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Development of an Efficient Anchorage Mechanism for RC Beam-Column Joints

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Abstract: The present study was thus focused on the development of the headed bar which is fulfil the aforesaid requirements. To achieve the present objective, numerical analysis carried out to determine the maximum pull-out capacity of the headed bar with different head of the headed bar. Total nine head anchor were used having different head shape of circular, rectangular, square. Numerical analysis of the pull-out test behavior with headed bar were done using ABAQUS software based on finite element analysis. There were 9 different types of analysis were done with different types of mechanical anchor. The variable are considered as shape of mechanical anchor and deformation over the length of mechanical anchor. Grade of steel reinforcement, grade of steel used for headed anchor, grade of concrete, size of the concrete cube were taken constant during the analysis. The variable includes shape of head, length of anchor and deformation over the length of anchor. It was found that failure was bar fracture when headed bar were used while slippage of bar occurred in absence of anchor. From the result, it has been observed that the headed bar can be used over straight bar having several advantages such as reduced congestion, lower bond slip and greater pull-out capacity. The result of the analysis provides the understanding of the different mechanical anchor which can be appropriate for the beam-column joint.”

Keywords: anchorage, beam-column joint, bond and development, headed bar, finite elements, numerical analysis, pullout, diameter of bars.

I. INTRODUCTION

The present objective of the study is to understand behavior of different mechanical anchor fixed at the end of the bar and embedded in concrete under tensile loading. based on the literature review, design guidelines of the mechanical anchorage system are reviewed. It has been observed from the literature that very less information is available related to the length and deformations over the length of the mechanical anchor. Hence, looking at the research gap in the literature and keeping the objective stated, the scope of the present research is limited to the development of an effective and innovative mechanical anchorage to provide adequate bond strength and to reduce the congestion of reinforcement at beam-column joint. For the purpose achieving the goal, numerical study of pull-out behavior with different mechanical anchors is performed at the present study. The effective shape and size of anchor selected based on the pull-out testing. The present research is based on the numerical analysis in Abaqus study of pull-out behavior of reinforcement with mechanical anchor. Firstly the numerical modeling is done to understand the pull-out behavior with mechanical anchor.

II. MATERIAL PROPERTIES

A. Concrete Properties

The properties of concrete and reinforcing steel used in the design are given below,

Elastic Properties

Density : 2.5E-006kg/m³

Young's modulus (E) : 27386.127 MPa

Poisson's ratio (μ) : 0.3

B. Steel Properties

HYSD bars were used with yield Strength 500MPa (FE500 grade). Diameter of bars used were 12mm, 16mm and 20mm.

Density : 7850 kg/m³

Young's modulus (E) : 2×10^5 N/mm²

Poisson's ratio (μ) : 0.3

Thickness of head:

TABLE- 1 Thickness of head

Diameter of bar (mm)	Thickness of head (mm)
12	6
16	8
20	10

Thickness of head should be calculated as 0.5 of the diameter of the bar. We select the above three types of bar (i.e 12mm, 16mm, 20mm) because as per IS 13920 :2016 clause 6.2.1 beam shall have at least 12 mm bar in top and bottom.

III. NUMRICAL ANALYSIS

Material properties for concrete and steel can be defined by using their standard properties like elastic properties, density, poisson's ratio etc. Steel is assumed as elastic material and failure takes place linearly. Material properties for reinforcement bar, mechanical anchor and concrete are defined in Table 1. The theoretical stress-strain behaviour for M30 grade concrete is listed in Table (Mander et al., 1988). The behaviour of concrete in tension was modelled as tension stiffening model. The theoretical behaviour of concrete in tension was adopted as per Nayal and Rasheed, 2006.

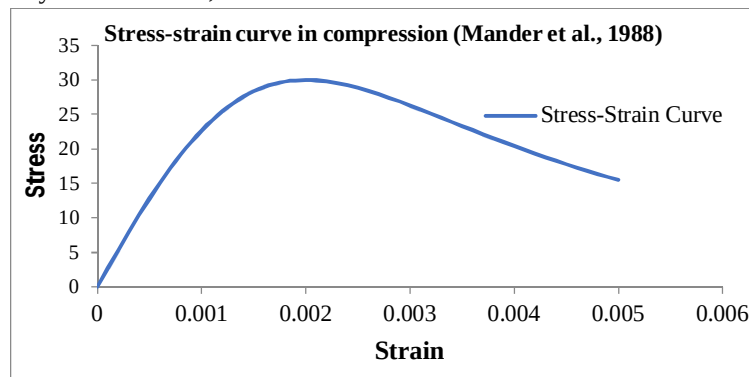


Figure 1 Stress-strain curve in compression (Mander et al., 1988)

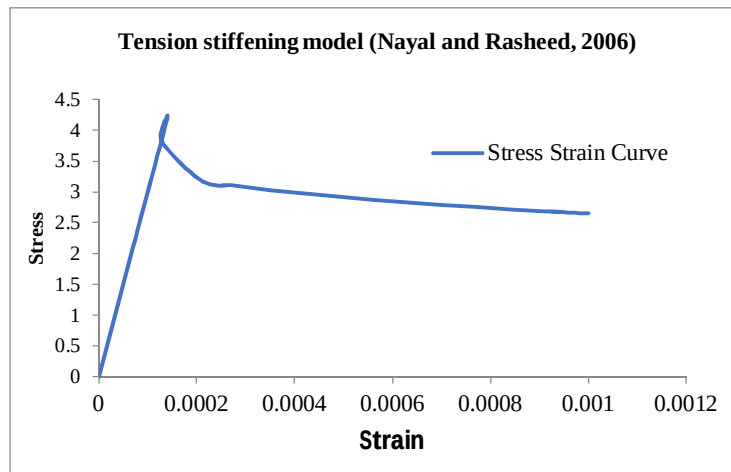


Figure 2 Tension stiffening model (Nayal and Rasheed, 2006)

A. Concrete Damage Plasticity

Beyond the linear limit of concrete, it possesses some plasticity nature. In the nonlinear behaviour of concrete, the young's modulus of elasticity of the concrete changes at every point. Damage occurs at the concrete and its behaviour in Abaqus can be modelled as smeared concrete model, brittle crack concrete model and concrete damage plasticity model (Abaqus Documentation 6.12). In the present study, concrete damage plasticity is chosen. In the plasticity damage model, the propagation of failure can be seen by the default colour notation (yellowish and reddish) in Abaqus after application of force.

Table 2 Tension Damage

Yield Stress	Damage Parameter	Inelastic Strain
3.83	0.000	0.00090
3.18	0.170	0.00101
3.10	0.191	0.00111
3.03	0.209	0.00122
2.97	0.225	0.00133
2.92	0.238	0.00145
2.87	0.251	0.00156
2.83	0.262	0.00168
2.79	0.272	0.00180
2.75	0.282	0.00192
2.72	0.291	0.00204
2.69	0.299	0.00216
2.66	0.307	0.00228

Table 3 Compression Damage

Yield Stress	Damage Parameter	Inelastic Strain
30.000	0.000	0.0009
29.946	0.001	0.001
29.552	0.014	0.0012
28.855	0.038	0.0014
27.939	0.068	0.0017
26.875	0.104	0.0019
25.722	0.142	0.0022
24.525	0.182	0.0024
23.921	0.202	0.0025
22.719	0.242	0.0028
21.542	0.281	0.0030
20.968	0.301	0.0031
19.853	0.338	0.0034
18.789	0.373	0.0036
17.780	0.407	0.0039
16.828	0.439	0.0041
15.505	0.483	0.0044

B. Loading

Loading in Abaqus is either applied as force or displacement loading. In the present study, displacement loading was applied for all the analysis. A maximum of 10 mm displacement loading was applied for the validation of the model and 50 mm loading was applied for analysis. At a time, maximum 10% load loading was applied in the form of static and monotonic in nature.

C. Interaction and Constraints

Interaction between concrete and reinforcement was surface to surface interaction (standard). For the interaction, properties were defined in normal and tangential direction. The interaction was assumed as friction interaction between steel and concrete. The frictional coefficient was taken as 0.57 (Rabbat et al., 1985).

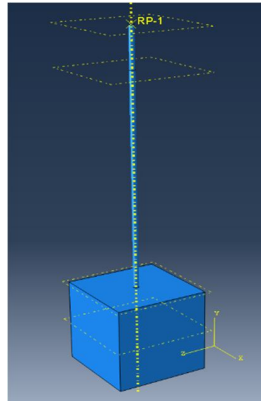


Figure 3 Interaction and Constraints

D. Meshing or Discretization

As the geometry of the anchor and concrete cube are irregular, free meshing was used for concrete cube and mechanical anchor. The approximate global size of meshing for model used in the validation is taken 8 mm. For final analysis, a mesh size of 5 mm was taken. In both the cases, meshing was done in the whole assembly at the same time.

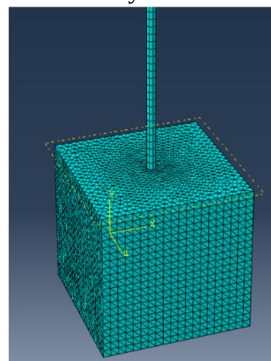


Figure 4 Meshing of Model

E. Boundary Conditions

Boundary condition is an important parameter during analysis. For the present study, the boundary condition was provided as fixed at the bottom of the cube that its upward movement was restricted during the application of uniaxial pull-out force.

F. Validation of Model

The present model was validated with the theoretical value of pull-out capacity as per IS 456, 2000. For the validation of model, 200 mm cube was modelled as per IS 2770-1, 1997 with 12mm diameter reinforcement. Two parts were modelled for the analysis – concrete cube and reinforcement. The embedment length of the bar was taken as 100 mm. the load is applied at the free end of the bar. Tensile loading was taken applied in which bar was pulled in the upward direction by providing fixity at the bottom part of the cube. No confinement was provided within the concrete cube.

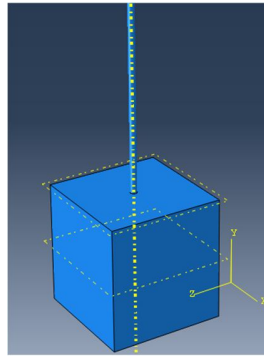


Figure 5 Validation of model subjected to loading

The assemblage of the model is shown in figure. The interactions were provided at interfaces as per section 4.3.6. The mesh size was taken as 8 mm for validation and other details regarding meshing or discretization were provided in section 4.3.7. the boundary condition for the model same as given section 4.3.8.

The maximum pull-out capacity was observed as 5.4 kN. The load vs displacement graph is shown in Figure below.

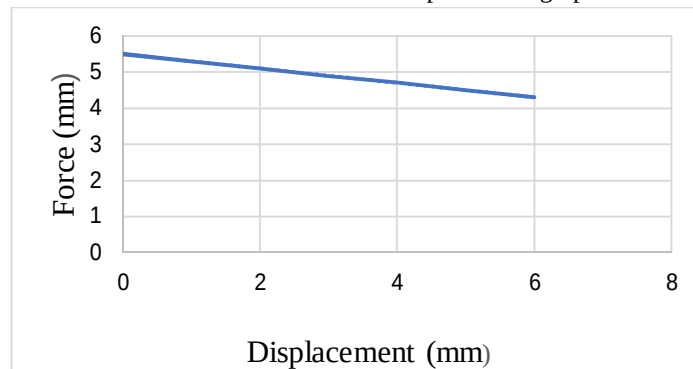


Figure 6 Load vs Displacement

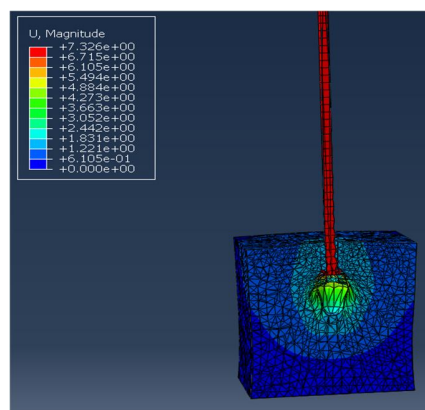


Figure 7 side split failure for concrete cover.

As per IS 456, 2000 formula for pull-out capacity of the bar can be calculated as per equation 4.3

$$T = (\pi d_b \times L_d) \times \tau_{bd} \quad \text{Eqn. 4.3}$$

Theoretical value of the pull-out force with 12mm diameter bar, 50mm development length can be calculated as,

$D_b = 12\text{mm}$, $L_d = 50\text{mm}$

$\tau_{bd} = 1.5 \times 1.6 = 2.4 \text{ N/mm}^2$ (Section 26.2.1, IS456, 2000)

Hence, the pull-out capacity = 4.52kN

The validation in the theoretical result and numerical result are 16.29 % which is reasonably acceptable (as per Abaqus Documentation 6.12).

G. Modelling of Test Specimens

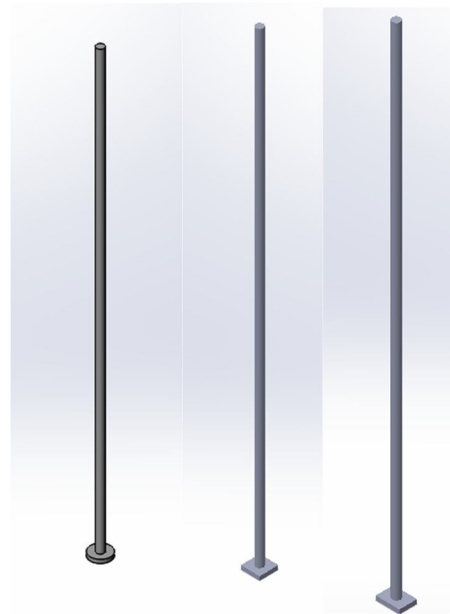


Figure 7 Circular, Square, Rectangular, headed bar modelled in the solid work.

For the different diameter of the bar, the size of head varying based on the net head area. The size of the head for different bar size are as shown in the following table.

1) For square shape head,

Table 4 Size of the square shape head

Diameter of bar	Size of the head (mm ²)
12 mm	30 x 30
16 mm	40 x 40
20 mm	50 x 50

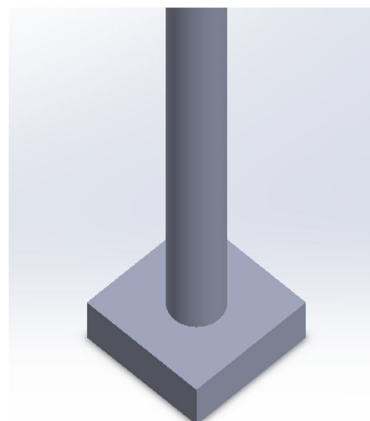


Figure 8 Square shape head

2) For Circular Shape Head

Table 5 Size of the circular shape head

Diameter of bar	Size of the head (Diameter)
12 mm	33 mm
16 mm	45 mm
20 mm	56 mm

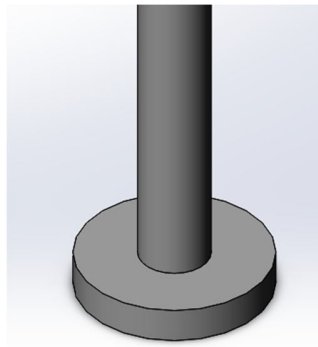


Figure 9 Circular shape head

3) For Rectangular Shape Head

Table 6 Size of the rectangular shape head

Diameter of bar	Size of the head (mm ²)
12 mm	26 x 35
16 mm	54 x 30
20 mm	84 x 30

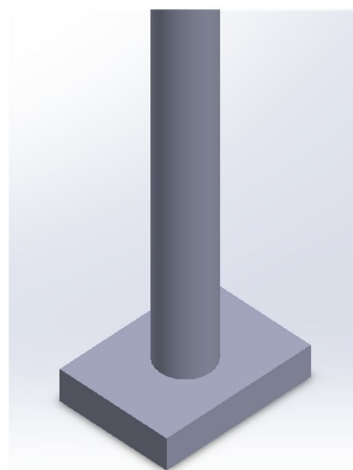


Figure 10 Rectangular shape head

The embedment depth for all the analysis was taken are different based on the work of (Thompson et al., 2005, 2006), ACI committee 318, 2014 has the formula in section 25.4.4.2.

Development length used for different diameter of the bar are as follows,

Table 7 development length for different diameter of bar

Diameter o bar (mm)	12	16	20
Development length (mm)	105	140	175

For the analysis of pull-out behavior of headed bar embedded in concrete, three parts were modelled separately – concrete cube, reinforcement bar and mechanical anchor. Concrete cube of size 200 mm was used for all analysis in M-30 grade concrete. The size of the cube was 200 x 200 mm constant for the all the analysis. The groove in the concrete cube are the important part of the concrete cube. The dimension of the groove inside the cube are not correct then its creates some problem in the surface to surface interaction. The concrete cube are modelled same like headed bar, first it was modelled in the solid work software then import into the abaqus.

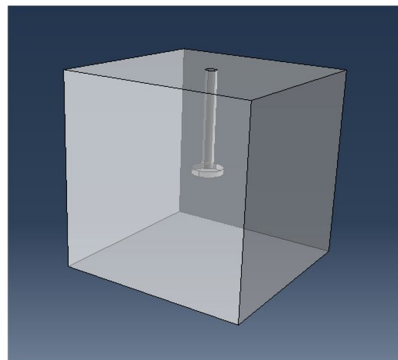


Figure 11 Concrete block import from solid work software

The three part modelled separately like concrete cube, reinforcement bar, and mechanical anchor assembled together to form a single model. The total parts such as the concrete cube, reinforcement bar mechanical anchor are modelled in solid work software. The all members are assembled together in solid work, the total assembly are shown in below,

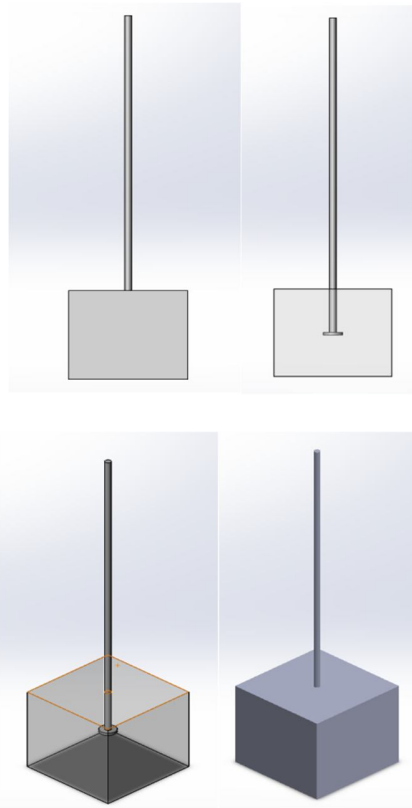


Figure 12 total assembly of the model in solid work software

IV. RESULT AND DISCUSSION

A. Effect Of Length Of Mechanical Anchor On Pull Out Capacity

For rectangular head bar, the maximum pull out capacity was found for 20 mm diameter of bar which is 47.52 kN corresponding to a 50 mm displacement loading. Similarly, for the square headed bar, again the maximum pull out capacity was found for 20 mm diameter of bar corresponding to a total of 50 mm displacement loading which was 47.05 kN. For the circular headed bar, the maximum pull out capacity was found for 16 mm diameter of the bar for a total of 50 mm displacement loading which was 46.68 kN.

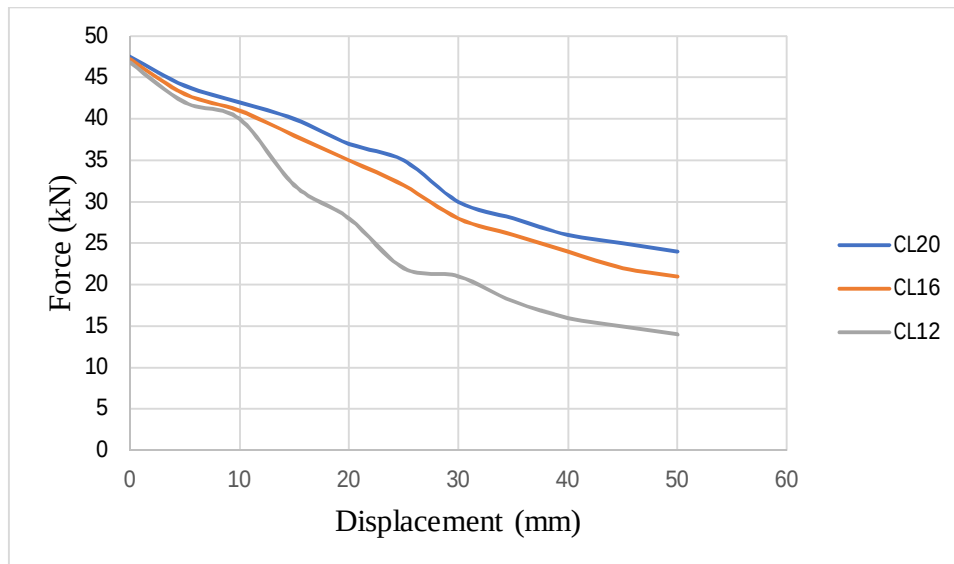


Figure 13 pull out capacity of headed bar of rectangular head.

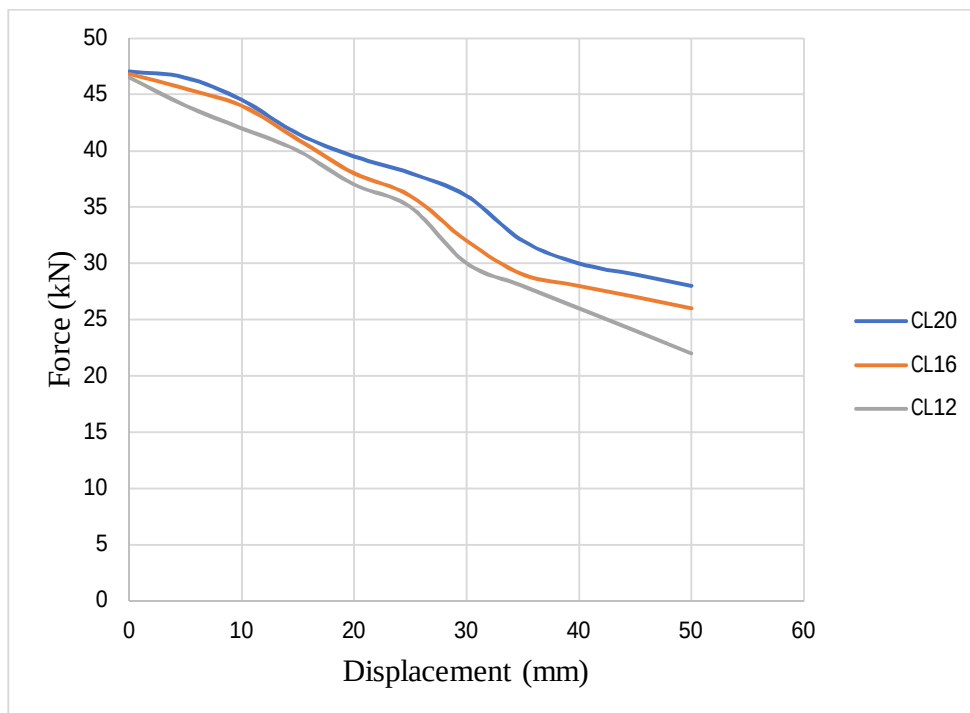


Figure 14 pulled out capacity of headed bar of square head.

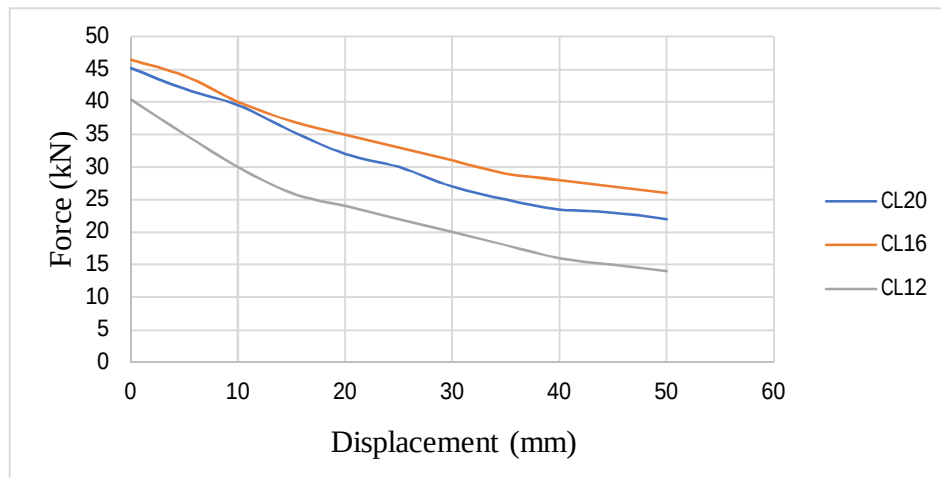


Figure 15 pulled capacity of the headed bar of circular head.

B. Effect Of Deformation Over The Diameter Of The Reinforcement On Pull Out Capacity

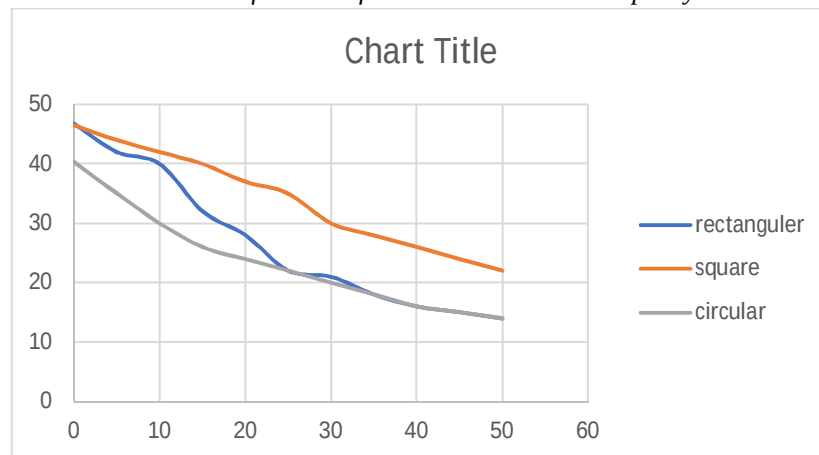


Figure 16 Effect of deformation over 12 mm diameter of reinforcement

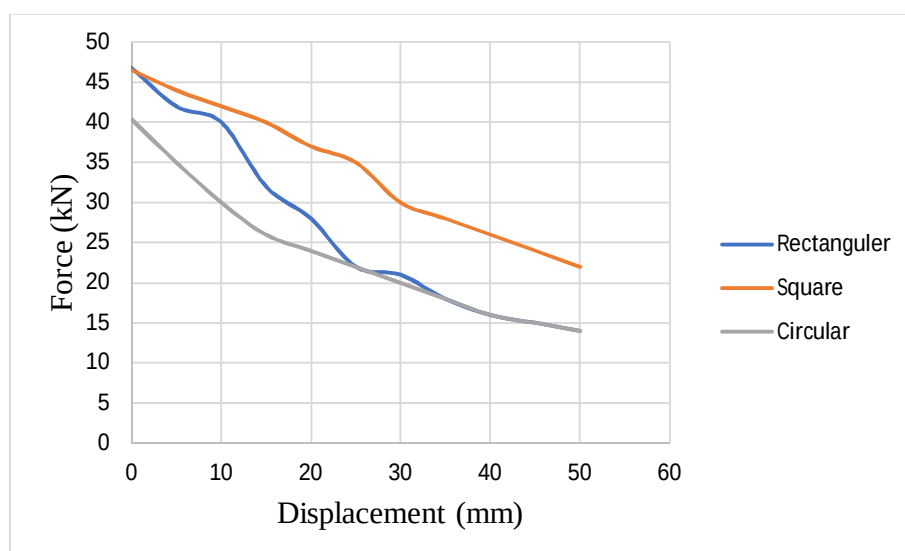


Figure 17 Effect of deformation over 16 mm diameter of reinforcement

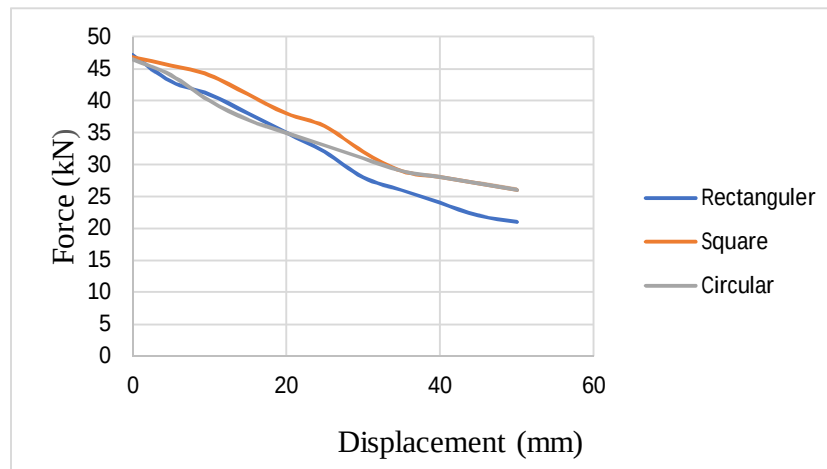


Figure 18 Effect of deformation over 20 mm diameter of reinforcement

C. Behavior Of Initial Cracking To Ultimate Failure

When the stress in the reinforcement exceeded the yield strength of the reinforcement then yielding occurred. The maximum pull out capacity was found due to yielding of bar. The failure was bar failure or ductile failure. Approximately at 5 mm displacement loading, the maximum pullout force occurred. After the maximum force when the displacement was further increased yielding occurred but at the lower value of force as compared to maximum pullout force. As the displacement loading was again increased then the pullout force as lower as 10 to 25 kN for the various analysis till 50 mm displacement loading. The initial crack and crack after 50 mm displacement loading (total loading). Is shown in the figure 5.7, 5.8 and 5.9 respectively.

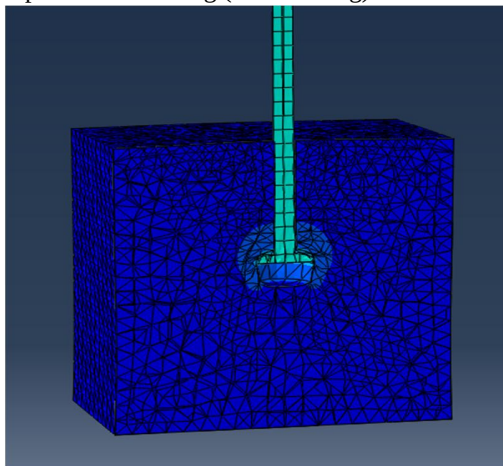


Figure 19 Initial crack pattern near head

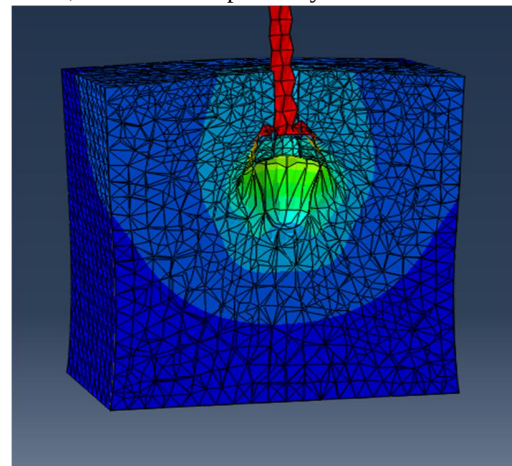


Figure 20 Final crack pattern at 50 mm displacement

V. CONCLUSIONS

Based on the work carried out, following conclusions can be drawn :

- The failure pattern during the pull out of the bar without anchor is slippage of the bar while the failure pattern of the bar with anchor is the fracture of the bar after yielding with higher pull out capacity. From these results, it can be concluded that the presence of mechanical anchor significantly modifies the pull out behavior of the bar in concrete and increases its pull out strength.
- Form the numerical analysis, it can be concluded that with an change in the shape of the mechanical anchor, there is a little effect on the pull out capacity of the headed bar.
- The numerical analysis reveals that the presence of circular and square deformations throughout the length of mechanical anchor has a minimum effect on the pull-out capacity of the headed bar.

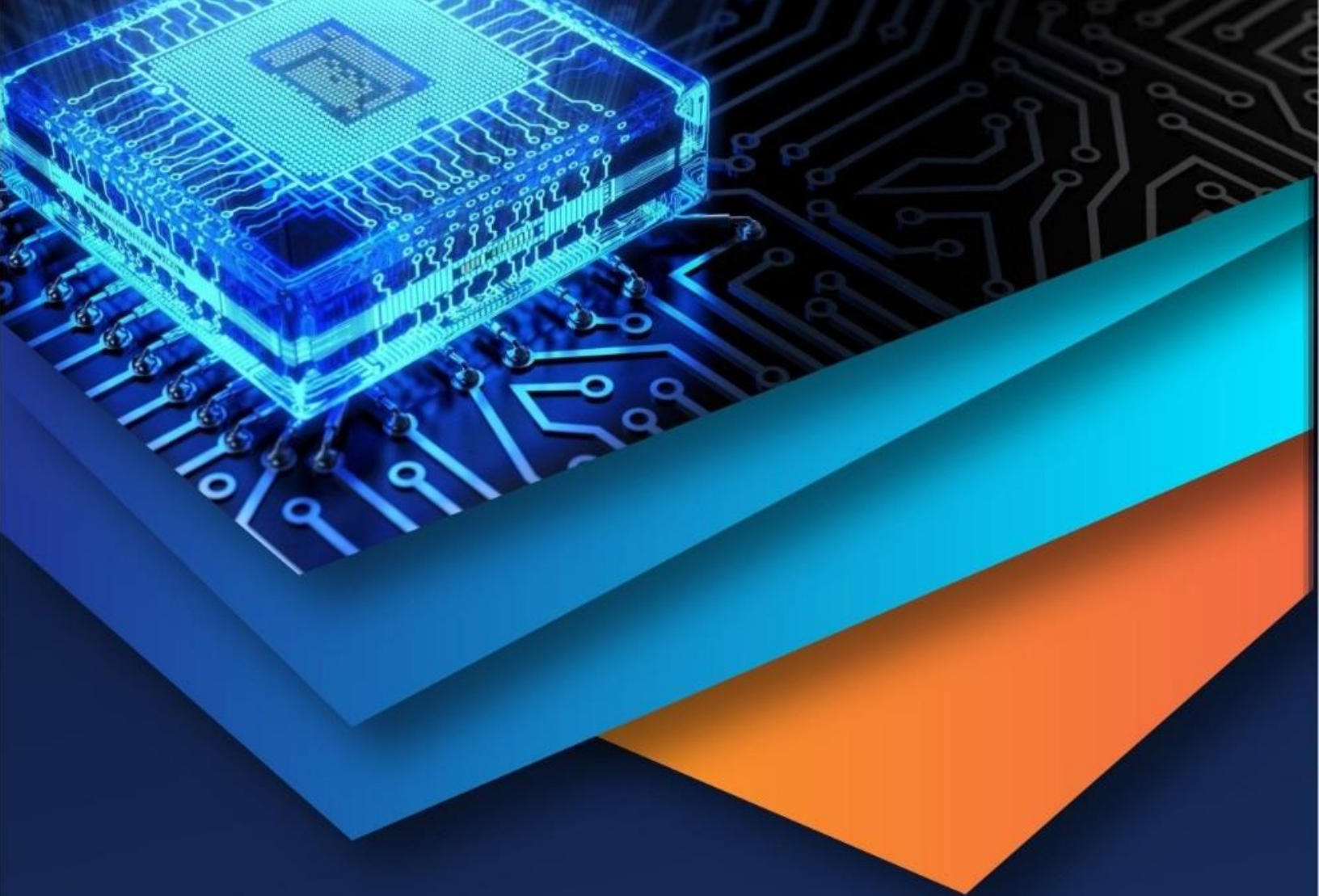


VI. ACKNOWLEDGEMENT

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