Effect of Base Opening in Reinforced Concrete Shear Wall

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Abstract
Shear walls (SW) are proven to be efficient in resisting and transferring the lateral/seismic loads in earthquake prone areas. In High raised buildings it is customary to provide basement parking also known as stilt parking which leads to the provision of openings at the base of shear walls. Therefore it is very important to study the logical positioning of the base opening and the behaviour of structure. This paper presents the study on SW with base openings, focusing on comparing the load carrying capacity with respect to that of solid SW. Finite element package in ANSYS software is used for modeling and analysis. A non-linear static analysis is performed for two parameters – a) location of the base opening and b) the percentage area of base opening for the SW. It is observed in the case of SW with symmetric base opening, the eccentric base opening leads to less load carrying capacity comparatively. Also it is found that the load carrying capacity decreases abruptly for the shear wall with base opening area greater than 50% of solid shear wall.
Keywords: ANSYS, Base opening, Non Linear Static Analysis, Seismic load, shear wall
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1. Introduction

One of the lateral force resisting systems consists of Shear walls, which are vertical structural members in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150mm, or as high as 400mm in high rise buildings. Shear walls are usually provided along both length and width of buildings Shear walls are like vertically-oriented wide beams that carry earthquake loads downwards to the foundation.

The multi-storey buildings rely on shear wall to resist transverse wind and seismic forces. The cantilever shear wall designed for the lateral loads, strong in the direction of their length. The rise from the fixity provided by strong and stiff foundations to cantilever up to the top of the building. The structural performance of shear walls under seismic loading depends on the strength of service level, while the performance at the life safety depends on the stiffness, as the shear walls undergo significant in elastic behaviour at this level.

. Lateral forces are generated either due to wind acting against the building or due to the inertia forces induced by ground shaking tend to snap the building in shear and push it over in bending. These forces can be resisted by the use of a shear wall system which is one of the most efficient methods of ensuring the lateral stability of tall buildings. [1]

Two popular schemes of modeling shear walls are the finite element method which is considered next to exact solution if the material properties are correctly implemented, and the equivalent frame method which involves less modelling effort, but less accurate results. [2]

These days construction of High raised building is very common, and this leads to have parking at the basement or ground level, causing for opening at the base, therefore proper positioning of base opening is very important for the structure to behave safe .

2. Validation of Software

In order to check if the model developed in the software is correct, it is very important to validate the results obtained. Here is the shear walls undergo significant in elastic behaviour at this level.

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2.1 Deep Beam Concept

For Validation purpose the shear wall is analyzed as a Deep Beam where the design lateral force, determined using Equivalent Static force Method according to IS 1983(Part 1):2002 is applied only at the top floor as shown in figure for the analysis in ANSYS.

Deep beams are structural elements loaded as simple beams in which a significant amount of the load is carried to the supports by a compression force combining the load and the reaction. As a result, the strain distribution is no longer considered linear, and the shear deformations become significant when compared to pure flexure.

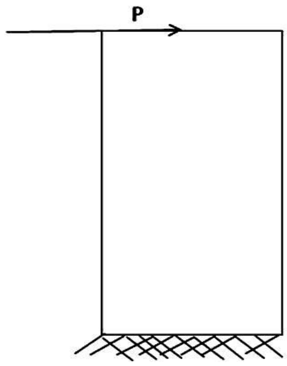


Figure 1: Cantilever Shear Wall
(Neuenhofer, 2006)

$$\Delta_{Total} = \Delta_{Flex} + \Delta_{Shear}$$

$$= \frac{PH^3}{3EI} + \alpha . \frac{PH}{GA} \qquad \text{Eq. (1)}$$

The flexure term considers the wall as a vertical cantilever with moment of inertia I. The shear term contains the shape factor α which accounts for the distribution of shear stresses across the section and the shear area A. The material properties E and G = modulus of elasticity and shear modulus, respectively, which are related by

$$G = \frac{E}{2(1+\upsilon)} \qquad \text{Eq. (2)}$$

Where υ=Poisson’s ratio. Using α =1.2, and I=bL3/12 for a rectangular wall and selecting υ=0.3 gives

$$\Delta_{Total} = \Delta_{Flex} + \Delta_{Shear}$$

$$= P/E.b\ [4(H/L)^3 + 3\ (H/L) \qquad \text{Eq. (3)}$$

Where Pmax=149kN (From Static Equivalent method), H=15m, L=8m, b=0.23, E=2x10Gpa Therefore substituting the above values in Equation 3. Maximum deflection in X direction = 0.104mm

Modeling and Analysing the shear wall considered in ANSYS 13 we get maximum Deflection in X axis direction = 0.109mm. Thus the result obtained in hand calculation and software is very close and hence we conclude that the software is validated.

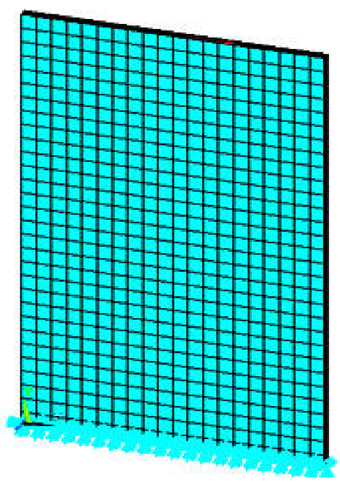


Figure 2: Shear wall modeled in ANSYS for validation

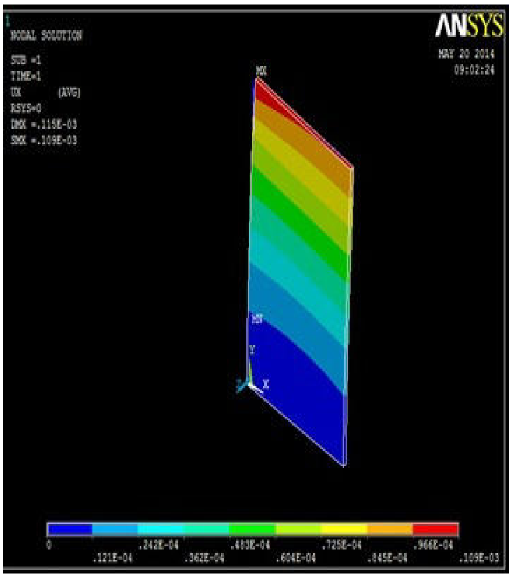


Figure 3: Resultant Displacement in mm (ANSYS)

Note: Red colour indicates the maximum displacement and blue colour indicates minimum displacement

3. Structural Modeling

Model of the Shear wall that is analysed in this study is well articulated in figure 2.The analysis method used in this research is the Non Linear Static method. A five storeyed Reinforced concrete building with shear wall, located in zone IV, has been considered for the analysis. The Lateral forces are resisted by the Special Moment Resisting Frames and Reinforced Shear wall. The Lateral Force at every Floor Level is Calculated Using Equivalent Static Method, IS 1893(Part 1):2002. The shear wall is isolated from the structural elements and further analysis is carried out for the considered shear wall.

A Nonlinear Analysis of a Shear wall is carried out using a Finite Element Software, ANSYS.

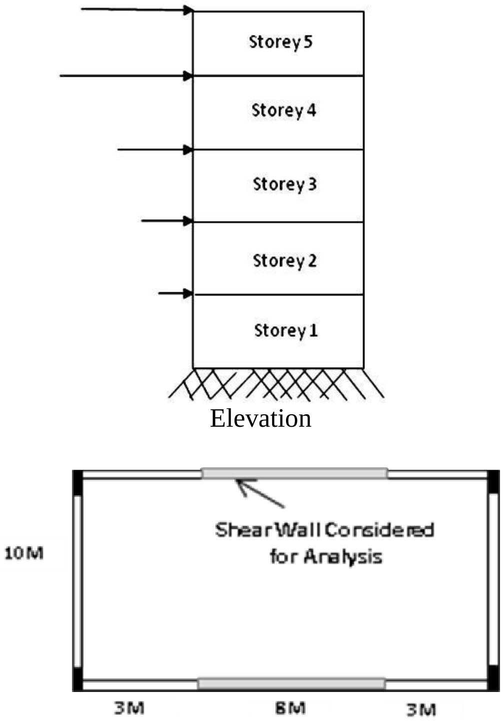


Figure 4: Structural Detail of the Building considered

3.1 Structure Definition

The building considered is 5 storeyed, of floor to floor height of 3 meter. The Structural walls and the columns have the same cross sections throughout the height of the building. The floor beams and the slab also have the universal dimensions at all the floor levels. Shear wall of 230mm is centrally located at the exterior frames in X direction, the thickness of floor slab and roof is 150mm. The dimensions of all the beams of frame are 230mm x 400mm and that of columns is 230mm x 450 mm. The structure is assumed to be fixed at the base. The grade of concrete is M20 and steel used is Fe415.

3.2 Boundary conditions and loading

The shear wall alone is isolated from the structural components to study its behaviour. The shear wall considered is fixed at the base.

Earthquake loading is considered to be the lateral force on the shear wall. The lateral load at each floor level is calculated according to Indian Standard code 1893(Part1):2002 considering equivalent static method of evaluation.

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} \qquad \text{Eq. (4)}$$

Where

Qi = Design lateral force at floor i,

Wi = Seismic weight of floor i,

hi = Height of floor i measured from base, and

n = Number of storeys in the building is the number of levels at which the masses are located.

4. The Computer Program for the Analysis

The software used to analyse the RC shear wall models in this study is ANSYS 13 which is finite element software. ANSYS is a Finite Element Modeling package for numerically solving a wide variety of problems. The material used to model the Shear wall in Ansys is Solid element under which Concrete 65 is chosen for the concrete and Link element under which 3D finite stn 180 is chosen for the Rebar in concrete as the reinforcing material.

4.1 Concrete element

SOLID 65 is an element used for the three-dimensional modeling of solids with reinforcing bars. SOLID65 is capable of cracking in tension and crushing in compression. In concrete applications, the solid capability of the element may be used to model the concrete.

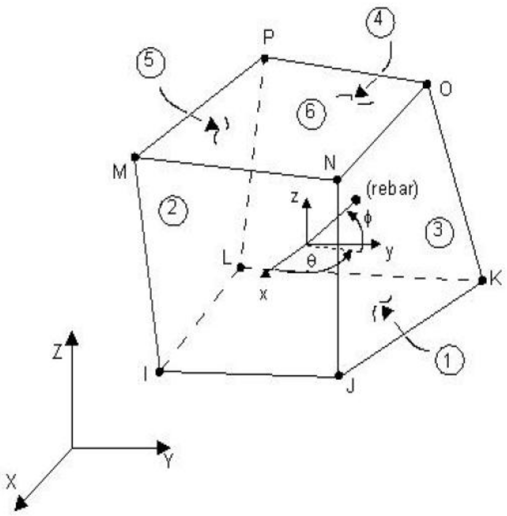


Figure 5: Solid 65 Geometry

4.2 Reinforcement Element

LINK180 is a spar that can be used in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, etc. This 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node, translations in the nodal x, y, and z directions.

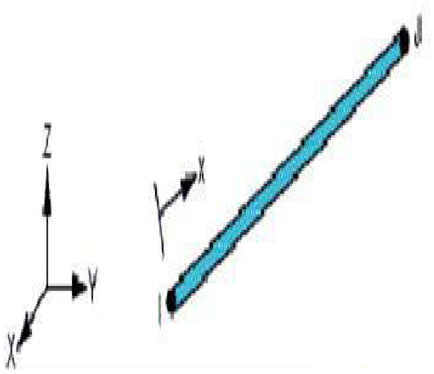


Figure 6: LINK180

4.3 Material Properties

From several earlier research studies made, following material properties are assigned for the RC shear wall model considered for the analysis.

Table 1: Concrete Properties

Material	Modulus of elasticity MPa	Poisson's ratio
Concrete	5000√ fck = 27386	0.3
Open shear transfer coefficient (βt)	0.2	
Closed shear transfer coefficient(βc)	0.9	
Ultimate uniaxial cracking stress (f'c),	3.78 Mpa	
Ultimate uniaxial crushing stress	30 Mpa	

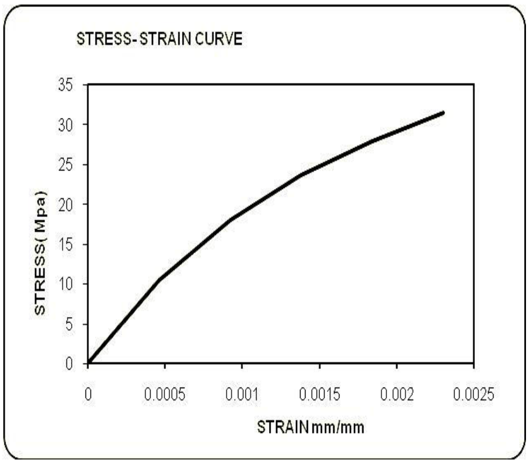
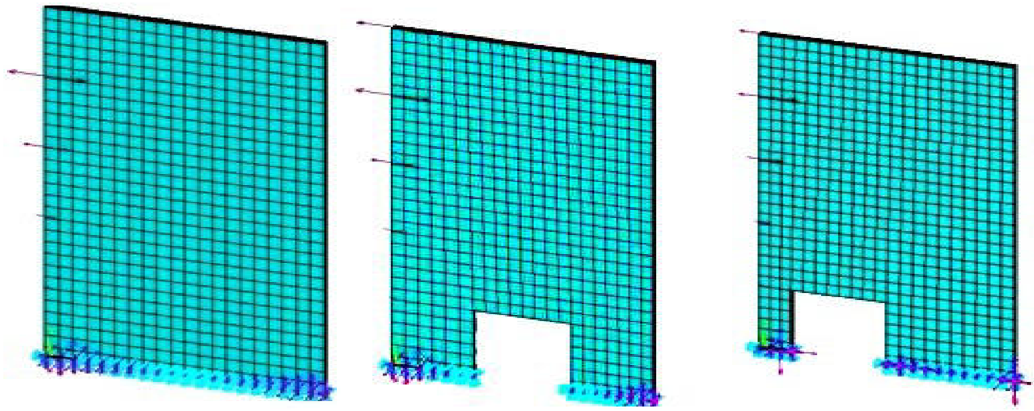


Figure7: Concrete stress strain curve for unidirectional monotonic compressive loading

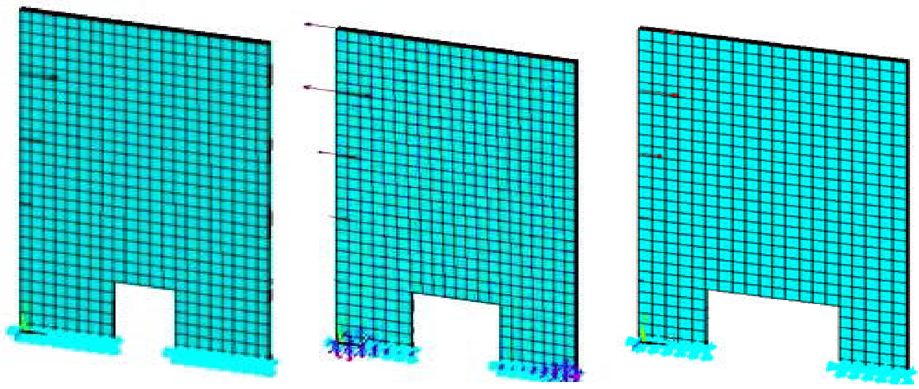
4.4 Parameters considered for study

1. Study of behaviour of Shear wall based on the location of base opening.
2. Study of behaviour of Shear wall based on different percentage of opening area.

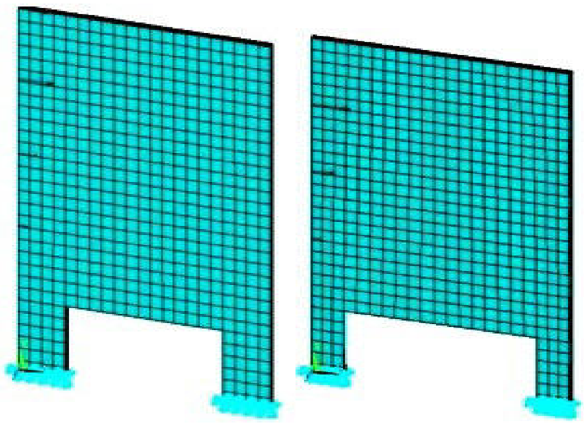


a. Solid Shear wall b.Shear wall with symmetric opening c. Shear wall with eccentric opening

Figure 8: Finite Element Models of Shear wall (ANSYS)



a.25% of base opening b.35% of base opening c.50% of base opening



d.60% of base opening e.75% of base opening

Figure 9: Finite Element Models of Shear wall (ANSYS)

5. Results and Discussion

The study focuses on the behaviour of shear wall with Base Opening. Mainly their load carrying capacity is determined by studying the load versus displacement curves which also defines the initiation of cracking. Several iterations were carried out to determine the proper lateral loads that are applied at each floor level.

The load was gradually increased following a non-linear static analysis until considered shear wall attains failure or cracks develop making the shear wall unstable.

5.1 Location of Base Opening

First parameter considered for the study is, the location of the Base Opening, and following results are interpreted.

1. From the analysis carried in ANSYS 13, it is studied that at a load value of 160 kN the Solid shear wall(Shear wall without base opening) starts cracking, for shear wall with symmetric opening at the base, it starts cracking at a load value of 143.6 kN, whereas shear wall with eccentric opening starts cracking at a load value of 106 kN.
2. From the studies made above, it is observed that the Shear wall with symmetric opening at the base has 10 % less load carrying capacity when compared to that of the solid shear wall (Shear wall without opening), whereas the Shear wall with eccentric opening has 44% less load carrying capacity when compared to that of the solid shear wall.

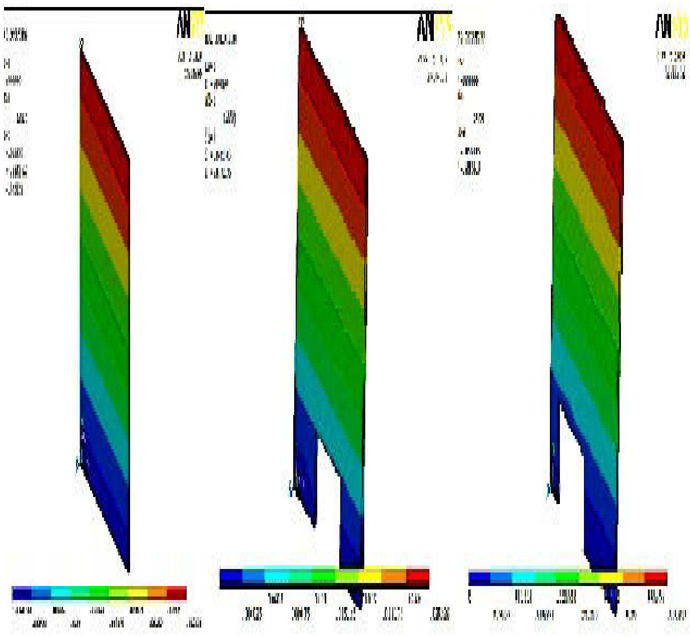


Figure 10: Resultant Displacement in mm (ANSYS)

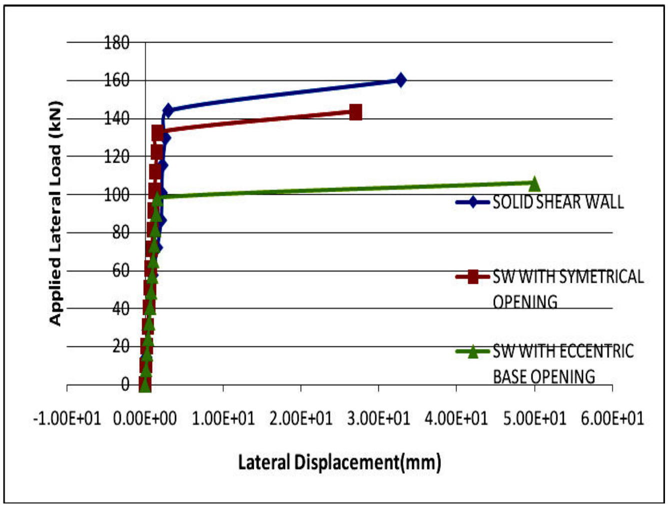


Figure 11: Applied lateral Load versus Lateral Displacement for SSW, SW with Symmetric Base Opening and SW with Eccentric Base Opening

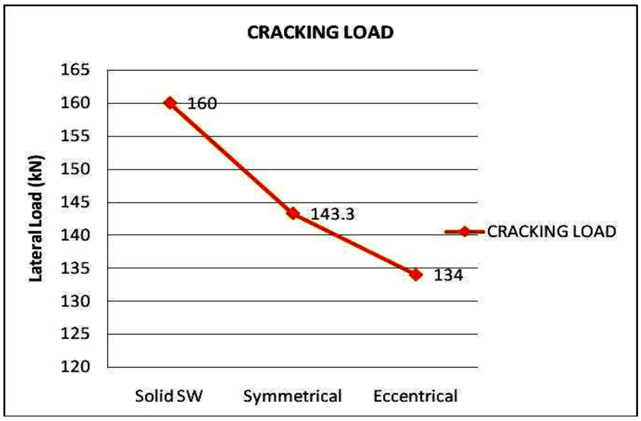


Figure 12: Cracking Load for the Three Models Studied

5.2 Percentage Area of base opening

1. From the analysis carried out for various opening sizes, maximum displacement for Shear wall with base opening size of 25% area of that of solid shear wall at ground storey is observed at 150.8 kN at which the shear wall starts cracking, and that for other opening sizes of 35%, 50%, 60% and 75% it is observed at 143.3kN, 122.6kN, 118kN and 52.8kN respectively.
2. Thus above discussion shows, that as the percentage opening area at the base increases the load carrying capacity decreases.
3. It is also observed that the load carrying capacity decreases abruptly beyond 50% base opening area, that is below 50% opening area, the decrease in load carrying capacity is small whereas that for opening area of 50% and above the load carrying capacity is less than 75%.

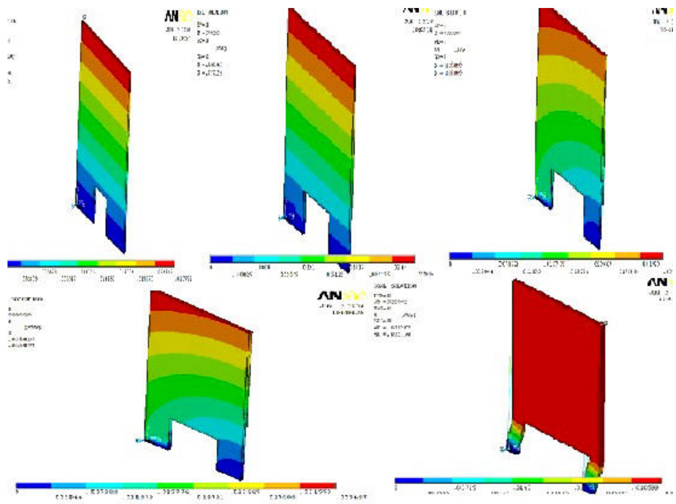


Figure 13: Resultant displacement at cracking in mm (ANSYS 13)

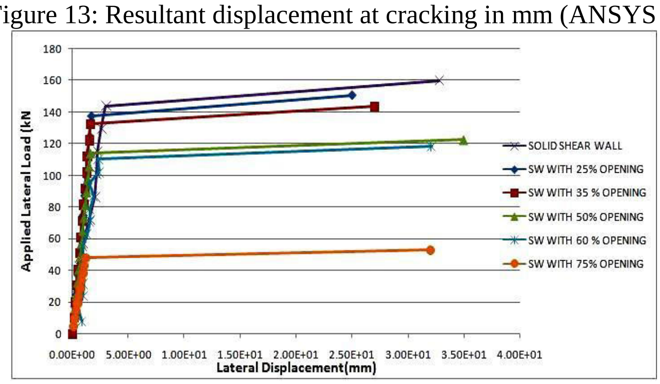


Figure 14: Applied lateral Load versus Lateral Displacement for Solid SW, SW with Symmetric Base Opening and SW with Eccentric Base Opening

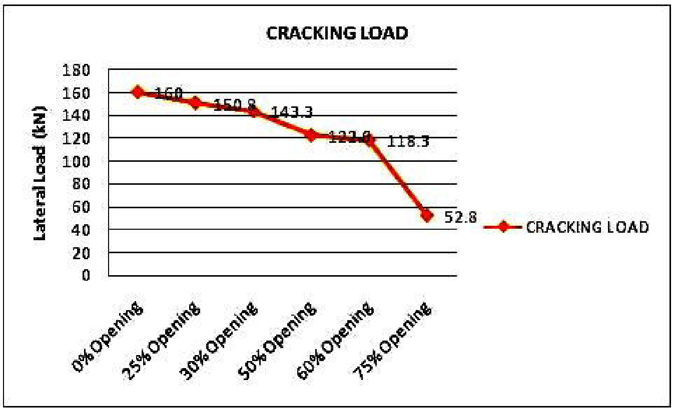


Figure 15: Cracking Load for Different Shear Wall Models with Different Percentage Openings

5.3 Crack pattern

The nature of cracks developed for the shear wall with opening and without opening is different. The red patches seen in the figure 3.2 are the cracks that are developed at cracking load. It is observed that in Solid Shear wall (without base opening) the initiation of cracks is at the base level which is uniformly spread, whereas in case of shear wall with base opening, cracks developed is concentrated at the opening and moves towards the top.

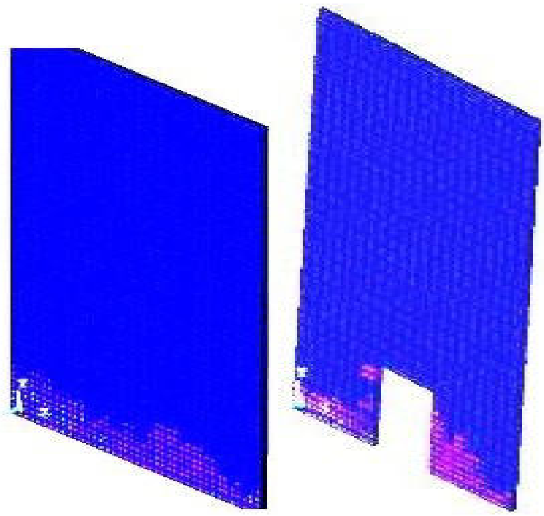


Figure 16: Initiation of Cracks

Conclusions

On the basis of the study carried for shear wall with and without base opening following conclusions were made:

1. Load carrying capacity is higher for shear wall without opening.
2. Load carrying capacity of shear wall with symmetric opening is 90% of that of solid shear wall which is higher, compared to that of shear wall with eccentric opening that is 56 % of that of solid shear wall hence eccentricity in the base opening must be avoided as far as possible.
3. As the area of base opening increases the load carrying capacity decreases.
4. Load carrying capacity for solid shear wall and up to opening sizes below 50% area of that of solid shear wall at ground floor are relatively close and above this the load carrying capacity values are about 75% and less than that of solid shear wall.
5. Thus the percentage of base opening greater than 50% of that of that of solid shear wall must be avoided.
6. The cracks developed in shear wall without opening is close to the base where as that of shear wall with opening the cracks initiate at the base and move upwards.

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