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Seismic Performance Analysis of Unreinforced Masonry Wall Structure

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Abstract: *From the previous earthquake (Nepal 2015, Bhuj2001,Utharakhand 2005, Gujarat 2006) it is observed that the seismic performance of masonry building is worst. Hence there is a need of retrofitting of existing masonry buildings. The above need is incomplete without seismic performance of masonry buildings. Before retrofitting of building the first step is to obtain its performance. In the present work it is proposed to obtain the seismic performance of unreinforced masonry wall using non-linear static analysis with SAP2000 software. The present work investigates the seismic evaluation of unreinforced masonry (URM) walls when subjected to seismic (lateral) loading. The work consists of modelling the geometry and property of masonry wall. After which non-linear analysis was performed using SAP 2000 software. The present work is divided in to two parts.(a) Revealing the size of finite element meshing suitable for modelling an unreinforced masonry wall in SAP 2000 software.(b) Investigating the result of nonlinear static analysis performed on selected model.*

Keyword- *Masonry building, Finite element method, Non-linear static analysis, pushover analysis, SAP2000.*

I. INRODUCTION

Till the early twentieth century, most buildings were masonry constructions. Gradually, reinforced concrete and steel constructions became popular because of their inherent advantage. However, since it is economical, good for insulation, has a good finishing, and is easy to procure, masonry is still in use in most countries. Primarily, it is used in walls for buildings. It is also used as infill panels, partitions etc. in framed buildings, where it is subjected to forces from the displacement of the frame and inertia forces. In such situations, the designer must be concerned by the interaction between the masonry and the frame, which may modify the frame's response and the forces operating on it.

Masonry covers a very wide range of materials, such as bricks, stones, blocks etc. jointed with different types of mortars such as lime mortar, cement mortar etc. that exhibit different mechanical properties. Masonry may be used with or without reinforcement; the latter is not suitable for use in seismic areas. Reinforced masonry may be used as a primary structural system and can be designed to resist earthquake forces. In many countries, most masonry, as well as wooden buildings, is constructed in the traditional manner with little or no intervention by qualified engineers and architects.

Such buildings are constructed spontaneously and informally without any due regard to the stability of the system under horizontal seismic forces and are called non-engineered buildings.

Due to poor performance of some forms of masonry in earthquakes, the official attitude towards masonry is generally cautions in most moderate or strong motion seismic areas. Also there is a need to obtain the seismic performance of existing non-engineered or masonry buildings. Once the performance is obtained the retrofitting of existing masonry building can be done. The present work suggests the size of finite element meshing suitable for performing a pushover analysis of masonry building. Finally the pushover analysis is performed on masonry wall to obtain its performance.
The above need is incomplete without seismic performance of masonry buildings. In the present work the work done by Sharme & Khare (2016) is studied and matched. Further the same procedure is performed for 50KN load and results are calculated. In order to avoid the collapse of masonry buildings due to earthquake retrofitting of the existing masonry building is required. Before retrofitting of building the first step is to obtain its performance. In the present work it is proposed to obtain the seismic performance of unreinforced masonry wall using non-linear static analysis with SAP2000 software. The present work investigates the seismic evaluation of unreinforced masonry (URM) walls when subjected to seismic (lateral) loading. The work consists of modelling the geometry and property of masonry wall. After which non-linear analysis was performed using SAP 2000 software. The present work is divided in to two parts. (1) Revealing the size of finite element meshing suitable for modelling an unreinforced masonry wall in SAP 2000 software. (2) Investigating the result of nonlinear static analysis performed on selected model.

II. SELECTION OF MASONRY MODEL

2.1 Material Modeling of Masonry Wall

A homogeneous modeling approach is applied. In the homogeneous modeling approach the test results and analytical curve suggested by Kaushik et al. are adopted. The details are given in section III.

2.2 GEOMETRIC MODELING OF MASONRY WALL

In the present study a 3m×3m free standing wall fixed at its end is considered. The thickness of wall is 200mm. A vertical working load of 20KN/m is considered on the wall. The wall is designed manually for the above load. All the stresses (tensile and shear) are found within the permissible limit as per IS1905:1987. In the present work the same model taken by sharma and khare (2016) is considered for analysis.

2.3 Modeling in SAP 2000 Software

In order to model the wall in SAP2000 shell area element is adopted. In SAP 2000 the shell element is a three or four node formulation that combines separate membrane and plate-bending behavior. The shell element can be of two types homogenous and shell layered. In the present study the layered shell area element is considered in order to obtain full shell behavior.

2.4 Nonlinear Static Analysis of Masonry Wall

Masonry 1 and Masonry 2 are weaker masonry mortar properties as given by Kaushik et al. (2007) is considered for analysis.

In case of masonry 1 non-linear stress strain properties are considered as $0.25f'_m$ as per IS 1905:1987.

In masonry 2 nonlinear stress strain properties are considered as $0.33f'_m$ as per ACI 530-02.

Table 1. Parameters considered for masonry 1 and masonry 2

Parameters	Masonry 1	Masonry 2
Prism strength (f'_m)	1025 KN/m^2	1353 KN/m^2
Modulus of elasticity	563750 KN/m^2	744150 KN/m^2
Poisson's ratio	0.16	0.16
Coefficient of expansion	5.5×10^{-6}	5.5×10^{-6}
Modulus of rigidity(G)	242995.69 KN/m^2	320754.31KN/m^2
Weight per unit volume	20 KN/m^2	20 KN/m^2
Density(p)	2.038	2.038

Masonry 3 and Masonry 4 are intermediate masonry mortar properties as given by Kaushik et al. (2007) is considered for analysis.

In case of masonry 3 nonlinear stress strain properties are considered as $0.25f'_m$ as per IS 1905:1987.

In masonry 4 nonlinear stress strain properties are considered as $0.33f'_m$ as per ACI 530-02.

Table 2. Parameters considered for masonry 3 and masonry 4

Parameters	Masonry 3	Masonry 4
Prism strength (f'_m)	1650 KN/m^2	2178 KN/m^2
Modulus of elasticity	907500KN/m^2	1197900KN/m^2
Poisson's ratio	0.16	0.16
Coefficient of expansion	5.5×10^{-6}	5.5×10^{-6}
Modulus of rigidity(G)	391163.79KN/m^2	516336.206KN/m^2
Weight per unit volume	20 KN/m^2	20 KN/m^2
Density(p)	2.038	2.038

Masonry 5 and Masonry 6 are stronger masonry mortar properties as given by Kaushik et al. (2007) is considered for analysis.

In case of masonry 5 nonlinear stress strain properties are considered as $0.25f'_m$ as per IS 1905:1987.

In masonry 6 nonlinear stress strain properties are considered as $0.33f'_m$ as per ACI 530-02.

Table 3. Parameters considered for masonry 5 and masonry 6

Parameters	Masonry 5	Masonry 6
Prism strength (f'$_m$)	1875 KN/m^2	2475 KN/m^2
Modulus of elasticity	1031250 KN/m^2	1361250 KN/m^2
Poisson's ratio	0.16	0.16
Coefficient of expansion	5.5×10^{-6}	5.5×10^{-6}
Modulus of rigidity(G)	444504 KN/m^2	586740 KN/m^2
Weight per unit volume	20 KN/m^2	20 KN/m^2
Density(p)	2.038	2.038

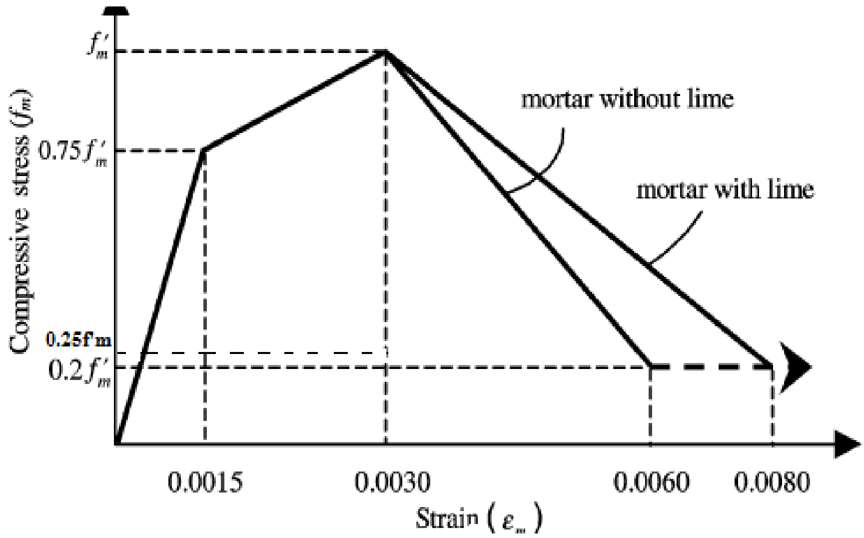

Figure 1 Stress-strain model taken up to0.25f'm as per IS 1905:1987.

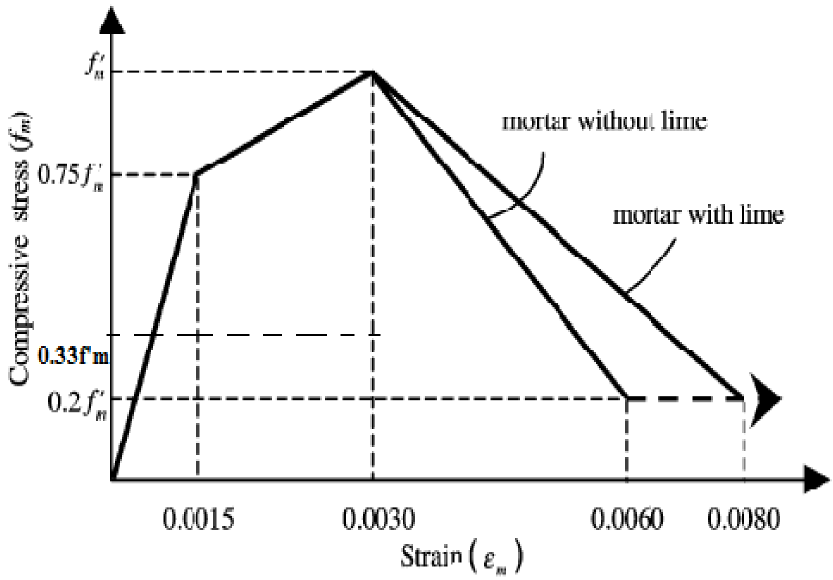

Figure 2 Stress–strain model taken up to 0.33f'm as per ACI 530-02

1.2 Modelling in SAP2000 Software

The present work uses both linear and non-linear shell element. The model is validated by increasing the mesh size from 1x1, 2x2, 4x4, 8x8, 12x12, 16x16, 20x20, 24x24, 28x28 and 32x32 respectively. While on the other hand a lateral force of 50KN is taken. The manually calculated deformations (displacements) are compared with the software results. The deformation values for different mesh size and lateral loadings are shown in Table 4 to Table 15. The various mesh size models considered for analysis are shown from Figure 9 to Figure 18.

Table 4. Shell layered linear displacement for a lateral load of 50KN for masonry 1

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 7.52E-04	
	Left hand node	Right hand node
Panel without meshing	5.81E-04	5.81E-04
2×2	6.83E-04	6.83E-04
4×4	7.61E-04	7.61E-04
8×8	7.89E-04	7.89E-04
12×12	7.94E-04	7.94E-04
16×16	7.95E-04	7.95E-04
20×20	7.96E-04	7.96E-04
24×24	7.96E-04	7.96E-04
28×28	7.96E-04	7.96E-04
32×32	7.96E-04	7.96E-04

Table 5. Shell layered non-linear displacement for a lateral load of 50KN for masonry 1

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 7.52E-04	
	Left hand node	Right hand node
Panel without meshing	1.13E-03	1.13E-03
2×2	1.28E-03	1.28E-03
4×4	1.43E-03	1.43E-03
8×8	1.48E-03	1.48E-03
12×12	1.49E-03	1.49E-03
16×16	1.50E-03	1.50E-03
20×20	1.50E-03	1.50E-03
24×24	1.50E-03	1.50E-03
28×28	1.50E-03	1.50E-03
32×32	1.50E-03	1.50E-03

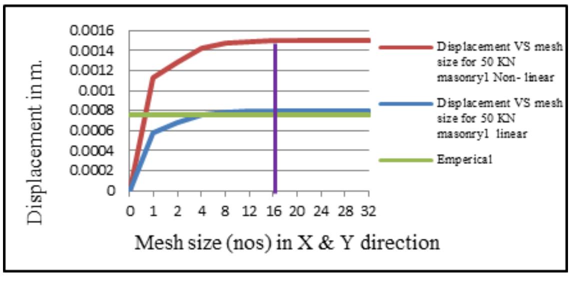

Figure 3. Graph representing mesh size vs. displacement.

Table 6. Shell layered linear displacement for a lateral load of 50KN for masonry 2

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 7.52E-04	
	Left hand node	Right hand node
Panel without meshing	5.81E-04	5.81E-04
2×2	6.83E-04	6.83E-04
4×4	7.61E-04	7.61E-04
8×8	7.89E-04	7.89E-04
12×12	7.94E-04	7.94E-04
16×16	7.95E-04	7.95E-04
20×20	7.96E-04	7.96E-04
24×24	7.96E-04	7.96E-04
28×28	7.96E-04	7.96E-04
32×32	7.96E-04	7.96E-04

Table 7. Shell layered non-linear displacement for a lateral load of 50KN for masonry 2

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 7.52E-04	
	Left hand node	Right hand node
Panel without meshing	8.68E-04	8.68E-04
2×2	9.84E-04	9.84E-04
4×4	1.09E-03	1.09E-03
8×8	1.14E-03	1.14E-03
12×12	1.14E-03	1.14E-03
16×16	1.15E-03	1.15E-03
20×20	1.15E-03	1.15E-03
24×24	1.15E-03	1.15E-03
28×28	1.15E-03	1.15E-03
32×32	1.15E-03	1.15E-03

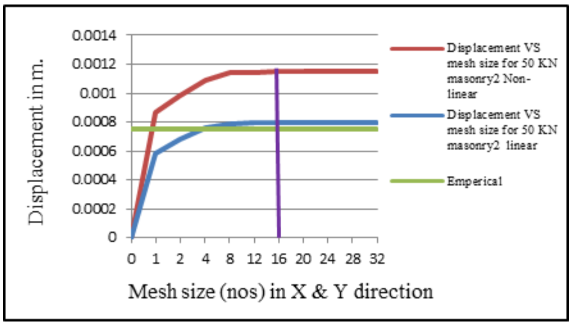

Figure 4. Graph representing mesh size vs. displacement

Table 8. Shell layered linear displacement for a lateral load of 50KN for masonry 3

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.67E-04	
	Left hand node	Right hand node
Panel without meshing	3.61E-04	3.61E-04
2×2	4.24E-04	4.24E-04
4×4	4.73E-04	4.73E-04
8×8	4.90E-04	4.90E-04
12×12	4.93E-04	4.93E-04
16×16	4.94E-04	4.94E-04
20×20	4.94E-04	4.94E-04
24×24	4.94E-04	4.94E-04
28×28	4.94E-04	4.94E-04
32×32	4.94E-04	4.94E-04

Table 9. Shell layered non-linear displacement for a lateral load of 50KN for masonry 3

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.67E-04	
	Left hand node	Right hand node
Panel without meshing	7.17E-04	7.17E-04
2×2	8.12E-04	8.12E-04
4×4	9.03E-04	9.03E-04
8×8	9.38E-04	9.38E-04
12×12	9.45E-04	9.45E-04
16×16	9.47E-04	9.47E-04
20×20	9.47E-04	9.47E-04
24×24	9.47E-04	9.47E-04
28×28	9.47E-04	9.47E-04
32×32	9.47E-04	9.47E-04

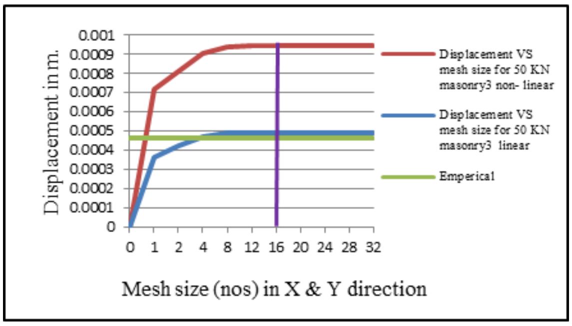

Figure 5. Graph representing mesh size vs. displacement.

Table 10. Shell layered linear displacement for a lateral load of 50KN for masonry 4

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.67E-04	
	Left hand node	Right hand node
Panel without meshing	3.61E-04	3.61E-04
2×2	4.24E-04	4.24E-04
4×4	4.73E-04	4.73E-04
8×8	4.90E-04	4.90E-04
12×12	4.93E-04	4.93E-04
16×16	4.94E-04	4.94E-04
20×20	4.94E-04	4.94E-04
24×24	4.94E-04	4.94E-04
28×28	4.94E-04	4.94E-04
32×32	4.94E-04	4.94E-04

Table 11. Shell layered non-linear displacement for a lateral load of 50KN for masonry 4

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.67E-04	
	Left hand node	Right hand node
Panel without meshing	5.48E-04	5.48E-04
2×2	6.20E-04	6.20E-04
4×4	6.89E-04	6.89E-04
8×8	7.21E-04	7.21E-04
12×12	7.22E-04	7.22E-04
16×16	7.23E-04	7.23E-04
20×20	7.23E-04	7.23E-04
24×24	7.23E-04	7.23E-04
28×28	7.23E-04	7.23E-04
32×32	7.23E-04	7.23E-04

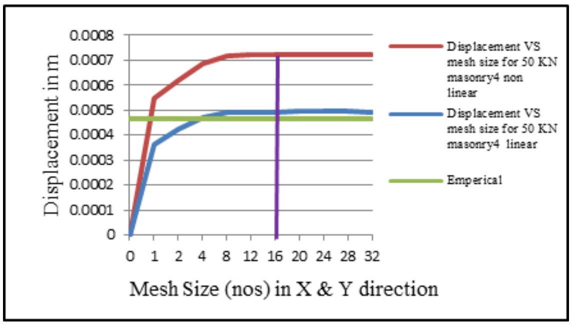

Figure 6. Graph representing mesh size vs. displacement

Table 12. Shell layered linear displacement for a lateral load of 50KN for masonry 5

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.11E-04	
	Left hand node	Right hand node
Panel without meshing	3.18E-04	3.18E-04
2×2	3.73E-04	3.73E-04
4×4	4.16E-04	4.16E-04
8×8	4.31E-04	4.31E-04
12×12	4.33E-04	4.33E-04
16×16	4.35E-04	4.35E-04
20×20	4.35E-04	4.35E-04
24×24	4.35E-04	4.35E-04
28×28	4.35E-04	4.35E-04
32×32	4.35E-04	4.35E-04

Table 13. Shell layered non-linear displacement for a lateral load of 50KN for masonry 5

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.11E-04	
	Left hand node	Right hand node
Panel without meshing	6.34E-04	6.34E-04
2×2	7.17E-04	7.17E-04
4×4	7.98E-04	7.98E-04
8×8	8.27E-04	8.27E-04
12×12	8.34E-04	8.34E-04
16×16	8.36E-04	8.36E-04
20×20	8.36E-04	8.36E-04
24×24	8.36E-04	8.36E-04
28×28	8.36E-04	8.36E-04
32×32	8.36E-04	8.36E-04

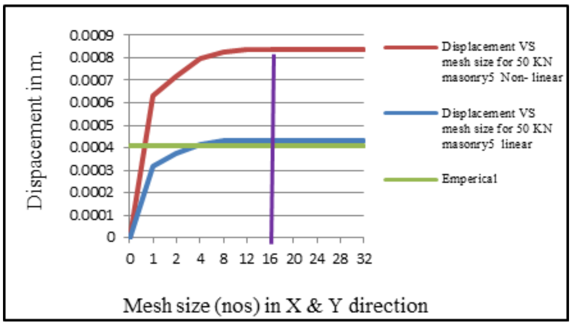

Figure 7. Graph representing mesh size vs. displacement

Table 14. Shell layered linear displacement for a lateral load of 50KN for masonry 6

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.11E-04	
	Left hand node	Right hand node
Panel without meshing	3.18E-04	3.18E-04
2×2	3.73E-04	3.73E-04
4×4	4.16E-04	4.16E-04
8×8	4.31E-04	4.31E-04
12×12	4.33E-04	4.33E-04
16×16	4.35E-04	4.35E-04
20×20	4.35E-04	4.35E-04
24×24	4.35E-04	4.35E-04
28×28	4.35E-04	4.35E-04
32×32	4.35E-04	4.35E-04

Table 15. Shell layered non-linear displacement for a lateral load of 50KN for masonry 6

Panel Type	Displacement (in m.)	
	Theoretical calculated displacement 4.11E-04	
	Left hand node	Right hand node
Panel without meshing	4.83E-04	4.83E-04
2×2	5.46E-04	5.46E-04
4×4	6.08E-04	6.08E-04
8×8	6.31E-04	6.31E-04
12×12	6.35E-04	6.35E-04
16×16	6.37E-04	6.37E-04
20×20	6.38E-04	6.38E-04
24×24	6.38E-04	6.38E-04
28×28	6.38E-04	6.38E-04
32×32	6.38E-04	6.38E-04

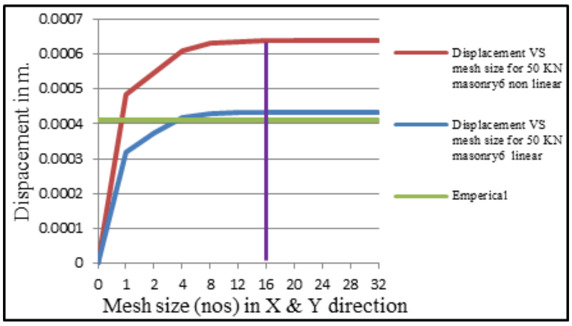

Figure 8. Graph representing mesh size vs. displacement

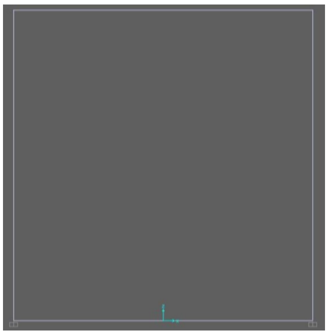

Figure 9. Modelling of masonry wall 1x1 mesh size (3m X 3m panel size)

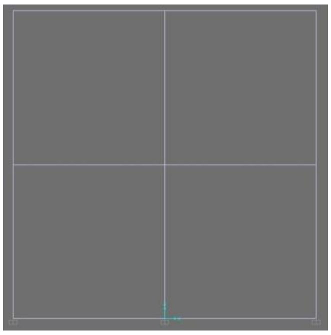

Figure 10. Modelling of masonry wall 2x2 mesh size (1.5m X 1.5m panel size)

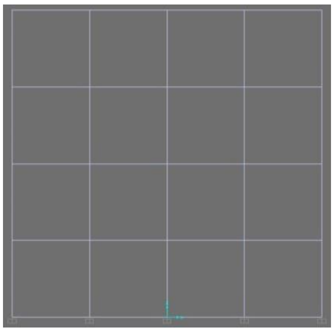

Figure 11. Modelling of masonry wall 4x4 mesh size (0.75m X 0.75m panel size)

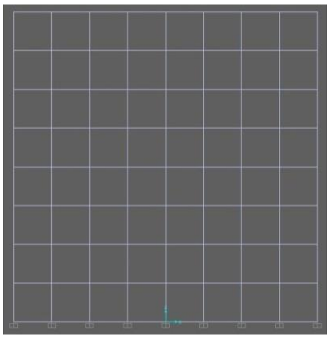

Figure 12. Modelling of masonry wall 8x8 mesh size (0.375m X 0.375m panel size)

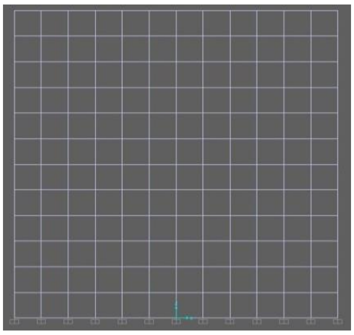

Figure 13. Modelling of masonry 12x12 mesh size (0.25m X 0.25m panel size)

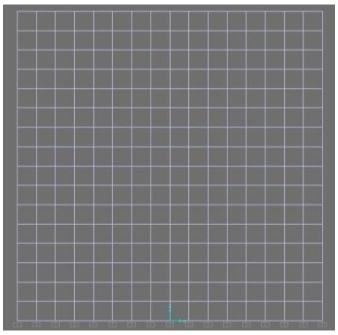

Figure 14. Modelling of masonry wall 16x16 mesh size (0.188m X 0.188m panel size)

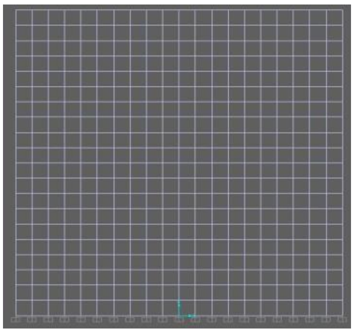

Figure 15. Modelling of masonry wall 20x20 mesh size (0.15m X 0.15m panel size)

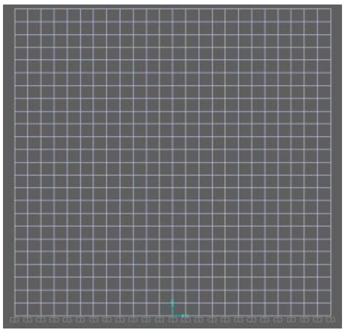

Figure 16. Modelling of masonry wall 24x24 mesh size (0.125m X 0.125m panel size)

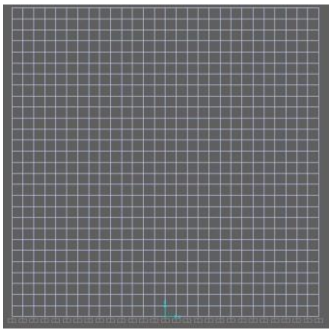

Figure 17. Modelling of masonry wall 28x28 mesh size (0.11m X 0.11m panel size)

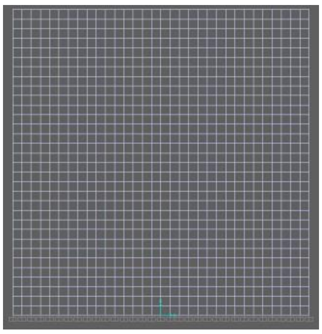

Figure 18. Modelling of masonry wall 32x32 mesh size (0.093m X 0.093m panel size)

III- MESH SIZE MODEL SELECTED FOR MASONRY

In the present work a 3m x 3m masonry wall is considered for analysis. The property of masonry considered are weaker (masonry 1 & masonry 2), intermediate (masonry 3 & masonry 4) and Strong (masonry 5 & masonry 6). For each masonry, both linear and non-linear properties are considered. Figure 3 to Figure 8 shows the graph between displacement vs. mesh size for different sets of mesh size, property (linear & non-linear) and lateral load considered for analysis.

Thus from the above Tables (Table 4 to Table 15) and graphs (Figure 3 to Figure 8) the following salient features were observed-

- The percentage difference between theoretically calculated and software calculated deformation values for 1x1, 2x2, 4x4, 8x8, 12x12, 16x16, 20x20, 24x24, 28x28 and 32x32 panel sizes are 22.68%, 9.25%, 1.25%, 4.84%, 5.50%, 5.70%, 5.70%, 5.70%, 5.70% and 5.70% respectively.
- While the difference between linear and non-linear deformations for the same panel sizes are 48.60%, 46.84%, 46.71%, 46.83%, 46.88% , 46.91%, 46.91%, 46.91%, 46.91%and 46.91% respectively.
- On moving towards higher meshing the percentage difference between calculated lateral deformation and software calculated deformation results are reducing i.e. higher meshing increases the accuracy of result. Thus satisfying the principle of finite element method.
- The percentage difference between calculated lateral deformations and software lateral deformations are almost same for 16x16 and 32x32 finite element meshing of masonry wall
- For each set of load and mesh size the difference between linear &nonlinear values and also difference between software &manually calculated values are same.
- The percentage difference between linear lateral deformation and non-linear lateral for all loads as calculated by SAP 2000 were also same for 16x16 and 32x32 mesh sizes.
- Thus for further analysis of masonry wall 16x16 mesh size masonry wall has been selected.

IV- NON-LINEAR STATIC (PUSHOVER) ANALYSIS OF MASONRY WALL

The pushover analysis of a structure is a non-linear static analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. For the pushover analysis the procedure given by FEMA 356 is adopted in the present work.

4.1 Material Modeling of Masonry Wall

A homogeneous modeling approach is applied. The masonry units, mortar elements are assumed to be smeared and considered isotropic. In the homogeneous modeling approach the test results and analytical curve suggested by Kaushik et al. (2007) are adopted. For the pushover analysis in Zone V for design based earthquake (DBE) in the selected masonry wall model (16x16 finite element mesh size) three different properties of masonry with weaker, intermediate and strong mortar as evaluated are used. The pushover curve adopted for zone V.

V- OUTCOME OF PUSHOVER CURVE

- ➢ The salient features observed from the pushover curves (Figure 19. to Figure 24.) are illustrated as follows-
- For weaker mortar :

For masonry wall having property masonry 1 and masonry 2 target base shear value are 139.088 KN and 175.009 KN respectively. While the target values come to be as 0.0047m and 0.0035m respectively.

- For intermediate mortar :

For masonry wall having property masonry 3 and masonry 4 target base shear value are 197.382 KN and 202.812 KN respectively. While the target values come to be as 0.0029m and 0.0019m respectively.

- For stronger mortar :

For masonry wall having property masonry 5 and masonry 6 target base shear value are 204.328 KN and 210.277 KN respectively. While the target values come to be as 0.0027m and 0.0017m respectively.

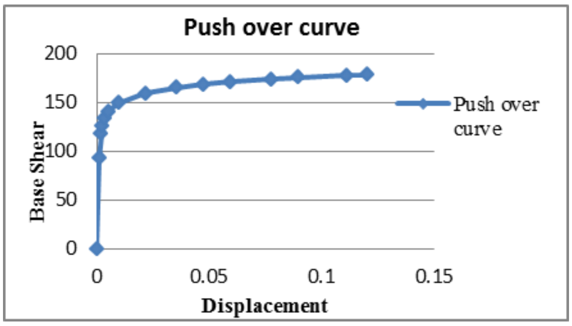

Figure 19. Pushover curve for masonry 1 with 0.25f'm as per FEMA-356

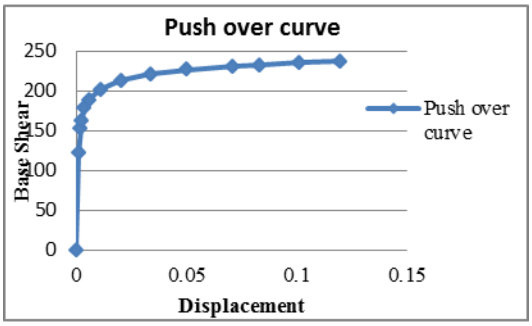

Figure 20. Pushover curve for masonry 2 with 0.33f'm as per FEMA-356

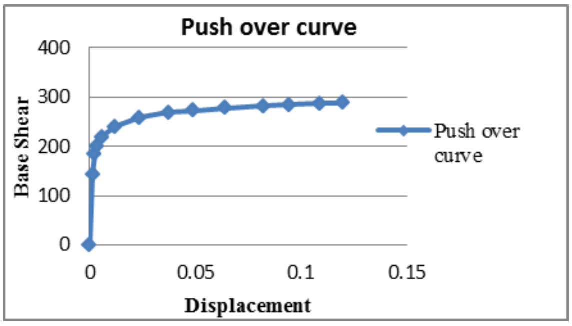

Figure 21. Pushover curve point for masonry 3 with 0.25f'm as per FEMA-356

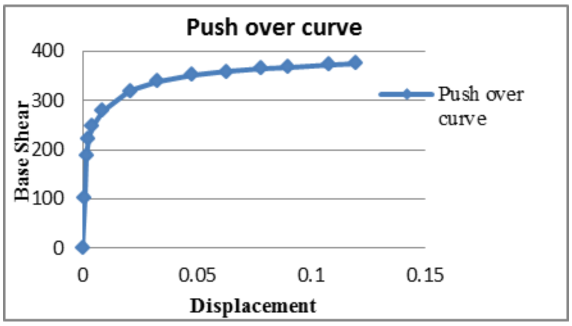

Figure 22. Pushover curve for masonry 4 with 0.33f'm as per FEMA-356

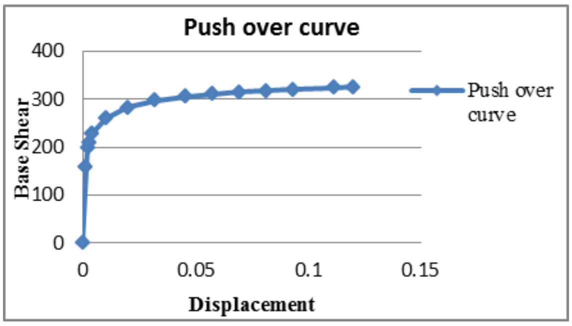

Figure 23. Pushover curve for masonry 5 with 0.25f'm as per FEMA-356

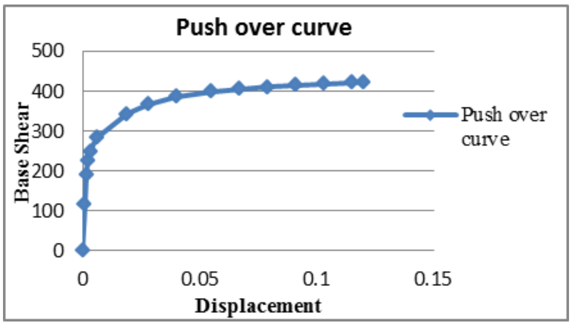

Figure 24. Pushover curve for masonry 6 with 0.33f'm as per FEMA-356

➢ **From the pushover curve of different properties the following observations are made-**

- For masonry with weaker mortar as the stress level increases from 0.25f'm to 0.33f'm the base shear increases by 25.82% while the displacement decreased by 25.53%.
- For masonry with intermediate mortar as the stress level increases from 0.25f'm to 0.33f'm the base shear increases by 2.75% while the displacement decreased by 34.48%.
- For masonry with stronger mortar as the stress level increases from 0.25f'm to 0.33f'm the base shear increases by 2.91% but the displacement is reduced by 23.97 %.
- From the above outcomes we can conclude that intermediate mortar is suitable for analysis and for further studies we are using intermediate mortar for analysis in zones. II, III, IV and V.

VI- Pushover curve for various zones

After deciding the mesh size (as selected 16 x 16) and the property (intermediate property) the pushover curves are run for zone V, IV, III, II respectively.

- **Zone V**

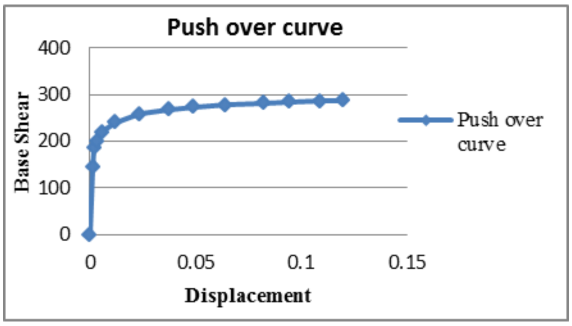

Figure 25. Pushover curve for masonry 3 with 0.25f'm as per FEMA-356

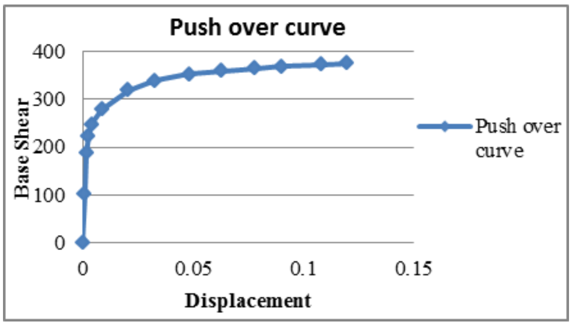

Figure 26. Pushover curve for masonry 4 with 0.33f'm as per FEMA-356

Table 16. Performance parameter for zone V

Item	Value 0.25	Value 0.33
C0	1.2294	1.22
C1	1.5	1.5
C2	1	1
C3	1	1
Sa	0.6658	0.6236
Te	0.099	0.0836
Ti	0.099	0.0836
Ki	101869.7	153091.6
Ke	101869.7	153091.6
Alpha	0.2465	0.4233
R	1.5147	1.7615
Vy	163.5553	131.7244
Weight	372.0877	372.0877
Cm	1	1
Vt	197.382	202.812
δt	0.0029	0.0019

- **Zone IV**

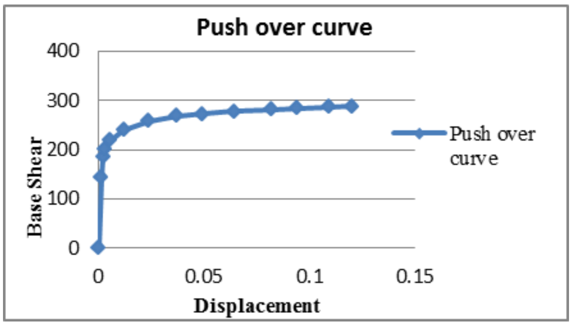

Figure 27. Pushover curve for masonry 3 with 0.25f'm as per FEMA-356

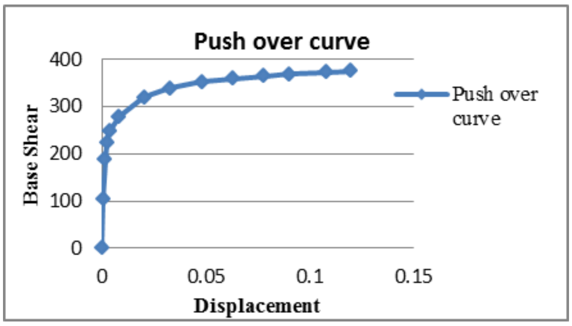

Figure 28. Pushover curve for masonry 4 with 0.33f'm as per FEMA-356

Table 17. Performance parameter for zone IV

Item	Value 0.25	Value 0.33
C0	1.2277	1.2143
C1	1.5	1.5
C2	1	1
C3	1	1
Sa	0.6391	0.5927
Te	0.099	0.0836
Ti	0.099	0.0836
Ki	101869.7	153091.6
Ke	101869.7	153091.6
Alpha	0.2677	0.4423
R	1.4711	1.7096
Vy	161.6567	129.0045
Weight	372.0877	372.0877
Cm	1	1
Vt	195.218	198.360
δt	0.0028	0.0018

- **Zone III**

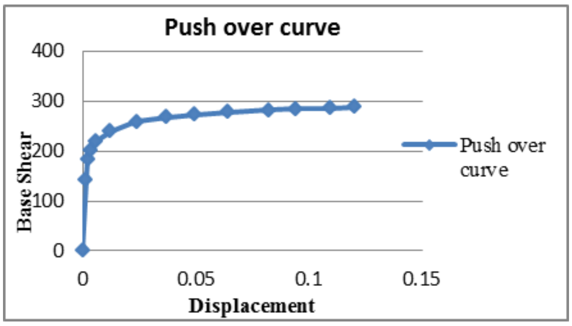

Figure 29. Pushover curve for masonry 3 with 0.25f'm as per FEMA-356

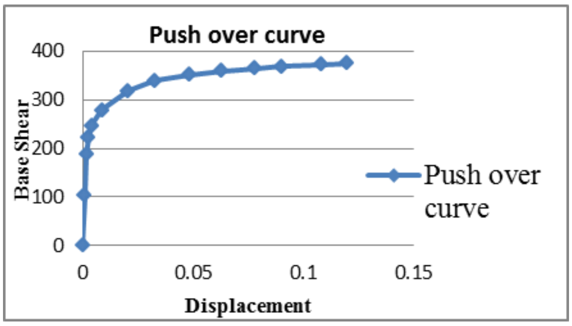

Figure 30. Pushover curve for masonry 4 with 0.33f'm as per FEMA-356

Table 18. Performance parameter for zone III

Item	Value 0.25	Value 0.33
C0	1.1944	1.1684
C1	1.2871	1.5
C2	1	1
C3	1	1
Sa	0.4134	0.3762
Te	0.099	0.0836
Ti	0.099	0.0836
Ki	101869.7	153091.6
Ke	101869.7	153091.6
Alpha	0.4957	0.6278
R	1.0698	1.3536
Vy	143.7791	103.4027
Weight	372.0877	372.0877
Cm	1	1
Vt	144.830	149.623
δt	0.0015	0.0011

- **Zone II**

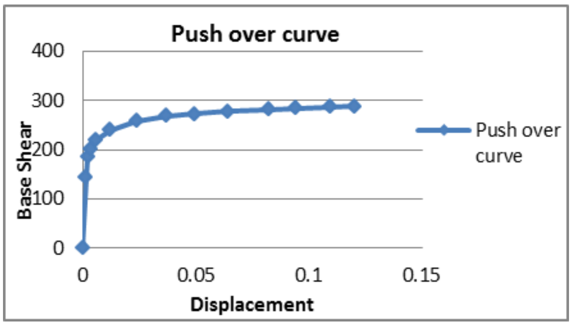

Figure 31. Pushover curve for masonry 3 with 0.25f'm as per FEMA-356

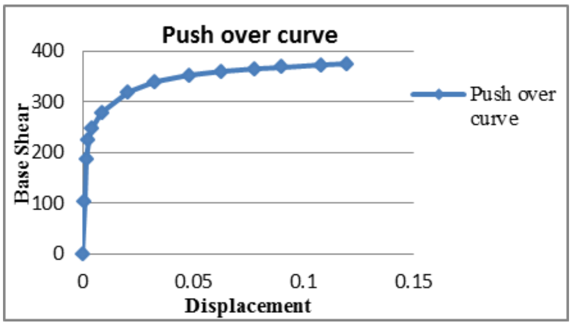

Figure 32. Pushover curve for masonry 4 with 0.33f'm as per FEMA-356

Table 19. Performance parameter for zone II

Item	Value 0.25	Value 0.33
C0	1.0539	1.0506
C1	1	1
C2	1	1
C3	1	1
Sa	0.155	0.1413
Te	0.099	0.0836
Ti	0.099	0.0836
Ki	101869.7	153091.6
Ke	101869.7	153091.6
Alpha	1	1
R	0.4011	0.5085
Vy	143.7791	103.4027
Weight	372.0877	372.0877
Cm	1	1
Vt	39.685	40.688
δt	0.0039	0.0025

6.1 Following observation of Pushover Curve for various zone are:

- For zone V:

  For masonry wall having property masonry 3 and masonry 4 target base shear value are 197.382 KN and 202.812 KN respectively.
  In masonry 3, the maximum base shear obtained from capacity curve is 288.190 KN.
  In masonry 4, the maximum base shear obtained from capacity curve is 375.607 KN.

- For zone IV:

  For masonry wall having property masonry 3 and masonry 4 target base shear value are 195.218 KN and 198.360 KN respectively.
  In masonry 3, the maximum base shear obtained from capacity curve is 288.190 KN.
  In masonry 4, the maximum base shear obtained from capacity curve is 375.607 KN.

- For zone III:

  For masonry wall having property masonry 3 and masonry 4 target base shear value are 144.830 KN and 149.623 KN respectively.
  In masonry 3, the maximum base shear obtained from capacity curve is 288.190 KN.
  In masonry 4, the maximum base shear obtained from capacity curve is 375.607 KN.

- For zone II:

  For masonry wall having property masonry 3 and masonry 4 target base shear value are 39.685 KN and 40.688 KN respectively.
  In masonry 3, the maximum base shear obtained from capacity curve is 288.190 KN.
  In masonry 4, the maximum base shear obtained from capacity curve is 375.607 KN.

- Hence, our structure is safe in all the zones.

VII- CONCLUSION

The conclusions of the research work are:-

- Mesh size used for finite element method is 16X16 after which displacement becomes constant.
- Intermediate masonry mortar is selected for pushover analysis.
- Pushover analysis for existing brick masonry is done for every zone i.e. zone II, zone III, zone IV, and zone V.
- Target displacement and target base shear decreases for zone V to zone II respectively.
- At last we found that our building is safe for every zone.

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