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Seismic Retrofitting of Historic Masonry Buildings – Case Study

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Abstract Masonry heritage building built during early part of 19th century have characteristic colonial architecture using masonry walls and jack arch roofing supported on steel beams. They are highly vulnerable to failure during earthquakes. This paper describes a methodology to quantify their vulnerability and then based on this a scheme of structural retrofitting is suggested. The aim of this presentation, through 4 case studies of buildings located in Delhi, India, is to exemplify various aspects of analysis, design and execution methodology of the retrofitting scheme for such important heritage structures. The assessment of vulnerability is based on its location, codes of practice with respect to materials and loading. The main challenge in choosing the appropriate retrofitting scheme lies in retaining the architecture and aesthetics. Also the retrofitting has to be completed in the least possible time causing minimum disturbance to the occupants. This has been achieved through a combination of Ferro-cement bands and FRP sheets. The execution of retrofitting was considered to make use of available local materials and expertise. The building is analysed in detail and the areas where stress concentration takes place is further strengthened.

Keywords: Retrofitting, load-bearing masonry, ferro-cement, ferrocement bands, carbon fibre sheet, brick, burnt clay brick, lime concrete, wire-mesh

Introduction

During 1920's, when Britishers were ruling India, several bungalow type residential buildings were built in Delhi. These 'Lutyens Bungalow Zone' (LBZ) bungalows includes the '1, K.Kamaraj Lane', '12, Teen Murthi Marg', '14, Ashok Road' and '9, Janpath Road'. They are used to accommodate members of the parliament or senior government officials and their families. The buildings are load-bearing masonry structures with roof made of lime concrete and steel joists. At present these buildings are treated as having historic value. In a typical LBZ building there are number of walls in both X & Y direction making the structure act like a box under lateral load. The walls parallel to lateral load act as web and that perpendicular act as flanges. The resistance of the box is much higher than resistance of individual wall. The box action in walls results from interaction between web and flanges. T and L junction becomes effective zones and their satisfactory functioning is responsible for developing this interaction. The detail for the Kamaraj Lane building is presented here.

Description of the Historic LBZ Bungalow

The approximate plan size of the building is (21.4 X 18.1m). The building is a (unreinforced) load bearing masonry structure. The walls are made of unreinforced burnt-clay brick masonry. The thickness of the wall of the main portion of the building was 450 mm and for a few peripheral walls the thickness was 290 mm. There are no visible cracks in the wall or roof. The brick or the mortars are not deteriorated. The roof was made of lime concrete and was in the form of jack arches in between steel joists. The spaces above the arches are filled to have a flat roof top. The plan, front elevation and photographs of the building is shown in Figs. 1, 2 and 3.

Structural Model

The computer model of the building consists of wall and slab segments created using the plate elements in the structural analysis program STAAD Pro 2006. Brick properties were assigned to wall elements with 290 mm thickness for the outer walls, 450 mm thickness for the inner walls and 650mm at the fire place. Similarly lime concrete properties were assigned for the slab elements with thickness 150 mm for all slabs. The parapet wall also has brick property and is 290 mm thick. The building rests on continuous wall foundation and is assumed to be hinged at the base at the plinth level in the analysis model.

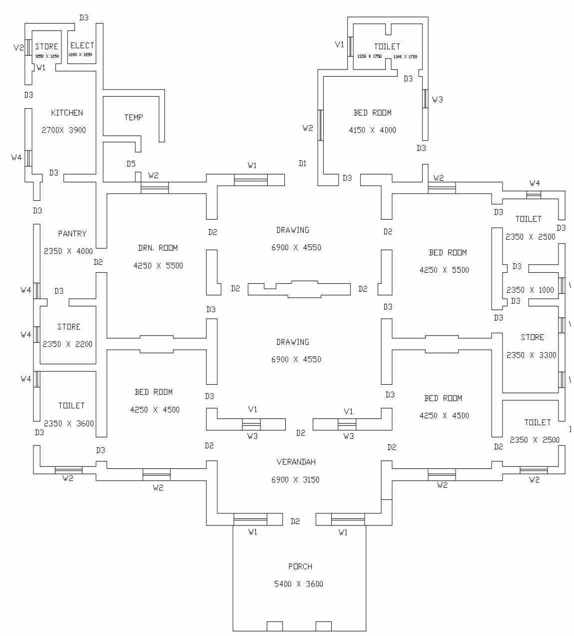

Figure 1: Typical Plan of Building

Figure 2: Front Elevation of Building

Figure 3: Photography of Front Elevation of Building

The structural model of the building with seismic loading in X&Z directions is shown in Fig. 4.

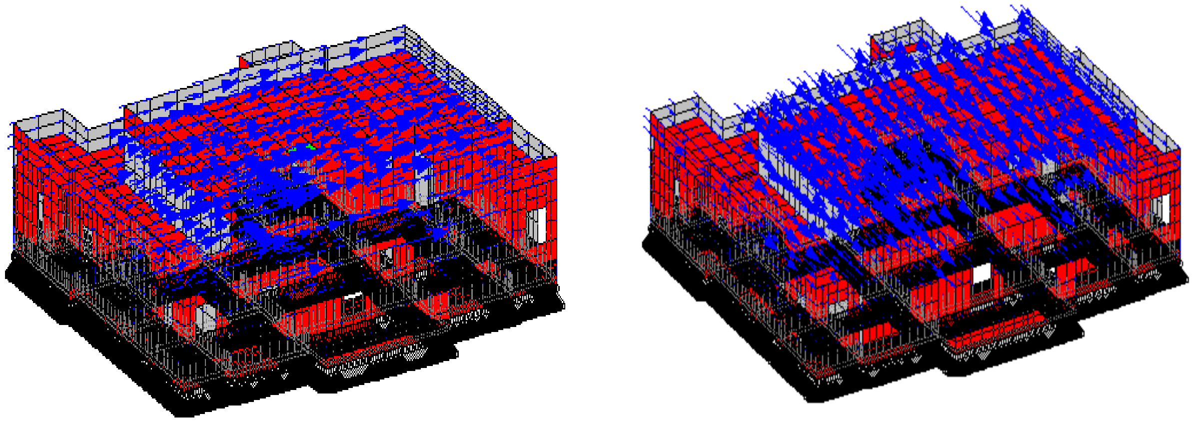

Figure 4: Structural model of building with seismic load in X and Z directions

Computer Method of Analysis

Equivalent static (linear elastic) method of analysis is used. In the equivalent static analysis, the essential provisions in IS 1893: 2002, "Criteria for earthquake resistant design of structures", is considered. In static analysis, the vibration, mode shapes or the time-wise variation of the quantities are not considered. Because of the difficulties and uncertainties in a non-linear dynamic analysis, this is not used in the current design. Table 1 shows the parameters used in the analysis.

Table 5: Parameter used for Seismic Analysis

No.	*Parameter*	*Values*
1	Zone Factor	0.24
2	Importance Factor	1.5
3	Response Reduction factor	1.5
4	Fundamental Natural Period	0.1 sec
5	Rock and Soil Site Factor	2
6	Damping ratio	5%
7	Type of structure	3
8	Depth of foundation	1m below Ground Level

Results of Analysis

Maximum Compressive stress in Brick Element = 0.385 N/mm^2
Permissible Compressive stress in Brick Element = 0.75 N/mm^2
Maximum Tensile stress in Brick Element = 0.133 N/mm^2
Permissible Tensile stress in Brick Element = 0.0 N/mm^2

It can be seen that the compressive stress in the brick elements is within the permissible compressive stress. But the tensile stress in brick masonry exceeds the permissible limit. It was concluded that the structure is unsafe under earthquake loading and the structure will be subjected to a large amount of cracks (which may be beyond repair) in the event of an earthquake.

Retrofitting Scheme

In order to increase the permissible tensile stress of the walls, it is proposed to retrofit the walls of the masonry building utilizing the concept of applying Ferro-cement bands. Ferro-cement band is a concrete element made of concrete mortar and wire meshes. These bands are provided on the exterior

and interior surface of the building both in the vertical and horizontal directions (as per IS:13935-1993). The exterior and interior bands are connected at intervals with 8 mm tie rods. These bands are provided in the different levels of the building. They are described as follows.

Plinth band: The Ferro-cement bands (300mm wide and 50mm thick) are provided at the plinth level on both sides of the wall.

Sill band: The Ferro-cement bands (300m wide and 50mm thick) are provided at the sill level on both sides of the wall.

Lintel band: The Ferro-cement bands (300m wide and 50mm thick) are provided at the lintel level on both sides of the wall.

Roof band: The Ferro-cement bands (200m wide and 50mm) thick are provided at the roof level on both sides of the wall. The roof band are folded and connected to the Steel I section at the roof level.

At openings: At the openings like door, windows and ventilator, vertical bands (300mm wide and 50mm thick) are provided on both sides of the wall till the roof slab. They are inter-connected with the horizontal bands.

At L joints: At the L joints vertical bands are provided on both the intersecting walls (without any discontinuity at the junction) with ferro-cement, 300mm wide and 50mm thick. The bands are provided on both sides of the wall.

At T joints: At the T joints vertical bands are provided similar to L joints meeting together with 300mm wide and 50mm thick ferro-cement bands. The bands are provided on both sides of the wall.

The details of the retrofitted building plan and elevation of the building are shown in Fi. 5.

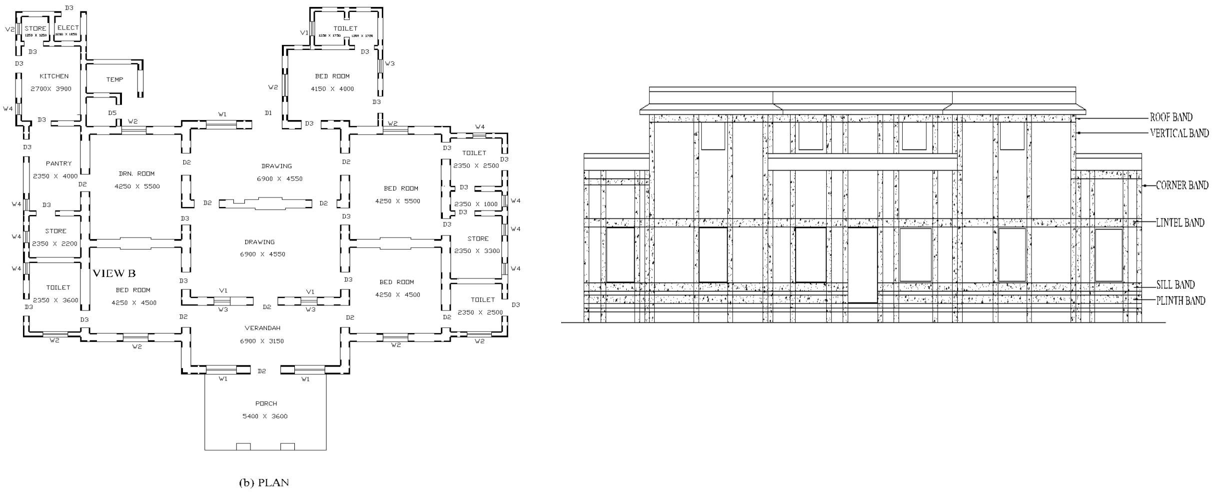

Figure 5: Plan and Front Elevation of Retrofitted building

Computer Model Incorporating Retrofitting Scheme

The plate elements that are retrofitted with the Ferro-cement bands are chosen and updated with the combined property of 'masonry with Ferro-cement'. The property for the Ferro-cement band for different thickness of wall is shown in Table 2.

Table 2: Properties of Ferrocement Band

No.	*Description*	*For 450 mm Wall*	*For 290 mm Wall*
1	Elastic Modulus kN/m^2	8684460	12229630
2	Poison ratio	0.17	0.17
3	Density kN/m^3	20.5	20.5
4	Thermal co-efficient	Thermal co-efficient	11X10^{-6}

Results of Computer Analysis of Retrofitted Model

The stress values of the computer analysis of the retrofitted model are shown Fig. 6. The stress obtained from the analysis is compared with permissible stress values.

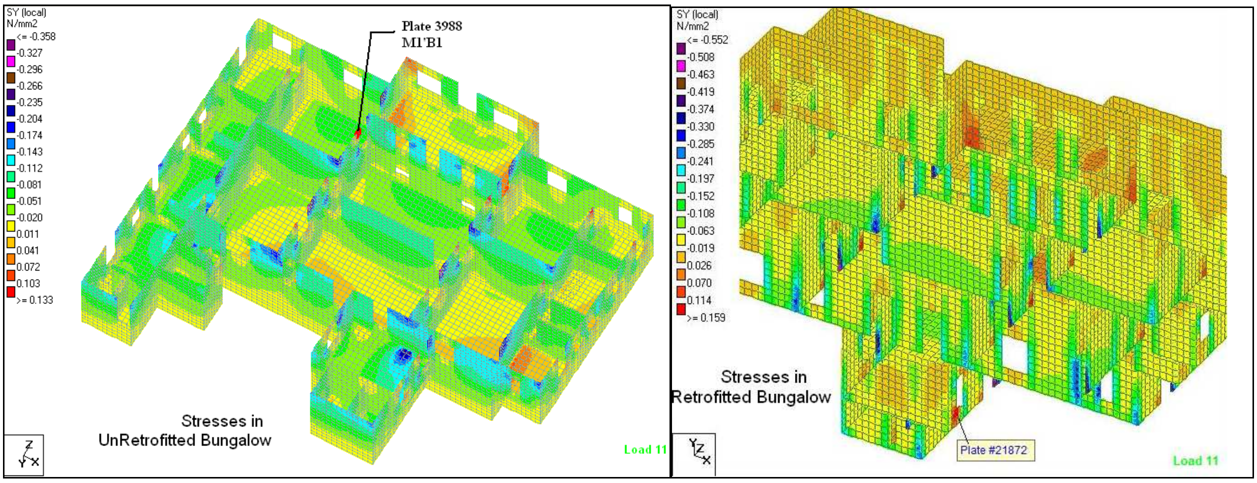

Figure 6: Stress Values at Critical locations

Maximum Compressive stress in Brick Element = 0.129 N/mm^2
Permissible Compressive stress in Brick Element = 0.75 N/mm^2
Maximum Tensile stress in Brick Element = 0.036 N/mm^2
Permissible Tensile stress in Brick Element = 0.0 N/mm^2
Maximum Compressive stress in Ferro-cement Element = 0.619 N/mm^2
Permissible Compressive stress in Ferro-cement Element = 2.87 N/mm^2
Maximum Tensile stress in Ferro-cement Element = 0.159 N/mm^2
Permissible Tensile stress in Ferro-cement Element = 1.124 N/mm^2

After retrofitting also, it was seen that there is tensile stress in a few brick elements. But this is very low (< 0.05 N/mm^2). Due to these tensile stress in brick masonry, only minor cracks will appear and the tensile stress is taken care of by the Ferro-cement bands.

Method and Sequence of Retrofitting

The method of constructing the Ferrocement band is given below:

1. *Chipping of the plaster and brick work*: Chip the plaster for 25mm thickness and brickwork 30mm thickness, amounting to a total thickness of 55mm from the building in all the vertical and horizontal banded areas.
2. *Providing the first coat of mortar on chipped area*: Provide the first coat of cement mortar in the ratio of 1:2 (water cement ratio of 0.4) on the chipped area for a thickness of 25mm.
3. *Providing chicken mesh on the first coat of mortar*: Provide a chicken mesh of 22 gauge on the first coat.
4. *Providing wire mesh on the chicken mesh*: The next step is providing wire mesh of 4mm diameter at 25 mm x 25 mm spacing (or equivalent). The wire meshes are attached to the brick walls with steel pins.
5. *Providing the second coat of mortar on the wire mesh*: Second coat of mortar of same mix over the wire mesh of thickness 25mm is provided.
6. *Providing the third coat of mortar*: 5 mm fine plaster is provided over the Ferrocement band.

The retrofitting is done room by room. It must be ensured that there's sufficient overlapping of meshes where construction joints are created. The overlapping of meshes must be for 450mm length. Also lapping of meshes is avoided at corners and joints.

Conclusion

The procedure described shows how the building can be made safe against earthquake by retrofitting. Retrofitting brings down the stresses to permissible levels, thus enhancing safety. Even after the retrofitting is complete, the original look and feel of the building is retained. Also the strengthening of some beams/slabs was done using Carbon fibre sheet and the overhead tank was strengthened using steel plates. The method used is economic and also recommended by standards.

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