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# Review on concrete structural wall with openings

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**Abstract –** *The growth of reinforced concrete building is increasing day by day, especially the mid and high rise building. So the importance of structural wall also increases. Normally, buildings are subject to vertical loads and horizontal forces like wind and earthquake loads. The vertical loads that transferred to the structural concrete walls can be eccentric. This can be due to the imperfections in construction, uneven loading conditions and truss elements which is supported on corbel placed on the wall and temporary loading during operation and/or maintenance. Openings are frequently provided in walls to meet the current 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. These openings are source of weakness and depending on their size and orientation they influence adversely the load carrying capacity of the member. Many studies can be seen in the literature for RC walls with and without. So here, in this paper the behavior of the structural concrete walls with opening are reviewed.*

***Key Words***: Concrete structural wall, opening characteristics, slenderness ratio, aspect ratio, layered finite element method.

## 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. Wall is a vertical load bearing member, whose breadth is more than four times its thickness. If the percentage compression of steel is less than 0.4% and the it is provided in single layer centrally in a wall then, it is regarded as plain concrete wall / structural concrete wall. With the increase in tilt-up construction, the importance of concrete walls also increases.

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).

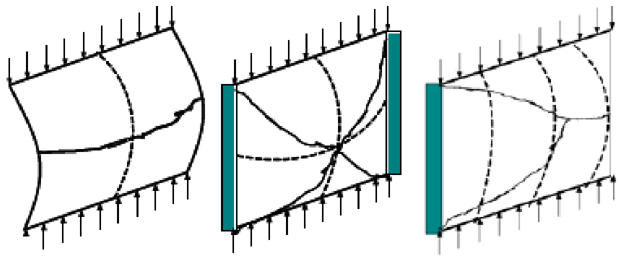


**Figure 1.** Behaviour of vertically loaded wall panels (J.H. Doh, Y.C. Loo and S. Fragomeni 2010)

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 some of which are reviewed here. But none came to conclusion regarding the optimal size of the openings and the size of the opening at which the structural behavior of the RC wall changes to RC frame. Here the behavior of concrete wall under axial load is discussed.

## 2. PARAMETERS INFLUENCES THE LOAD CARRYING CAPACITY

### 2.1 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.

## 2.2 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.

## 2.3 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.

## 4. LITERATURE REVIEW

Various literature reviewed on concrete structural wall is presented in this section. A number of works have been performed on structural concrete walls with and without opening. A review of literatures is presented in brief summarizing the work done by different scholars and researchers on the structural with opening.

**Philip Hallinan, Hong Guan (2006)**, in this paper the scholars explained the influence of opening and side restrain on the behaviour of concrete wall panels with high slenderness ratio. Here non-linear finite element method (LFEM) was adopted for numerical analysis of walls. The results were then compared to previously done experiment. The scholar found that the LFEM can predict the load-deflection responses, failure loads, the crack pattern and the deformed shape of the tested wall specimens. In order to predict connection of slenderness ratio and eccentricity with the ultimate load carrying capacity the scholar conducted parametric study on 54 OW and TW concrete walls specimens.

**Lee (2008)**, performed an experimental study on the behaviour of RC walls with openings. Scholar tested about forty-seven wall panels in one-way and two-way action having different slenderness ratio and opening configuration with an eccentricity of one sixth of the wall thickness. The experiments were done in three stages where in first stage, seventeen identical wall specimen in OW action with one and two opening tested while in second stage about eighteen specimens in TW were tested. In third stage scholar tested twelve specimens to draw conclusions on the influence of the opening configuration, its size and orientation.

LFEM was adopted by the scholar to perform the numerical analysis and he concluded that the method was reliable and it can be used to predict the ultimate load carrying capacity of the wall. It can also be seen that the LFEM predicts the load-deflection responses, the ultimate load, crack pattern and the deflected shape giving values close to experimental results.

**Hong Guana, Carlia Cooper and Dong-Jun Lee (2010)**, in this study the researchers validated LFEM and found it was reliable and had satisfactory accuracy. And the numerical analysis was done LFEM by conducting a parametric study by varying the length, height and both of an opening. and concluded that varying length and size of the opening had significant effects on the ultimate load and axial strength ratio of the wall. But varying the height of the opening along had no effects on the ultimate load and deflection. So the author proposed a new formula for the ultimate load of the RC wall, which incorporated the influence of both the length and height of the openings.

The scholar also states that the ultimate load carrying capacity of the TW action wall panels are greater than the OW wall panels. This was due to the positive influence of side restrains in TW wall panels. But as the size of the opening increases the extra strength gained by provision of the side restrain starts losing.

**J.H. Doh, Y.C. Loo and S. Fragomeni (2010)**, these researches had done experimental tests to study the behaviour of RC walls restrained on three sides as there were only limiting information regarding it. The load was applied at an eccentricity of one sixth of wall thickness. The six test specimens were provided with different opening configurations. In wall panels restrained on the three sides, the propagation of cracks was diagonally from the side restrained corners and it continued towards the corners of the openings while the cracking propagation was the opening edge to unrestrained wall edge. The scholar concluded that the behaviour of three sides restrained TW wall panels is a combination of both OW and TW restrained on four sides. If the opening was placed near to the restrained side of the three sides restrained wall, then the behaviour of wall converges to OW wall. Authors also concludes that addition of side restrains increase the load carrying capacity.

**S. Fragomeni, J.H. Doh and D.J. Lee (2012)**, in order to understand the behaviour of one and two way wall panels with opening under axial compressive loading, in this paper the scholars performed an experimental study on about forty-seven reinforced wall specimens with different opening configurations. Study was conducted on specimens varying their slenderness ratio, i.e., 30, 35 and 40 and the specimens are loaded with an eccentricity of one sixth wall thickness. The test results concluded that the opening configuration and support conditions of wall panel influence the failure loads and crack patterns. It can also be seen that as the number of opening increases failure loads decreases. And the failure loads of two-way wall panels is greater than one-way wall panels. The authors were able to explain about the influence of slenderness ratio on the axial strength ratio of the OW wall panel, i.e., as slenderness ratio increases the axial strength ratio gradually decreases. But the scholars were unsuccessful to draw conclusion regarding the effects of the slenderness ratio on the axial strength ratio of two-way wall panels. Here the authors verified various failure load formulae in research papers and code and concluded that the formula given in codes are giving more conservative results than the former equations.

**N. Ganesan, P.V. Indira and Anjana santhakuma (2013)**, in this paper fresh and hard concrete properties of geopolymer concrete (GPC) and steel fibre reinforced geopolymer concrete (SFRGPC) were discussed. To obtain the fresh concrete properties authors employed slump test and Vee-Bee test. The workability of the SFRGPC decreased with increase in fibre volume fraction. In order to maintain the slump values the researches applied superplasticizer. Dynamic workability tests showed that the Vee-Bee time increased with an increase in fibre content.

Hardened concrete properties are compressive strength, splitting tensile strength, modulus of rupture, modulus of elasticity and Poisson's ratio. Standard tests were employed to determine these properties of both GPC AND SFRGPC. The results of both materials were compared. From the test it was concluded that addition of steel fibres to GPC helped to increase its compressive strength. The addition of fibres increases the engineering and mechanical properties of the SFRGPC. The authors also developed equations relating the engineering properties to fibre parameters.

**Cosmin Popescu et. al (2015)**, has published a review paper on the advances and till now research on the structural wall with and without openings under axial compression. Here eccentrically loaded both monolithic and precast reinforced concrete walls were considered. The scholar created a database in order to check the reliability of existing design models employing previous experimental results of different tests. And concluded that the most conservative results were given by the codes compared to other design models. The parameters studied by the author were the boundary conditions, the size and position of openings and geometric characteristics. This paper showed that the most of the researches in the past were confined to one- way action walls compared to two-way action wall panels that too with fixed eccentricity of one-sixth of wall thickness. And the author also demanded more test on two-way action wall panels with different eccentricities and opening configuration to have better understanding of the behaviour of TW wall panels under axial compressive loading and generate the appropriate design models. The simplified methods do not consider the contribution of steel reinforcement in axial load carrying wall even if it is placed in two layers. For wall with single layer reinforcement mesh it was valid but for two layered reinforcement wall it is not valid since reinforcement increase the capacity of wall. At the time of failure these reinforcements contribute to the ductility of specimens. The author also states that the strength of walls with opening can be enhanced using FRPs.

**D.J. Lee, H. Guan, J.H. Doh & S. Fragomeni (2016)**, in this paper authors employed Layered Finite Element Method to perform the nonlinear analysis of RC wall panels under axial compressive loading. LFEM was used to study structural behaviour of such walls. The design aspects highlighted in this paper includes the one- and two-way actions, the number of openings, high compressive strength concrete and the slenderness ratio. The author verified the accuracy and reliability of the LFEM by comparing with the previous design models.

**Cosmin Popescu et. al (2016)**, studied the behaviour of RC wall with and without opening under axial compressive loads. Here the load is applied with an eccentricity and the openings were cut-out openings with no diagonal bars at the opening corners as in case of predesigned openings. The diagonal bars provided at the opening corners prevents the premature cracking due to shrinkage and the cut out openings are provided after casting the solid wall. Here three half scaled reinforced concrete specimens exhibiting two-way action were employed for testing.

It can be seen that the reduction in the cross sectional area of the similar specimen directly reduce the load carrying capacity of the structural wall member. The author in this experiments employed digital image correlation technique to capture the failure progression. The scholar also concluded that even if the reinforcement provided in single layer centrally may not make any significant contribution at serviceability limit states but at the time of yielding contributes to overall ductility of the member. It also states that the effect of the eccentricity on the axial strength is more when opening size ratio is less and effects decrease with increase in the ratio.

## 5. CONCLUSIONS

Based on the above literature survey, a review paper is prepared. The main points that can be concluded are;

- The most of the previous study of wall panel mainly focused on the designed opening and OW Panels. So more research is needed for TW panels and cut out openings.

- It can be also seen that the slenderness ratio, aspect ratio and opening can influence the load carrying capacity of both OW and TW wall panels.
- Slenderness ratio is inversely proportional to the axial load carrying capacity of the wall. As slenderness ratio increases the load carrying capacity decreases.
- As the aspect ratio for OW wall panel increase its load carrying capacity also increase but TW wall shows reverse tendency.
- Opening also decrease the load carrying capacity depending on its characteristic.
- If the reinforcement is provided in single layer mesh its contribution to the ultimate load carrying capacity and strength of the wall is neglected in most of the design codes. But at the time of the failure the reinforcement contributes to the overall ductility of the member.

To apply further changes to existing structure cut-out openings are needed to provided, so it is important to know the influence of shape, size and position of the opening and various strengthening methods and their implementation.

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