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BEHAVIOR OF REINFORCED CONCRETE FRAME WITH SHORT COLUMN EFFECT UNDER LATERAL CYCLIC LOADING

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ABSTRACT

In this paper an attempt was made in reinforced concrete structures where windows or door openings have been left in the infill walls due to architectural necessities. The columns with partial infill has been damaged seriously during the past earthquakes due to short column effect and this type of column leads to major failure of structure during earthquake. The behaviour of such columns is not known fully. This paper investigates analytically the behaviour of short column under cyclic lateral loading. The aspect ratio of infill wall (L_w/H_w, where L_w = infill length, H_w = infill height) and its placement configurations were the parameters of the analytical study. The behaviour of the three short columns in the frame with different aspect ratios were studied for load displacement hysterisis curve, stiffness degradation, ductility ratio, Von Mises Stress and crack pattern. Test results indicates that when the aspect ratio of the infill was increased, the lateral strength and rigidity increased and at the same time displacement and ductility of structure were decreased. In addition to this, crack pattern results indicates that in the bare frame without infill, initial cracks are developed at the beam column joint and at the ultimate load level, a series of wide cracks are developed at the support which makes the structure instable and leads to failure. In the partial infill frame, cracks are developed at the junctions of beam column and masonry infill. Nominal cracks are developed at the support since the portion below is completely restrained by the tight fitted masonry infill. So this tends to the formation of short column effect in the frame member with partial infill, which leads to major collapse.

Keywords: Short column effect; cyclic loading; aspect ratio; partially infilled frame; stiffness; ductility.

1. INTRODUCTION

From past earthquakes in India and world, several buildings were subjected to failure

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predominantly due to short column effect. The short column effect occurs in a wall (masonry or RC) of partial height, built to fit a window over the remaining height. The adjacent columns behave as short columns due to the presence of these walls. In many cases, other columns in the same storey are of regular height, as there are no walls adjoining them. Many of the existing buildings are having short column because of partially infilled frames. So it is necessary to study the behaviour of frames with short column effect. In the past research, which is related to reinforced concrete infilled frames, many different types of infill wall and infill reinforcement arrangements were studied. In addition many types of connections of infill wall to the surrounding frame were also studied, such as shear key, dowel and chemical anchors [1–16]. In these studies, one-bay one-storey infilled frame and one-bay two-storey infilled frames were tested under monotonic or cyclic lateral loading. The test results indicated that an infill wall increased the lateral load capacity of the frame and reduced the lateral drift at failure.

The researchers showed that the following criteria's were affected due to the behavior of infilled frames significantly: (a) Properties of infill and frame, such as the ratio of column flexural reinforcement, column and beam type stirrups ratio, concrete compression strength, infill material type- whether masonry brick or reinforced concrete, etc., (b) Type and effectiveness of connections made between the infill and the frame members (c) Infill reinforcement arrangements (d) Reinforced concrete infill not filling the entire frame openings for windows and doors.

All reviewed studies in the literature were investigated fully on the behavior of infilled reinforced concrete bare frames and partially infilled concrete frames, while carrying larger lateral forces; but no studies were encountered in the literature about the formation of short column effect and its behavior because of partially infilled frames under seismic loads. The fact that there was insufficient knowledge about the short column effect raised the necessity of analytical studies on this subject. Hence the objective of this paper is to report an analytical investigation on short column and its behavior on partially infilled frame under cyclic load. The displacement, stiffness, ductility, crack pattern of one-bay one-storey RC bare frame with RC partially infilled frame, with short column effect were investigated. In this research, the experimental parameter that was studied is the ratio of infill length to infill height (L_w/H_w).

2. ANALYTICAL WORK

2.1 Descriptions of model and material properties

In this analytical study, three models were made and tested. The test frame was a 1/3 scale, one-bay, one-storey RC frame. During design phase of the frames, weak-column, strong-beam which is encountered frequently in practice was taken into account. The properties of test specimens were summarized in Table 1, 2 & 3. Geometrical dimensions and reinforcement of all specimen frames were selected to be the same. Dimensions and reinforcement details of test frames were shown in Fig. 1. The two columns and the beam were constructed with dimensions 100 × 150 mm and 150 × 300 mm respectively. In columns, four 10 mm diameter deformed bars were used as longitudinal reinforcement. Plain bars with a diameter of 6 mm, spaced at 80 mm were used as closed ties in columns. Stirrups were spaced at 40 mm at the end section of columns. Eight deformed bars with a diameter of 8 mm were used as longitudinal reinforcement in beams. Plain bars with diameter of 4 mm, spaced at 40 mm were used as closed ties in beams as shown in Fig. 1.

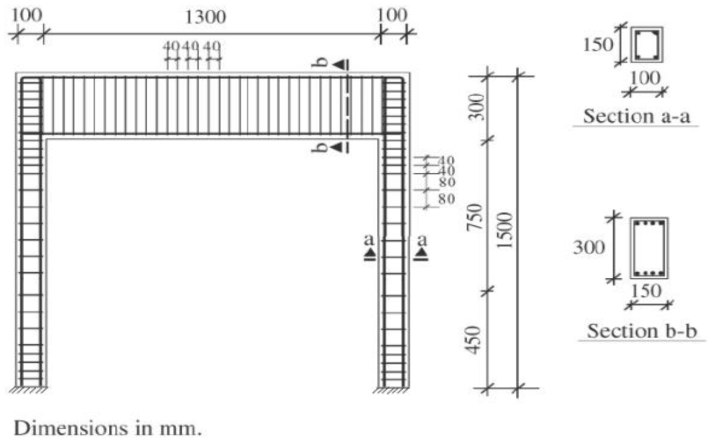

Figure 1. Reinforced concrete frame size and reinforcement details

In ANSYS, SOLID 65 element is used for 3-D modeling of solids without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

Brick walls are numerically modelled by two micro and macro modelling categories. Brick wall consists of three main components: brick, mortar and brick mortar contact surface. In micro modelling, each component is modelled separately but in macro modelling, the wall is assumed as a homogeneous and integrated material with equivalent mechanical properties which makes this method feasible, wherein the amount of calculations is much lesser than that of micro modelling; although the accuracy is not very high. It is usually applied for modelling larger sizes.

In the numerical modelling of brick walls, two different types of behaviour were envisioned, regarding the behavioural and crack-failure mechanism. The former case applies to the walls with high tensile and shear cohesion between brick surfaces and mortar, where shear cracking and crushing passes through both brick and mortar, with almost no slide between them. In the latter case, shear cracking and crushing never passes through the bricks and masonry units and that cracking occurs entirely within the mortar and the contact surface between brick and mortar.

In this paper, infill walls were modelled according to the latter case of brick wall behaviour, with Solid 65 element, with zero percentage of reinforcement. The property of masonry infill was simulated within the element by defining its properties through material models as shown in Table 1. The non-linearity of the concrete material is considered in the finite element model by giving non-linear isotropic properties to the concrete element as shown in Table 2. Bi-linear isotropic properties are used for steel reinforcement. Grade of steel is Fe 415. The properties are given in Table 3.

Table 1: Brick properties

Density	18 KN/m^3
Linear Isotropic Properties	
Elastic Modulus	10300 N/mm^2
Poisson's ratio	0.2

Table 2: Concrete properties

Density	25 KN/m^3
Linear Isotropic Properties	
Elastic Modulus	30000 N/mm^2
Poisson's ratio	0.2
Multi Linear Isotropic Properties	
0.0005	15 N/mm^2
0.0010	21 N/mm^2
0.0015	24 N/mm^2
0.0020	27 N/mm^2
0.0030	24 N/mm^2

Table 3: Rebar properties

Density	78.5 KN/m^3
Linear Isotropic Properties	
Elastic Modulus	200000 N/mm^2
Poisson's ratio	0.3
Bi-linear Isotropic Properties	
Yield Stress	415 N/mm^2

The aspect ratio of the infill wall was taken as the study parameter and the behaviour of all the three samples were studied under cyclic load. In ANSYS, Reinforced Concrete frame is modelled through volume blocks, which were further fragmented to a number of finite elements by making the maximum size as 25 mm. Different types of meshing were adopted to check its convergence criteria and based on that, the final results are plotted for the optimized mesh with optimized size of the element. Rectangular eight node brick elements were used in all samples. The load application method is a force approach method and the self-weight of the specimen is taken as a gravity load and the same is applied in the Inertia tab in ANSYS. All the loads and degrees of freedom are applied in the solution tab. The finite element model of Reinforced Concrete bare frame is shown in Fig. 2. Partially infilled reinforced concrete frame with aspect ratio 2.17 is presented in Fig. 3. Similarly partially infilled reinforced concrete with wall aspect ratio 1.44 is presented in Fig. 4.

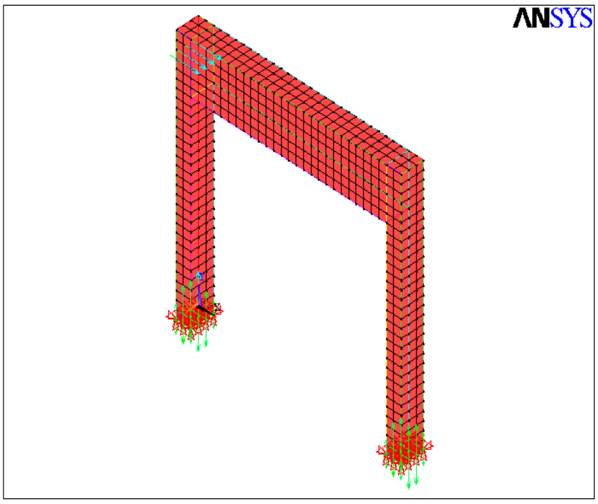

Figure 2. Finite element model of reinforced concrete bare frame

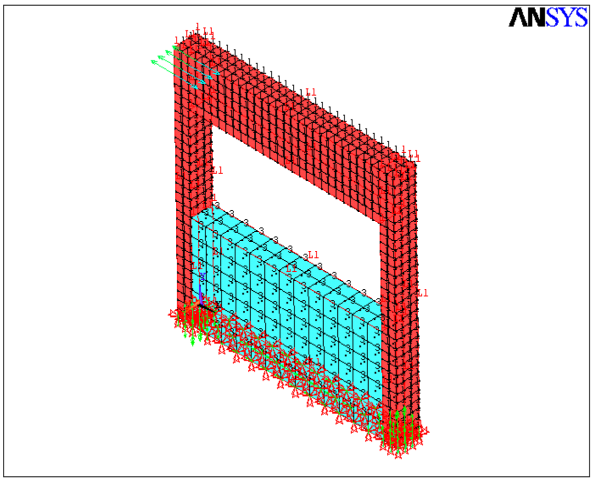

Figure 3. Finite element model of a partially infilled frame with aspect ratio of 2.17

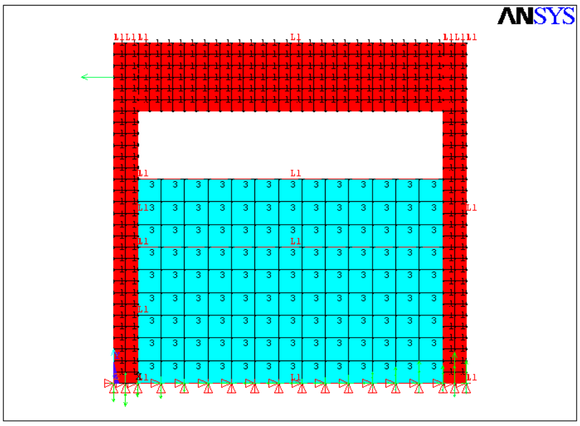

Figure 4. Finite element model of partially infilled frame with aspect ratio of 1.44

3. RESULTS AND DISCUSSION

3.1 Hysteresis curves for specimens

The Load-displacement hysteresis curves that were observed for Reinforced Concrete bare frame and partially infilled frames with aspect ratios of 2.17 and 1.44 are illustrated in Fig. 5, Fig. 6 and Fig. 7 respectively. The specimen's load carrying capacity was named as ultimate load. The ultimate load of the specimen was equal to the maximum load value. Before cracking of the specimen, the hysteresis curve follows a straight line and the deformation is recovered in the elastic deformation stage.

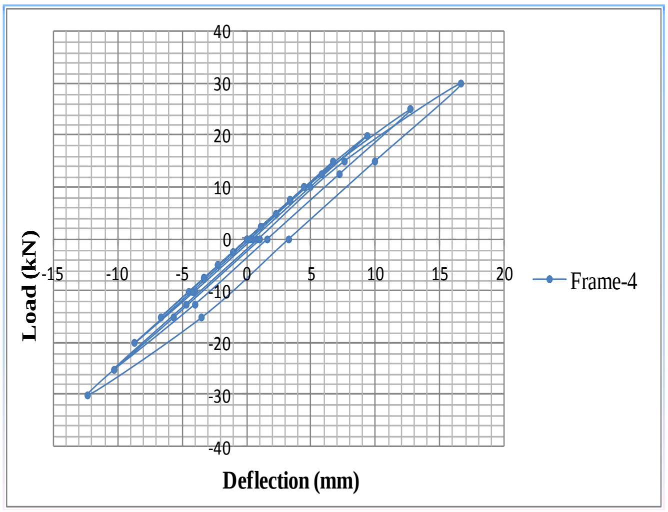

Figure 5. Load displacement hysterisis curve for reinforcedconcrete bare frame

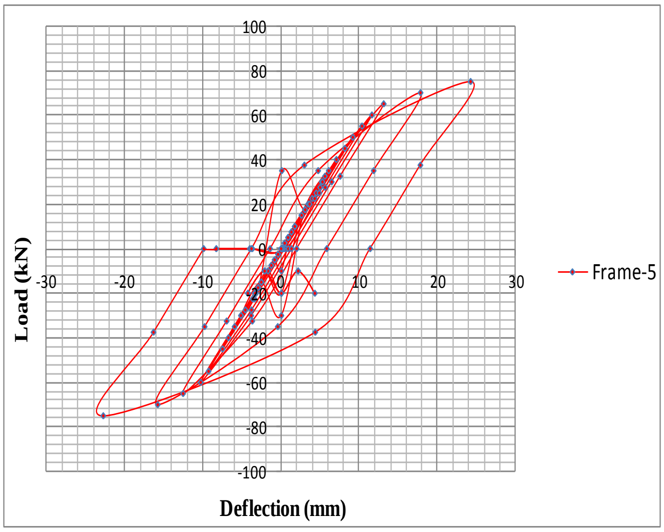

Figure 6. Load displacement hysteresis curve for partially infilled reinforced concrete frame with aspect ratio of 2.17

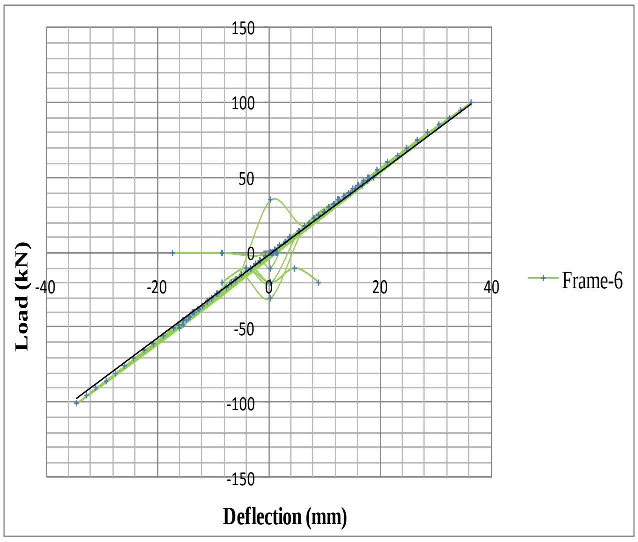

Figure 7. Load displacement hysteresis curve for partially infilled reinforced concrete frame with aspect ratio of 1.44

After cracking, the hysteresis loop gradually tilts towards an horizontal line (i.e., a fast increase in displacement rate corresponding to a slow increase in the load rate). With an increase of the lateral load, the area of the hysteresis loop gradually increased. In the early loading, the area of the hysteresis loop was stable. However, the area of hysteresis loop gradually increased because of degradation of stiffness in the specimen, as shown in Fig. 6 and its area decreased as the stiffness increases, as shown in Fig. 7.

The ultimte load of the bare frame at 30 KN shows 16.66 mm displacement, but the frame with partial infill having aspect ratio 2.17 & 1.44 reaches ultimate load in 70 KN & 100 KN because of the short column effect. The displacement of the frame with partiall infill is 5.19 mm & 10.73 mm; this is because of the increase in the stiffness.

3.2 Stiffness degradation

Many structural components and systems will exhibit some level of stiffness degradation when subjected to reverse cyclic loading. This is especially true for reinforced concrete components subjected to several large cyclic load reversals. Stiffness degradation in reinforced concrete components is usually the result of cracking, loss of bond or interaction with high shear or axial stresses. The level of stiffness degradation depends on the characteristics of the structure (e.g., material properties, geometry, level of ductile detailing, connection type, etc.,) as well as on the loading history (e.g., intensity in each cycle, number of cycles, sequence of loading cycles, etc.,). The stiffness of the member was obtained from the following relationship:

$K=P/\Delta$

Where,

K= Stiffness of the member

P= Load applied in the structure in KN

Δ= Deflection in mm

From the load displacement values derived from ANSYS, the stiffness at each load cycle was calculated for all the three frames. The stiffness of the Reinforced Concrete bare frame and partially infilled Reinforced Concrete frames with aspect ratios of 2.17 and 1.44 for various load cycles were calculated and presented in Fig. 8.

For Reinforced Concrete bare frame, the initial stiffness value for Load cycle 1 is 2.24 KN/mm and at the seventh cycle, it was reduced to 1.42 KN/mm. But for Partial infill frame with aspect ratio 2.17, the initial stiffness at first cycle is 8.98 KN/mm and at twenty cycles it was reduced to 2.83 KN/mm. Similarly for frame with aspect ratio 1.44, the initial stiffness was 11.97 KN/mm and even after twenty cycles its stiffness was 10.44 KN/mm. This behaviour shows that the initial stiffness of bare frame was comparatively very low at an early stage of loading, but as the provision of infill inside the frame increases the initial stiffness and it lasts high, even up to twenty cycles.

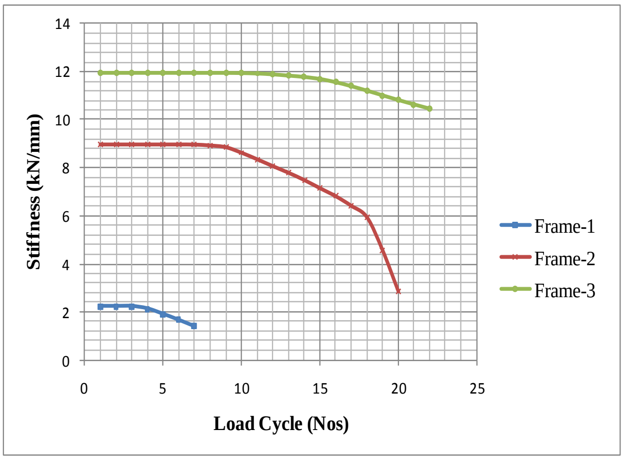

Figure 8. Stiffness degradation curve

3.3 Ductility ratio

One of the most common types of strength degradation is the cyclic strength degradation in which a structural component or system experiences a reduction in lateral strength, as a result of cyclic load reversals. In cyclic strength degradation, reduction in lateral strength occurs after the loading has been reversed or during subsequent loading cycles. Cyclic reduction in the lateral strength is a function of peak level displacement, experienced in the system. Hysteresis model that incorporates this type of strength degradation typically specifies the reduction in strength as a function of the ductility ratio, which is taken as the ratio of peak deformation to yield deformation. It is shown in Fig. 9.

The ductility ratio was found out to be increasing as 1 in the first cycle and reaches 2.63 at the seventh cycle for bare frame, but for partially infilled frame with aspect ratio 2.17 & 1.44, the ductility ratio reached 1 in twelfth cycle only. This behaviour shows the reduction in ductility of the structure, due to the provision of masonry insert which made the column to behave in a brittle manner, as shown in Fig. 9.

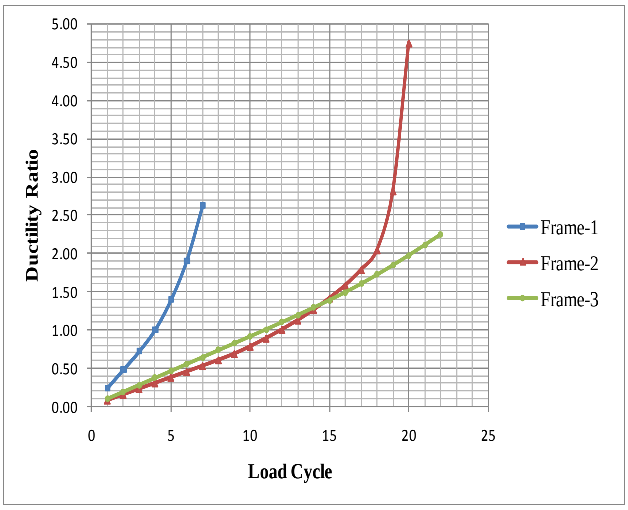

Figure 9. Ductility ratio curve

3.4 Crack pattern

The crack patterns were taken out with the help of Maximum strain plot. For Reinforced Concrete bare frame (Frame-1), initial cracks were developed at the beam column junction. And at the ultimate load of 30 KN a series of wide cracks were developed at the support which makes the structure instable and leads to failure. The crack pattern of Reinforced Concrete bare frame was shown in Fig. 10.

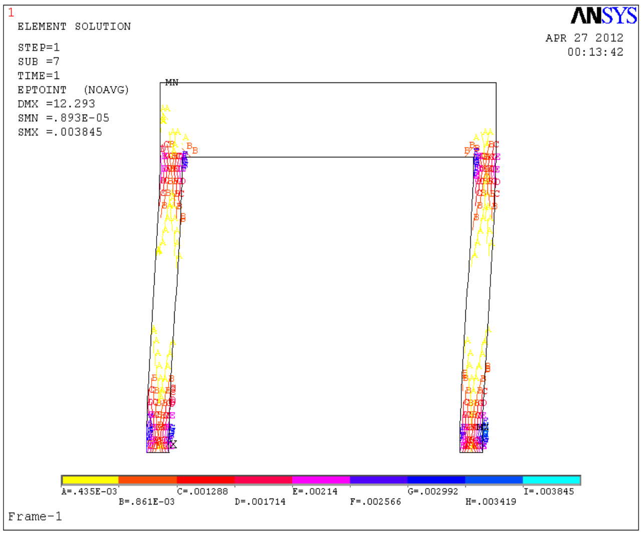

Figure 10. Crack pattern for reinforced concrete bare frame

During the testing of Partial infill Reinforced Concrete frame, the crack patterns seemed to be entirely different from a Reinforced Concrete bare frame. In the partial infill frame with Aspect ratio of 2.17 (Frame-2), cracks were developed at the junctions of beam-column and masonry infill junction. The crack pattern of partial infill frame with aspect ratio of 2.17

(Frame-2) is shown in Fig. 11. And for partial infill frame with aspect ratio of 1.44 (Frame-3), the crack pattern was shown in Fig. 12. Shear cracks were developed at the junctions of beam-column and masonry infill junction, in x-shape. Very minimum cracks were developed at the support since the portion below was completely restrained by the tight fitted masonry infill.

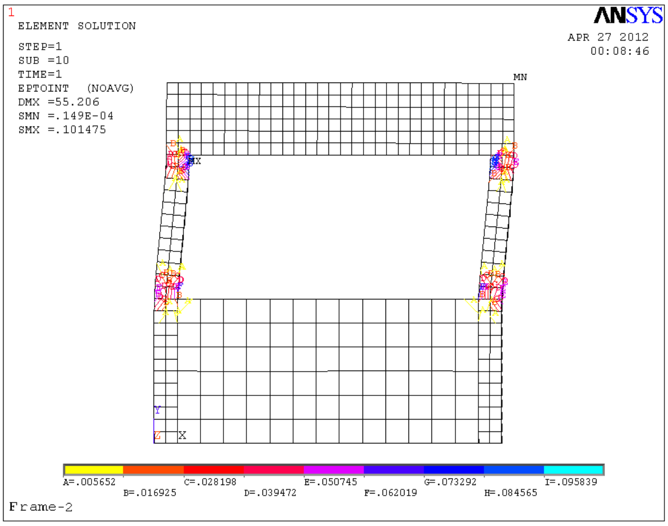

Figure 11. Crack pattern for partially infilled frame with aspect ratio of 2.17

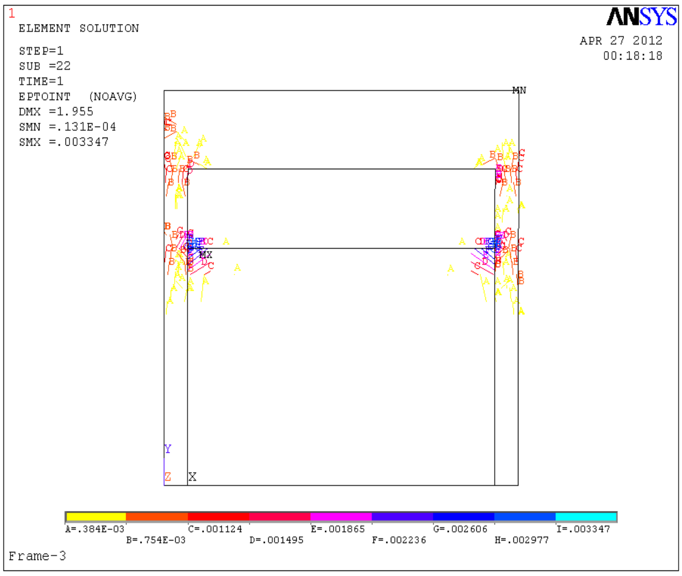

Figure 12. Crack pattern for partiall infilled frame with aspect ratio of 1.44

3.5 Von mises stress

Von Mises stresses were taken from the post processing mode for the numerical study using element solution. Appropriate colour scales were shown below as the stress diagram to identify the stress intensity. The Von Mises stresses for Reinforced Concrete bare frame, partially infilled reinforced concrete frame with aspect ratio of 2.17 and partially in filled reinforced concrete frame with aspect ratio of 1.44 were shown in the Fig. 13, Fig. 14 and Fig. 15 respectively.

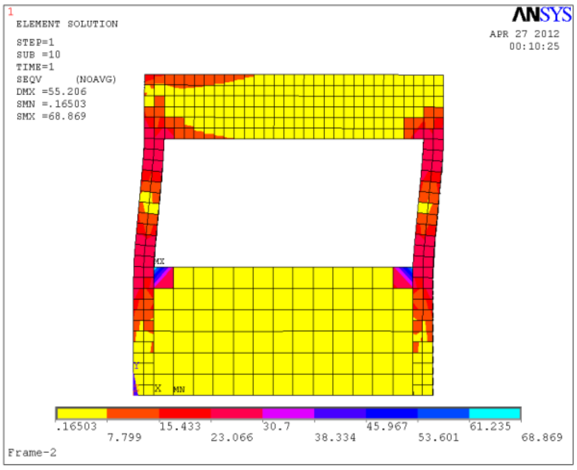

Figure 13. Von mises stress for reinforced concrete bare frame

In the stress diagram, the dark blue colour indicates the maximum stress intensity region. Bare frame has maximum stress intensity at its joints and support as its initial cracks were developed at the beam column junction and at the ultimate load a series of wide cracks were developed at the support which makes the structure instable and leads to failure. But the partially infill frame with aspect ratio 2.17 & 1.44, the cracks were developed at the junctions of beam column and masonry infill junction which leads to short column effect. Very minimum cracks were developed at the support since the portion below is completely restrained by the tight fitted masonry infill.

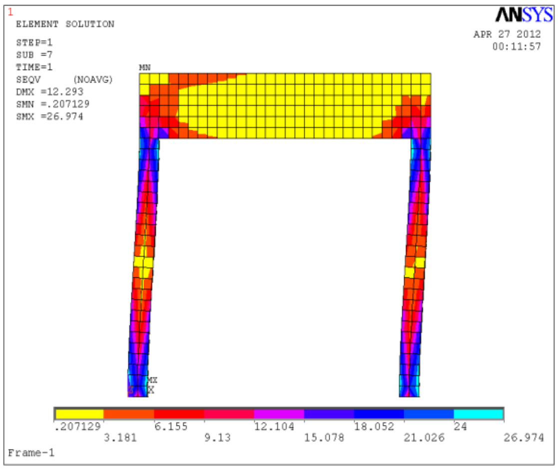

Figure 14. Von mises stress for partially infilled frame with aspect ratio of 2.17

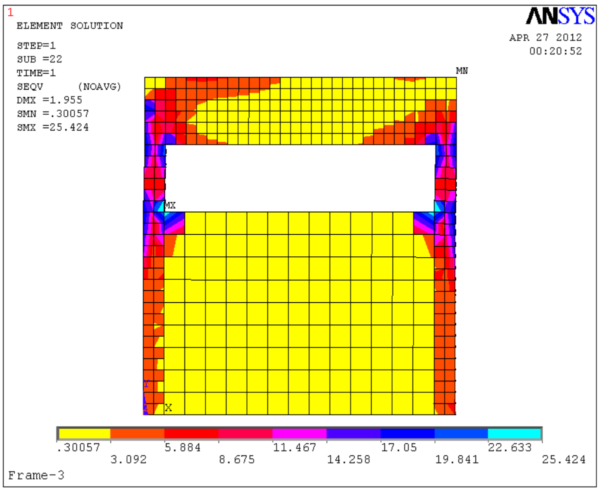

Figure 15. Von mises stress for partially infilled framewith aspect ratio of 1.44

4. CONCLUSIONS

In this study, the behaviour of partially infilled Reinforced Concrete frame was examined under lateral cyclic load. Three dimensional finite element model was created using ANSYS. The reinforcement steel is generated by smeared rebar method. Reversed cyclic loads are generated using load step option and Load displacement relationships are obtained from ANSYS after solving the analysis. The key observations are presented below.

- The partially infilled frame having aspect ratio 2.17 & 1.44 shows the displacement of 5.19mm and 10.73mm at the ultimate load of 30KN, which is less than the bare frame displacement 16.66mm.This is because of the formation short column in masonary infill junction and beam column joint. So as the short columns is stiff and brittle it leads to very less displacement.
- The ductility ratio is found out to be increasing in first cycle as 1 for bare frame, but for the frame with short column effect, it reached 1 in twelfth cycle only. The reduction of the ductility of the structure is due to the provision of masonry infill which made the column to behave in a brittle manner.
- For the Reinforced Concrete bare frame, the initial stiffness value for the first load cycle is 2.24 KN/mm, but for partial infill frame with aspect ratio 2.17 & 1.44, the initial stiffness at first cycle is 8.98 KN/mm & 11.97KN/mm respectively. Due to the provision of masonry insert, which made the column to behave brittle, it leads to short column effect which made the frame 5 times stiffer than bare fame.

Partially infilled Reinforced Concrete frame when tested under lateral loads, the crack patterns are found to be entirely different from a Reinforced Concrete bare frame. In the partial infilled frame the cracks were developed at the junctions of beam column and masonry infill junction. Very minimum cracks were developed at the support and that shows clearly the formation of short column between joint and masonry insert.

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