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Estimating Performance Point of Existing Masonry Buildings and Study on their Improvement using Retrofitting Method

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Abstract- The masonry construction have many advantages like easy availability in many forms, colors and textures, comparative cheapness, thermal and sound insulation, fire resistance, durability, etc. So the masonry construction is still adopted as a most common construction technique in rural and even in urban areas. Unfortunately, due to its complex material nature the behavior of masonry is still not identified clearly under the effect of seismic action. Hence, the masonry buildings with structural deficiencies seems to be a most sensitive class of structures which have experienced heavy damage or even total collapse in previous seismic actions, especially in developing countries like India. This demands modern methods for designing safer masonry structures and judging their performance. Considering all these facts, this study aims at modeling and analyzing the performing seismic analysis of unreinforced brick masonry structures and their improvisation using different retrofitting techniques. For this, a macro level modeling is preferred. Macro modeling proposed by MIDAS GEN is finding appropriate for this project work.

1. INTRODUCTION

Masonry is one of the ancient known building materials which is still in use for the construction of modern building systems. Since the beginning of modern civilization, masonry structures have been built not only for homes but also for aesthetic churches and arenas. Stone was the primary masonry unit and was used for basic structures. The Stonehenge ring on England's Salisbury Plains is an example of ancient structures composed of masonry which is 4000 years old. The Great Wall of China, the Egyptian pyramids in Giza, the pyramids of Yucatan and Teotihuacan in Mexico, the stone walls at Machu Pichu, The Taj Mahal are another well-known examples for masonry over the centuries. In the United States, masonry has been used as one of the primary building materials for construction since the 18th century. It is a well proven building material possessing excellent properties not only in terms of appearance, durability, thermal and acoustic insulation as well as fire and weather protection but also provision of subdivision of space and cost in comparison with alternatives. In spite of all these advantages, masonry is a complex composite material and its mechanical behavior, which is influenced by a large number of factors, is not generally well understood. In addition to these, the design and construction of unreinforced masonry buildings are carried out without using any scientific methods and engineering tools. It is completely on a traditional manner based on experience. That is why a significant percentage of physical losses in past earthquakes were due to insufficient performance of non-engineered masonry buildings with low construction quality.

Since masonry construction is a traditional, widely used, extremely flexible and economical construction method, it has considerable potential for future developments. However, possibly due to the substantial empirical knowledge collected over several centuries of utilization of masonry as a structural material, the need for establishing a more modern basis for the design of masonry structures has not been developed in the same manner as for concrete structures. Most of those older masonry buildings are designed primarily to resist gravity loads only since the provision for earthquake loading codes were not developed at that time

Considerable attention to the means of evaluation and strengthening of the all older masonry buildings that exists in seismic prone area is necessary. Research in the field is essential to understand masonry behavior to develop innovative products, to define reliable approaches to measure the safety level and to design possible retrofitting measures.

Foti.D (2015) proposes the pushover analysis of masonry structures using the experimental values combined with an analogy of rock masses for mechanical characteristics of masonry and compared the results obtained with Italian codes. In this method, the mortar joints are considered to be similar to the discontinuities found in a rock mass. The strength criterion used is the Mohr-Coulomb failure criteria. It establishes a linear relationship between shear strength obtained on a sliding plane and normal stress acting on the plane according to characteristics of the material.[1]

D.N. Shinde, Nair Veena V and Pudale Yojana M (2014) study a building frame is designed as per Indian standard i.e. IS 456:2000 and IS 1893:2002 and check the kind of performance a building can give when designed as per Indian Standard. For this pushover analysis of the building frame is carried out. Building designed with IS 1893:2002 found to have a better performance under given earthquake. After performing the analysis the base shear at performance point is found to be greater than design base shear.[2]

Park.J et al. (2011) presents a macro element for unreinforced masonry shear walls developed to allow for the seismic design of masonry structures under consideration of the wall-slab interaction effect. The proposed macro element basically consists of three rigid beams. One vertical beam is placed between two horizontal ones. The beams are jointed rigidly at mid span of the horizontal beams. The length of vertical beam corresponds to the wall height, the length of horizontal beams to the wall length. The horizontal beams at top and bottom of the element are connected to the support though non-linear springs.[3]

Milani,G et al.(2009) conducted a pushover analysis by a equivalent frame model. He discover the strength of spandrel beam more precisely. This was done by two stages. The first step is done at meso level; the spandrels are extracted from the whole structure and their strength in terms of ultimate bending moment and shear forces are determined by means of an upper bond finite element heterogeneous approach. The obtained strength characteristics are stored in database. In the second stage, considering at a macro level, a frame model of the masonry wall is built. In this model, spandrels and piers are modeled as elastic Timoshenko beam elements. The strength of the spandrels is defined by the strength domains stored in the database.[3]

Retrofitting denotes the addition of new technology or features to existing systems. Seismic retrofitting is the alteration of existing structures to make them more seismic resistant. From the past experience of seismic action on structures, the importance of retrofitting is very much acknowledged. Retrofitting reduces the severity of damage of an existing structure during a future earthquake

A large number of masonry constructions, mostly concentrated in the core of important cities. However the researches performed for the behavior of constructions against the effect of earthquakes are focused on reinforced and steel constructions. As a result the project engineer has inadequate information about the behavior of masonry construction against earthquake. It is very difficult to define the mechanical characteristics in order to assure the reliability and stability of the masonry building due to the heterogeneity of various components in the structure. This work will make a contribution to the seismic vulnerability assessment of masonry buildings by assessing the existing models and checks how the retrofitting improves seismic resistance of buildings

2. EARTHQUAKE AND STRUCTURAL BEHAVIOR OF BUILDING

2.1. *Earthquake*

Ground motion, which is generated by sudden displacements within the earth’s crust is called an earthquake. Earthquakes are caused by natural phenomena, such as tectonic processes, volcanic eruptions etc. The seismic waves generated in the focus, propagate through different layers of rock and soil. Therefore the seismic waves reach the surface and induce vibration according to the characteristics of bedrock and soil on their way of propagation also.

Earthquake ground motion is a tridimensional phenomenon. For simplification of design, these seismic movements are subdivided into horizontal and vertical vibrations. The horizontal vibrations are much severe than vertical vibrations, so they are considered as main factor in designing earthquake resistant structures. Due to these ground vibrations inertial forces will be generated at areas of mass in the building. The path of these force will be through the roof and walls to the foundation. Proper care should be taken to ensure that the force is reaching foundation safely. The absence of structural integrity is major sources of weakness responsible for severe damage leading to collapse. Out of the three constituents of a masonry building (roof, wall and foundation) the walls are most susceptible to damage caused by horizontal forces due to earthquake. It is however not known which will be the main direction of ground motion during an expected seismic event. Therefore the resisting elements of each structure in a seismic zone should be designed to resist the seismic excitation in both principle direction of the building. Symmetric distribution of resisting elements in the plan of the building will prevent possible torsional vibration, which often causes unexpected behavior of the structure when subjected to strong seismic ground motion. For the same reason the dimensions of setbacks and recesses should be limited.

2.2. *Structural behaviour*

Masonry building, when subjected to earthquake ground motion, inertia forces proportional to the mass of building develops, and produce acceleration, which cause the vibration of structural system. As a result of vibration, additional bending and shear stresses develop, which often exceed the strength of materials and cause damage to structural systems. Although masonry is strong in compression, the bending and shear stresses caused will result in severe damage or even collapse of building

Buildings suffered from earthquakes are generally observed cracks at corners and wall intersections; these are due to insufficient c are subjected to diagonal cracks. Structural walls which are perpendicular to seismic action are subjected to out of plane bending. This will cause vertical cracks at the corners and middle of the walls. In the inplane walls, bending and shear causes horizontal and diagonal cracks respectively. General earthquake damage observed can be summarized as follows

a. Cracks between wall and floors.
b. Cracks at the corners and at the wall intersections.
c. Out of plane collapse of walls.
d. Cracks in spandrel beams.
e. Diagonal cracks in structural walls.
f. Partial disintegration or collapse of structural walls

3. Modelling and analysis of the unreinforced masonry building

From the past experiences it is necessary that, the masonry building which are constructed in the traditional manner without formal design by a qualified engineer or architect has to be analysed properly and strengthened using a suitable retrofitting technique. For this study, some existing masonry buildings are selected. These structures are failure obtained buildings on seismic action. They are existing on the seismic area, zone III and soil type 2. They are located in the Trissur district. Trissur is the mostly affected seismic district in Kerala. Mainly diagonal type failures are identified in these buildings. So retrofitting of masonry buildings in these areas is necessary. Study on the performance point of three building plans from the above mentioned area using pushover analysis and their improvement when retrofitted using steel strips is discussed in this paper.

3.1. *Retrofitting using steel plates*

The retrofit method suggested here consists of adding diagonal strips of steel on masonry walls. The diagonal steel strips that extend between the corners of the wall to strengthen it, while preventing diagonal tension failure and compression crushing under shear forces. The minimal increase in wall thickness due to the steel plates makes this an interesting substitute for existing walls. Retrofit was accomplished by adding a 200 mm wide diagonal steel strips of 4mm thickness on wall face.

The steel strips can be fasten on the wall using one layer of bolts at certain interval. But the connection using bolts will lead to a local failure at the junction of connections. So the number of connections has to be limited. When thickness and width of steel strips increase, its dead weight on walls increases and it will be difficult to fix the plate on walls using minimum number of bolts and single layer of bolts

3.2. *Material properties*

IS 1077:1992, IS 1905:2002, IS 2212:2005 specifies requirements of common burnt clay building bricks used in buildings. The standard modular size of common building bricks considered is 190mm x 90mm x 90mm. IS 2250:1990 specifies mortars specifications using for masonry construction. Since the project work is based on locations of Kerala, the properties of brick and mortar tested at Kollam is used for this project.

Table 1. Material properties.

properties	**Brick**	**Mortar (1:6)**
Young's Modulus(MPa)	166.7	2000
Compressive strength (MPa)	3.5	2.5
Tensile strength(MPa)	0.75	0.32(Bed joint) 1.15(Head joint)

Poisson's ratio	0.21	0.12
Mass density(kg/m3)	1650	2049

3.3. *Seismic quantities*

For the seismic analysis, response spectrum method of analysis is adopted here. Various input requirements for the analysis is as per IS 1893:2002. Seismic zone of Kerala is under Zone III, and a medium type soil is selected. Other input data's are as follows.
Importance factor: 1.0
Percentage damping: 5
Response reduction factor: 1.5

3.4. *Model 1*

The plan of the building is shown below

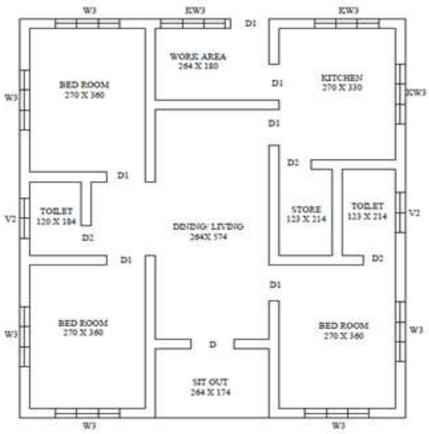

Fig. 1. Model-1 Plan

The modelled view is

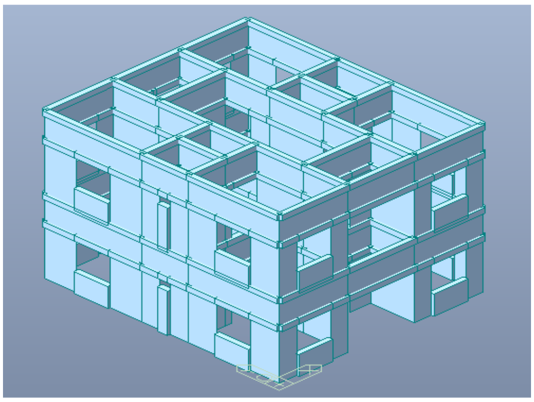

Fig. 2. Model-1 Model view

The pushover curve obtained is

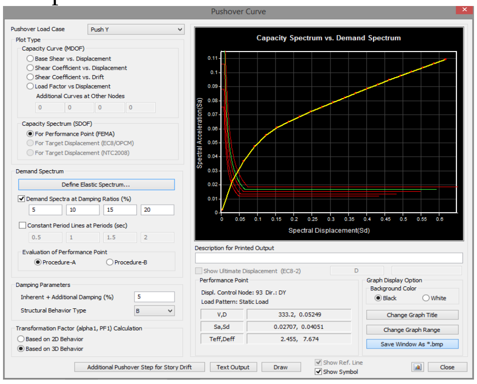

Fig. 3. Model-1 Pushover result

The maximum base shear capacity obtained after analysing is 333.2 KN

3.4.1 Retrofitted using shotcrete

The modelled view after retrofitting is

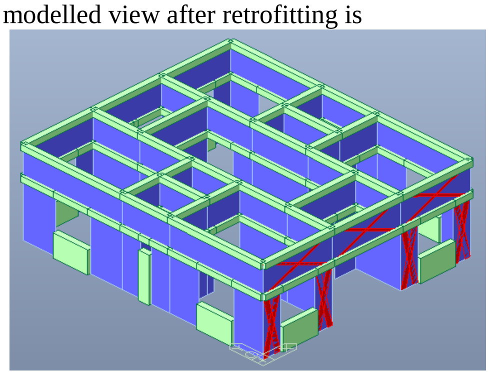

Fig. 4. Model-1 view after adding steel strips

The pushover curve obtained after retrofitting is

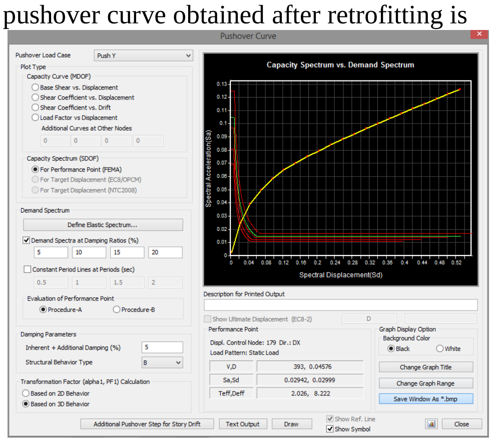

Fig. 5. Model-1 Pushover result after adding steel strips

The performance point of the building is found as increasing after analysing the retrofitted structure with steel strips and the base shear capacity obtained is 393 KN. It shows 18.08% increase in base shear capacity.

3.5. *Model-2*

The plan of the model-2 is shown below

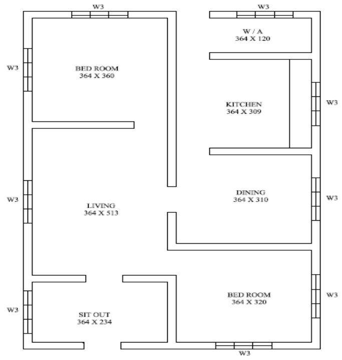

Fig. 6. Model-2 Plan

The modelled view is

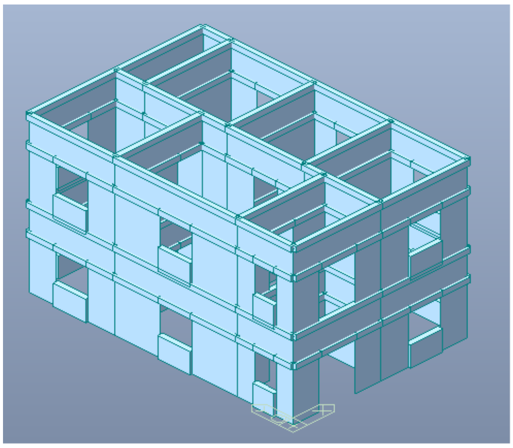

Fig. 7. Model-2 Model

The pushover curve obtained is

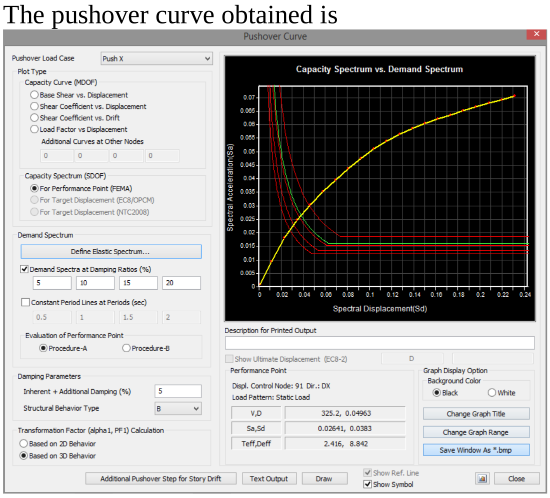

Fig. 8. Model-2 Pushover result

The base shear capacity obtained after analysing is 325.2 KN.

3.5.1 Retrofitted using steel strips

The modelled view after retrofitting is

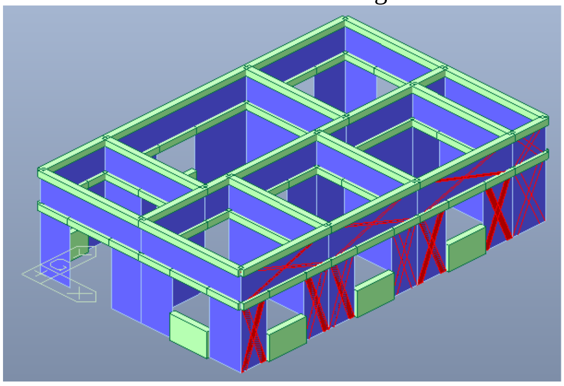

Fig. 9. Model-2 view after adding steel strips

The pushover curve obtained after retrofitting is

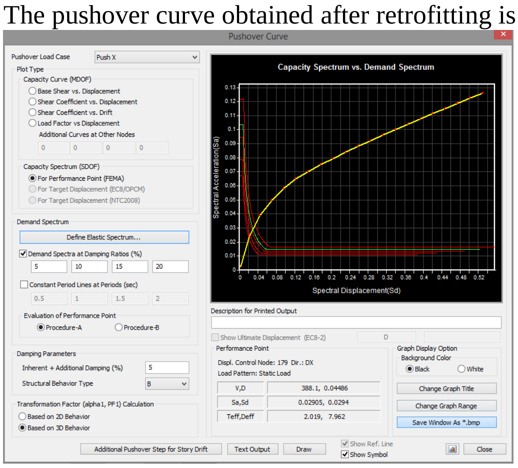

Fig. 10. Model-2 Pushover result after adding steel strips

The performance point of the building is found as increasing after analysing the retrofitted structure with steel strips and the base shear capacity obtained is 388.1 KN. It shows 19.31% increase in base shear capacity.

3.6. *Model -3*

The plan of the model-3 is shown below

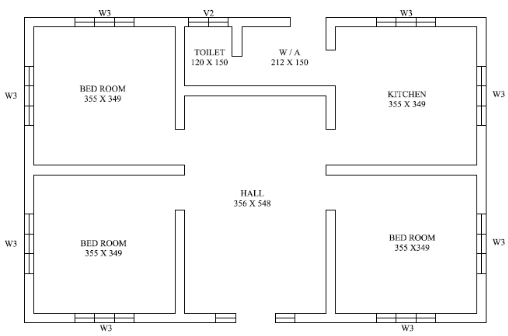

Fig. 11. Model-3 Plan

The modelled view is

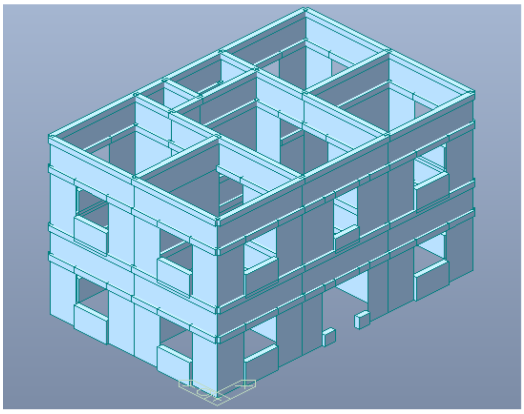

Fig. 12. Model-3 Model view

The pushover curve obtained is

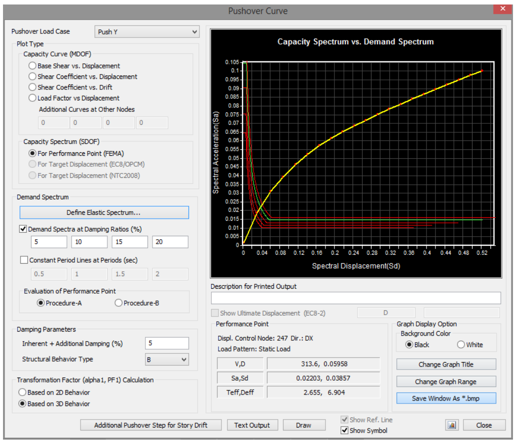

Fig. 13. Model-2 Pushover result

The base shear capacity obtained after analysing is 313.6 KN.

3.6.1 Retrofitted using steel strips

The modelled view after retrofitting is

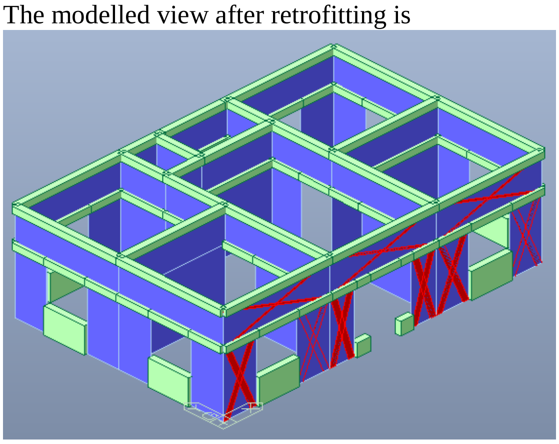

Fig. 14. Model-3 View after adding steel strips

The pushover curve obtained after retrofitting is

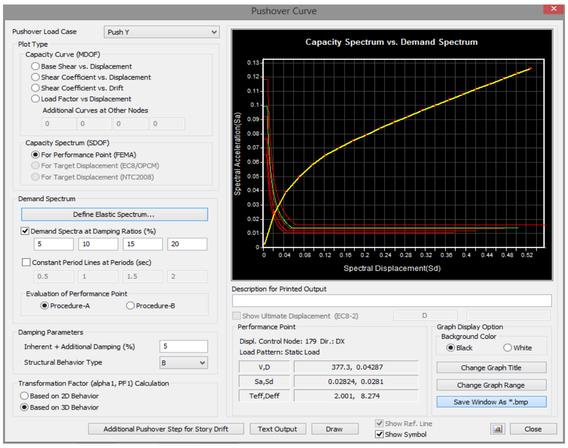

Fig. 15. Model-3 Pushover result after adding steel strips

The performance point of the building is found as increasing after analysing the retrofitted structure with steel strips and the base shear capacity obtained is 377.3 KN. It shows 20.31% increase in base shear capacity

4. RESULT

The results obtained from the analysis is tabulated below

Table 2: Results

Model	Base shear capacity	Base shear capacity (After adding steel strips)	Percentage increase in Base shear capacity (After adding steel strips)
Model-1	333.2 KN	393 KN	18.08 %
Model-2	325.2 KN	388.1 KN	19.31 %
Model-3	313.6 KN	377.3 KN	20.31 %

5. CONCLUSION

The points can be concluded from this work are

- The performance point can be considered as an effective tool for defining the behaviour structure.
- Addition of steel strips can be used as a best retrofitting techniques for existing masonry buildings.
- Addition of steel strips also increase the base shear capacity about 18 to 21%.
- When steel is used as a retrofitting method, there will be chance of local failure at the junctions of fastening. So at-most care should be given at the time fastening using nuts and the number of connections should be minimum.

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