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# Study on the Behavior of RC Infilled Frames with Multiple Bays Using ATENA 2D

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***Abstract:-*** In the developing countries around the world especially in India, the reinforced concrete (RC) frame is the most popular construction in multi-storey buildings. Due to economically and abundant availability, brick infill is being used in multi-storey building. During the gravity load analysis, brick infill in RC frames is treated as nonstructural member. But during the lateral load subjected to infilled frame, infill wall tends to interact with the bounding frame by providing in-plane stiffness. Thus infill plays an important role in resisting lateral load. In RC frame with Multiple Bays are common in all structures in which it is necessary to understand the behaviour of RC frame with multiple bay with infill subjected to lateral load. To understand the complex of RC frame behaviour with multiple bay infill frame subjected to lateral load, analytical modeling is very popular to encompass the global behavior of the system. In the present study ATENA 2D (2015), software were used to capture the nonlinear behavior of the multiple bay infilled frame. Here a four storey 2D infilled frame with one-bay, two-bay and three-bay models were considered to study the behavior of RC frame with infill. The parameters like Load displacement curves, stresses distribution and pattern of cracks were identified to understand the behavior of RC frame with infill by conducting nonlinear analysis. As the numbers of bays are increased, the lateral stiffness and load carrying capacity of the frame also increased. Due to the presence of infill in multiple bays, overall performance of structure increased by increasing lateral stiffness.

***Keywords***: *ATENA 2D, Masonry infill, Multiple bay, Compressive and tensile stress, crack pattern.*

## 1. Introduction

The multi-storey buildings in India causing a great demand due to urbanization or industrialization. In metropolitan city cost of land increasing day by day, due to this, structure are elevated in vertical direction with number of bays, thereby increasing the number of storey. From this, the structural engineers met to have great responsibility for safety, economy and durability of multi-storey buildings in execution and design. When it comes to the safety and durability of multi-storey buildings, wind load and earthquake load has to be taken care while designing. These loads cause the tall buildings to sway sideways, so importance to be given in preventing sway. The provision of masonry wall as an infill is best alternative in providing lateral stiffness and it is cheapest retrofitting technique that can be adopted in developing and undeveloped countries in seismic prone areas. In India, RC frame with masonry as an infill is the most common type of structure; masonry units like clay bricks, soil cement blocks, stone and cement blocks are used. In 20th century many researchers have done both experimental and analytical studies on influence of brick masonry on the bounding frame, many of them observed that there is increase in lateral stiffness and strength when brick masonry are used in RC frame. From this there is great advantage for India and other developing countries because many residential and commercial buildings are constructed by RC frames with multiple bays with masonry infill. Due to number of bays in multistorey building, shear resistance and lateral stiffness capacity of RC frame aslo increases. In multi-storey buildings the masonry panels are constructed either by integral or non-integral to the bounding frame but in the present study it is taken as integral connection.

## 2. Methodology

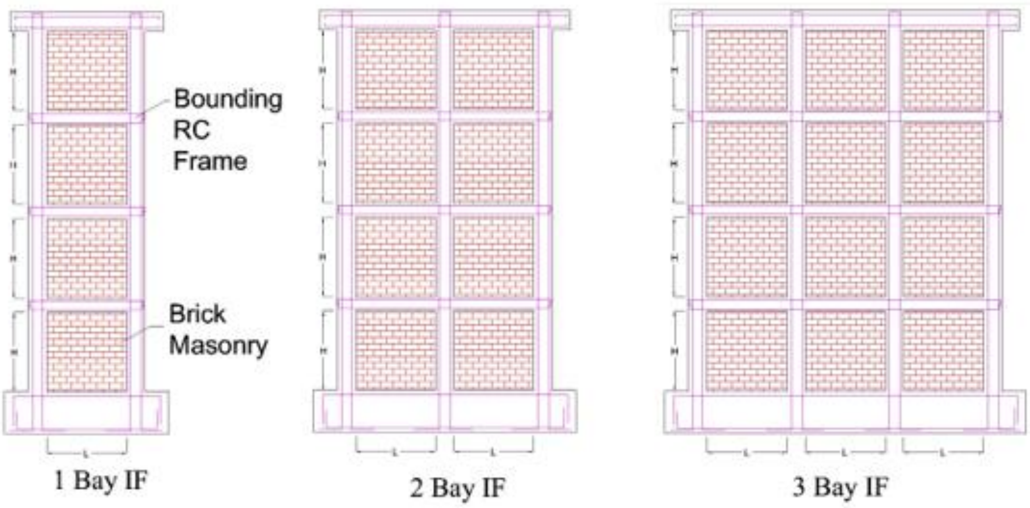
The modeling of infill frame is carried out by two popular methods i.e Micro modeling and macro modeling of infill frames. Based on the complexity and necessity of the problem defined, suitable modeling method has to be adopted for the study. The macro modeling method of infill can be used to study the global behavior of the infill panel on the structure, Whereas Micro modeling method of infill is used to study the performance of infill and frame.The interest of the present study to understand the global behaviour of RC fram with multiple bays with infill. So macro modelling approach have considered in present study.

Equivalent diagonal strut (EDS) was used as a macro modeling in which to be used for analytical study of infilled RC frame. Many researchers like Holmes, Polyakov, Mainstone, Paulay and Priestly and other researcher had developed the model of EDS to pretend the effect of infill in reinforced concrete frame. They proposed the formulae to estimate the diagonal strut width but the width of diagonal strut values are different from different researcher. It varies from 1/3$^{rd}$ to 1/10$^{th}$ diagonal length of masonry infill. Stafford Smith and Carter formulae for diagonal strut width gives maximum value of diagonal strut width compared to other researchers formulae.

To study the behaviour of infilled frame experimental approach provides realistic results but the main disadvantage here is its very time consuming and it's not cost effective due to large number of trials have to be conducted and parameters included. Hence advancement in computing world and availability of software analytical modeling has given major importance providing a great alternative to physical experiments.

ATENA 2D (2015) V 4.3.1 was used in present study, it's a powerful finite element analysis tools developed by Cervenka Consulting Ltd. Czech Republic. This finite element software is very important tool for analyzing the non-linear behaviour of infilled frame in terms of principal stress distribution (Compressive stress and tensile stress) and crack propagation. This software is used for both static and dynamic analysis of any structure. In these models the bond between RC frame and masonry infill were assumed to be perfectly bond. So this software has given real behavior of structure subjected to lateral load

In present study, the four storey RC frame with multiple bay with infill were considered and crossection of boundary beam and column are shown in Figure 1. The dimension of beam and column consider in this study were 300mmx600mm and 600mmx600mm. Thickness of infill was 230mm. Floor to floor height of RC frame was 3m. Aspect ratio 1 was considered in this study.



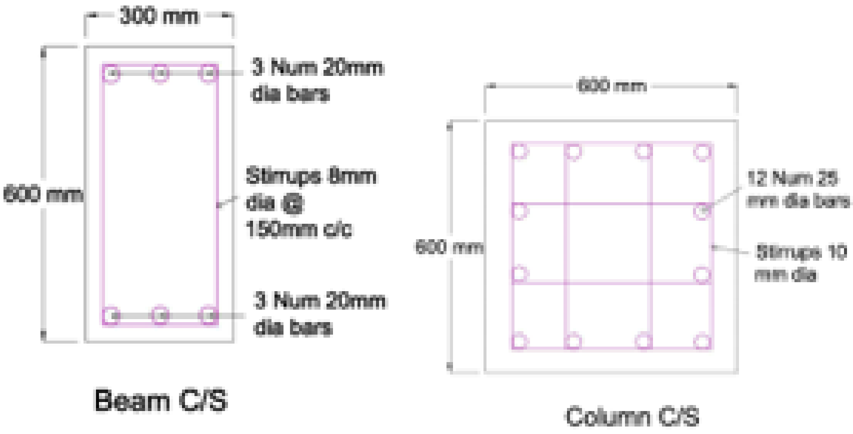



**Figure 1. Model considered for study (Four storey one bay, two bay and three bay) RC frame with infill.**

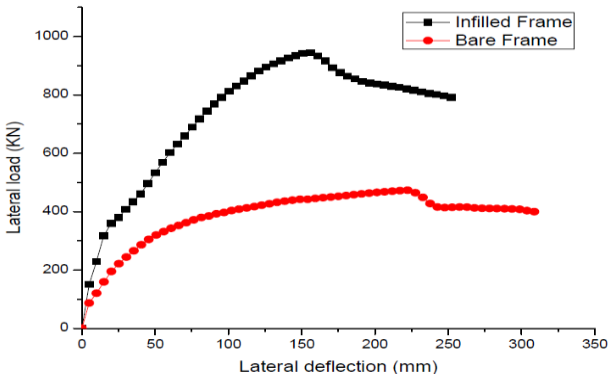
The property of the concrete used in this analysis are M30 grade concrete, Poisson's ratio (v) 0.2, Modulus of elasticity (Ec=5000√fck) 2.739x$10^4$MPa as per IS 456-2000, Tensile strength (fct=0.24fck$^{2/3}$) 2.317 MPa as per Cervenkaet.al.,2012 Atena. The property of masonry infill were Compressive strength ($f_{ck}$) 5.72MPa, Modulus of elasticity (Ec=550fck) 3148 MPa as per IS 456-2000, Tensile strength 0.4MPa as per Cervenka et.al.,2012 Atena, Thickness of masonry 230mm. For Interface between RC frame and infill were normal stiffness ($K_n$) 3.148x105MPa, tangential stiffness ($K_t$) 1.312x105MPa, Cohesion 0.2, Frictional coefficient 0.2 as per Cervenka et.al.,2012, Atena. The reinforcement grade Fe 550 and Modulus of elasticity of steel 2.1x105 MPa werw used. Each loading step(LS) correspond to 5mm of prescribed lateral displacement.

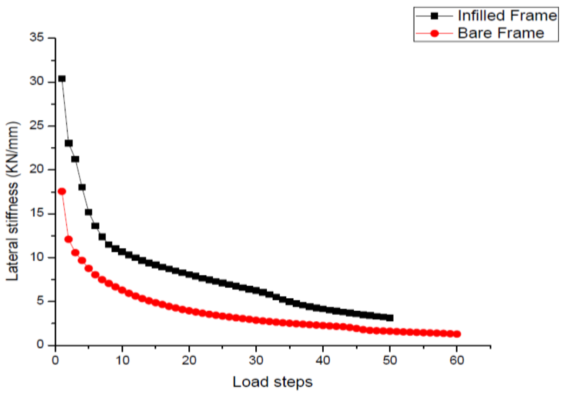
## 3. Results and Discussion

### 3.1 Behavior of infilled frame with multiple bay subjected to lateral load.

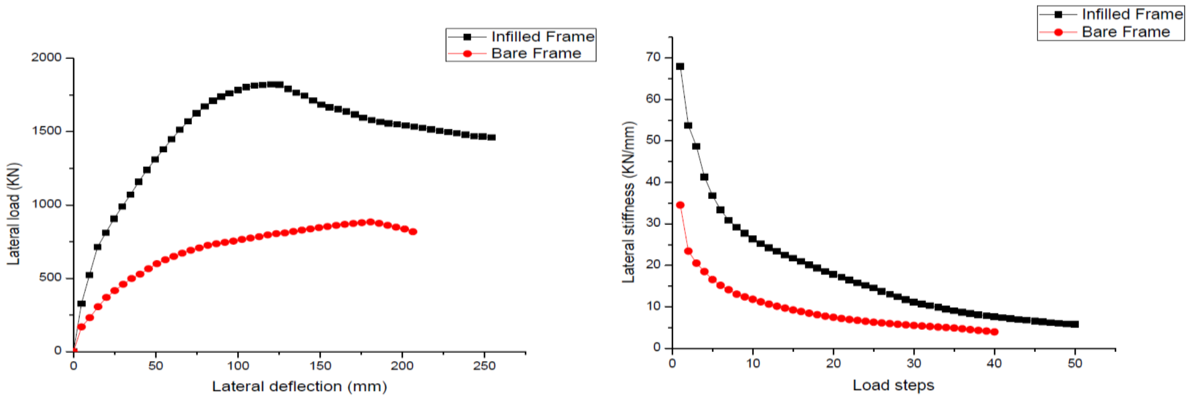
The effect of different bay of RC frame with infill are studied under Load displacement and lateral stiffness curve, compressive stress distribution and crack pattern.

Load displacement and lateral stiffness of multiple bay frame without infill and with infill(Bare Frame)

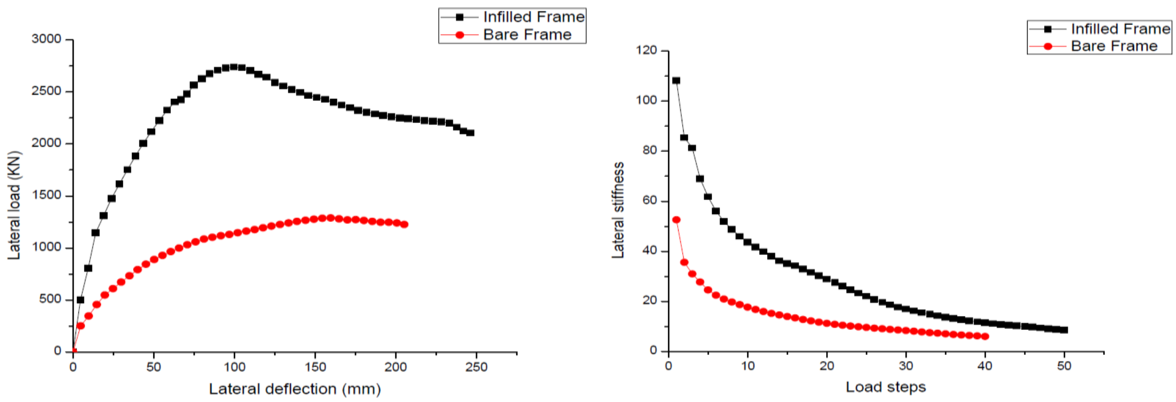



**Graph 1:** Load Displacement and Lateral stiffness curves of four storeys, single bay bare frame and infilled frame.



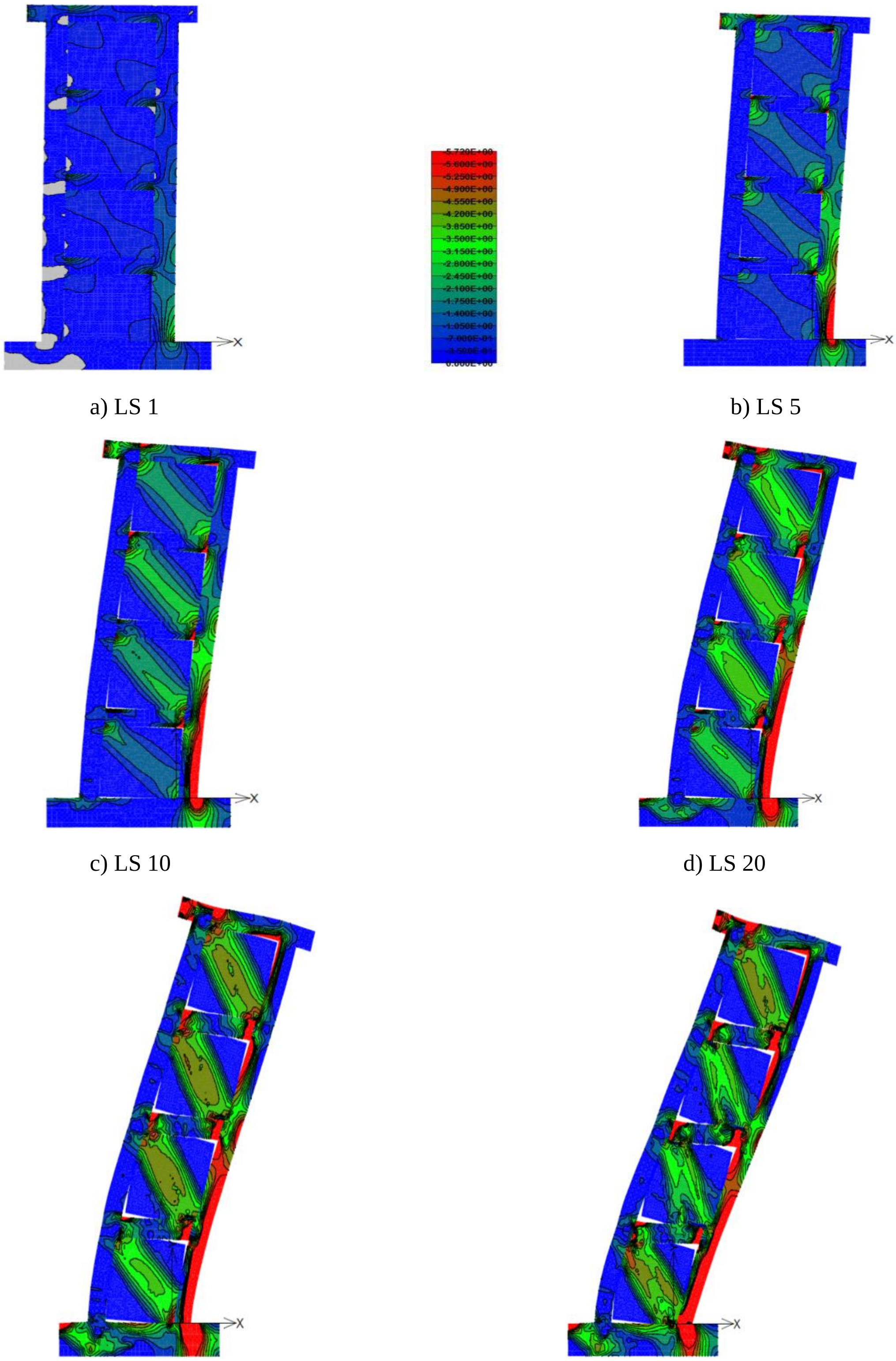

**Graph 2:** Load Displacement and Lateral stiffness curves of four storeys, two bay bay bare frame and infilled frame




**Graph 3:** Load Displacement and Lateral stiffness curves of four storeys, three bay bare frame and infilled frame.

The load carrying capacity was very less in frame without infill because of having lesser stiffness and bilinear behaviour shown in graph 1, 2 and 3. The load resistance capacity of infilled frame was very high because of the contribution of the infill along the loaded diagonal. The compressive strut was formed during transfer of lateral load in infill. The load carrying capacity gradually decreases if the diagonal strut fails. The load-displacement curve from the graph 1, 2 and 3 shows that infilled frame has high energy absorption capacity compared to bare frame. The lateral load resisting capacity of two bay infilled frame was 77% greater than single bay infilled frame and the lateral load carrying capacity for three bay infilled frame is 211% greater than single bay infilled frame. The lateral stiffness reduction for bare frame and infilled frame at different LS were shown in graph 1, 2 and 3. At initial stage, lateral stiffness of infilled frame was very high than bare frame. Due to formation of initial cracks in frame and infill, there was drop in the stiffness and after few steps stiffness of both frames were same.ie infill frame behaves like bare frame. The lateral stiffness of two bay infilled frame was 122% greater than one bay infilled frame and lateral stiffness of three bay infilled frame was 254% greater than one bay infilled frame.

**3.2 Distribution principle compressive stress (one bay RC frame with infill).**



a) LS 1 b) LS 5

c) LS 10 d) LS 20

e) LS 30 f) LS 40

**Figure 2. Principal compressive stress variations of one bay RC frames with infill for different load steps (LS) (a) LS 1, (b) LS 5, (c) LS 10, (d) Load LS 20, (e) LS 30, (f) LS 40.**

Figure 2 shows the variation of principal compressive stress for a different load steps. Each load steps corresponds to 5mm of prescribed lateral displacement.

At LS '1', the principal compressive stress at the diagonal strut was initiated on the loaded diagonal, though the values of principal compressive stress were very small. As the LS increases at the LS '5', formation of compressive diagonal strut was seen clearly.

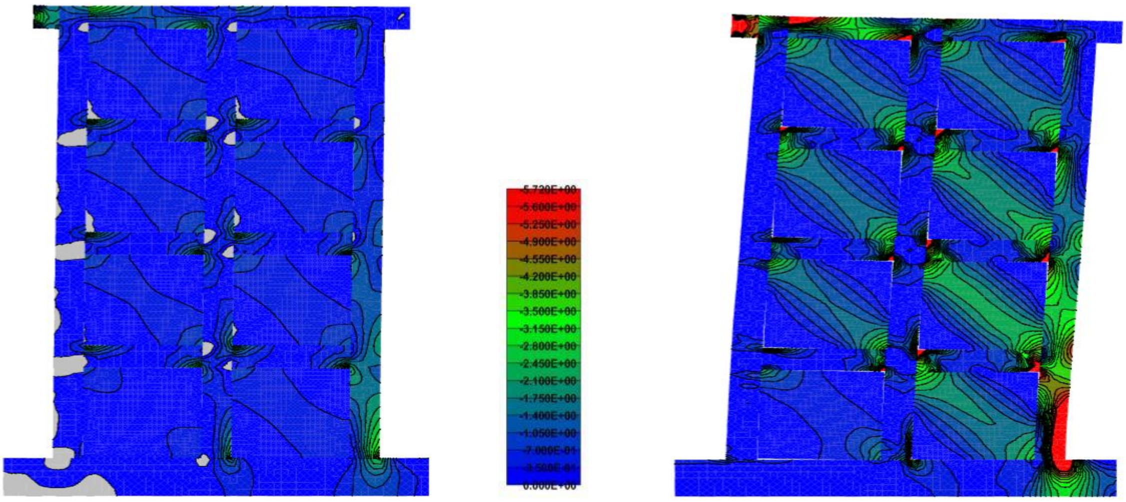
At the LS '10' the diagonal strut was formed in all the storey, this shows that participation of infill in lateral load transformation in all storey and also there was gap between boundary frame and infill at this stage.

LS '20' at this stage nearly 66% of the peak load had been achieved. From this stage the principal compressive stress value keeps on increasing until failure at the diagonal strut occurs. And there was the separation of infill from the bounding frame in the entire stories. Near the unloaded diagonal there was the separation of boundary frame and infill. LS '25' at this load step, there was an initiation of peak compressive stress on the compressive diagonal strut. Here about 83% of peak load had been achieved.

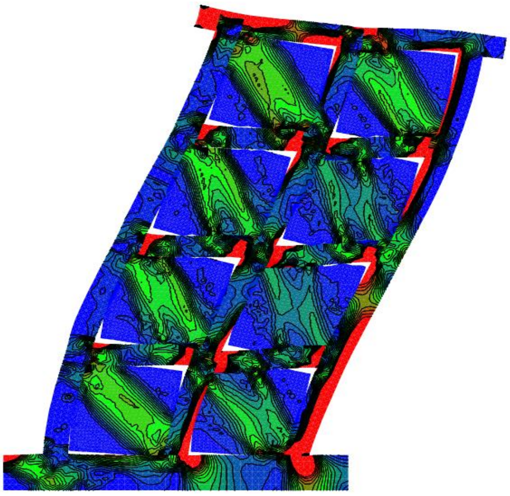
LS 30, Here the peak load had been achieved and also maximum principal compressive stress was along the loaded diagonal when compared to other load steps. From here the load carrying capacity and principal compressive stress was decreasing and also disturbance in diagonal strut had been initiated.

At the LS '35' disturbance in compressive diagonal strut was seen at the storey 2 and 3, because infill was not capable of transfer lateral load. However it was observed that infill at storey 1 and 4 were still participating in load transfer mechanism. This mechanism continues up to load step '45' and there after failure in diagonal strut initiates at storey 1 and 4. LS '50', there was complete disturbance of diagonal strut at entire storey. It was worth noting that up to load step 30 major load transfer took place at storey 2 and 3 this shows that until peak load capacity, 2 and 3 storey were playing major role in providing lateral stiffness and strength.

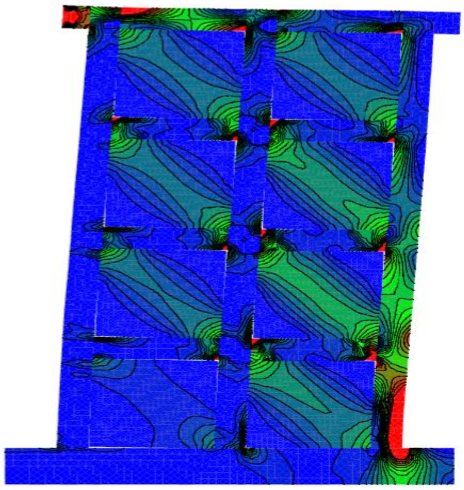
### 3.3 Distribution principle compressive stress (Two bay RC frame with infill)



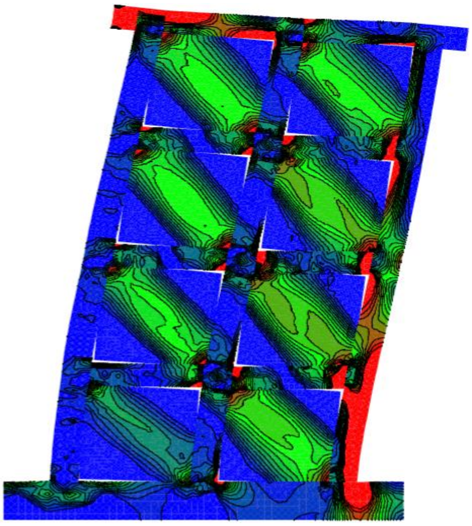
a) LS 1 b) LS 5



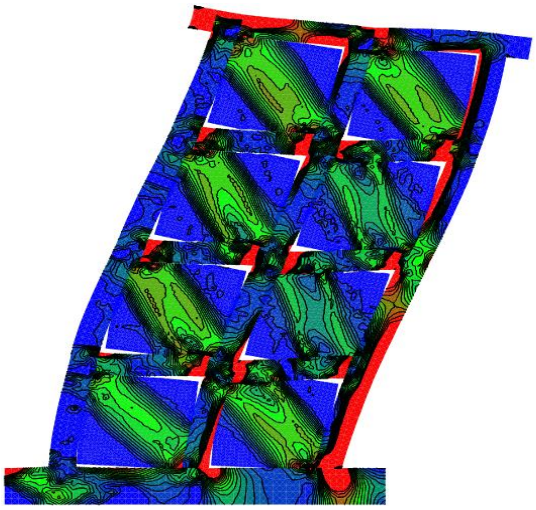
c) LS 10



d) LS 15



e) LS 30



f) LS 35

**Figure 3. Principal compressive stress variations of two RC frames with infill for different LS (a) LS 1 (b) LS 5 (c) LS 10, (d) LS 15 (e) LS 30 (f) LS 35.**

The LS ‘1’ to LS ‘15’, in the figure 3, shows the same mechanism occurs as seen on infilled frame with one bay.LS ‘20’ at this load step the initiation of peak compressive stress on the compressive diagonal strut was observed, Here about 80% of peak load has been achieved.LS 25, here the peak load has been achieved and also maximum principal compressive stress was observed along the loaded diagonal when compared to other load steps, from here the load carrying capacity and principal compressive stress keeps on decreasing and also disturbance in diagonal strut has been initiated. At the LS ‘30’ disturbance in compressive diagonal strut was observed at the storey 2 and 3, this is because inadequacy of the infill in transfer of lateral load. When the two bay infill frame subjected to lateral load most of the load transfer mechanism takes place at infill present at the right bay i.e. bay far from loading point. This was observed through variation of principal compressive stress values shown in figure 3. In figure 3 shows that the values of principal compressive stress on the infill present at the right side is more compared to infill present on the left side. It was also worth noting that the infill present on the left side of storey one, it has the least participation in force transfer mechanism and the infill present on the right side of storey two and three, shows major contribution in load transferring i.e. highest value of compressive stress. At the load step ‘35’ shows complete degradation of diagonal strut at the infill present on the right side of storey two and three, also indicating plays a major role in force transfer mechanism.

### 3.4 Distribution principle compressive stress (Three bay RC frame with infill)

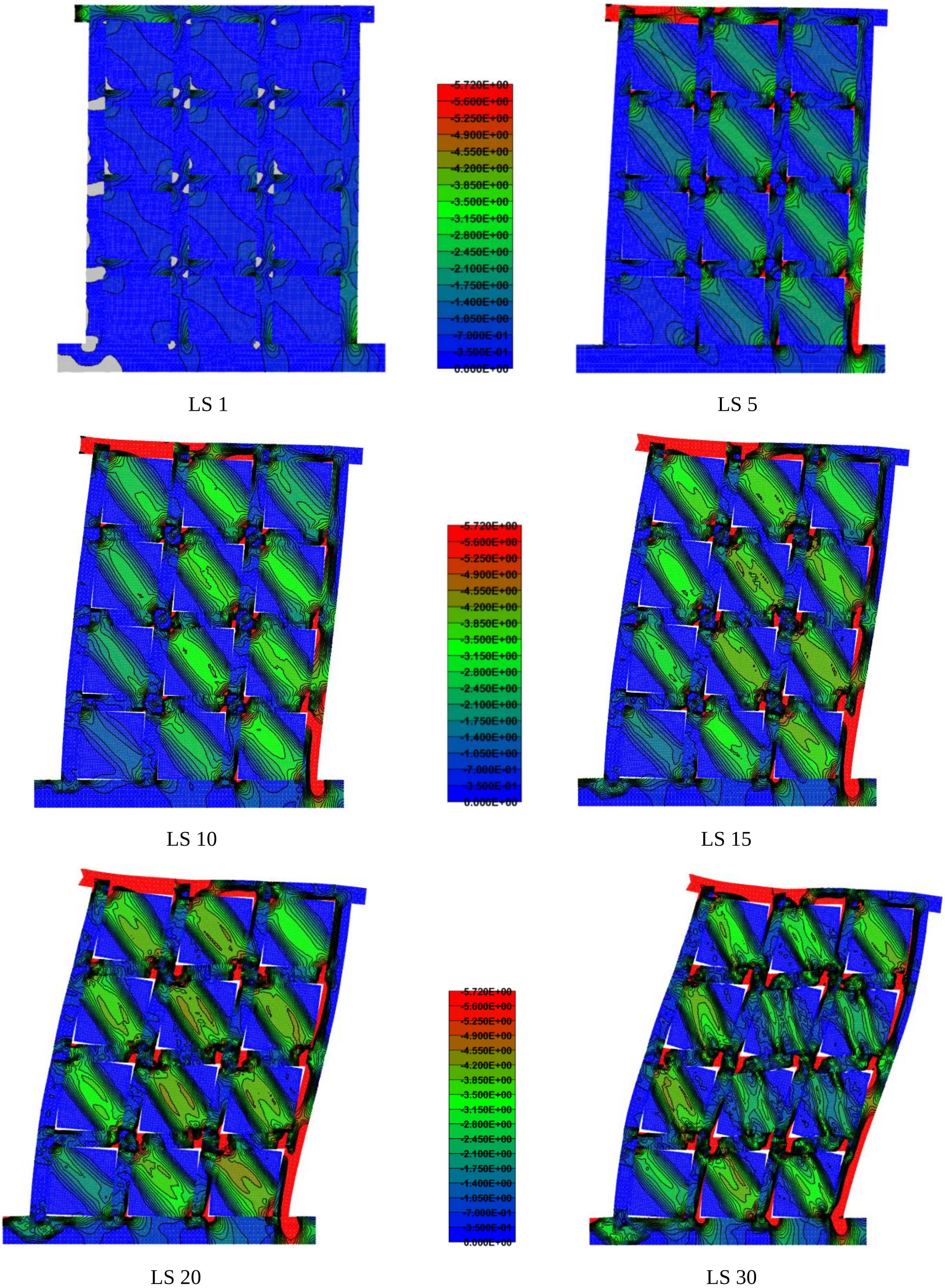
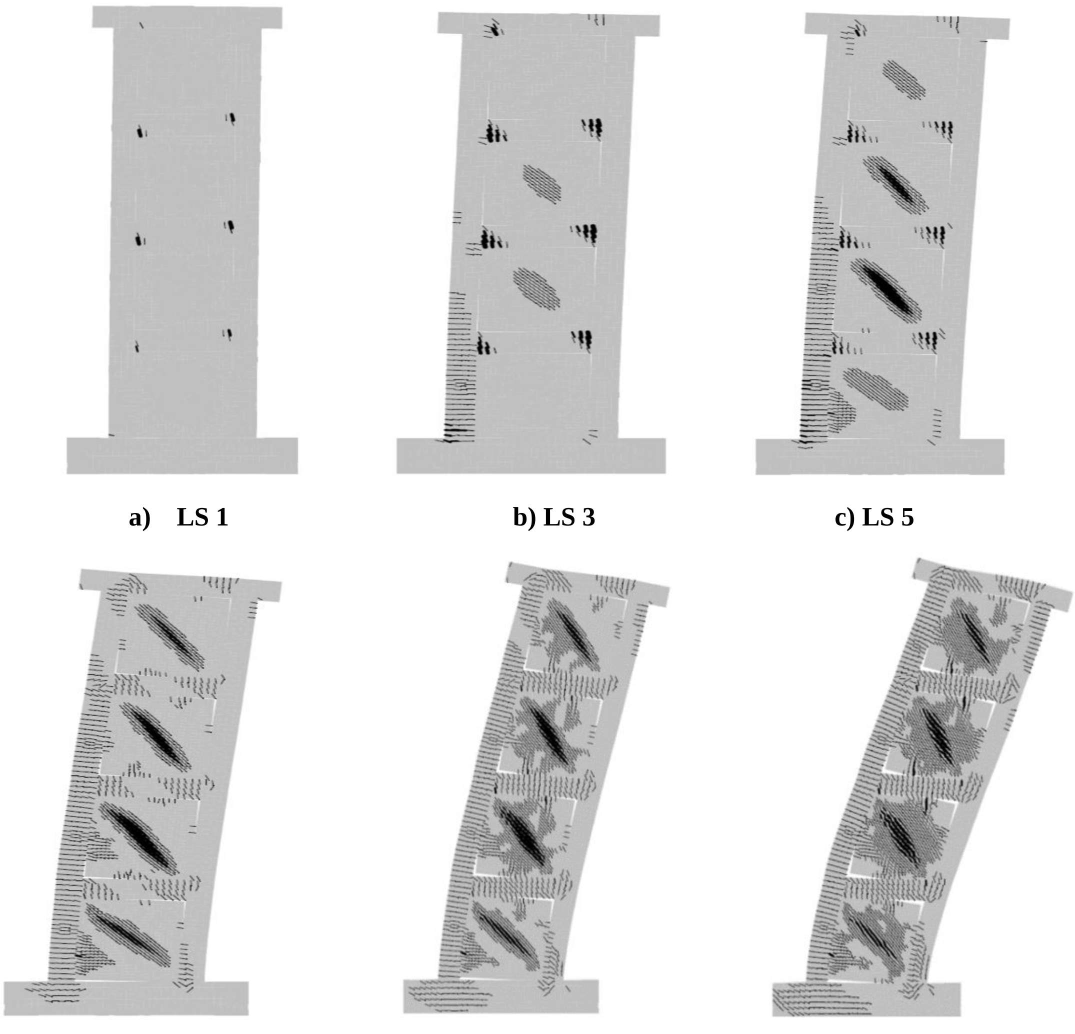



**Figure 4. Principal compressive stress variations of three bay RC frame with infill for different LS a) LS1 b) LS 5 c) LS 10 d) LS 15 e) LS 20 f) LS 30**

The load step '1' to load step '15', in the figure 4, shows the same mechanism occurs as seen on infilled frame with one bay and two bay infilled frame.

As it said earlier the infill present at bay far from loading point have major contribution on transferring loads hence from the figure 4 it shows that infill present at left most side i.e. near the loading point shows less contribution compared to other two bays and the infill present at storey 2 and 3 shows major contribution in load transfer, especially infill present at middle and right bay. Load step '20', here the peak load has been achieved and also maximum principal compressive stress was observed along the loaded diagonal when compared to other LS. From here the load carrying capacity and principal compressive stress keeps on decreased and also disturbance in diagonal strut has been initiated. Load step '30', at this stage destruction of compressive diagonal strut was observed at infill present at the storey 2 and 3 in all the bays.

### 3.5 Crack propagation in one bay RC frame with infill.



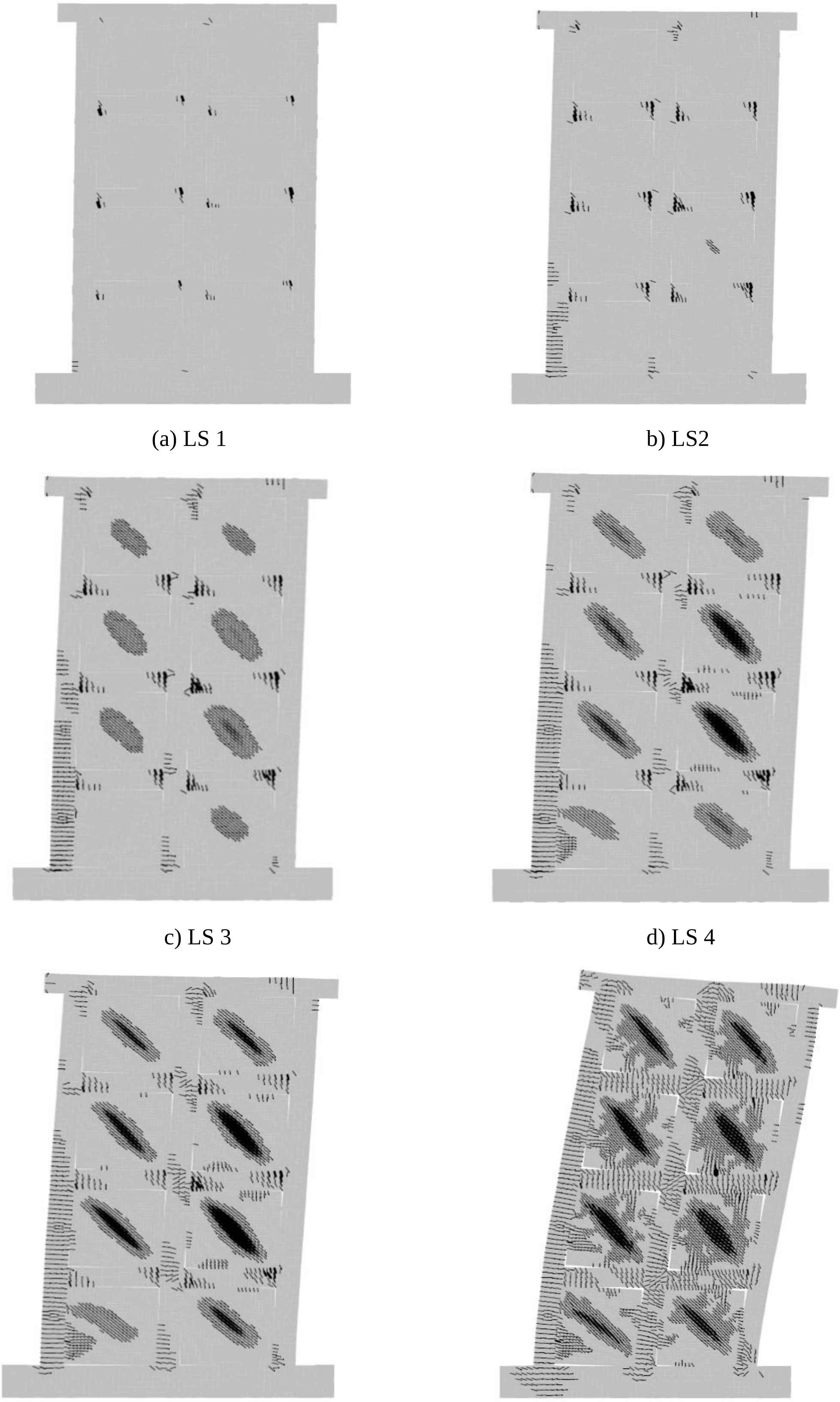
**a) LS 1** **b) LS 3** **c) LS 5**

**d) LS 10** **e) LS 20** **f) LS 30**

**Figure 5. crack pattern variations at different LS for one bay infilled frame.**

Figure 5 represents the crack pattern variations of one bay infilled frame at different LS. Once the masonry tensile stress reached maximum limit, there was a crack along the loaded diagonal. At load LS 5, there were small gap between infill and boundary frame, because of principle tensile stress. At LS 30, there was an ultimate load and large gap between infill and boundary frame. There was a crack in RC frame along loaded column, in which column is subjected to tensile stress

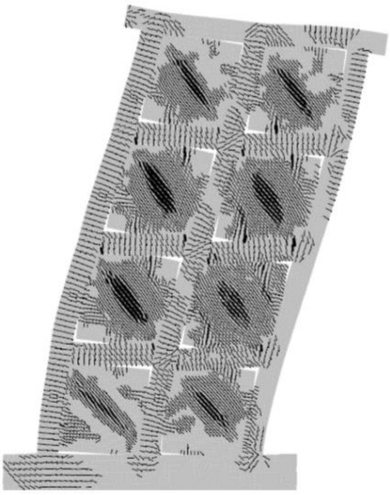
### 3.6 Crack propagation in two bay RC frame with infill



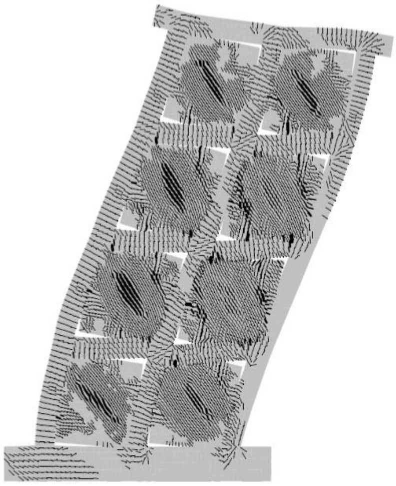
(a) LS 1 b) LS2

c) LS 3 d) LS 4

e) LS 5 f) LS10



g) LS 25

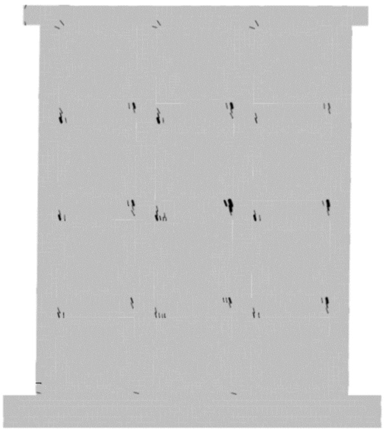


h) LS 35

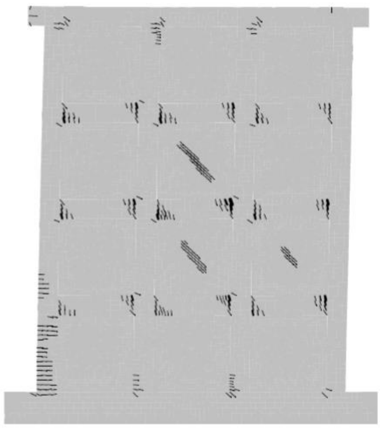
**Figure 6. crack pattern variations at different LS for two bay RC frame with infill.**

The separations of infill were observed at unloaded corner of frame because of principle tensile stresses reached maximum level. These maximum levels of tensile stresses were observed at LS 30. Above these LS, infill was completely collapsed and resistance of infilled frame was decreased.

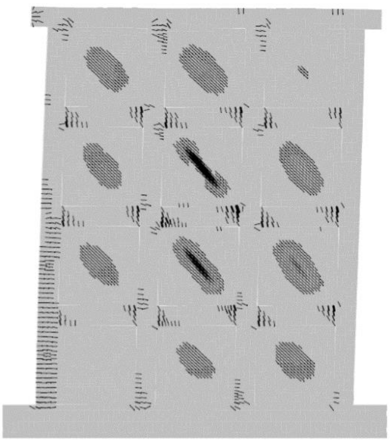
### 3.7 Crack propagation in three bay RC frame with infill



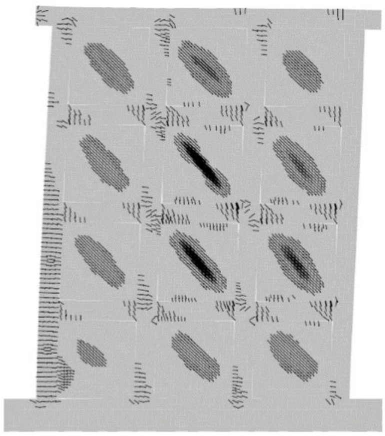
a) LS 1



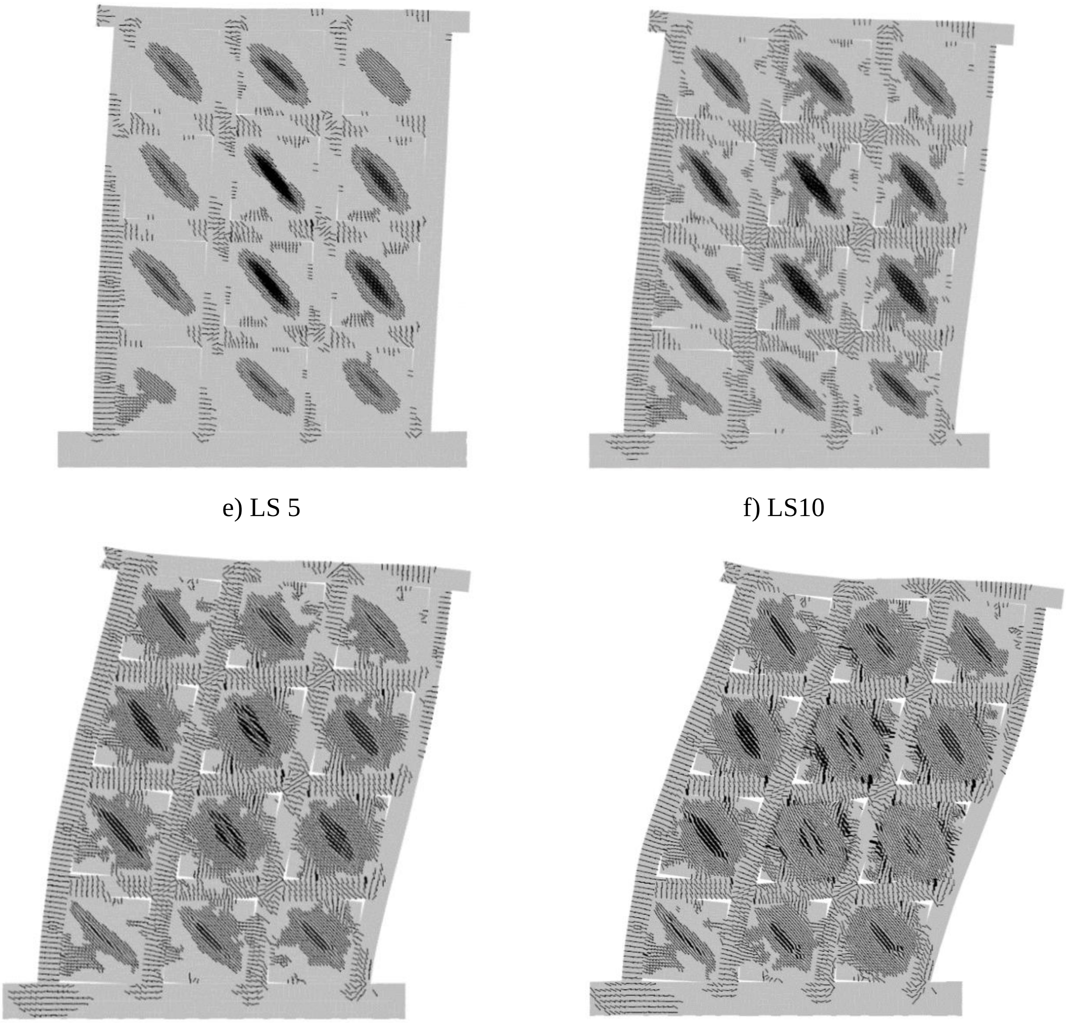
b) LS 2



c) LS 3



d) LS 4



e) LS 5 f) LS10

g) LS 20 h) LS 30

**Figure 7. crack pattern variations at different LS for three bay RC frames with infill.**

Figure 7 shows the crack pattern variations at different LS for three bay RC frames with infill. As the LS reaches no.2, cracks were observed in infill along the loaded diagonal in second and third bay and cracks in RC frame at bottom of first column because of tensile stress. At LS 10, cracks were observed in infill in all floors and bays and separation of infill were observed at unloaded corner because of maximum principle tensile stress. At LS 20, the formation of strut was observed at all bays and all floors.

## 4. Conclusions

The numbers of bays in RC structure are very common in multi-storey building. As the number of bays increased, the load resisting capacity and lateral stiffness of the frame also increased. Due to the presence of infill in multiple bays, overall performance of structure increased by increasing lateral stiffness.

In multiple bays RC frame with infill, as the number of bays increased, principal compressive stress were minimum at loaded side of infilled frame and maximum in extreme side of infilled frame. Infill present on the left side of storey, ie loaded side has the least participation in force transfer mechanism and the infill present on the right side of storey was major contribution in load transferring i.e. highest value of compressive stress.

The infill in the RC frame plays a very important role in increasing ultimate load resisting capacity and lateral stiffness to the frame by truss mechanism because of higher energy absorption capacity of infill. Under the lateral load, two modes of failure occurred in infill. First crack was diagonal tensile failure occur at the center and

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propagate towards loaded diagonal corner. Second crack was crushing failure of infill at one of loaded corners.ie principal compressive stress reaches maximum level, infill was subjected to failure. Due to the lateral load, the infill behaves like equivalent diagonal strut because of principle compressive stress distribution is concentrated along the loaded diagonal in infilled frame. At very early stage, when the load reaches 20% to 30% of the peak load, at unloaded corner of frame, infill separate from the boundary frame.

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