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Optimum Shape of Cut-Out Opening on Concrete Structural Wall

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Abstract – *As the construction of reinforced concrete structures increases and to keep up with the necessity of growing population, new buildings are need to be constructed by preserving old buildings. Old buildings are sometimes need to be modified to meet with current standards. Openings are frequently provided in walls to meet the functional, architectural and / or mechanical requirements of buildings. Requirements typically includes the provision of doors and windows or the services like air-conditioning and ventilation ducts. Openings are need to be cut in old buildings and in newly constructed buildings due change in the functional requirement of the building. These openings are source of weakness and depending on their size and orientation they influence adversely the load carrying capacity of the member. Hence the influence of cut openings on concrete structural wall are needed to be thoroughly understood.*

Key Words: Concrete structural wall, opening, optimum shape, equivalent area, OW and TW wall panels.

1. INTRODUCTION

Structural concrete walls are important structural elements in mid and high-rise buildings which effectively transfer vertical and horizontal forces acting on the building to the foundation. The centrally reinforced wall in both horizontal and vertical direction are considered as concrete wall. The influence of reinforcement in such walls, even though they contributes to overall ductility of the member at the time of failure, is neglected. With the increase in tilt-up construction, the importance of concrete walls also increases. Figure 1 shows a general model of concrete structural wall.

Seeing this importance of concrete structural wall in modern construction, many studies are conducted to study their structural behaviour. Literature shows that the most of the experimental studies are focused on the behaviour of solid concrete walls compared to one with opening. The most relevant research has focused on one-way (OW) action walls (panels restrained only along their top and bottom edges than two way (TW) action panels (walls or panels restrained along three or four sides).

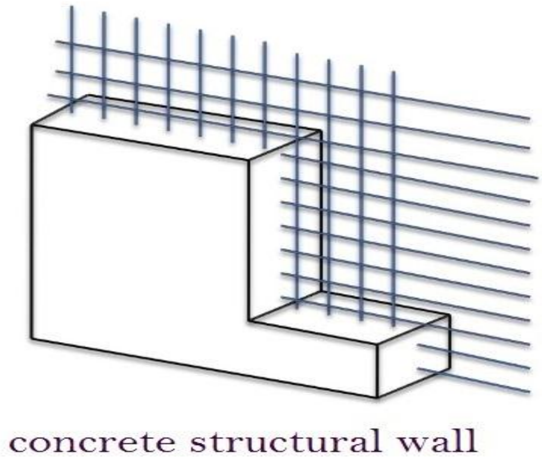

Figure 1- Concrete structural wall

Many researchers have worked on behavior of RC wall panel with openings with different aspect ratio, area ratio, position, size and loading conditions and researchers also tried to develop formulae which account effect of location and sizes of openings. Almost all researches were regarding predefined opening. Only two scholars Mohammeda et. al (2013) and Cosmin Popescu et. al (2015), to the best of author's knowledge, studied the behaviour of cut out opening. In this paper the most optimum shape that can be cut in one-way and two-way action concrete structural wall is determined.

2. CONCRETE STRUCTURAL WALL

A vertical load bearing member, whose breadth is more than four times its thickness, is called a wall. In all major design codes a distinction is made between reinforced and unreinforced walls. It should be noted that unreinforced members does not only refer to plain concrete but also when the reinforcement provided is less than the minimum required for reinforced concrete. As per IS 456 (2000), a wall is called a reinforced concrete wall if the percentage of total compression steel in it is not less than 0.4% of the gross area of concrete so that the strength of the wall will include the strength of steel as well.

But seeing the importance of the concrete structural wall, as load bearing wall, many studies are conducted to study the structural behaviour of centrally reinforced member. The literature and the foreign codes also defined the axially loaded concrete structural wall as one-way (OW) action wall panel (hinged at the top and bottom and carrying in-plane vertical loads developing a curvature along the loading direction) and two-way (TW) action wall panel (an axially loaded wall supported on all four edges exhibiting biaxial curvature under load).

Openings that cut on these walls weakens the load carrying capacity considerably. So before cutting the opening, were should be cut in what shape and the influence after cutting should be understood thoroughly to take proper measures that can effectively regain the strength of member.

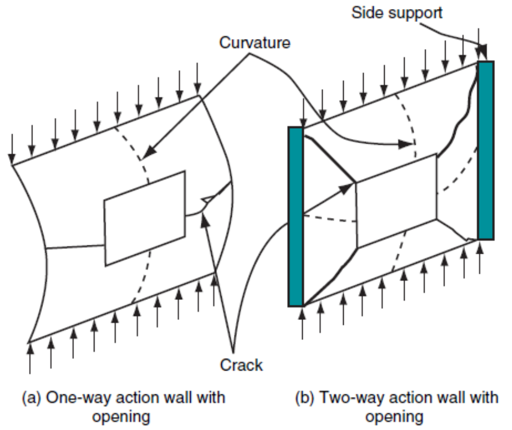

Figure 2- Walls with and without side supports (Doh and Fragomeni 2006)

3. WALL SPECIFICATION

3.1 IS 456:2000

The design of R. C. walls subjected to direct compression or combined flexure and direct compression should be done by treating wall as column under direct compression or combined flexure and direct, provided vertical reinforcement is provided on each face. Braced walls subjected to only vertical compression may be designed as per empirical procedure. Code specify the minimum thickness of the wall as 100 mm and allows a maximum slenderness (Effective Height to Thickness) ratio of 30. Minimum eccentricity allowed is within middle third of thickness. No provision for openings is undertaken.

3.2 Foreign codes

In the literature the structural concrete walls are designated as OW and TW walls based on the side restrained provided. EN1992-1-1 (2004) and AS3600 (2009) are the codes which recognized the effect of side restraint. ACI318 (2011), AS3600 (2009) and CAN/CSA-A23.3 (2004) allows an eccentricity of one sixth of the wall thickness so that the resultant of all loads on the wall must be located within the middle third of its overall thickness. Within this eccentricity codes are providing empirical formulae to find the ultimate strength of walls. The effect of openings are yet to be discussed in theses codes but still some guide lines are provided.

3.3 Literature research

The majority of all studies performed to date concerned walls with designed openings (i.e. with diagonal bars around the opening corner to avoid premature cracking). Walls with cut-out openings (i.e. openings sawn in a solid panel) are still unexplored yet; to the best knowledge of the author, only two research studies (Mohammed, et al. 2013 and Cosmin Popescu, et al.2015) have focused on this problem type. The findings showed that the presence of the opening in a solid panel led to disturbance zones. The variation in behaviour of wall with cut should be studied thoroughly.

4. CONCRETE STRUCTURAL WALL WITH OPENING: PARAMETERS THAT INFLUENCES THE STRENGTH

Openings are source of weakness and depending on their size and orientation, openings influences adversely the load carrying capacity of the member. So before cutting the opening, the influence of increasing the length and height of opening should be thoroughly understood. Following parameters influences the load carrying capacity of concrete structural wall.

4.1 Slenderness ratio

The load carrying capacity of structural concrete walls depends on its slenderness ratio. Their design is similar to the design of design of masonry walls and is lesser of the following two ratios:

(a) Ratio of effective height along vertical direction and thickness = H_e/t

(b) Ratio of effective length along the horizontal direction and thickness = L_e/t.

Where H_e is the effective height and t the thickness and Effective length of plain walls is L_e.

As per IS 456, when the slenderness ratio is equal to or more than 12, walls are considered slender. And according to BS 8110, walls are slender when this ratio exceeds 15 for a braced wall and 10 for unbraced wall. Slender walls will have a lower ultimate strength. Influence of slenderness ratio is predominant in case of high strength concrete walls than normal strength concrete walls. Short walls or less slender walls fail by crushing on the compressed face and bending on the tension face, while slender walls may additionally fail through buckling. All experimental studies showed a brittle types of failure.

4.2 Aspect ratio

For OW walls the ultimate strength tends to decrease with an increase in aspect ratio, while for TW walls the opposite trend is found. Aspect ratio is the height to length ratio.

4.3 Openings

Openings are required to be provided in the reinforced concrete wall panel for functional requirements of newly constructed structures or functional modifications to the existing structures. These openings are essential in order to design the building for space efficiency and reuse for long-term conditions. The openings are a source of weakness and can size-dependently reduce the structures' stiffness and load-bearing capacity. The presence of openings in a wall considerably reduces its ultimate load capacity relative to the equivalent solid wall. Here the influences of opening is studied in detail.

5. ANALYSIS AND MODELLING

Static structural linear analysis using ANSYS17.0 software and element SOLID186 is done to find the influence of opening is cut in OW and TW wall panels. For this a model with small door opening, same as the one in reference 2, is modelled and validated. Changing the type and dimension of opening and having constant material property and loading condition different models are created and analysed.

5.1 MATERIAL PROPERTIES

The material properties assigned to steel and concrete in workbench is as shown in table 1. The property of the specimen is kept constant throughout this work.

Table 1- Material properties of concrete and steel.

Material No.	Material	Material Property
1	Concrete	Density = 2300kg/m^3
		Young's modulus, E = 35355 MPa
		Poison's ratio = 0.18
		Tensile ultimate strength = 5 MPa
		Compressive ultimate stress = 50 MPa
2	Structural Steel	Density = 7850 kg/m^3
		Young's modulus, E = 2 x 10^5 MPa
		Poison's ratio = 0.3

The reinforcement bars are placed centrally in both horizontal and vertical directions at a spacing of 200 mm centre to centre. The rebars used are deformed bars of tensile yield strength of 500 MPa. The diameter of the bars are 10mm. the permissible stress for

- Concrete, M50=12
- Reinforcement, Fe500= 275MPa

The original wall model has a dimension of 3600mm X 2700mm X 120mm. And for analysis half scale model is adopted here.

5.2 MODEL GEOMETRY

For various study in this work a model, wall specimen, of same outer dimension of 3600 mm X 2700 mm X 120 mm is used. Here the properties of opening is varied. Figure 3 shows general geometry of the specimen models that are analysed in this work. Depending on the study the dimension and the position of opening from the wall edge varies.

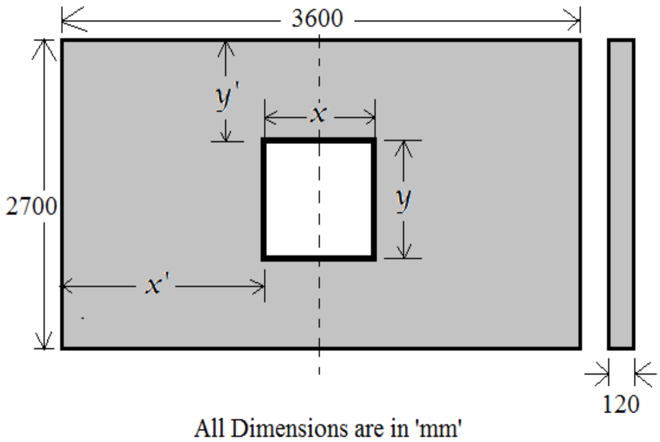

Figure 3-Geometry of specimen under study

5.3 MODELLING AND MESHING

The wall having dimensions 3600mm X 2700mm X 120mm is the actual specimen taken for study. The analysis is done on the half scale of this specimen. That is the study is done on structural concrete specimen having dimension 1800mm X 1350mm X 60mm with reinforcement bar of 5mm diameter at 100mm centre to centre spacing. This wall is modelled in ANSYS Workbench using various tools. The rebars used are deformed bars of tensile yield strength of 500 MPa. The above said material properties are then assigned to corresponding model.

Meshing is done by using generate mesh tool in ANSYS Workbench. Different kinds of meshing can be done in ANSYS. In normal meshing option we can't control minimum edge length of meshing but have a control on meshing element size. Which may affect the results of analysis and subsequently the conclusion derived.

5.4 BOUNDARY CONDITION AND LOADING

Boundary condition is also called support conditions. Here the study is done for both OW and TW wall panels. For one-way wall panels, the constraint is applied at top and bottom. At top displacement is arrested in Z direction and bottom displacement is arrested in all direction X, Y and Z. In TW wall panels in addition to these constraints the sides are restrained in both X and Z directions. Here Z indicate the direction perpendicular to the plane of the paper and along the direction of thickness of the wall. The XY plane is the plane of the paper and X and Y directions corresponds to the direction along length and height of wall respectively.

A uniformly distributed load is applied as a line pressure in ANSYS at an eccentricity of 1/6 of thickness from the centre of wall. The eccentricity allowed by the various codes are within the central middle third of thickness. And the 1/6 of the thickness from the centre line of thickness is the maximum eccentricity allowed. This eccentricity in applied load will make the wall to undergo the out of plane displacement which the parameter employed to study the behaviour of the wall with cut out openings. The loads are applied in such a magnitude the study is constrained to the linear analysis making use of the linear portion of stress and strain. To maintain linear analysis a load of 50N/mm is applied as line pressure in the half scale plan model for all the analysis hereafter.

6. OPTIMIZATION OF SHAPE OF OPENING

For finding the optimum shape of the opening that can be cut in OW and TW walls, four sets of analysis is done. In each set, seven models having same opening area but varying shape of opening are analysed. the four sets are as follows:

Set 1: 810000 mm^2

Set 2: 921600 mm^2

Set 3: 1000000 mm^2

Set 4: 1440000 mm^2

Under each set, seven models with different opening shape are done. The shape is varied from rectangles with narrow height (wide rectangular opening) to narrow width (slit rectangular opening) and that is compared with square of equivalent area. The model with a particular shape of opening which gives the least value for total deformation is the optimum shape for axially loaded structural concrete wall. The study is done for both OW and TW wall panels. Figure 4 to Figure 6 represent the types of opening that are analysed for optimizing the shape of opening. In each of following graph, studying optimization, the first three opening represent a wide rectangular opening and the last three represents the slit rectangular opening while the middle one is a square rectangular opening. The openings are placed concentric with the centre of wall in this study of optimization.

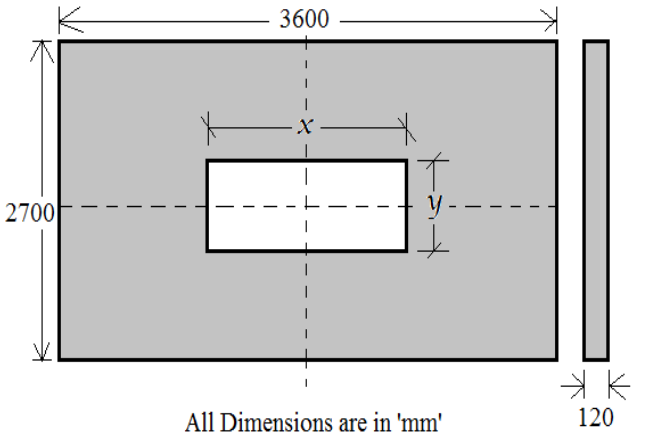

Figure 4- Geometry of the wall with wide rectangular opening.

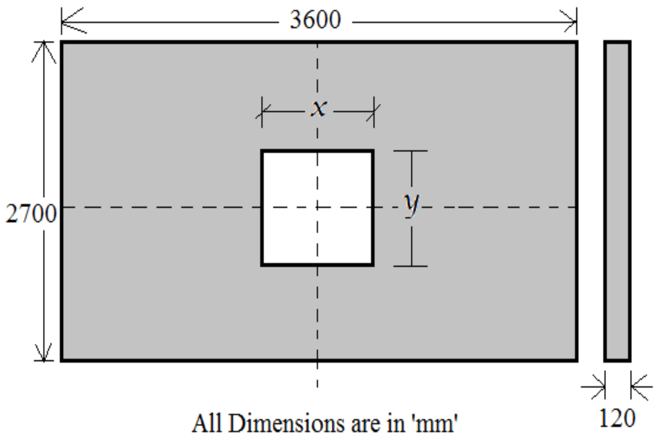

Figure 5- Geometry of the wall with square opening.

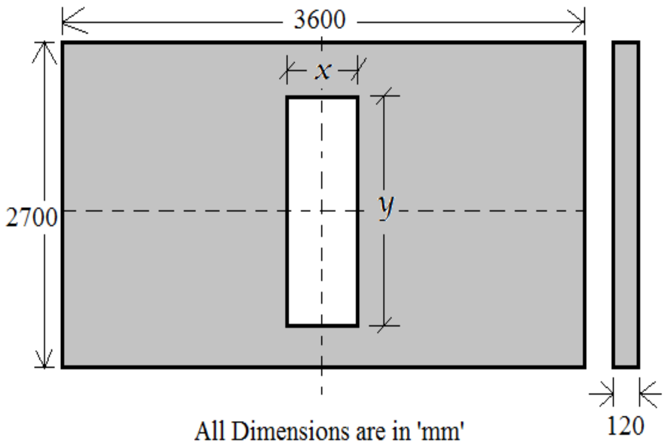

Figure 7- Geometry of the wall with slit rectangular opening.

6.1. ONE-WAY ACTION WALL PANEL

The variation of deformation for various shape of opening in a one-way action wall panel under each set is shown in Figure 8 to Figure 11. It can be seen that as the length of opening decreases and the height increases the out of plane displacement of wall decreases implying that the slit rectangular opening is the most optimum shape of the opening. That is, the most optimum shape of the opening that can be cut in OW wall panel is slit rectangular opening. The graph also indicates the significance of varying length on the strength characteristics of wall.

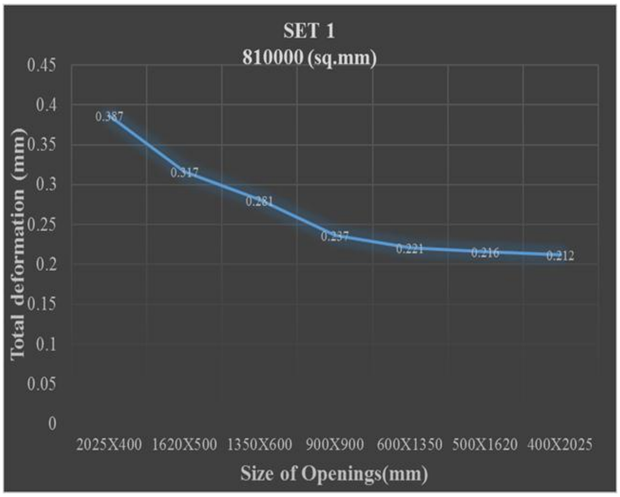

Figure 8- Variation in deformation with opening size of set 1 equivalent area.

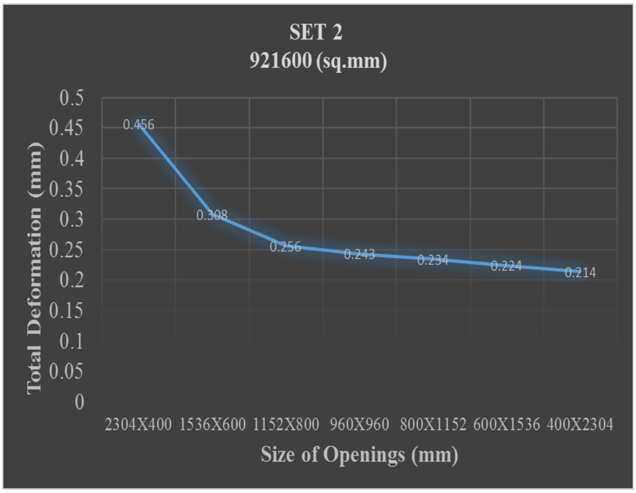

Figure 9- Variation in deformation with opening size of set 2 equivalent area.

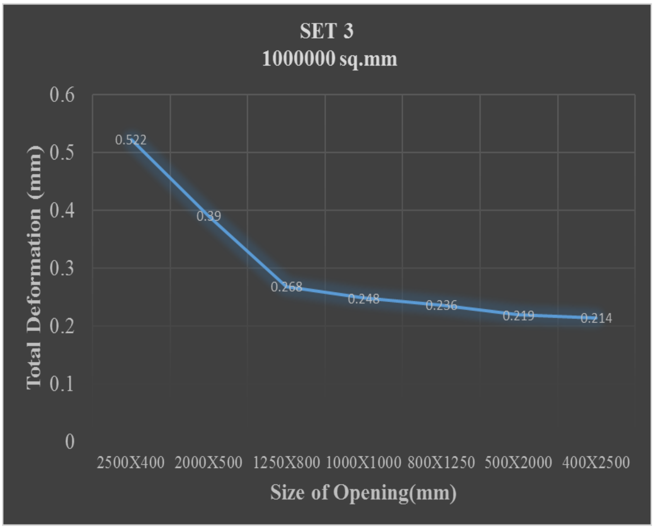

Figure 10- Variation in deformation with opening size of set 3 equivalent area.

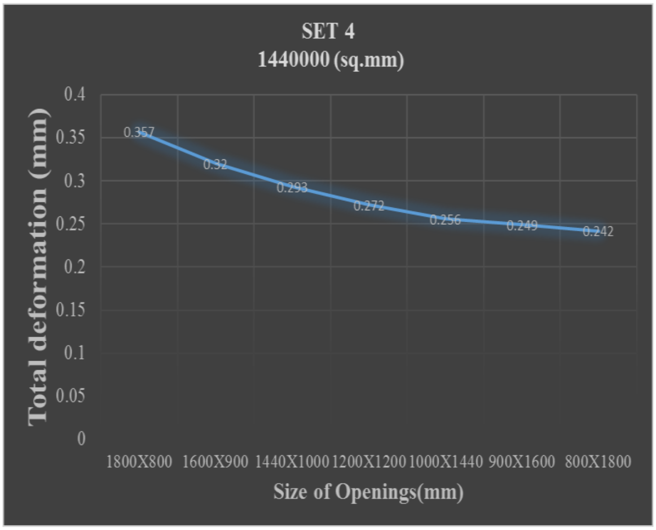

Figure 11- Variation in deformation with opening size of set 4 equivalent area.

6.2. TWO-WAY ACTION WALL PANEL

The figures 12 to 15 represent deformation variation of the TW walls with varying shape of the opening. Even though the shape is changing the area of the opening is same for each sets. It is clear, from these graphs that, the most optimum shape for the opening is square opening.

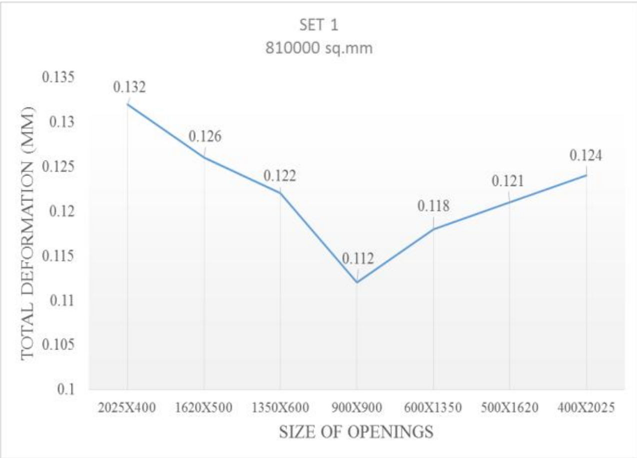

Figure 12-Variation in deformation with opening size of set 1 equivalent area.

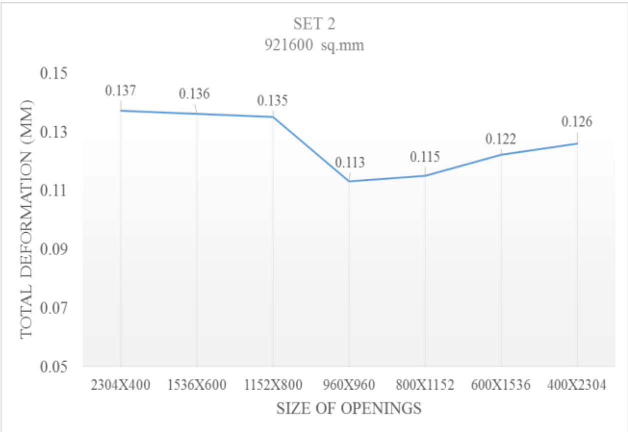

Figure 13-Variation in deformation with opening size of set 2 equivalent area.

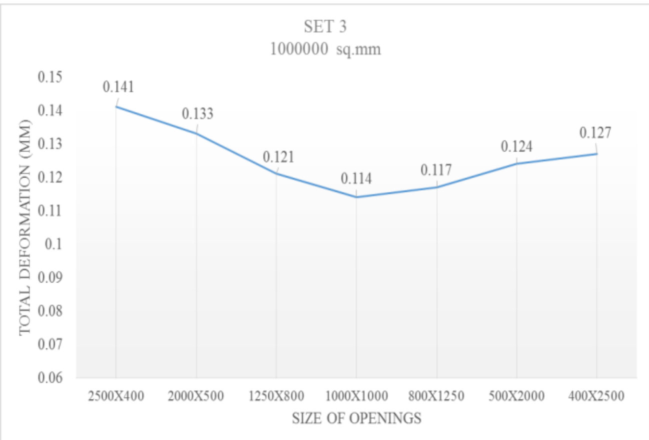

Figure 14- Variation in deformation with opening size of set 3 equivalent area.

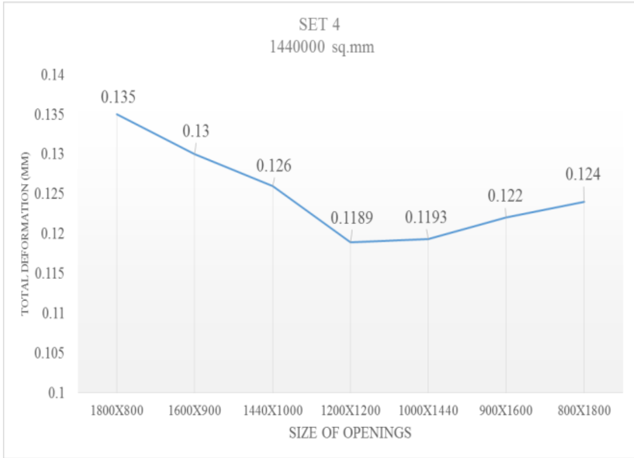

Figure 15- Variation in deformation with opening size of set 4 equivalent area.

7. CONCLUSION

This study is conducted to find the optimum shape of the opening that can be cut on a centrally reinforced axially loaded compression member. Here the influences of cutting an opening on both OW and TW walls are studied. The optimum shape that can be cut in an OW wall is slit rectangular shape while on a TW the square opening is the best suited shape. More studies are conducted on concrete structural wall the result will be published soon. The parametric study to find the influences of cut out opening's configuration, number of opening and eccentricity in position of openings are carrying out and the results will be published shortly.

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