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# Seismic Performance Evaluation and Retrofitting of L-Shaped RC Building

**Suchita Vasantrao Jenekar[1], Prof. Sandip Tupat[2], Prof. Girish Sawai [3]**

[1] PG Scholar, Civil Engineering Department, V.M. Institute of Engineering and Technology, Dongargaon, Nagpur, Maharashtra, India

[2] Guide, Assistant Professor, Civil Engineering Department, V.M. Institute of Engineering and Technology, Dongargaon, Nagpur, Maharashtra, India

[3] Co-Guide, Head of the Department, Civil Engineering Department, V.M. Institute of Engineering and Technology, Dongargaon, Nagpur, Maharashtra, India

**ABSTRACT:** The maintenance work is done periodically to avoid the building from degrading and hence preventing it from non-functioning or ill functioning. The Reinforced cement concrete components are mainly responsible for taking the load and hence are vital elements in any building structure. Retrofitting is the process of repairing existing structures, such as buildings, commercial building structures, bridges, and historic buildings, to make them resistant to seismic forces such as earthquakes, volcanic eruptions, and other natural disasters such as landslides, tsunamis, floods, and thunderstorms. The main objective of retrofitting RCC structural elements is to recover the strength of the deteriorated concrete element structure. It also helps to prevent further damage in concrete elements. The deficiency in the strength of the concrete element could be because of design errors flaws or poor construction workmanship. There could be another reason too for the damage such as the aggression of harmful and hazardous agents. The purpose of this project was to assess the seismic vulnerability of an existing RC structure and to provide for retrofit in case the members fail. 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.

**KEYWORDS:** STAAD PRO, RETROFITTING, EARTHQUAKE, SEISMIC ANALYSIS, DCR VALUES

## I. INTRODUCTION

Several existing reinforced concrete (RC) buildings fail to conform to current seismic codes, increasing its susceptibility to damage and collapse during earthquakes. A concern for building upgrading and rehabilitation has grown considerably in the last decades. However, there is limited information related to the seismic performance of RC buildings retrofitted with steel jacketing. Once the right methodology of retrofitting is implemented and specified, the required ability to the structure could be returned and it completely depends on the type and seriousness of the damage caused. There are numerous techniques that are utilized in the process of retrofitting such as outside plate bonding, grouting, outer post-tensioning, section extension, and fiber built reinforced polymer materials. The need for rebuilding and restoration of buildings and engineering construction may arise once they are damaged to a point that they are not qualified for general use purpose. The building cannot withstand, with good reliability, a further sequence of the same action or unintended accidental actions and consequently, the chance of lives and thus the raising of any structural and content damage would be not justifiable. An appropriate strengthening replacement that can bring back an adequate magnitude of wellbeing and assurance against such moves is described as retrofitting. Retrofitting of structures implies making changes to a present day building to provide protection from various hazards in future such as high wind flows, flooding and earthquakes.Every building structure is built to serve some particular function service, after this service life is completed; the structure is subjected to repairs. In order to keep the structure in fair condition such that it fulfils all desire purpose, time to time maintenance and repair work are necessary. The maintaining work of structure is done time to time and properly to avoid the building from degrading and thereby preventing any future repairing works. For different types of construction of structures mostly reinforced concrete is used a construction material. Distress and deterioration are main cause of major failure of rock structures. With the help of various repair techniques, the minor defects in structures such as cracks and leakages are removed. Restoration is really necessary if the damage extend to a considerable damage. The building should be kept in such a condition such that it provides its main purpose of construction to improve the strength of the building and service of a constructed building structure.

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**[7] Vasant A.Matsagar and R.S.Jangid (2008)** studied in their paper the analytical response of structures retrofitted using base isolation . It has specific objectives to study the usefulness of base isolation in seismic retrofitting of historical buildings, a bridge and liquid storage tank and to substantiate the efficacy of different isolation devices in seismic retrofitting works and also to study the various aspects influencing the retrofitting works using seismic isolation technique. Conventionally designed building is more vulnerable as compared to building designed with seismic provisions related to confinement at the possible location of plastic hinges. They have pointed out the fragility analysis indicates that conventionally designed buildings.

**[8] L Di Sarno and A.S.Elnasai** (On steel and composite structure retrofitting) studied traditional rehabilitation methods and provides a detailed discussion of the design issues along with advantages and disadvantages of retrofitting of steel and composite structures. It also depicts the viability and cost-effectiveness of base isolation and supplemental damping devices on the basis of multiple limit states within the framework of performance based design. A number of parameters which govern the selection and choice of intervention devices are thoroughly investigated.

**[9] L Di Sarno and A.S Elnasai** (On application of special metals in retrofitting) briefly studied about special metals such as aluminium alloys, stainless steel and shape memory alloys which can be implemented in retrofitting of steel buildings. Furthermore, it compares their mechanical characteristics in order to assess a) relative merits and b) the cost-effectiveness in the practical execution of these special metal in case of strengthening of existing structures.

**[10] Mustafa Taghdi, Michael Bruneau and Murat Saatcioglu (2015)** reported the results of tests on several full-scale, low-rise masonry and concrete wall specimens with intention to retrofit low-rise masonry and concrete walls using steel strips. The following results showcase that the in-plane strength, ductility and energy dissipation capacity significantly increase with addition of steel strips.

## III. METHODOLOGY

1. In the present study an attempt has been made to evaluate an existing building located in Nagpur (seismic zone II) using equivalent static analysis.
2. Indian Standard IS-1893:2002 (Part-1) is followed for the equivalent static analysis procedure.
3. Building is modeled in commercial software STAAD Pro.
4. Seismic force demand for each individual member is calculated for the design base shear as required by IS-1893:2002.
5. Corresponding member capacity is calculated as per Indian Standard IS456:2000.

### MODELLING IN STAAD PRO

I adopted a scientific approach to modelling 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.

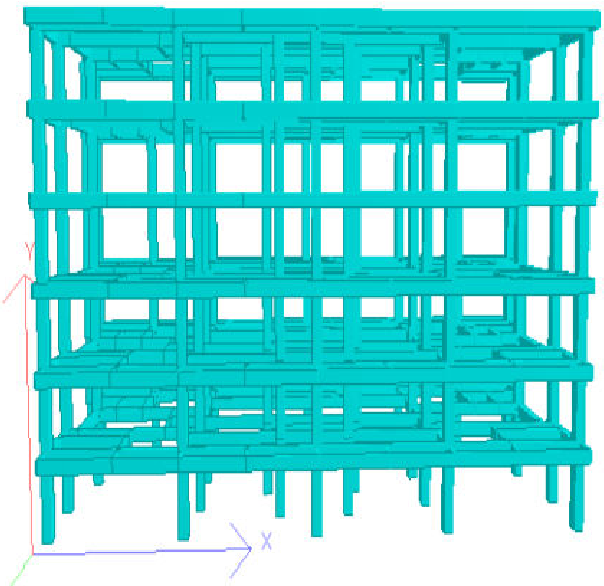

**[Figure 5.1: Highlighting all nodes of same z level ( 10) of level 1 (1)]**

**Table 5.1: showing process of nomenclature of nodes in X direction**

| X in metre | Allotted No. | X in metre | Allotted No. |
|---|---|---|---|
| 0 | 10 | 24.87 | 50 |
| 0.326 | 11 | 25.20 | 51 |
| 0.924 | 12 | 3.56 | 15 |
| 3.415 | 14 | 21.655 | 44 |
| 6.515 | 18 | 9.45 | 21 |
| 6.8 | 20 | 15.80 | 35 |
| 10.274 | 22 | 5.1625 | 17 |
| 10.924 | 23 | 20.0374 | 42 |
| 12.65 | 30 | 23.225 | 46 |
| 14.375 | 33 | 1.9755 | 13 |
| 14.952 | 34 | 11.075 | 31 |
| 18.32 | 40 | 14.125 | 32 |
| 18.725 | 41 | 4.925 | 16 |
| 21.77 | 45 | 20.275 | 43 |
| 24.276 | 47 | | |

**Table 5.2: showing process of nomenclature of nodes in Z direction**

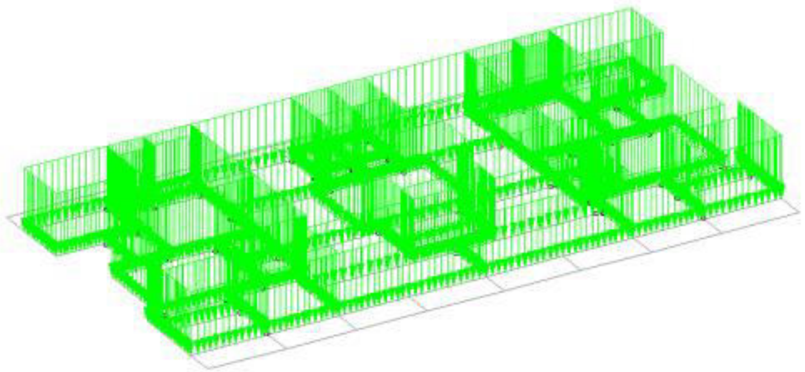
| Z in metre | Allotted No. |
|---|---|
| -1.2755 | 10 |
| -3.526 | 12 |
| -4.45 | 20 |
| -6.225 | 22 |
| -8.00 | 30 |
| -9.825 | 31 |
| -10.45 | 40 |
| -11.875 | 42 |
| -12.675 | 50 |
| -3.276 | 11 |
| -4.525 | 21 |
| -10.93745 | 41 |




**[Figure 5.2: Whole building with member properties applied to all the members]**

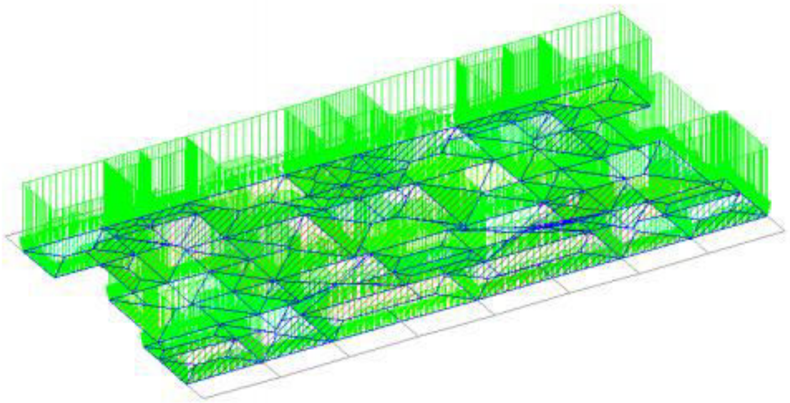
**5.3 LOADING**

• 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/m3 density =2.4*0.25*2=1.2 T per udl.



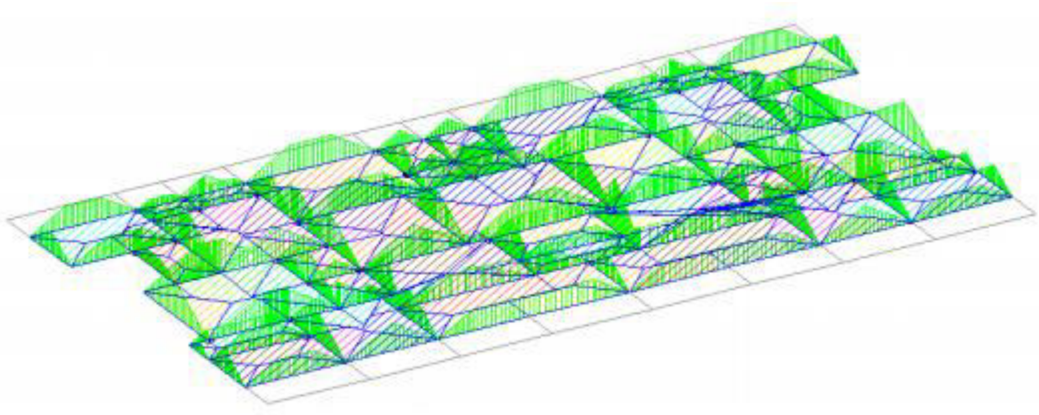
**[Figure 5.3: Showing application of brick load]**

• Floor load due to Slab: Considering 150 mm thickness of slabs and 2.5 T/m3 density of concrete =.15*2.5*1=0.375 T per m



**[Figure 5.4: 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/m2



**[Figure 5.5: 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 5.3: Seismic weight calculation**

| Weight Calculation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| sl no. | category | no. | length (m) | breadth (m) | height (m) | volume (m3) | density (T/m3) | 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 |
| | | | | | | | | |
| | | | | sesimic 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 5.4: 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 5.5: Distribution of base shear along vertical direction**

| | Calculation of Seismic force per storey in X direction | $V_b$ per storey |
|---|---|---|
| **Floor** | $W_i h_i^2$ | $W_i h_i^2 / \sum_1^n W_i h_i^2$ *(in Tonnes)* |
| 1st | 13401.8 | 18.87 |
| 2nd | 30154.0 | 42.45 |
| 3rd | 53607.0 | 75.47 |
| 4th | 83761.0 | 117.93 |
| Roof | 72090.0 | 101.50 |

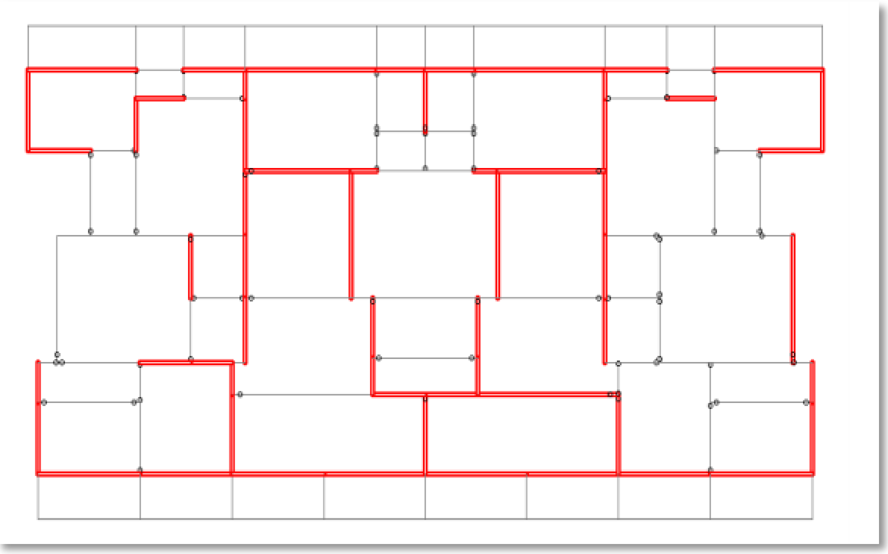
**Table 5.6: Distribution of base shear per node in X and Z directions for each floor**

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

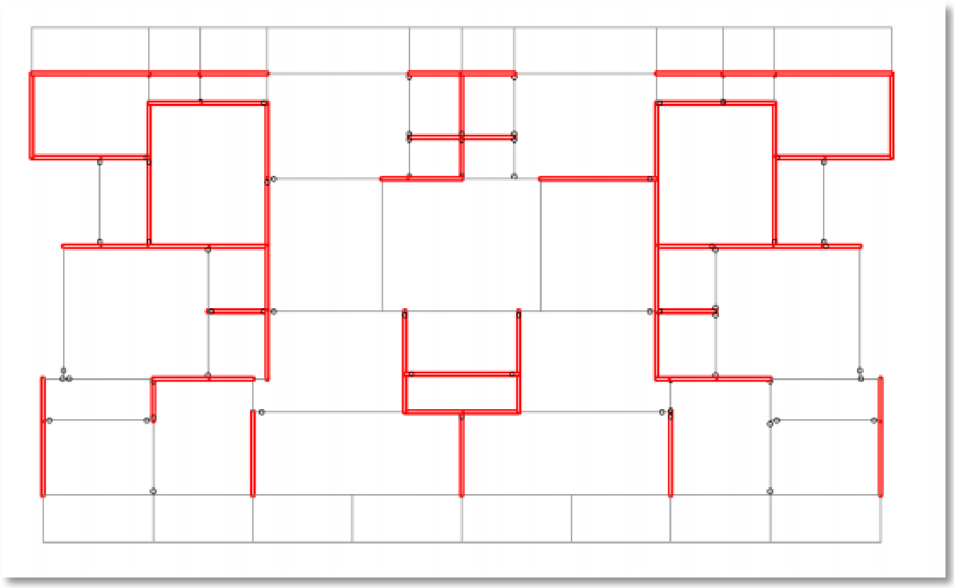
- **Load combinations applied**

**Table 5.7: 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** |

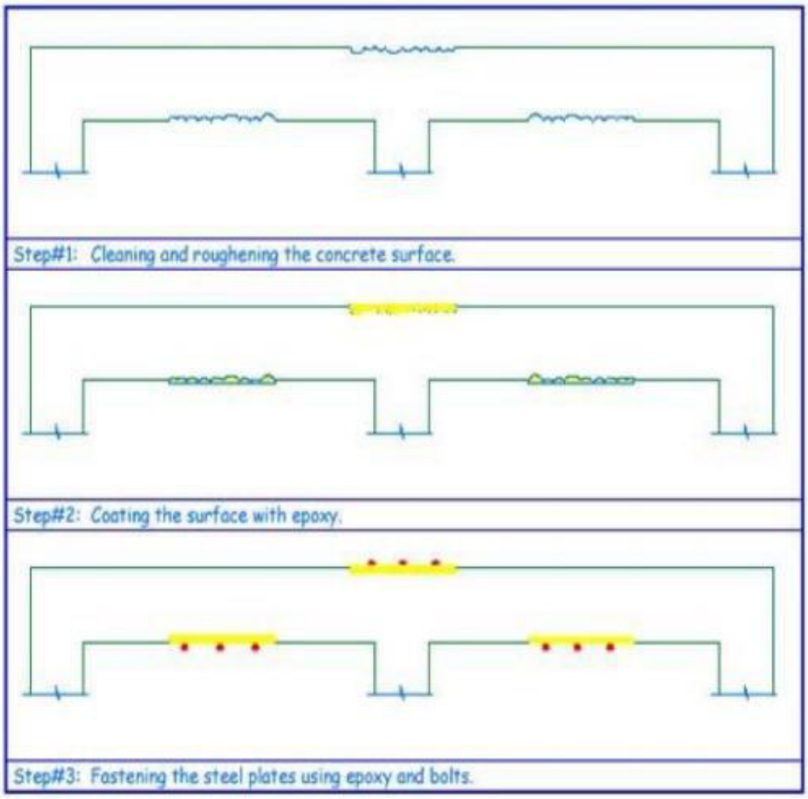


**[Figure 5.6: Beams failing under flexure]**

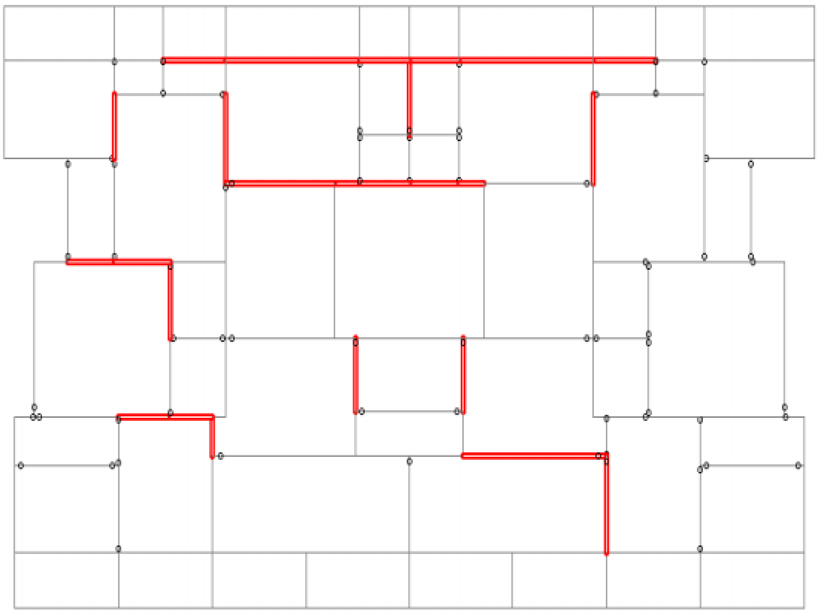


[Figure 5.7: Beams failing under shear]

## IV. RESULTS




[Figure 6.2: Showing steps of steel plating]



[Figure 6.3: showing beams of 1st floor eligible for steel plating]

## V.CONCLUSION

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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**[5] Reza Amiraslanzadeh , Toshikazu Ikemotoand Masakatzumiyajima (2012)** In this paper, they have studied the seismic retrofitting methods of masonry brick walls with their advantages, drawbacks and limitations. They have introduced surface treatment technique with 'Bamboo-Band retrofitting technique, shortcrete, fiber reinforced polymer laminates, posttensioning, confinement technique, central core technique, grout and epoxy injection. They have also made a comparative study of these aforesaid retrofitting methods.

**[6] Michael P. Schuller, Richard H .Atkinson and Jeffrey T. borgsmiller (2004)** studied to strengthen existing masonry buildings which often contain voids, cracks and other weaknesses which can be minimized by applying injection of grout to restore the structure into its original structural conditions. This study also indicates that by injecting grout into voids in the collar joint and enhancing the masonry structure by increasing the composite action between adjacent wythes.

**[7] VasantA.Matsagar and R.S.Jangid (2008)** studied in their paper the analytical response of structures retrofitted using base isolation . It has specific objectives to study the usefulness of base isolation in seismic retrofitting of historical buildings, a bridge and liquid storage tank and to substantiate the efficacy of different isolation devices in seismic retrofitting works and also to study the various aspects influencing the retrofitting works using seismic isolation technique. Conventionally designed building is more vulnerable as compared to building designed with seismic provisions related to confinement at the possible location of plastic hinges. They have pointed out the fragility analysis indicates that conventionally designed buildings.

**[8] L Di Sarno and A.S.Elnasai** (On steel and composite structure retrofitting) studied traditional rehabilitation methods and provides a detailed discussion of the design issues along with advantages and disadvantages of retrofitting of steel and composite structures. It also depicts the viability and cost-effectiveness of base isolation and supplemental damping devices on the basis of multiple limit states within the framework of performance based design. A number of parameters which govern the selection and choice of intervention devices are thoroughly investigated.

**[9] L Di Sarno and A.S Elnasai** (On application of special metals in retrofitting) briefly studied about special metals such as aluminium alloys, stainless steel and shape memory alloys which can be implemented in retrofitting of steel buildings.

Furthermore, it compares their mechanical characteristics in order to assess a) relative merits and b) the cost-effectiveness in the practical execution of these special metal in case of strengthening of existing structures.

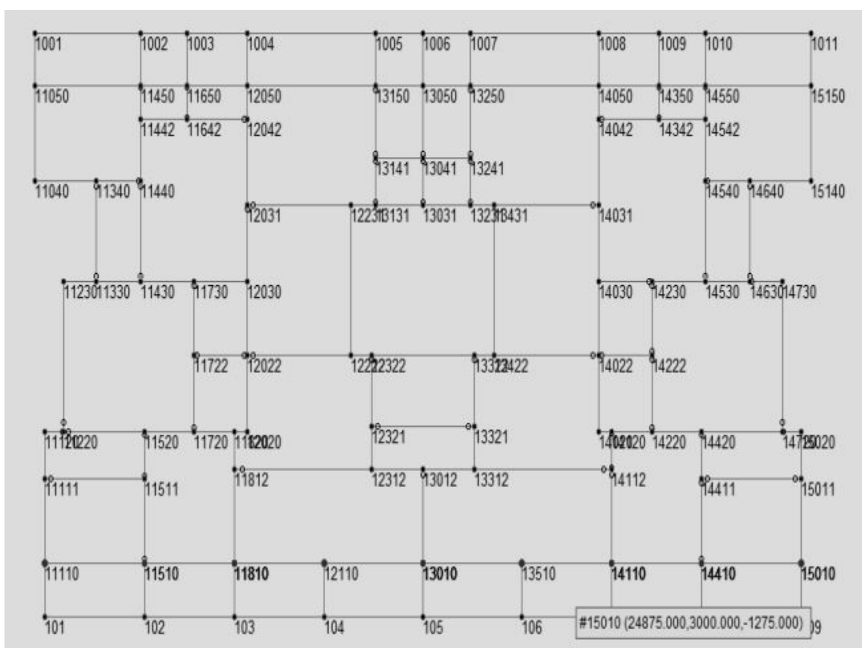
**[10] Mustafa Taghdi, Michael Bruneau and Murat Saatcioglu (2015)** reported the results of tests on several full-scale, low-rise masonry and concrete wall specimens with intention to retrofit low-rise masonry and concrete walls using steel strips. The following results showcase that the in-plane strength, ductility and energy dissipation capacity significantly increase with addition of steel strips.

## III. METHODOLOGY

1. In the present study an attempt has been made to evaluate an existing building located in Nagpur (seismic zone II) using equivalent static analysis.
2. Indian Standard IS-1893:2002 (Part-1) is followed for the equivalent static analysis procedure.
3. Building is modeled in commercial software STAAD Pro.
4. Seismic force demand for each individual member is calculated for the design base shear as required by IS-1893:2002.
5. Corresponding member capacity is calculated as per Indian Standard IS456:2000.

### MODELLING IN STAAD PRO

I adopted a scientific approach to modelling 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 5.1: Highlighting all nodes of same z level ( 10) of level 1 (1)]**

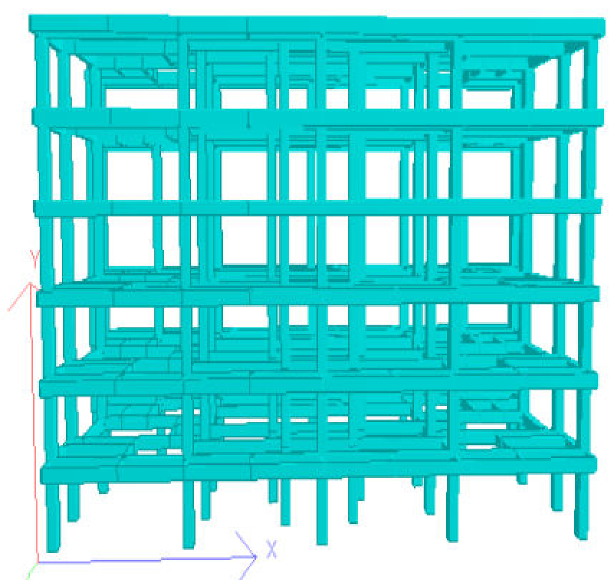
**Table 5.1: showing process of nomenclature of nodes in X direction**

| X in metre | Allotted No. | X in metre | Allotted No. |
|---|---|---|---|
| 0 | 10 | 24.87 | 50 |
| 0.326 | 11 | 25.20 | 51 |

| | | | |
|---|---|---|---|
| 0.924 | 12 | 3.56 | 15 |
| 3.415 | 14 | 21.655 | 44 |
| 6.515 | 18 | 9.45 | 21 |
| 6.8 | 20 | 15.80 | 35 |
| 10.274 | 22 | 5.1625 | 17 |
| 10.924 | 23 | 20.0374 | 42 |
| 12.65 | 30 | 23.225 | 46 |
| 14.375 | 33 | 1.9755 | 13 |
| 14.952 | 34 | 11.075 | 31 |
| 18.32 | 40 | 14.125 | 32 |
| 18.725 | 41 | 4.925 | 16 |
| 21.77 | 45 | 20.275 | 43 |
| 24.276 | 47 | | |

**Table 5.2: showing process of nomenclature of nodes in Z direction**

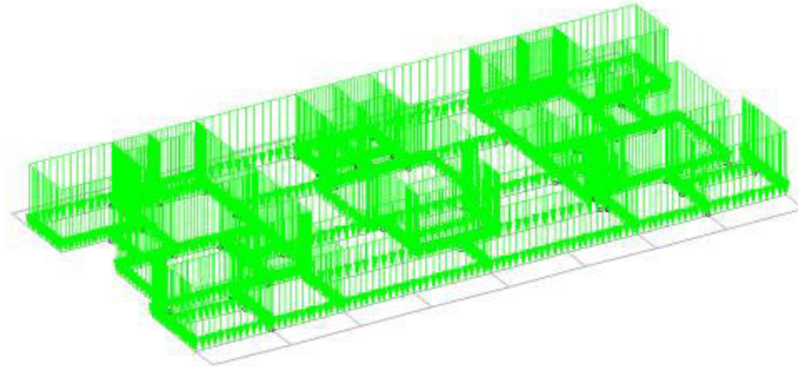
| Z in metre | Allotted No. |
|---|---|
| -1.2755 | 10 |
| -3.526 | 12 |
| -4.45 | 20 |
| -6.225 | 22 |
| -8.00 | 30 |
| -9.825 | 31 |
| -10.45 | 40 |
| -11.875 | 42 |
| -12.675 | 50 |
| -3.276 | 11 |
| -4.525 | 21 |
| -10.93745 | 41 |




**[Figure 5.2: Whole building with member properties applied to all the members]**

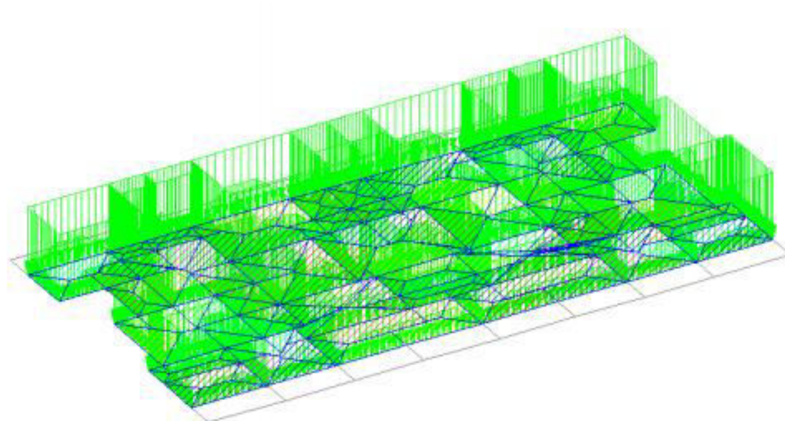
**5.3 LOADING**

• 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/m3 density =2.4*0.25*2=1.2 T per udl.



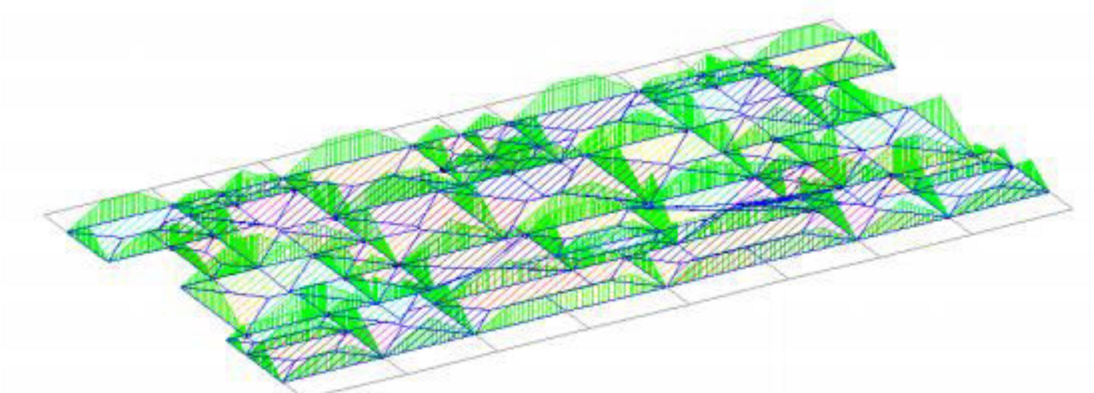
**[Figure 5.3: Showing application of brick load]**

• Floor load due to Slab: Considering 150 mm thickness of slabs and 2.5 T/m3 density of concrete =.15*2.5*1=0.375 T per m



**[Figure 5.4: 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/m2



**[Figure 5.5: 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 5.3: Seismic weight calculation**

| Weight Calculation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| sl no. | category | no. | length (m) | breadth (m) | height (m) | volume (m3) | density (T/m3) | 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 |
| | | | | | | | | |
| | | | | sesimic 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 5.4: 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 5.5: Distribution of base shear along vertical direction**

| | Calculation of Seismic force per storey in X direction | $V_b$ per storey |
|---|---|---|
| **Floor** | $W_i h_i^2$ | $W_i h_i^2 / \sum_1^n W_i h_i^2$ $(in\ Tonnes)$ |
| **1st** | 13401.8 | 18.87 |
| **2nd** | 30154.0 | 42.45 |
| **3rd** | 53607.0 | 75.47 |
| **4th** | 83761.0 | 117.93 |
| **Roof** | 72090.0 | 101.50 |

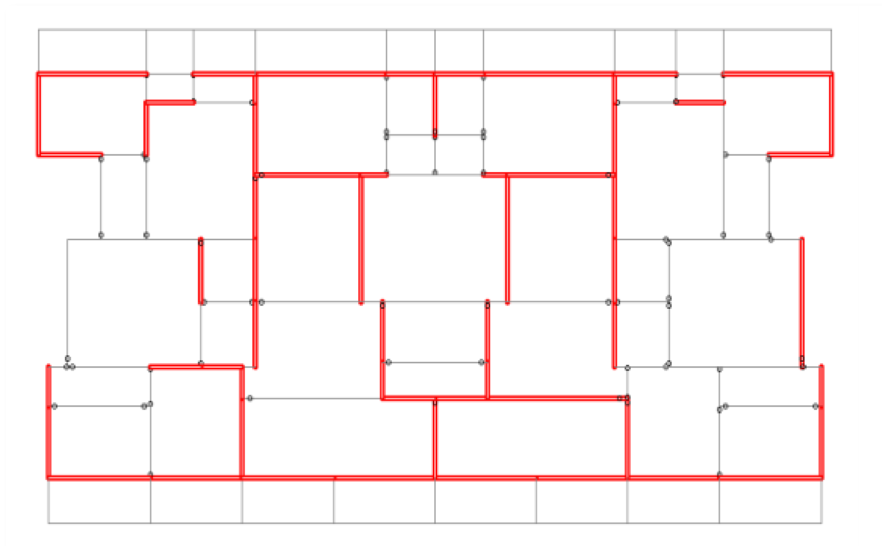
**Table 5.6: Distribution of base shear per node in X and Z directions for each floor**

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

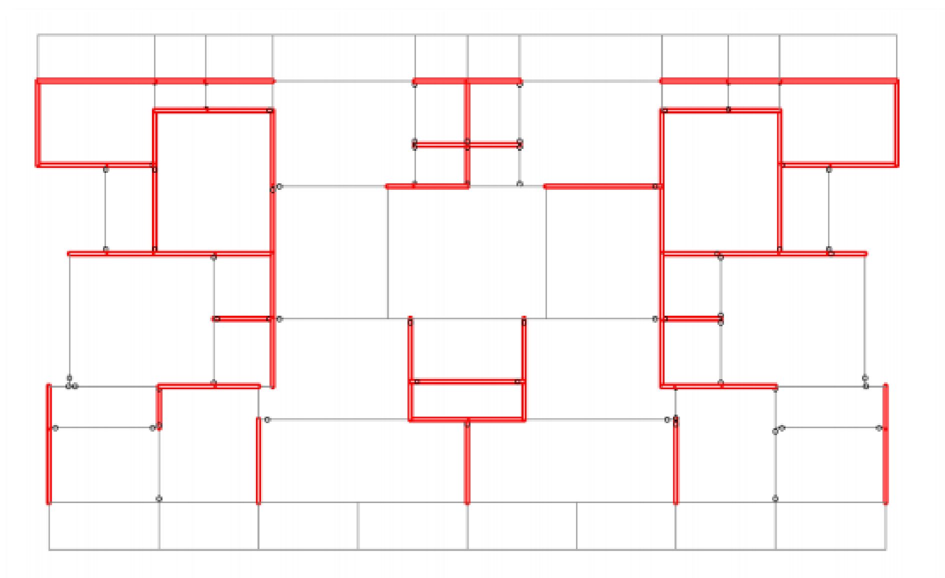
- **Load combinations applied**

**Table 5.7: 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** |

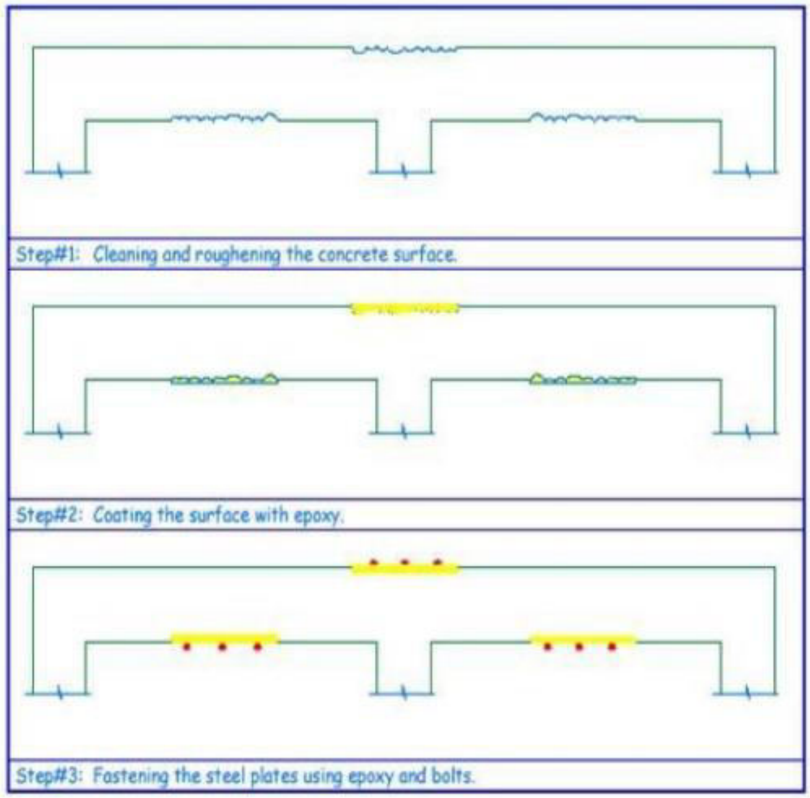


**[Figure 5.6: Beams failing under flexure]**

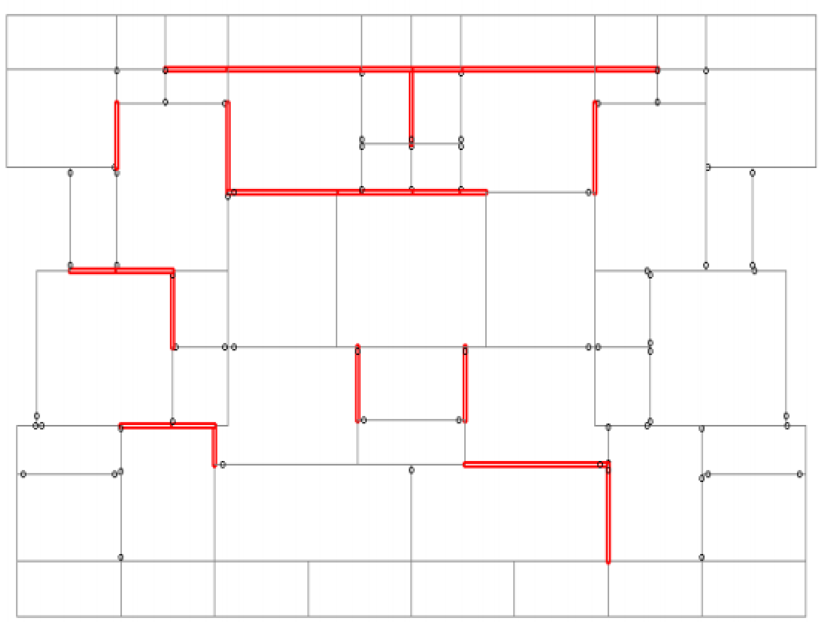


**[Figure 5.7: Beams failing under shear]**

## IV. RESULTS




**[Figure 6.2: Showing steps of steel plating]**



**[Figure 6.3: showing beams of 1st floor eligible for steel plating]**

## CONCLUSION

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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