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Effect of Lateral Reinforcement on Strength and Ductility of Reinforced Concrete Columns

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ABSTRACT

One of the most important functions of transverse reinforcement in reinforced concrete column is to prevent the deformation of longitudinal bars and transfer of stresses from concrete to steel. ANSYS is used for research because it is capable analyzing the structure of their non-linear behavior. In this research reinforced concrete beams were modeled having various percentages of steel reinforcement and their behavior is studied in terms of deformation, stress, strain, crushing/cracking and force-displacement curves.

Keywords: ANSYS, Stress, Strain, Force-Displacement Curve.

I. INTRODUCTION

Earthquake is mostly an unpredictable natural phenomenon. Due to regular occurrence of earthquakes, it is no longer considered as an act of God but a scientific event that needs to be investigated. In earthquakes, ground oscillates in horizontal and vertical directions with random manners which results in vibration of structures and induces high inertia forces. Analysis of damages occurred in moment resisting RC framed structures subjected to past earthquake show that failure may be due to utilization of concrete not having sufficient resistance, soft storey, beam column joint failure for weak reinforcements or improper anchorage, column failure causing storey mechanism. Post-earthquake reconnaissance and experimental research around the world indicate that existing building columns with poor and inadequately detailed transverse reinforcement are vulnerable to brittle failure mode during earthquake activity. Such sudden and brittle failures take place in column members and it can lead to reduction in building lateral strength, change in inelastic deformation mechanism, loss of axial load-carrying capacity, and ultimately, building collapse. Recognizing the risk posed by column failures, it is required to evaluate existing buildings or designing new buildings for seismic effects of columns.

II. OBJECTIVE OF STUDY

Verification and validation of finite element analysis of reinforced concrete elements using software ANSYS will be done. Reinforced concrete columns will be modeled and designed with varying lateral reinforcement ratio according to IS-456:2000 and ductile detailing will be done as per IS-13920:2016. Effect of transverse reinforcement densification will be studied at top and bottom zone of columns as well as along length of columns with different slenderness ratio. The reinforced concrete columns will be subjected to axial loads and monotonic loads and their behavior will be observed in terms of crack pattern, fracture mode, ultimate load capacities and ductility ratios.

III. ANAYLSIS & MODELLING

Slender Column Subjected to Eccentric Axial Load

Slenderness in compression members, which affects both short-term and long-term behavior, leads to second-order effects (increases in demand to the structure due to the deflection of the structure). These effects can be significant, and designers must account for them when designing compression members. Columns having different slenderness ratio 40 and 70 from paper entitled "Improved Procedures for the Design of Slender Structural Concrete Columns" were tested for short term loading having eccentric axial loads and their results were compared.

Table 3.1 Specimen Configuration

Name	**Reinforcement**	**Length**	**Width**	**Depth**	**Slenderness ratio**	**Concrete strength (fc')**	**Steel yield stress (Fy)**
R5-40-10-ST	4#15.88mm bars + 6.35 mm Stirrups	1829mm	155mm	155m	40	38.4 MPa	577 MPa
R3-70-25-ST	4#9.5mm bars + 6.35mm Stirrups	3200mm	155mm	155mm	70	48.4 MPa	502 MPa

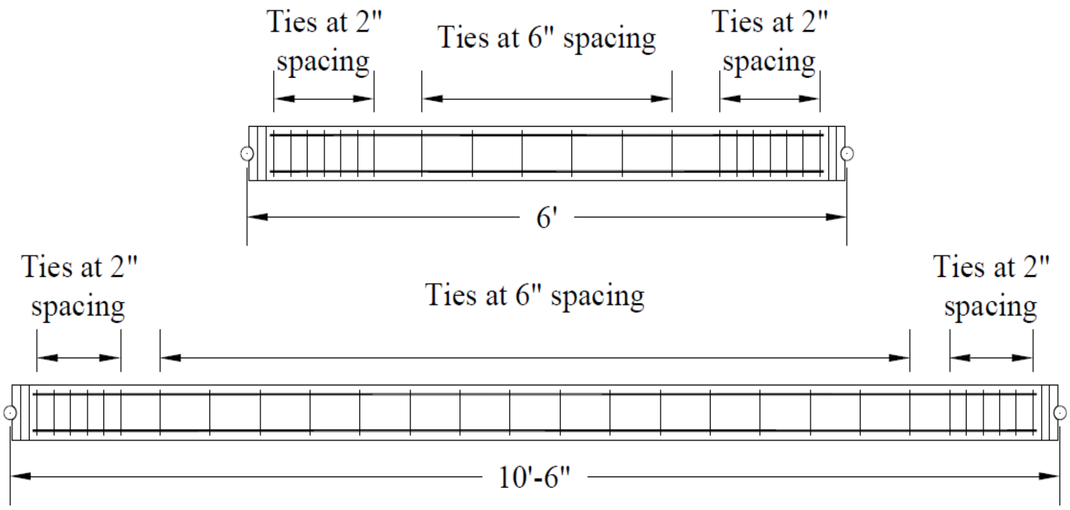


Figure 3.1 Experimental Schematic Setup

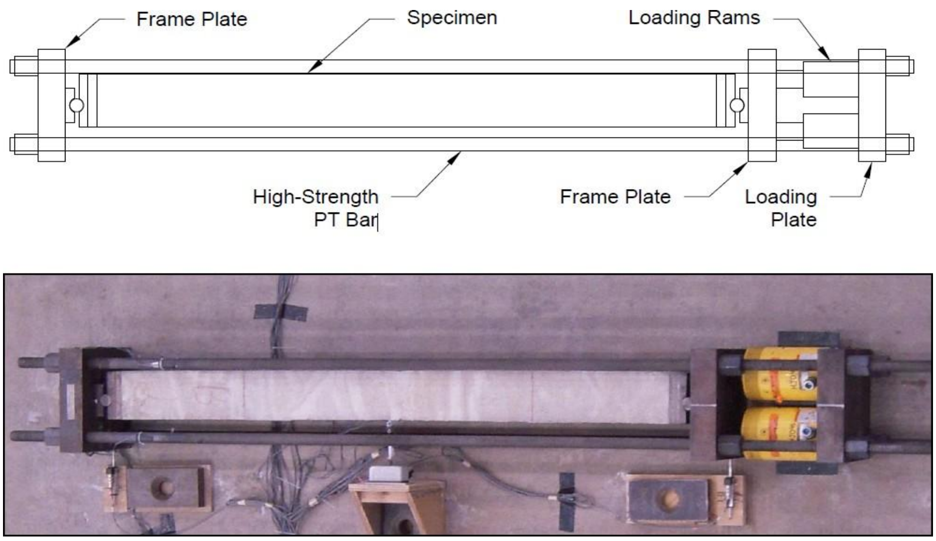


Figure 3.2 Experimental Test Setup

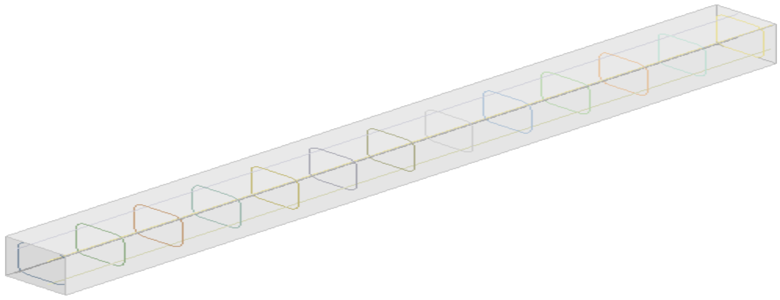


Figure 3.3 Finite Element Model

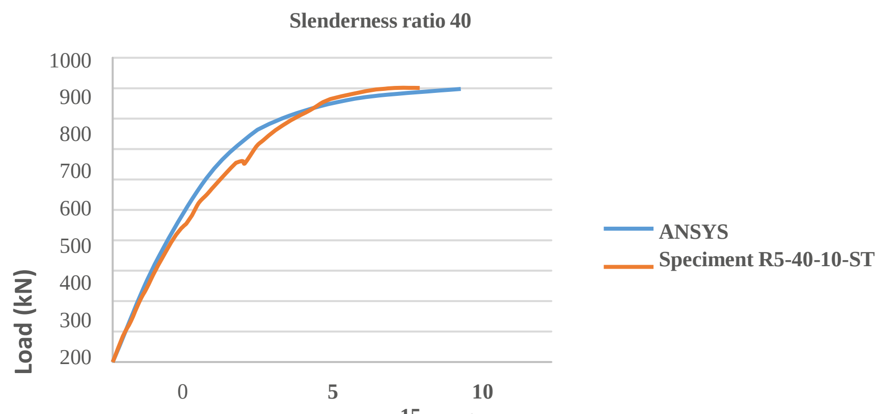
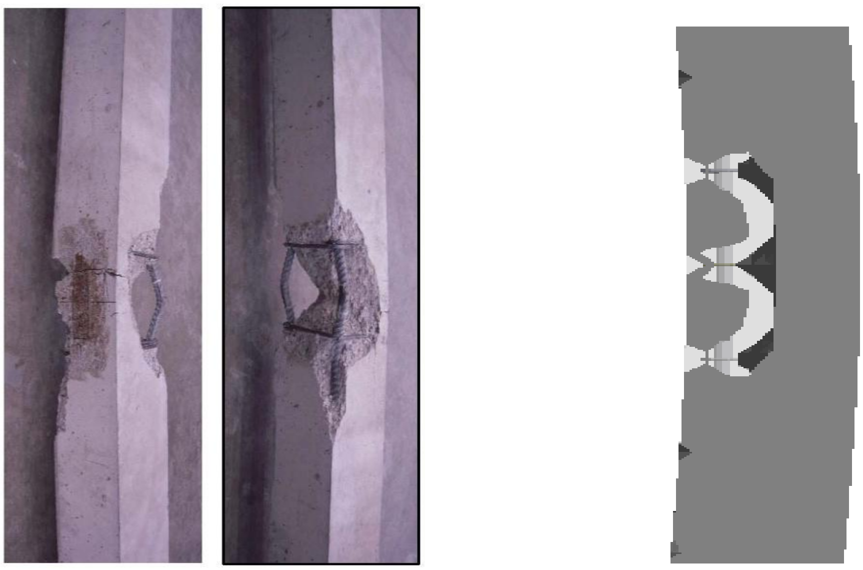


Figure 3.4 Force-Displacement Curve for Column with Slenderness Ratio 40

The force displacement curve obtained from experimental analysis and finite element analysis through ANSYS can be seen in the Figure 5.11, The results show good matchand a smooth curve is obtained. The compression damage can be seen in the Figure 5.12(a) and similarly the results from finite element analysis representing the crushing of concrete can be seen in the Figure 5.12 (b). From this it can be clearly interpreted that ANSYS is capable of producing good quality results with good accuracy with the help of SOLID65 element for concrete and LINK180 as discrete reinforcement.



(a) **(b)**

Figure 3.5 Compression Damage in Column with Slenderness Ratio 40

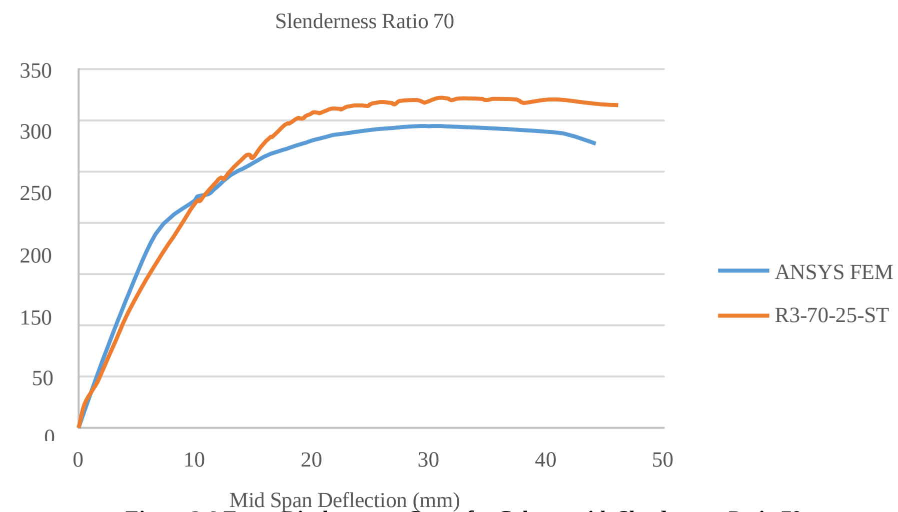
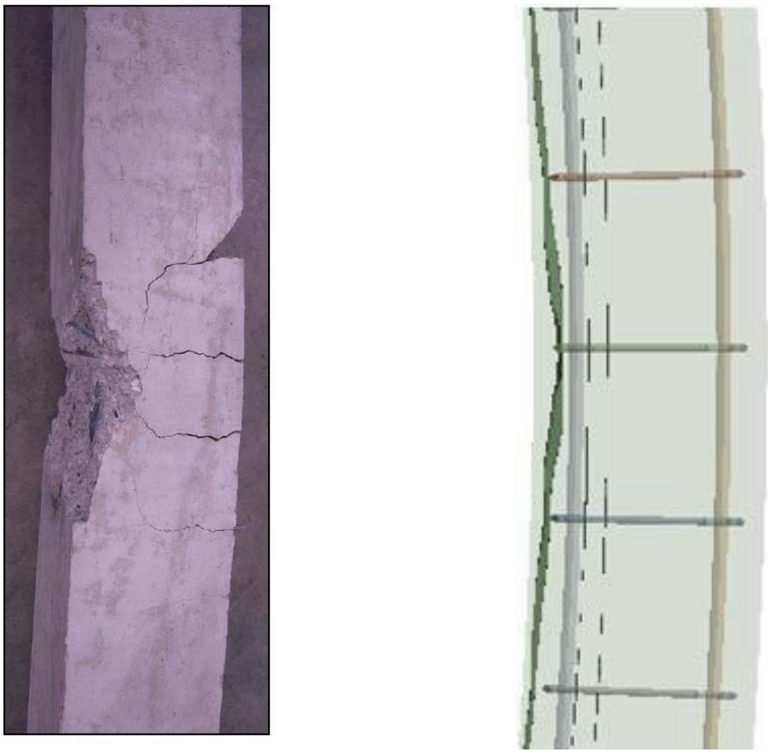


Figure 3.6 Force-Displacement Curve for Column with Slenderness Ratio 70



(a) (b)

Figure 3.7 Compression Damage in Column with Slenderness Ratio 70

(A) Experimental (B) FEA

Similarly, the experimental results of column having slenderness ratio of 70 were obtained and finite element analysis was done to compare the results of both simulations. The force displacement curves obtained are depicted in Figure 5.13 which shows good resemblance to the physical tests which tells us that ANSYS can be used for testing of materials like concrete. Similar to previous case, the compression crushing of concrete can be seen in the Figure 5.14 which representsvery high similarity in the results.

IV. RESULT & DISCUSSION

4.1 General: From the G+4 building, columns were selected having hinge in CP (collapse prevention) state along with their reinforcement details. These columns were modeled in ANSYS and their boundary conditions were set to simulate the behavior on site. The loading details were taken from analysis and then the model was subjected to a lateral displacement of 100mm to see the response of the column and other characteristics. In order to see the effect of transverse reinforcement, the columns were modeled with 2 stirrups spacings i.e., 150mm and 300mm to see the difference in the behavior of columns. For comparison, one column without any reinforcement was also simulated to understand the effect of longitudinal reinforcement

4.2Analysis and Results

4.1.1 Interior Column

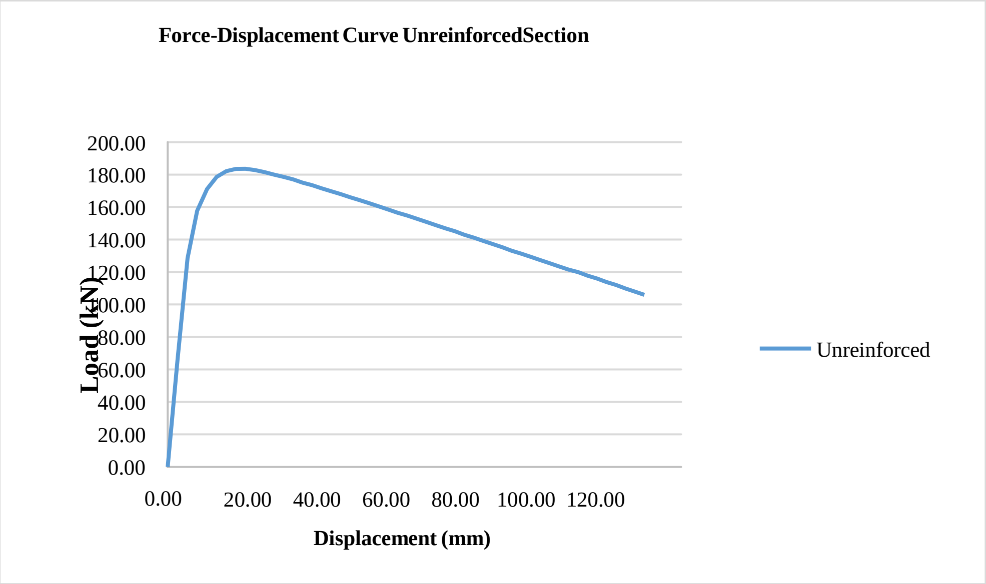


Figure 4.1 Force-Displacement Curve for Unreinforced Section

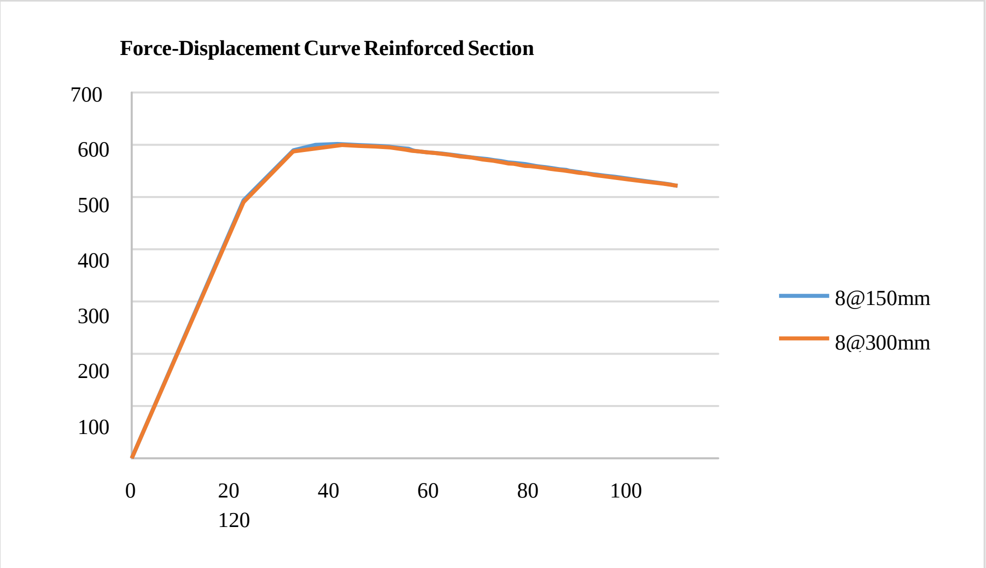
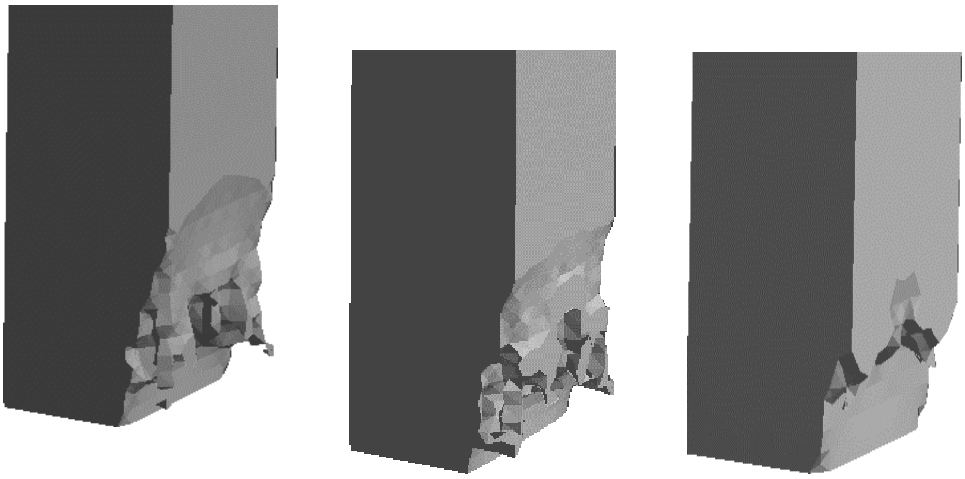


Figure 4.2 Force-Displacement Curve for Reinforced Section

Fig.4.2 shows that the change in stirrup spacing does not affect the strength and capacity of the column. However, it is clearly visible that longitudinal reinforcement played a major impact in increasing the load carrying capacity of the finite element model of column. The final load (capacity) is of about 600kN as compared to only 183kN for the unreinforced concrete model. We can also see that the unreinforced column a free fall slope post peak indicating a brittle mode of failure whereas the reinforced columns have a smooth down slope which indicates a ductile behavior of column which is a desired trait specially for lateral loading conditions.

Damage Profile



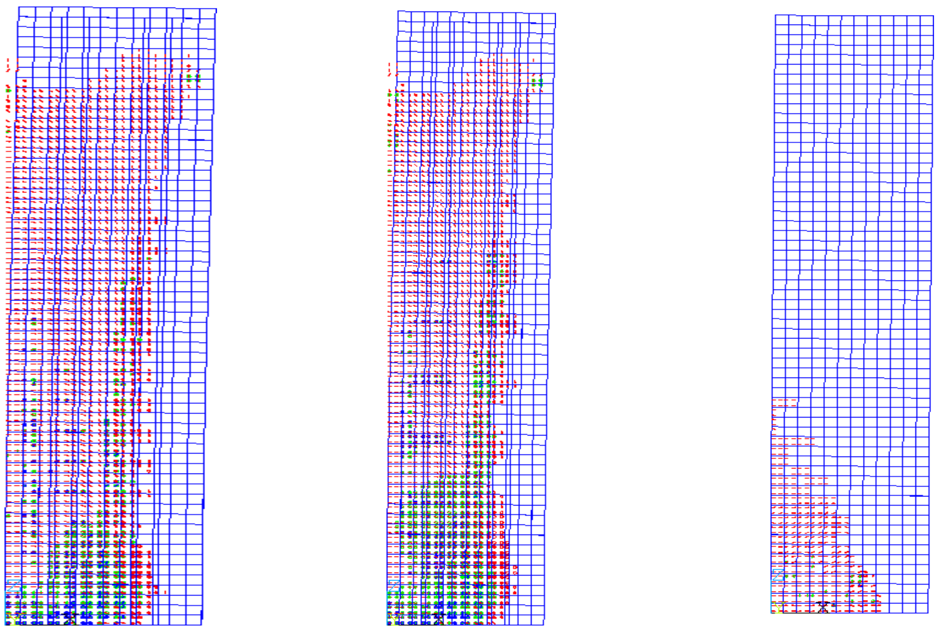
(a) (b) (c)

Figure 4.2 Concrete State at 100 mm Displacement for (a) 150 mm Spacing (B)300 mm Spacing (c) Unreinforced

From the Figure 4.2, it is clearly evident that damage in columns having 150mm and 300mm spacing are identical and does not undergo any major change in damage pattern. However, in case of damage in the unreinforced column, we find less damage to the concrete. This can be explained by the homogenous nature of unreinforced concrete as compared to the introduction of reinforcement leading to additional stresses in the cover zone of concrete, which leads to the spalling of concrete.

Cracking in Concrete

The crack patterns for the concrete columns were obtained at peak loads and at final displacement state. The cracks are formed due to tension generated in the concrete due to uplift and also due to the flexural crack due to the lateral loading.



(a) (b) (c)

Figure 4.3 Crack Profile at Peak Loads (a) 150 mm Spacing (b) 300 mm Spacing

(C) Unreinforced Concrete

4.1.2 Exterior Column Results

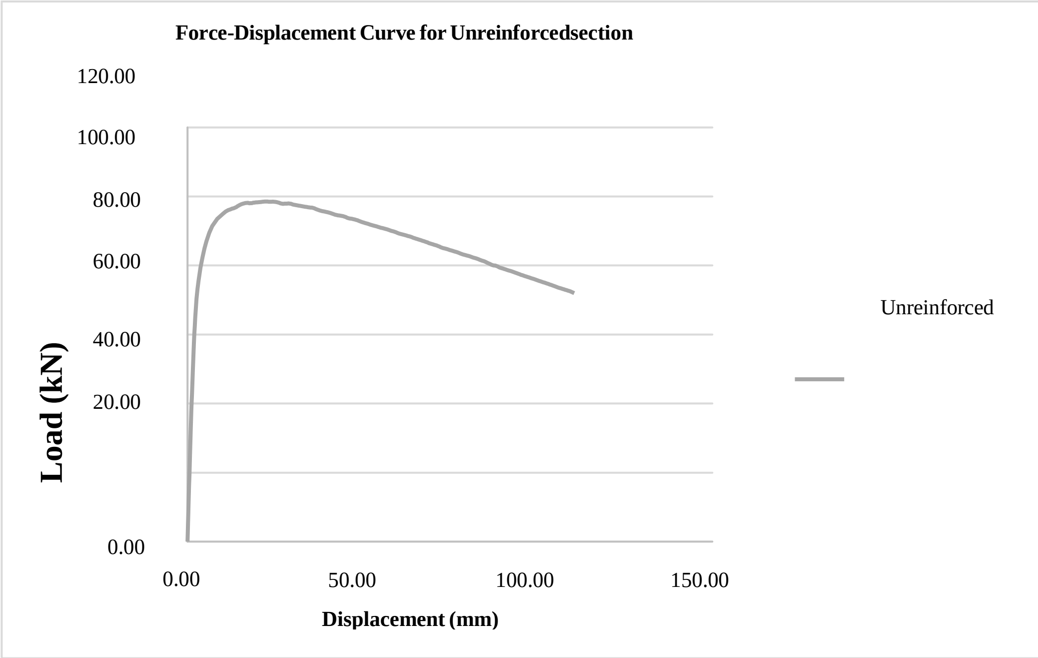


Figure 4.4 Force-Displacement Curves for Unreinforced Section

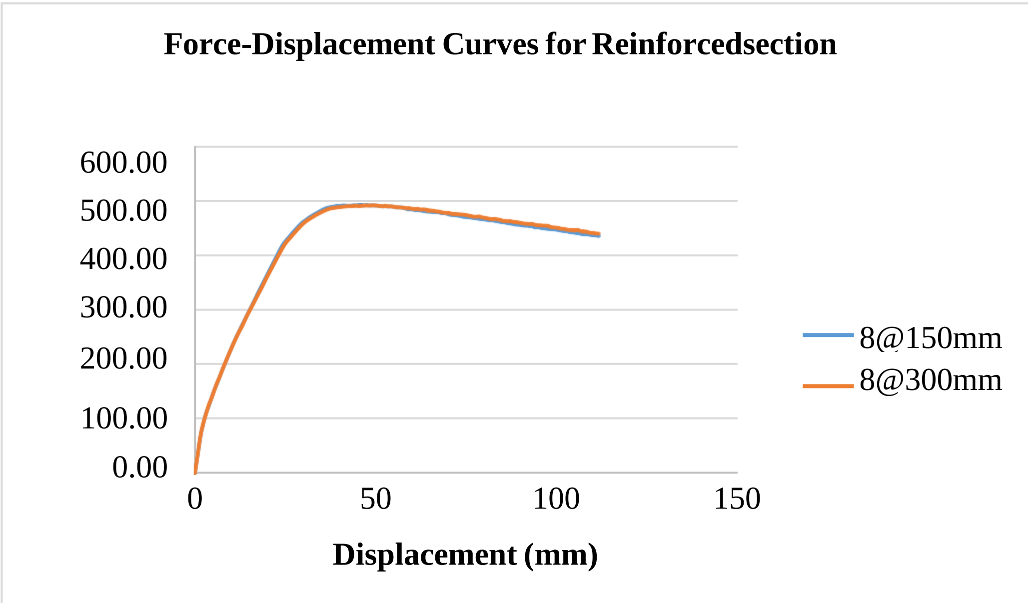
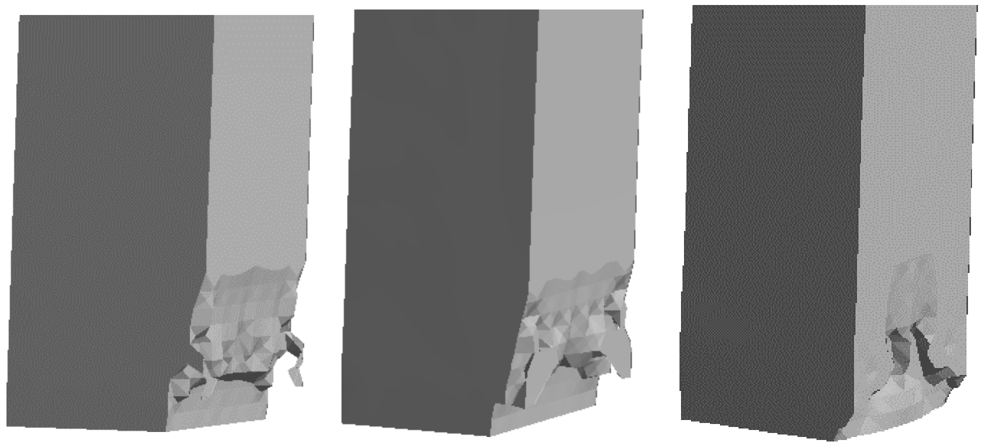


Figure 4.5 Force-Displacement Curves for Reinforced Section

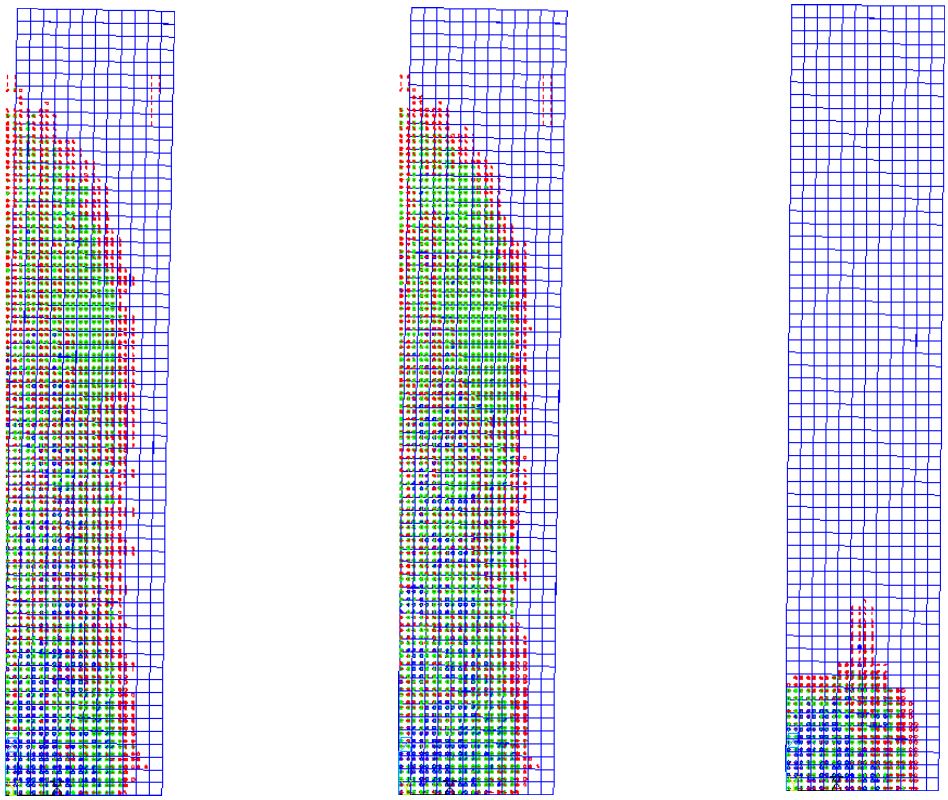
Similar to previous column results, here also it was observed that the total capacity of column is not influenced by the change in transverse reinforcement, and only the addition of longitudinal bars in the column cross section will affect the strength of column as we can observe that the unreinforced concrete column has a very less capacity to resist the lateral load and also will yield way earlier due to brittle nature. We also observe that in the unreinforced section, since the axial load was lesser for exterior columns, the capacity reduced since the axial load prevents the column from lateral movement and thus play a major role against lateral displacement.



(a) **(b)** **(c)**

Figure 4.8 Concrete State at 100 mm Displacement for (a) 150 mm Spacing (b) 300 mm Spacing (c) Unreinforced

For the damage profile, it is again seen that the introduction of reinforcement will lead to a higher compressive damage in concrete as the homogeneity is reduced and hence,we observed larger crushing of concrete in the cover zone where the stresses are transferred from steel to concrete.



(b) ***(c)***

Figure 4.9 Crack Profile at Peak Loads (a) 150 mm Spacing (b) 300 mm Spacing (c) Unreinforced Concrete

The cracking profile is shown above at peak loading, larger numbers of cracks represented in green color are observed for column having 300mm stirrup spacing which is due to the reduction in confinement of concrete at the intermediate locations and hence shear stresses are taken by concrete in these zones leading to more cracks. For the unreinforced concrete, we can see that the damage zone is localized in the bottom zone of the concrete where we can observe large number of tension and flexuralcracks. Similarly, for cracks at peak displacement condition, we can again observe presence of fewer cracks in the column with lesser spacing due to confinement of concrete is visible. For the unreinforced concrete, since there is no intermediate memberto take the stresses so there is a high damage zone at the bottom of the member.

V. CONCULSION

On the basis of finite element analysis of reinforced concrete columns subjected to axial and monotonic loading having different lateral reinforcement spacings, many interference can be seen. Conclusions of the research work are:

- The lateral load carrying capacity of reinforced concrete columns is purely dependant on the longitudinal bars present inside the concrete.
- The transerve reinforcement needs to be provided at critical sections such as joints where high amount of tensile and flexural bending occurs and may lead to failure.
- The transverse reinforcement helps in confining the concrete and prevent the buckling of longitudinal reinforcement thus inelastic deformation can be controlledand some part of the forces is transferred the the stirrups.
- In terms of cracking, it was observed that as the stirrups spacing increases, there is an increase in the number of cracks resulting from tensile forces and flexural bending which is due to reduction in the confinement of concrete.

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