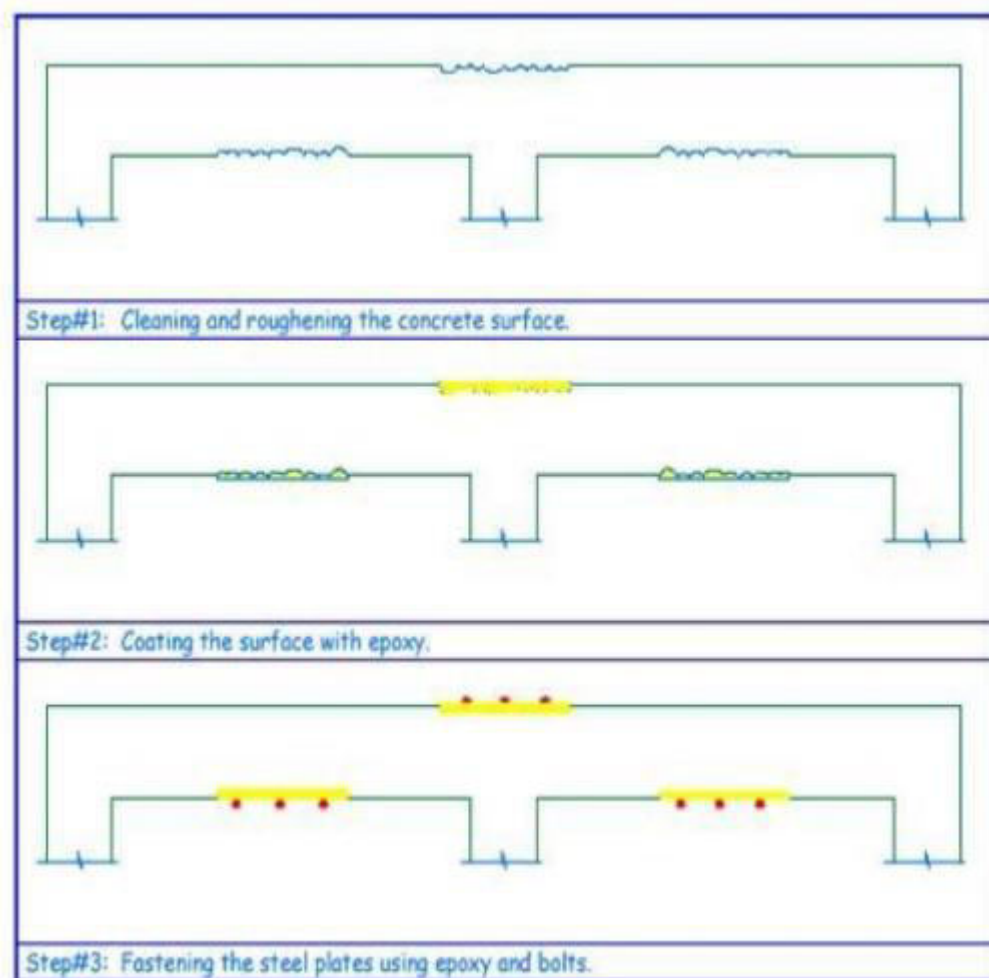


Figure 7: Showing steps of steel plating

#### IV. CONCLUSION

The purpose of this paper was to assess the seismic vulnerability of an existing RC structure and to provide for retrofit in case the members fail. The building under study in this project was an existing multi-storeyed residential building in Maharashtra. The plan and reinforcement details of the building were provided. I modeled the building in STAAD Pro software and applied seismic load combinations to it. Equivalent static procedure as per Indian Standard IS 1893:2002 (Part 1) was used to compute the seismic forces. The members' adequacy was assessed by computation of their dcr (demand to capacity ratio) values. The demand of individual members was obtained after analysis from STAAD Pro software and the capacity for the corresponding members was calculated, the ratio of the two gave the dcr values. The



simple concept that if the dcr of any member is greater than one would result in the failure of that member under the applied loads was used to find out the status of the members under flexure and shear.

The results for first floor beams and a large sample of columns showed that a number of beams and all the foundation columns checked were found to be deficient under the applied seismic load combinations. Number of beams failing under flexure was more than the number of beams failing under shear. The dcr of columns under biaxial bending gradually decreased with height, although it was greater than one in most of the cases.

For providing retrofit measures for the deficient members, concrete jacketing was found to be a suitable method for retrofitting of columns. It was also concluded that steel plating would be an efficient method of retrofitting of a number of deficient beams.

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