Influence of Openings on Stress Reduction Factors in Unreinforced Masonry Panels: A Structural Health and Injury Risk Assessment Approach

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ABSTRACT

Masonry is the oldest building material which still finds a wide range of use in today's buildings, because of the easy availability of the material as well as its economic application. Moreover, masonry is a composite material. It is made up of brick and mortar. The stress reduction factor is an important factor for designing a masonry structure. From the stress reduction factor, the value of compressive stress is obtained. In this study, to find out the effect on stress reduction factor, models are prepared considering different kinds of thicknesses and openings using FEM analysis. From the study, it is observed that with the increase in thicknesses and openings, maximum compressive stress increases. It is also observed that with increase in slenderness ratio the stress reduction factor decreases.

Keywords: Unreinforced Masonry, Stress Reduction Factor, Opening, Thickness, Compressive stress, FEM Analysis.

I. INTRODUCTION

Masonry has been used from many decades in the construction industry. Many researches have been carried out in the construction industries since long time. Despite the using of RC frame structure in today's life,masonry is still used in many regions due to availability of material, economic purpose, high compressive strength, fire resistance and low maintenance. Although masonry is used widely as a composite material yet it is least understood material in the matters of strength and deformation [1,2].

Stress reduction factor is mainly depending on the value of slenderness ratio and the eccentric loading. From the stress reduction factor thecompressive stress is obtained, which is used for the designing purpose[3].The objectives of this study are:

- To find influence of openings and thicknesses on stress reduction factor and maximum compressive stress.
- To study the effect of slenderness ratio on stress reduction factor and maximum compressive stress.

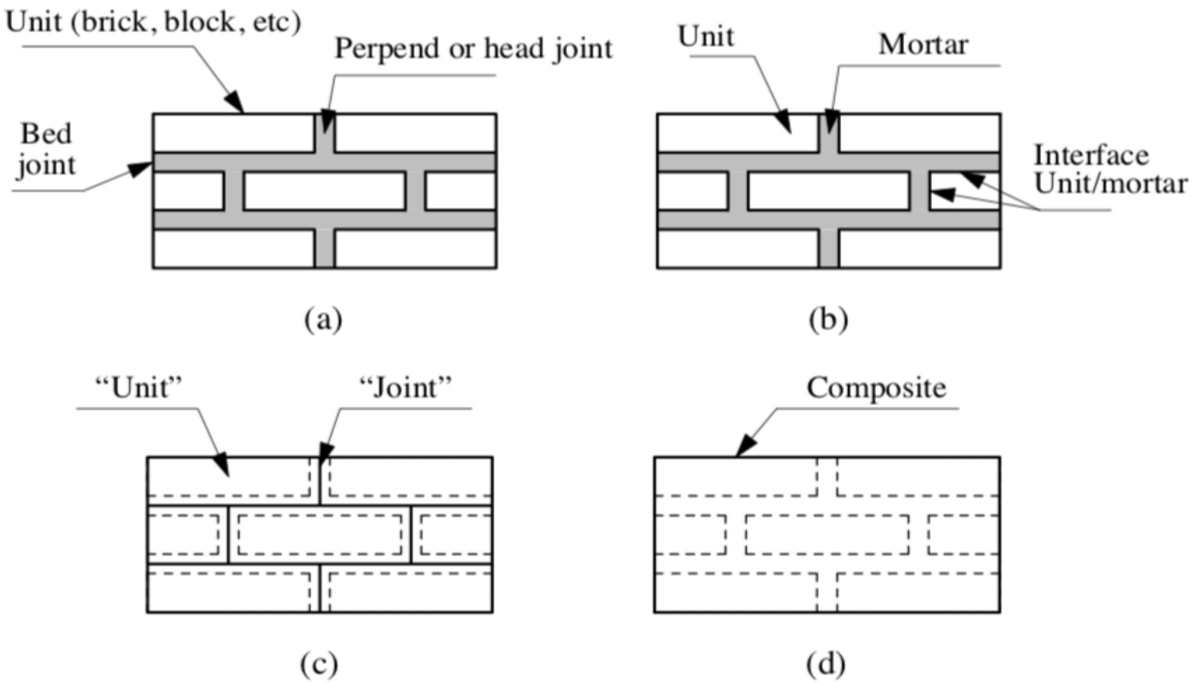
II. FINITE MODELLING

Many finite element software are available namely ANSYS, ATENA, ABAQUS, SAP2000 etc. But in this research work, the ABAQUS has been used for developing the Unreinforced Masonry (URM) Model. Masonry is nonlinear material. For modelling of masonry in ABAQUS, there are mainly three types of techniques namely macro modelling, micro modelling and simplified micro modelling used[4].

Micro modelling provides accurate results but it is time consuming, requires large resources and also requires large number of parameters from experimental study.In micro modelling, boththe brick and mortar joints are modelled as separate element. Simplified micro modelling is done on the basis of yield surface associates and scalar damaged elasticity used for cracking. In simplified micro modelling, the brick and mortar joints are modelled as a continuum element and interface respectively. The last method is macro modelling which is widely and commonly used in large models. In this method, the brick and mortar joints are modelled as one piece. This method is used because of the time reduction in computing in comparison to other two methods and required data is also less as compared to other two methods[4].

Figure 1 shows the different types of modelling techniques, which are used for modelling of masonry in ABAQUS.

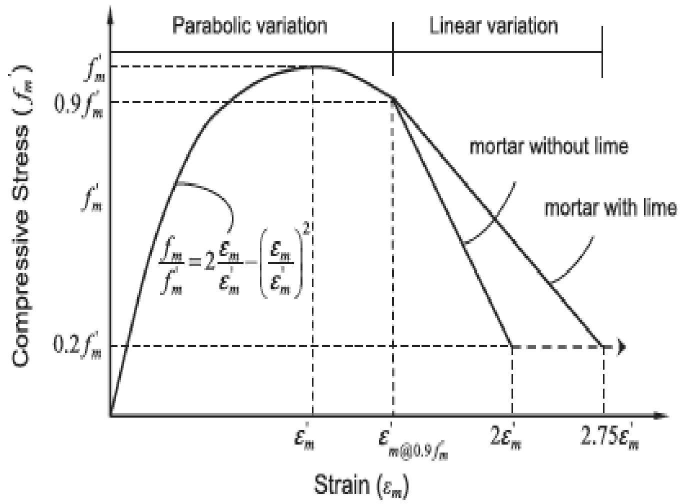
Figure 1:



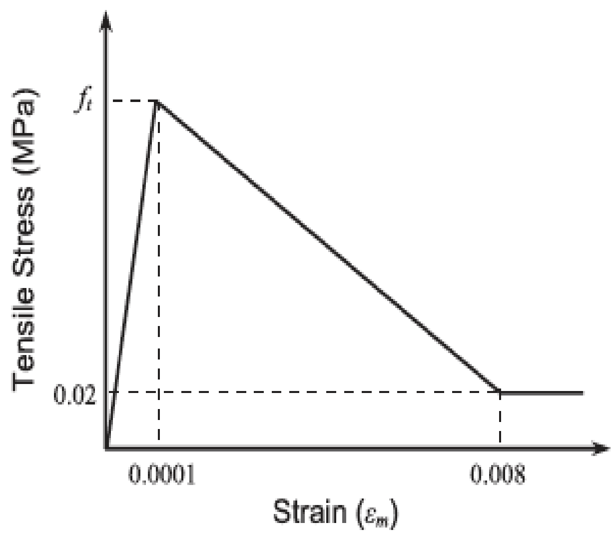
Model of unreinforced masonry: (a) Masonry Model, (b) Micro-Modelling, (c) Simplified Micro-Modelling, (d) Macro-Modelling [4]

For the inelastic behavior of masonry panel, the Concrete Damaged Plasticity(CDP) modeling technique is used in ABAQUS.The compression behavior proposed by Kaushik et al. [5] is used in this study for masonry panel.The compression behavior of masonry is shown in figure 2(a). It is further divided into two partsone which is parabolic (ascending) and another one is a linear degrading part.The tri linear curve is used for tension behavior of masonry panel, shown in Figure 2(b). The peak value of tensile stress was assumed at 0.0001 strain [6]. Other properties for the CDP modelare taken from Agnihotri et al.[6]:

Figure 2:



(a)



(b)

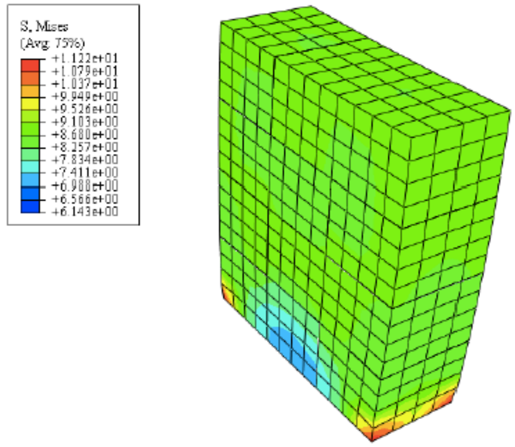
***Masonry Behavior (a) Compression Behavior (b) Tension Behavior [6*]

III. VALIDATION

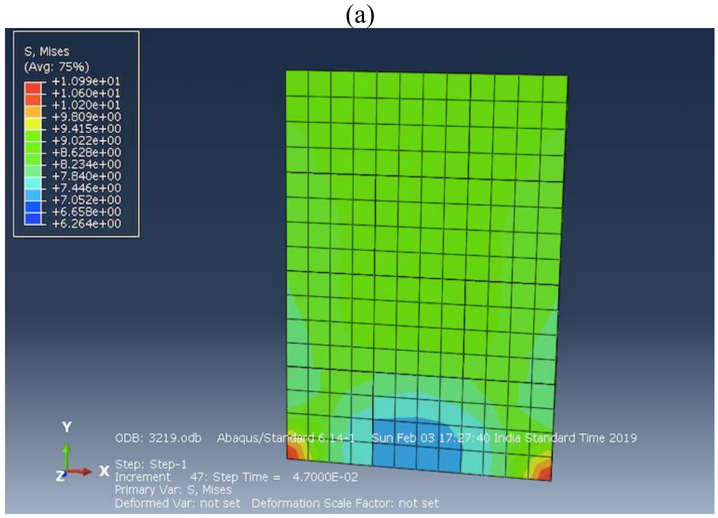
For validation work, comparison has been made with result of paper titled “Experimental and Numerical Analysis of the Compressive and Shear Behavior for a New Type Self-Insulating Concrete Masonry System” by Mohamad and Chen[7].In this paper, author have modeled and matched the compression prism. For compression prism model the CDP property had been used.

Figure 3 shows the comparison of results with the validation model and Mohamad and Chen [7]

Figure 3:



(a)



(b)

S-Mises Contour (a) Mohamad and Chen [7] (b) Validation Model

IV. MATERIAL

Macro modelling technique has been used to prepare the model of unreinforced masonry panels. For achieving the behavior of unreinforced masonry the CDP property was adopted. The Properties of CDP are shown in Table 1 [6]:

Table:

Table 1 Property of unreinforced masonry wall for Finite modelling [6]

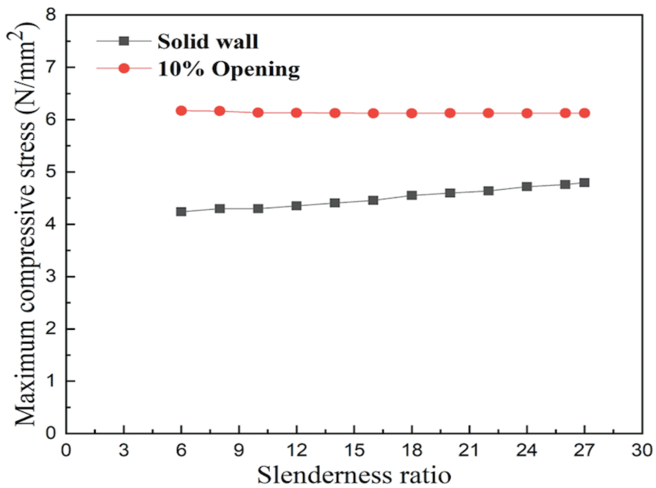
Property	**Symbol**	**URM wall**
Compressive strength	f_m'	18 MPa

Strain at peak	ε_m	0.0025
Poisson's ratio	ν	0.2
Young's modulus	E	1500 MPa
Density of masonry	ρ	1900 kg/m^3
Tensile strength	$f_t^{'}$	0.6 MPa

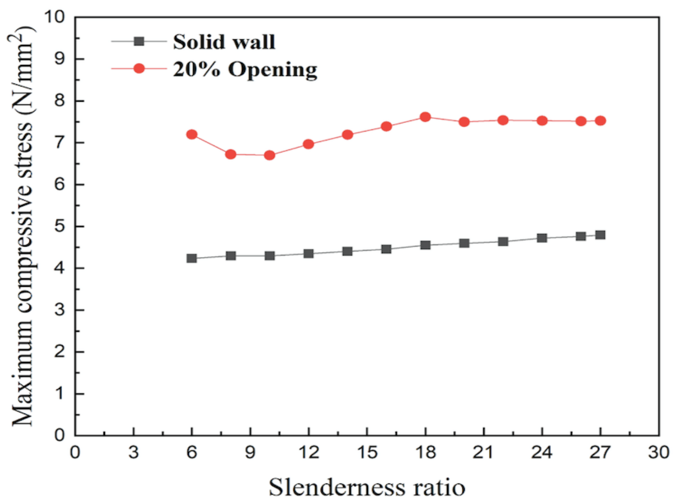
V. RESULTS AND DISCUSSION

To find out the effect of opening on stress reduction factor, then on linear model has been prepared. The models were discretized into eight noded 3D stress linear brick (C3D8R) element in ABAQUS. First of all, solid walls are prepared and 10%, 20%, 30%, 40% opening are provided to find their effects on stress reduction factor. Four types of thickness are used to prepare the model(150 mm, 175 mm, 200 mm and 230 mm). The size of panels was decided according to the thickness of model. The opening size is decided on the basis of size of panels. The bottom side was restrained and the compressive pressure has been applied on the upper side of the wall with zero eccentricity.

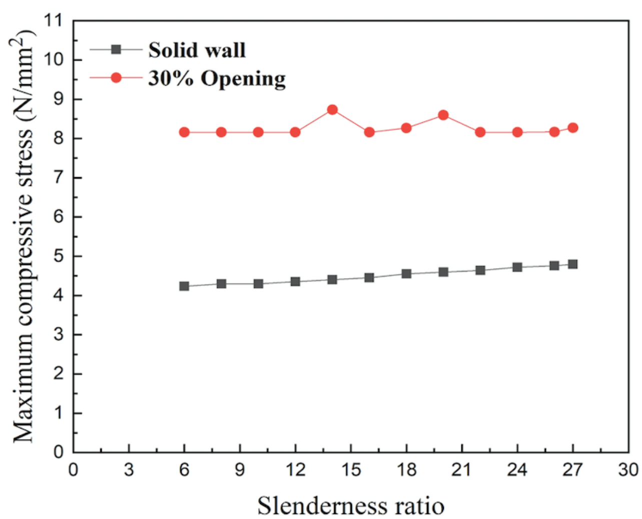
Figure 4:


Solid wall
10% Opening
Maximum compressive stress (N/mm^2)
Slenderness ratio
0 3 6 9 12 15 18 21 24 27 30
0 1 2 3 4 5 6 7 8

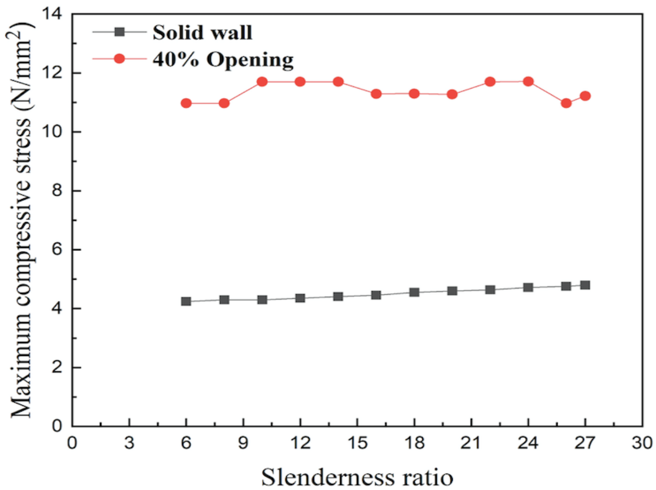
(a)


Solid wall
20% Opening
Maximum compressive stress (N/mm^2)
Slenderness ratio
0 3 6 9 12 15 18 21 24 27 30
0 1 2 3 4 5 6 7 8 9 10

(b)


Solid wall
30% Opening
Maximum compressive stress (N/mm^2)
Slenderness ratio
0 3 6 9 12 15 18 21 24 27 30
0 1 2 3 4 5 6 7 8 9 10 11

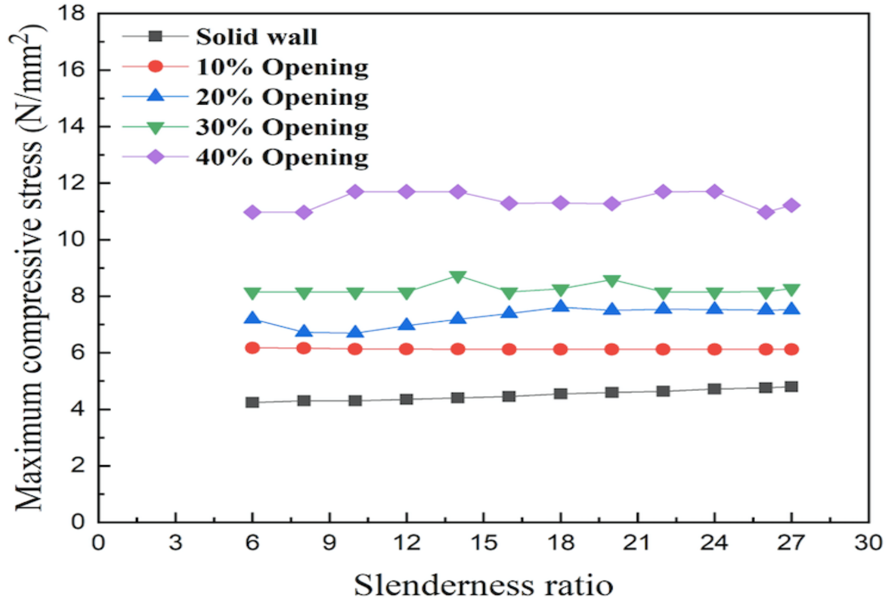
(c)



(d)

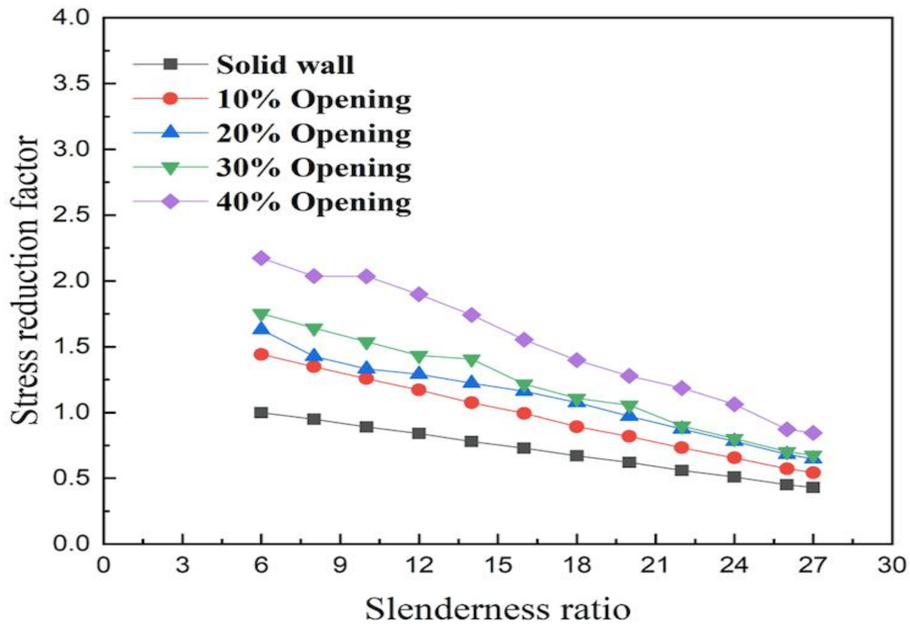
Slenderness Ratio v/s Maximum compressive stress when thickness t = 150 mm (a) 10% Opening,(b) 20% Opening, (c) 30% Opening, (d) 40% Opening

Figure 5:



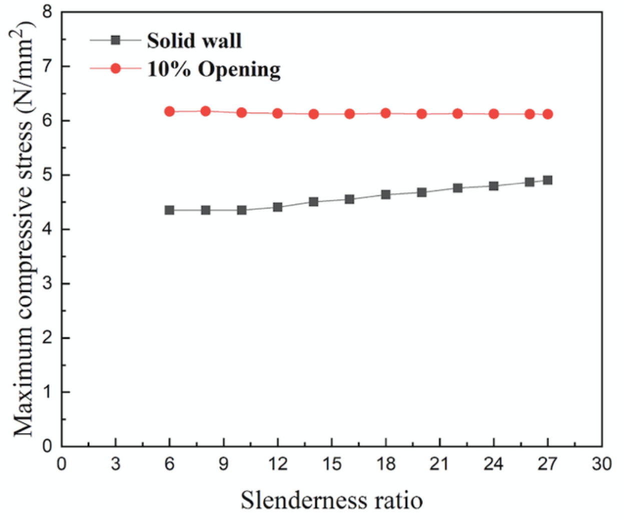
Slenderness ratio v/s Maximum compressive stress with all openings and solid wall (t = 150 mm)

Figure 6:

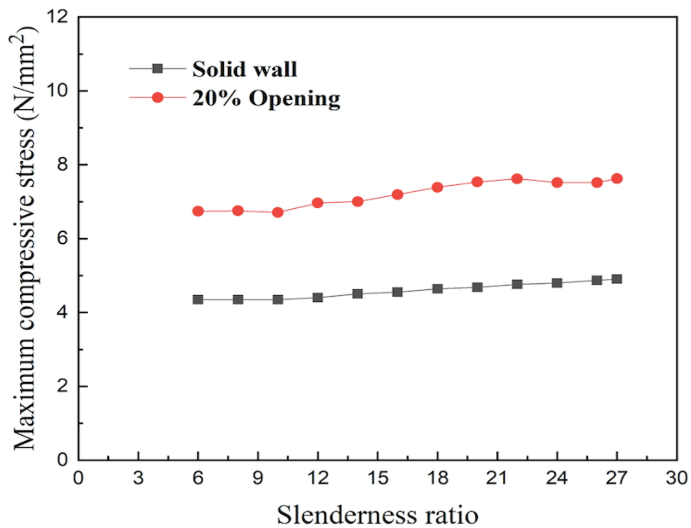


Slenderness ratio v/s Stress reduction factor with all openings and solid wall (t = 150 mm)

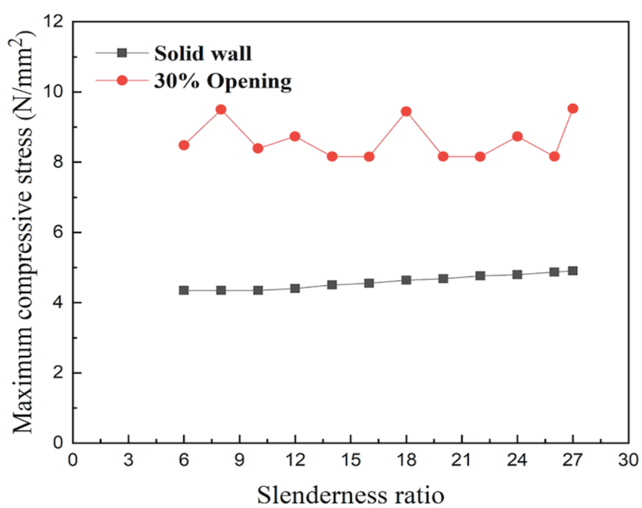
Figure 7:


Solid wall
10% Opening
Maximum compressive stress (N/mm^2)
Slenderness ratio
0
1
2
3
4
5
6
7
8
0
3
6
9
12
15
18
21
24
27
30

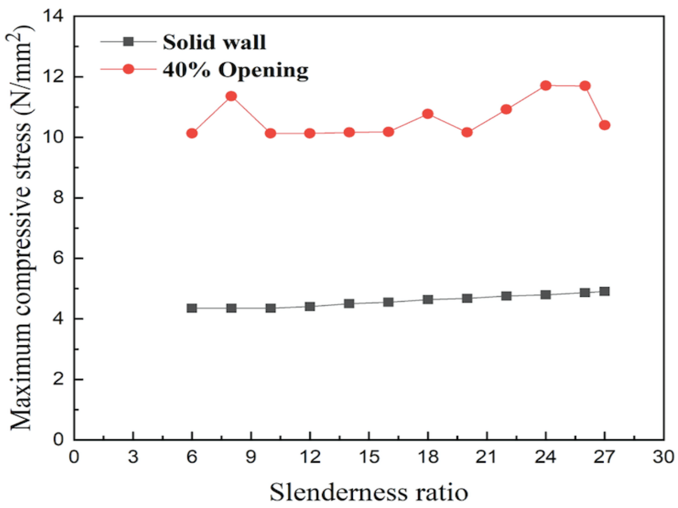
(a)


Solid wall
20% Opening
Maximum compressive stress (N/mm^2)
Slenderness ratio
0
2
4
6
8
10
12
0
3
6
9
12
15
18
21
24
27
30

(b)


Solid wall
30% Opening
Maximum compressive stress (N/mm^2)
Slenderness ratio
0
2
4
6
8
10
12
0
3
6
9
12
15
18
21
24
27
30

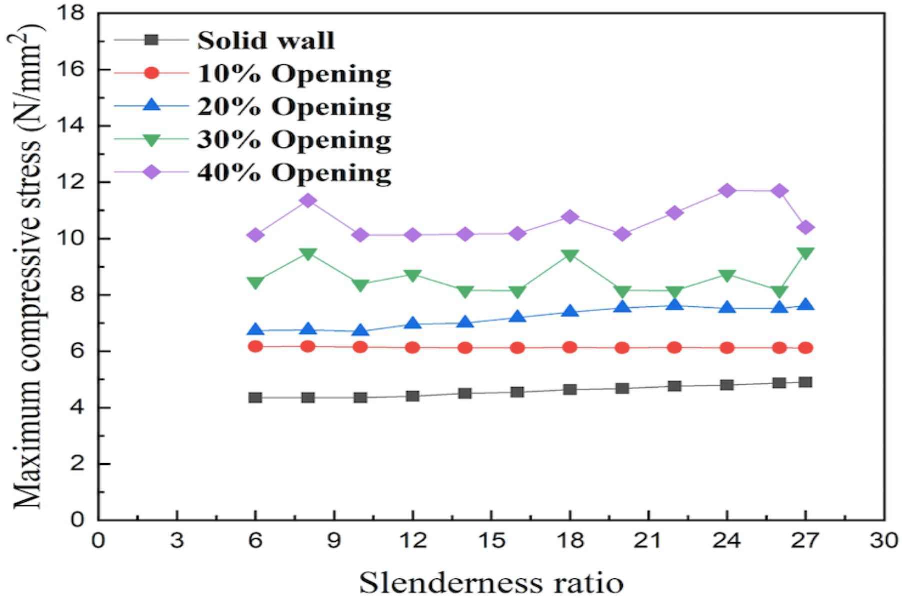
(c)



(d)

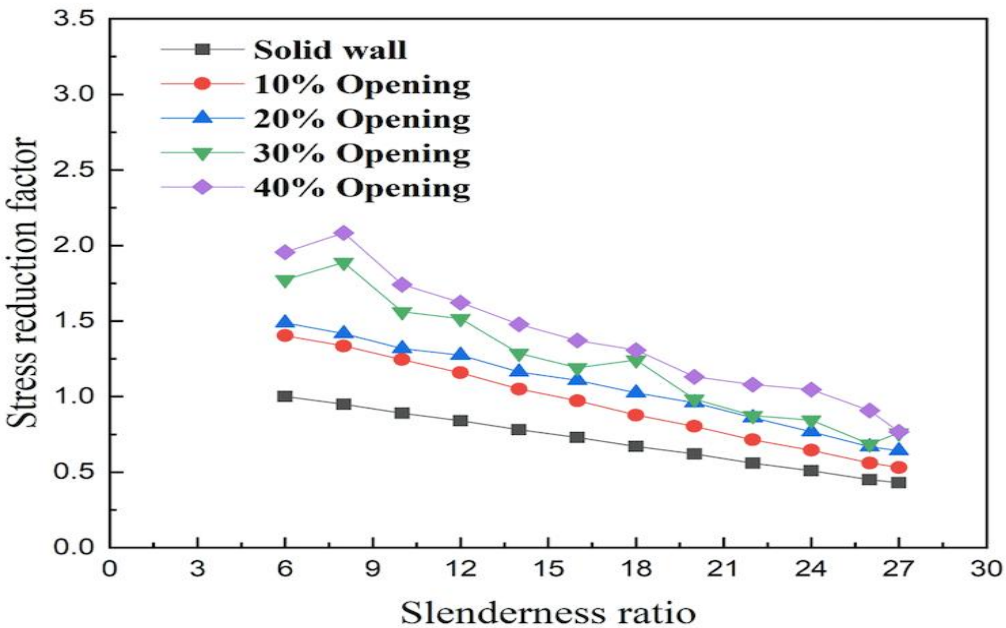
Slenderness Ratio v/s Maximum compressive stress when thickness t = 175 mm (a) 10% Opening, (b) 20% Opening, (c) 30% Opening, (d) 40% Opening

Figure 8:



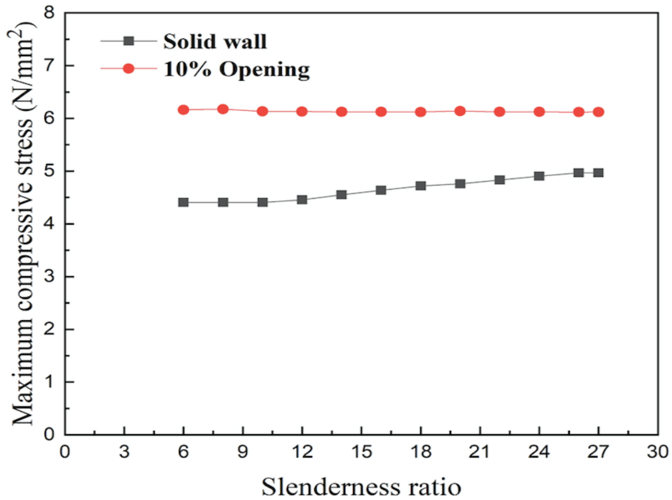
Slenderness ratio v/s Maximum compressive stress with all openings and solid wall (t = 175 mm)

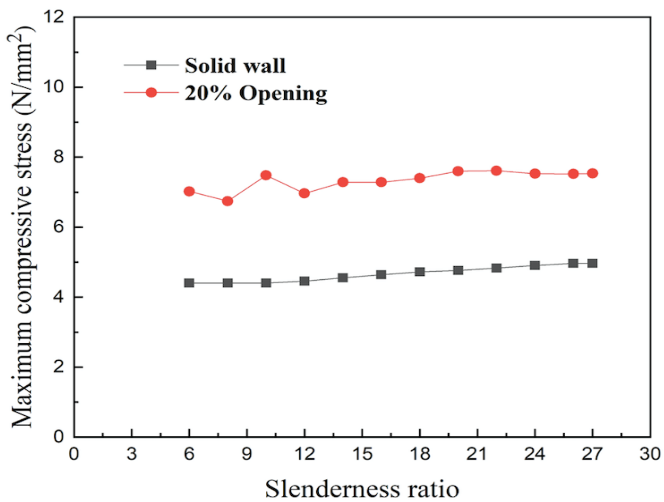
Figure 9:



Slenderness ratio v/s Stress reduction factor with all openings and solid wall (t = 175 mm)

Figure 10:


Solid wall
10% Opening
Maximum compressive stress (N/mm2)
Slenderness ratio
0
3
6
9
12
15
18
21
24
27
30
0
1
2
3
4
5
6
7
8
(a)


Solid wall
20% Opening
Maximum compressive stress (N/mm2)
Slenderness ratio
0
3
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9
12
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24
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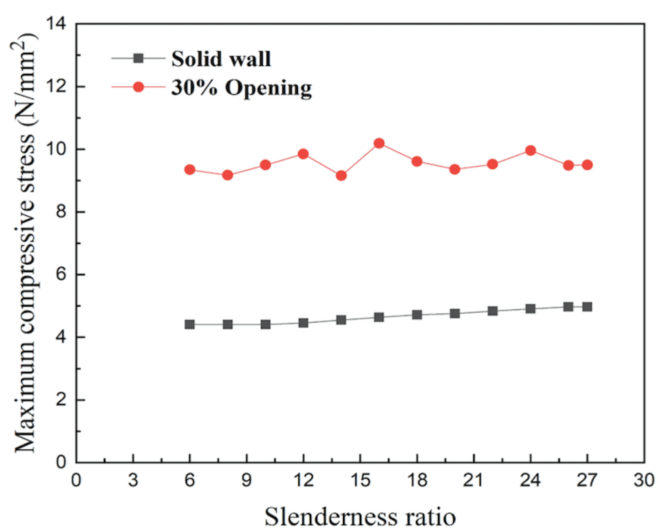
0
2
4
6
8
10
12
(b)


Solid wall
30% Opening
Maximum compressive stress (N/mm2)
Slenderness ratio
0
3
6
9
12
15
18
21
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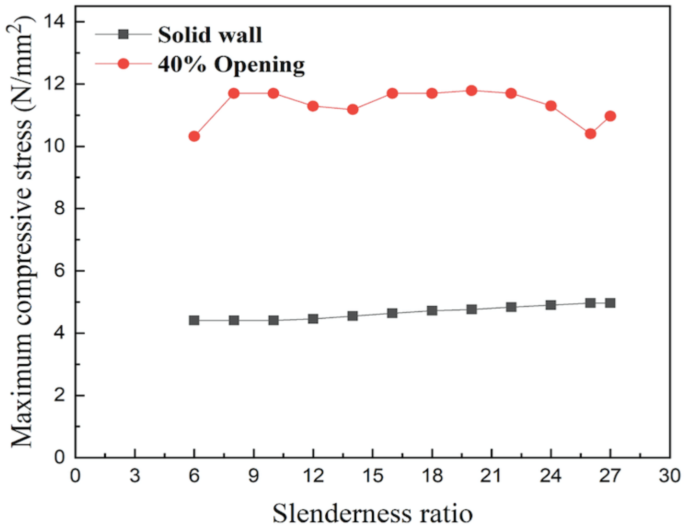
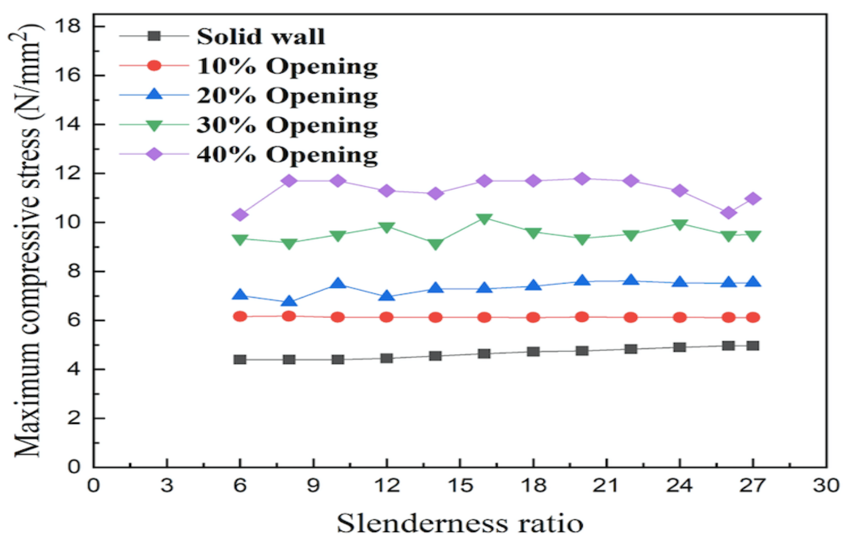
27
30
0
2
4
6
8
10
12
14
(c)



(d)

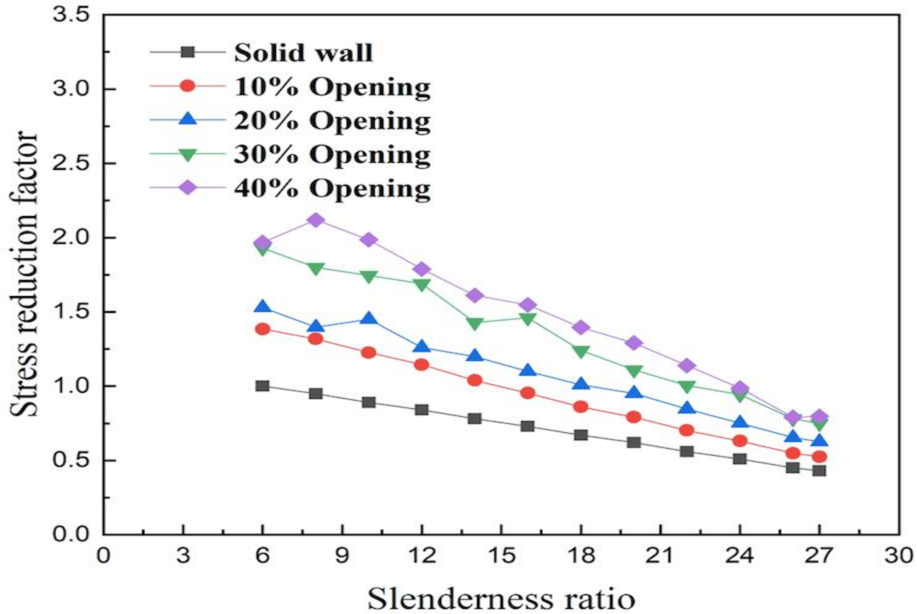
Slenderness Ratio v/s Maximum compressive stress when thickness t = 200 mm (a) 10% Opening, (b) 20% Opening, (c) 30% Opening, (d) 40% Opening

Figure 11:



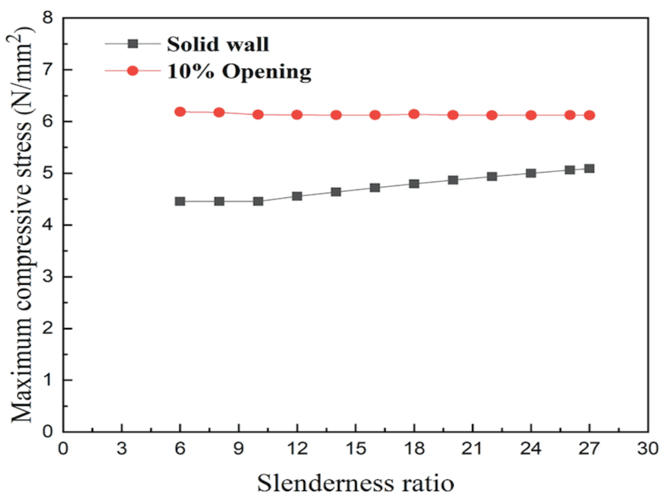
Slenderness ratio v/s Maximum compressive stress with all openings and solid wall (t = 200 mm)

Figure 12:

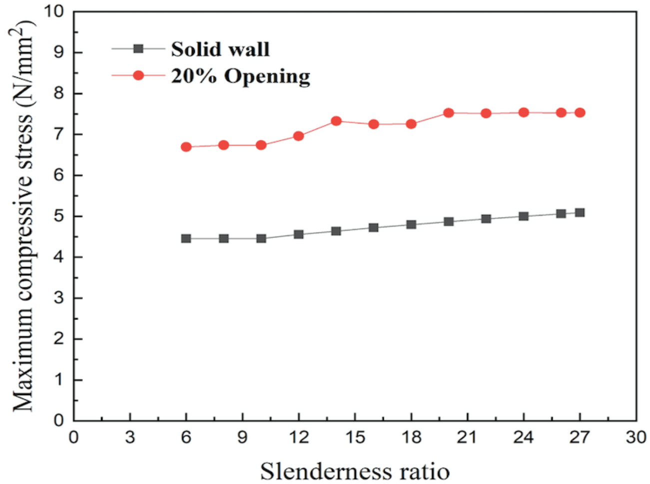


Slenderness ratio v/s Stress reduction factor with all openings and solid wall (t = 200 mm)

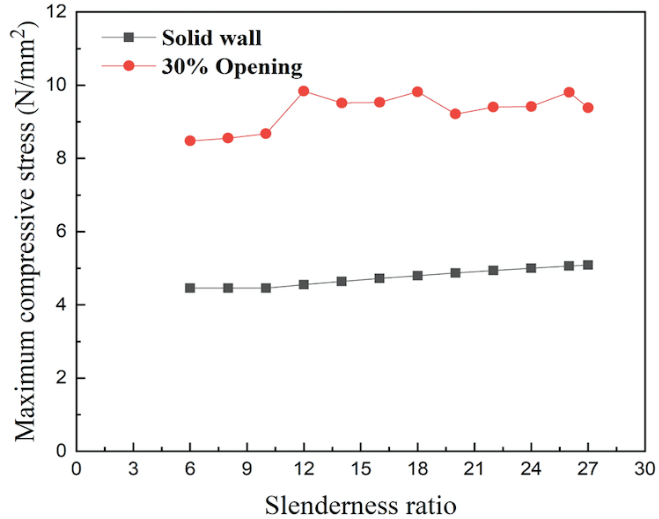
Figure 13:



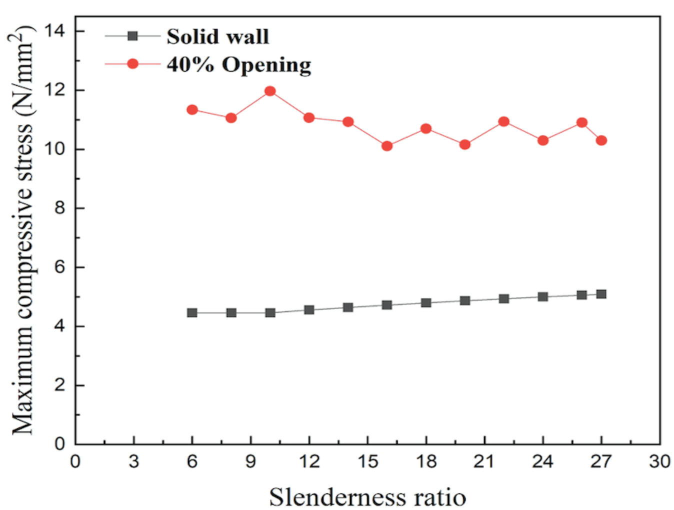
(a)


Maximum compressive stress (N/mm^2)
Solid wall
20% Opening
0
1
2
3
4
5
6
7
8
9
10
0 3 6 9 12 15 18 21 24 27 30
Slenderness ratio

(b)


Maximum compressive stress (N/mm^2)
Solid wall
30% Opening
0
2
4
6
8
10
12
0 3 6 9 12 15 18 21 24 27 30
Slenderness ratio

(c)

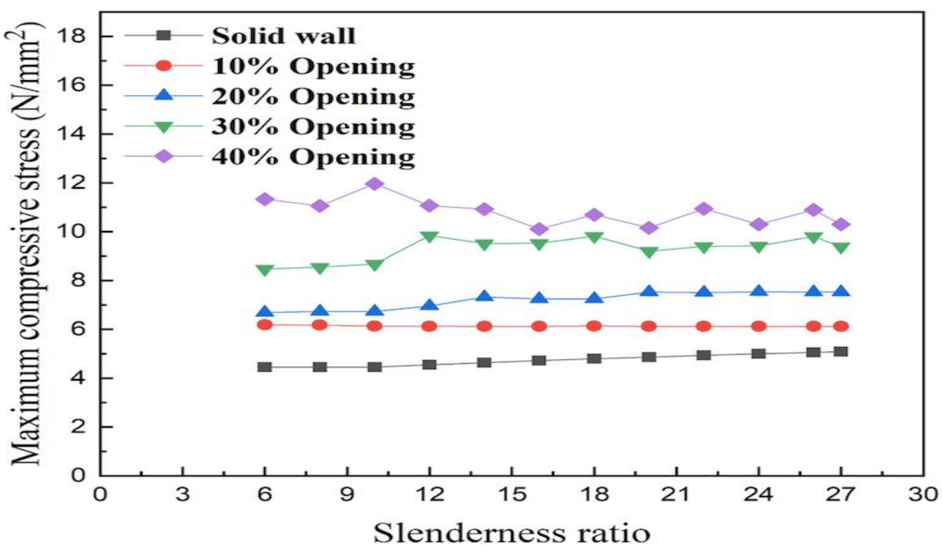

Maximum compressive stress (N/mm^2)
Solid wall
40% Opening
0
2
4
6
8
10
12
14
0 3 6 9 12 15 18 21 24 27 30
Slenderness ratio

(d)

Slenderness Ratio v/s Maximum compressive stress when thickness t = 230 mm (a) 10% Opening, (b) 20% Opening, (c) 30% Opening, (d) 40% Opening

Figures 4,7,10 and 13 show the graph of slenderness ratio v/s maximum compressive stress when the thickness of the wall is 150 mm, 175 mm, 200 mm and 230 mm respectively. It is also observed that with the increment in the size of opening, the maximum compressive stress increases.

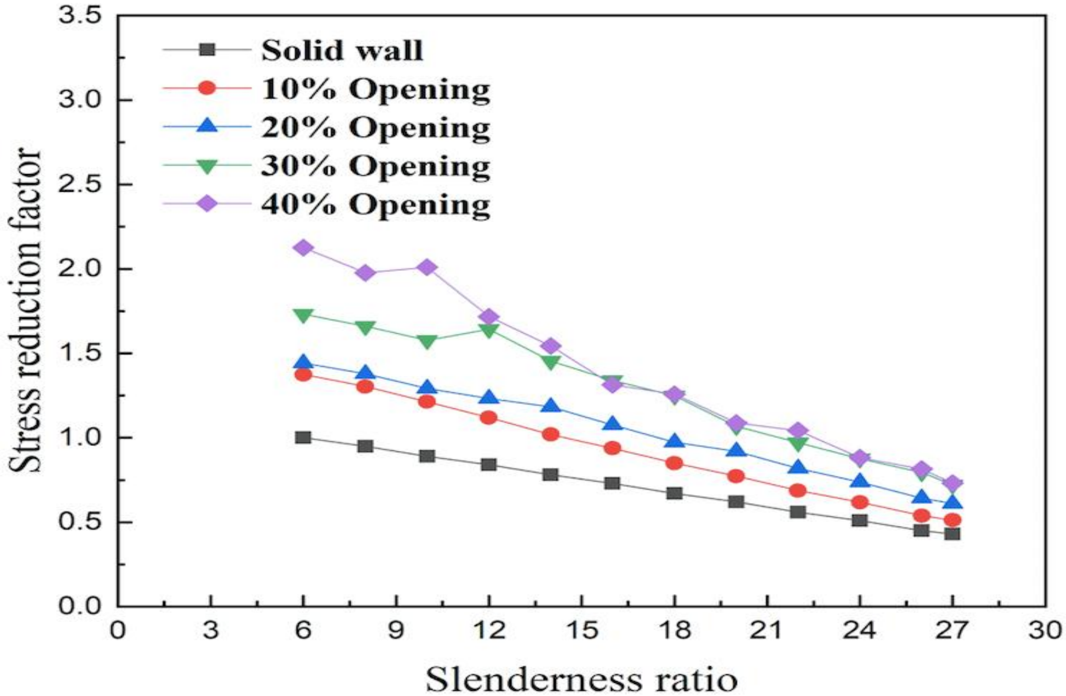
Figure 14:



Slenderness ratio v/s Maximum compressive stress with all openings and solid wall (t = 230 mm)

Figures 5,8,11 and 14 show the combined results of maximum compressive stress with the slenderness ratio when the thickness of wall is 150 mm, 175 mm, 200 mm and 230 mm respectively. It indicates the maximum value of compressive stress at the opening of 40%.

Figure 15:



Slenderness ratio v/s Stress reduction factor with all openings and solid wall (t = 230 mm)

Figures 6,9,12 and 15 show the results of slenderness ratio v/s stress reduction factor. It is found that the value of stress reduction factor is maximum when the opening is 40%.

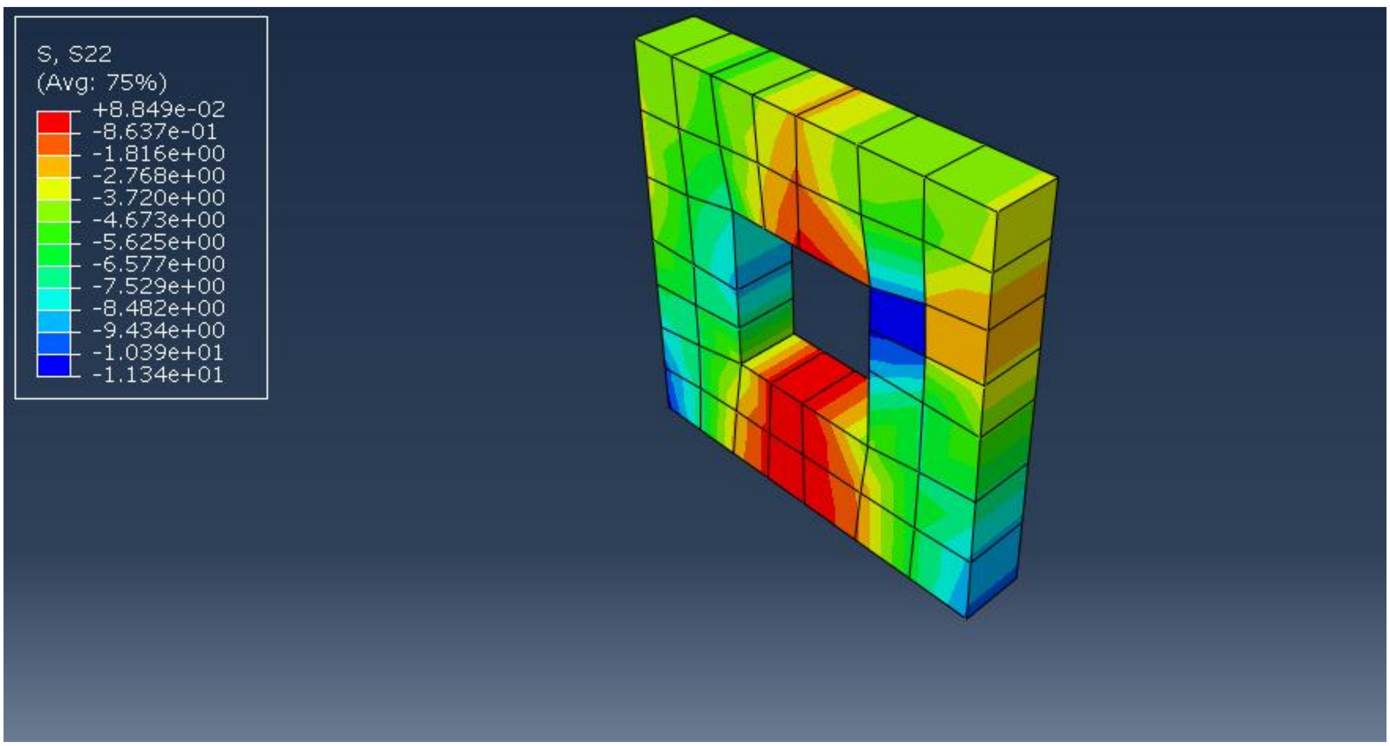
Table:

Table 2 Maximum compressive stress (N/mm^2) with slenderness ratio when thickness t = 230 mm

Slenderness ratio	**Maximum compressive stress (N/mm^2)**				
	Solid wall	**10% opening**	**20% opening**	**30% opening**	**40% opening**
6	4.455	6.186	6.694	8.479	11.340
8	4.455	6.175	6.736	8.555	11.060
10	4.454	6.132	6.736	8.677	11.970
12	4.555	6.129	6.962	9.837	10.070
14	4.638	6.123	7.327	9.516	10.930
16	4.720	6.123	7.249	9.532	10.110
18	4.796	6.141	7.255	9.820	10.700
20	4.868	6.123	7.527	9.211	10.160
22	4.936	6.122	7.513	9.404	10.940
24	5.000	6.122	7.535	9.421	10.300
26	5.061	6.124	7.531	9.808	10.900
27	5.090	6.122	7.532	9.385	10.300

Table 2 shows the value of maximum compressive stress (N/mm^2) with different slenderness ratio and openings when the thickness of masonry wall panelsis 230 mm. From the table, it is observed that the maximum value of stress is obtained at 40% of opening.

Figure 16:



Compressive stress value of thickness t = 230 mm with 40% opening

Figure 16 shows the result of compressive stress in ABAQUS. The value of maximum compressive stress is 11.34 N/mm^2 which is shown in the figure.The figure shows the thickness of230 mm and a slenderness ratio of 6 with 40% opening.

VI. CONCLUSIONS

The solid walls areanalyzed with the effect of opening on stress reduction factor using ABAQUS. To check the exact effect of opening,the different types models are prepared with 10%, 20%, 30% and 40% openings and the thicknesses of 150 mm, 175mm, 200mm and 230mm. Following conclusions have been derived from the comparative and parametric study:

- As the percentage of opening increases, the maximum compressive stress increases.
- The maximum compressive stress increases with increase of the thickness of solid wall.
- With the increase in percentage opening, the value of stress reduction factor is higher as compared to solid walls.
- With the increase in slenderness ratio, the stress reduction factor decrease and maximum compressive stresses remain more or less constant.

REFERENCES

1. *Akhaveissy, A. H. (2012), 'Finite element nonlinear analysis of high-rise unreinforced masonry building', Latin American Journal of Solids and Structures, Vol.1, pp. 1-22.*
2. *Abbasnejadfard, M. and Farzam, M. (2016), 'The effect of opening on stiffness and strength of infilled steel frames', Journal of Rehabilitation in Civil Engineering, Vol.4, pp. 78-90.*
3. *Colville, J. and Chyn, W. (1998), 'Stress reduction factor design for unreinforced masonry walls', Vth International Brick Masonry Conference, Session V, Paper 15, pp. 619-622.*
4. *Abbas, A. L. and Saeed, M. H. (2017), 'Representation of the masonry walls techniques by using FEM', Australian Journal of Basic and Applied Sciences, Vol.11, pp. 39-48.*
5. *Kaushik, H. B., Rai D. C. and Jain, S. K. (2007),'Stress-strain characteristics of clay brick masonry under uniaxial compression', Journal of Materials in Civil Engineering, Vol.19, pp.728-739.*
6. *Agnihotri, P., Singhal, V. and Rai, D. (2013),'Effect of in-plane damage on out-of-plane strength of unreinforced masonry walls', Engineering Structures, Vol.57,pp.1-11.*
7. *Mohamad, A. A. E. and Chen, Z. (2016), 'Experimental and numerical analysis of the compressive and shear behavior for a new type self-Insulating concrete masonry system', applied sciences, Vol.6, article 245.*