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EFFECT OF DRILLED CORES ON AXIAL LOAD CAPACITY OF REINFORCED COLUMNS WITH BRICK AGGREGATE CONCRETE

Manzur, Tanvir[1,2], Khomeni, Md. Ayatullah[1], Emon, Md. Abul Bashar and Ahmed[1], Ishtiaque[1]

[1]Department of Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh

[2]tmanzur.buet@gmail.com

Abstract: Determination of in-situ concrete strength using drilled cylindrical core from Reinforced Concrete (RC) structural members is an established and reliable practice. A number of available standards provide specifications and testing procedures; but literature on the effect of core drilling on load capacity of functional RC members is not very common. The tragic collapse of Rana Plaza in 2013 has triggered structural integrity assessment of existing Ready-Made Garment (RMG) factories in Bangladesh. As part of the material quality assessment, evaluation of concrete strength through core cutting from columns is being recommended for a large number of buildings at present. In these circumstances, a comprehensive study has been undertaken to investigate the effect of core extraction on capacity of RC columns. Since a large number of old factory buildings were made of brick aggregate concrete, column specimens were prepared using brick chips. A total of 27 column specimens (200 mm x 200 mm in cross section) were made having various mix ratios. Cores were drilled from two different locations of the columns. Control columns without any core were also tested for comparison. The specimens were tested for compressive strength and the failure patterns were observed. It was reported that with core at one-third height of the column, strength reduction can be as high as 25%; whereas, for columns with core at mid-height, maximum reduction in strength was around 16%. In addition, experimental results were used to simulate behavior of full scale columns with cores using ABAQUS. In fine, the finding of the study is of utmost significance to the practicing engineers and consultants in the field of structural safety assessment and retrofitting works.

Keywords: core, drilling column, ABAQUS, retrofitting,

1 Introduction

Bangladesh is a country where unplanned urbanization is quite common and many buildings are not designed according to the national building code. Several buildings were designed to serve one purpose but are being used for other purposes. However, there is hardly any consideration of increased loads in such cases. Moreover, in certain instances, poor quality control during construction results in weaker concrete. As a result, there exists a high potential of complete or partial structural failure of these types of buildings. One of such failures was the tragic collapse of Rana Plaza in 2013 where death toll exceeded a thousand. This incident instigated a drive for structural safety assessment of Ready-Made Garment (RMG) factory buildings throughout the country. As safety is the primary concern for every structure, detailed assessment of the structures has become indispensable so that resources are not wasted due to unnecessary rehabilitation (Buckland and Barlett, 1992). As a part of such ongoing assessment process, evaluation of concrete strength through core cutting has been recommended for a large number of buildings. Though, core cutting is one of the most reliable methods to determine strength of existing concrete work (Malhotra, 1976), it has the potential to reduce the capacity of structural element. The relevant ASTM Standard (ASTM C42, 2004) also delegates the safety issues to the prudent judgment of concerned engineers. However, the effect of core drilling on the RC column capacity has not been much addressed in the literature. A thorough literature review reveals two studies (Calavera et al., 1979 and Masi et al., 2012) where some indications can be found on the effect of core cutting on RC column capacity. It has been suggested by Masi et al. (Masi et al., 2012) that restoration can be ineffective in case of low strength concrete. An analytical study by Siddique and Khomeni (Siddique and Khomeni, 2014) also found that effect of core drilling is more pronounced in low strength concrete. Unfortunately, most of the structures that require safety assessment usually have concrete of low strength. Moreover, in many practical instances, cores were required to be cut from a large number of columns of a single building for conducting detailed engineering assessment (DEA). It is evident that effect of core cutting is different for different types of structure and it depends on concrete quality, aggregate type, member size, reinforcement detailing etc. With this end in view, a comprehensive study has been undertaken to investigate the effect of core extraction on capacity of a column and eventually, to develop a guideline that could be followed during core cutting. In this study, brick chips was used as coarse aggregate as many buildings (particularly the old ones) in our country use brick chips as it is cheaper, locally available and light-weight. In this article, results from the tests have been presented and comparison of axial capacity of different types of columns was made for different concrete mixes and core locations. It has been found that capacity of columns with core at one-third height can be reduced by more than 25%. On the other hand, columns with core at mid-height showed a maximum reduction in strength of around 16%. Finally, finite element analysis (FEA) of full scale columns with cores has been carried out in ABAQUS environment using experimental results to perform a parametric study. The findings of the FEA analysis provide information on reduction in capacity of full size columns of varying dimensions which will assist practicing engineers and consultants in structural capacity assessment of buildings.

2 Experimental Program

The primary objective of the experiments is to evaluate the ultimate capacity of the columns having three different concrete strengths and at three different conditions e.g. normal column (without any core), core drilled at mid depth of columns (CMD), and core drilled at one third depth of column (COD). Three different concrete strengths (all fall into low concrete strength category) were selected considering typical strengths of brick aggregate concrete of the country. In addition, crack pattern at various loading stages was also observed. The following tasks were performed in this study:

- Compressive strength of cylinder concrete specimens
- Tensile strength of reinforced bar
- Axial capacity of laboratory scale columns
- Observation of crack pattern of test columns
- Finite element analysis of full scale columns

2.1 Test Materials

2.1.1 Concrete

Three types of mixing ratio were used to achieve the target strength of 10.3-13.8MPa, 13.8-17.2MPa and17.2-20.6MPa. In this regard, the mixing ratios for three different strength ranges were1:2:4 (cement: fine aggregate: course aggregate by weight) with water cement ratio of 0.5, 1:1.5:3 with water cement ratio of 0.6, and 1:1.5:3 with water cement ratio of 0.4, respectively. No admixture was used in any mix. Ordinary Portland cement (Cem-1) was used with 18.25 mm downgraded brick chips as coarse aggregate.Locally available Sylhet sand (FM=2.42) was used as fine aggregate. Oven dry unit weight and absorption capacity of brick chips was found to be 1020 Kg/m^3 and 14.3 %, respectively. The 28 day compressive strengths of above three mixes were found as13, 15 and19MPa, respectively.

2.1.2 Steel Reinforcement

For construction of the test columns,10 mm and 12 mm diameter deformed bars was used. Twelve mm bar was used as longitudinal bar of columnsand 10 mm bar was used as tie bar. Yield and ultimate strength of 10 mm bar was found to be 513 MPa and 704 MPa, respectively and for 12mm bar these values were found as 378 MPa and 611 MPa, respectively. Average elongation for 10 mm bar was 14.33% and average elongation for 12 mm bar was 13.67% at rupture.

2.2 Design and Fabrication of Test Columns

Square concrete columns were made with three different mixes to gain three different target low strengths. Each column was 200 mm by 200 mm in cross-sectional dimension and 1250 mm in height. From previous study (Siddique and Khomeni, 2014), it was observed that crushing of columns occured at edges due to stress concentration during axial compressive loading. To eliminate this phenomenon, a column head was made with dimension of 300 mm x 300 mm x 150mm. The concrete cover was scaled down to 25 mm to account for smaller column dimension. According to ACI code (ACI 318, 2011), tie bar spacing at the ends (up to L/3 from support) was kept as 100 mm and at the middle was kept as 150 mm. Also, minimum 1% reinforcement ratio (in terms of gross area of column section) was maintained for columns. In order to ensure this, 4 number 12 mm diameter bars were used as longitudinal bars providing 1.25% reinforcement ratio. Details of column fabrication and dimension are shown in Figure 1. From core drilled columns, 50 mm diameter cores with length of 100 mm were cut.

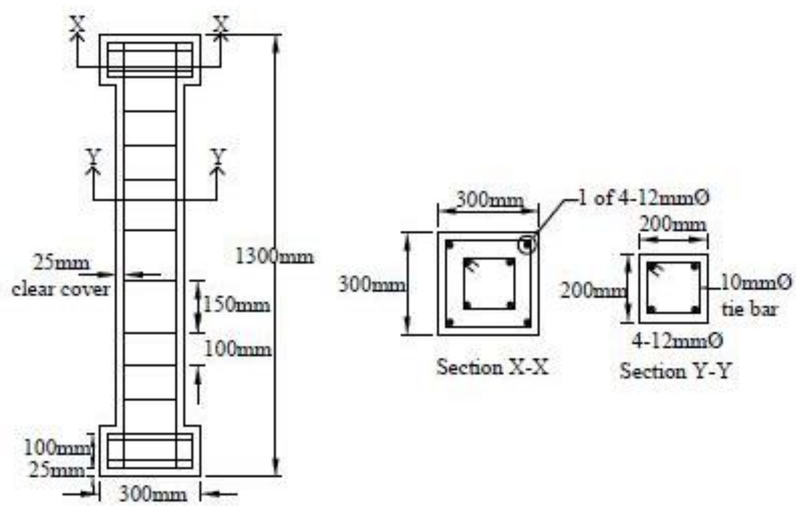

Figure 1: Column section and reinforcement details

2.3 Testing Methodology

For each sample type, three columns were tested. All the columns were subjected to pure axial loading. Steel cap was used to ensure uniform loading over column as shown in Figure 2. Geotextile is placed inside the cap to ensure uniform load over column. Column is centered properly to ensure pure axial loading by Tinius Olsen Universal Testing Machine. A constant deflection control loading was applied with the movement rate of the platform being 3 mm/min. Time versus load was continuously monitored and data was recorded through a data logger. Deflection and cracks of column were monitored with a video extensometer continuously. Figure 3 shows the overall setup for column testing.

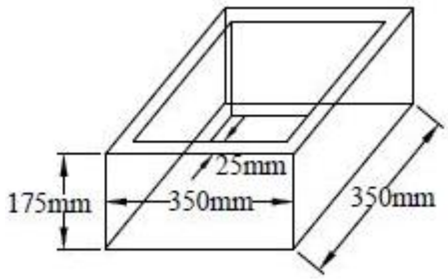

Figure 2: Steel Plate

3 Results and Discussion

The experimental campaign is reported and analyzed, with particular emphasis to the main goal of the study that is pointing out the effects of core drilling on axial capacity of columns. Figure 4 shows column capacity versus concrete strength and Table 1 summarizes the test results. From Figure 4, it is evident that ultimate capacity of normal columns (NC) is always higher than that of columns with core. On the other hand, ultimate capacity lines for columns having core at mid depth (CMD) and for columns having core at one third depth (COD) are always reasonably lower than the capacity of NC columns. Figure 5 shows the percent reduction in capacity of CMD columns and COD columns with respect to NC columns for different concrete mixes. It is apparent from both Figures 4 and 5 that capacity of core drilled column varies significantly depending on location of core. It has been observed that COD columns experienced greater reduction in capacity as compared to capacity of CMD columns. Moreover, reduction in capacity of core drilled columns has been found to be variable with concrete strength. However, core location has more pronounced effect on capacity of core drilled columns as compared to concrete strength. The percentage of reductions in capacity of CMD columns have been found as 12.1, 13.3and 16.1 % for 13, 15 and 19 MPa concrete, respectively with respect to capacity of NC columns. On the other hand, COD columns showed 23.6, 19.0 and 25.6% reduction in axial capacity as compared to NC columns for 13, 15 and 19 MPa concrete, respectively. The hypothesis behind such higher reduction in axial capacity of COD columns might be due to relatively larger stress concentration near support.

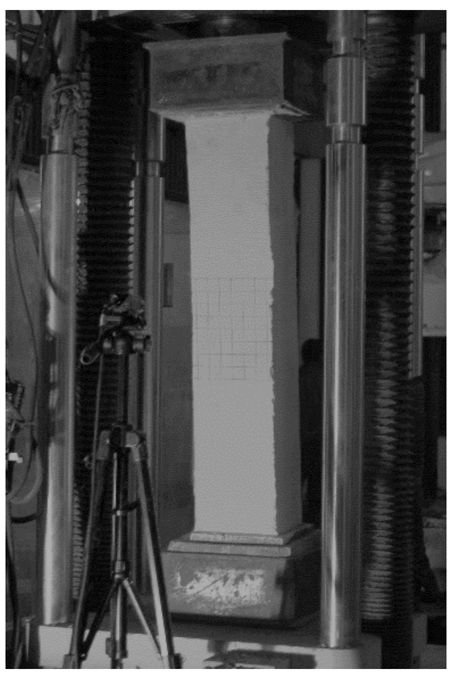

Figure 3: Test Setup for Pure Axial Loading

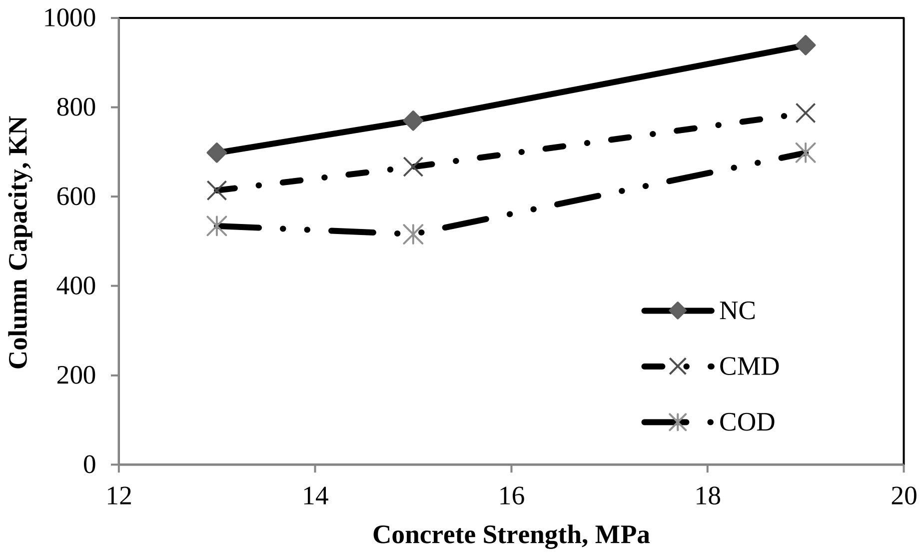

Figure 4: Concrete Strength Vs Column Capacity

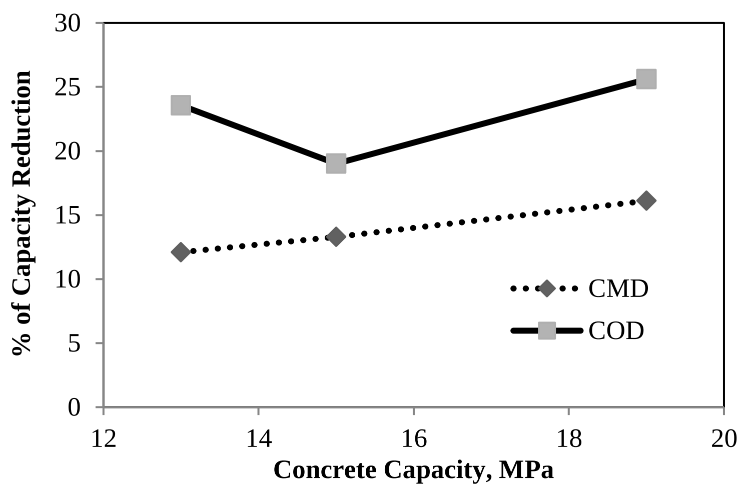

Figure 5: Concrete Strength Vs % of capacity reduced for CMD and COD

4 Comparison between FEA and Experimental Test Results

Finite element models of full scale columns were developed in ABAQUS environment. Before that, columns having same dimension of experimental samples were modeled and analyzed in ABAQUS in order to compare the experimental data with FEA results. Concrete damage plasticity (CDP) model was used to observe the failure pattern as well as load carrying capacity of the columns. A refine mesh size of 15mm as sweep mesh (Reddy, 1993 and Hibbit et al., 2009) was used to ensure uniform meshing at vicinity of the core region. The boundary conditions were defined at the bottom support by blocking translation in the vertical direction. The vertical displacement rate was kept same as laboratory test which was equal to 3 mm/min. It has been observed that crack starts initially at mid region of NC column. For CMD and COD columns, the initial cracks developed at the vicinity of core location and eventually propagated diagonally towards boundary region. Crack patterns observed from FEA analysis have been found to be in consensus with the experimental findings. Figure 6 shows the overall crack pattern found in laboratory tests and FEA analysis. The axial capacity of different types of columns found from FEA analysis also showed close proximity to the experimental results. The difference between experimental and FEA capacities of NC columns for 13 MPa strength was found as about 4.4 %. For 15 and 19 MPa concrete, the differences between experimental and FEA capacities of NC columns were obtained as 1% and 3.8%, respectively. For CMD and COD columns having strength of 13 MPa, the differences between experimental and FEA capacities were found to be 4.4% and 3.4%, respectively. For concrete strength of 19 MPa, the differences between experimental and FEA capacities of CMD and COD columns were found as 0.6% and 1%, respectively. In most cases, experimental values were found to be higher than the FEA results, showing that the FEA was slightly conservative in obtaining the column capacity. However, in all instances, the difference between experimental results and FEA analysis is insignificant. Therefore, it can be said that simulation of columns in ABAQUS environment has been validated by experimental results. Details of experimental and FEA results are provided in Table 1.

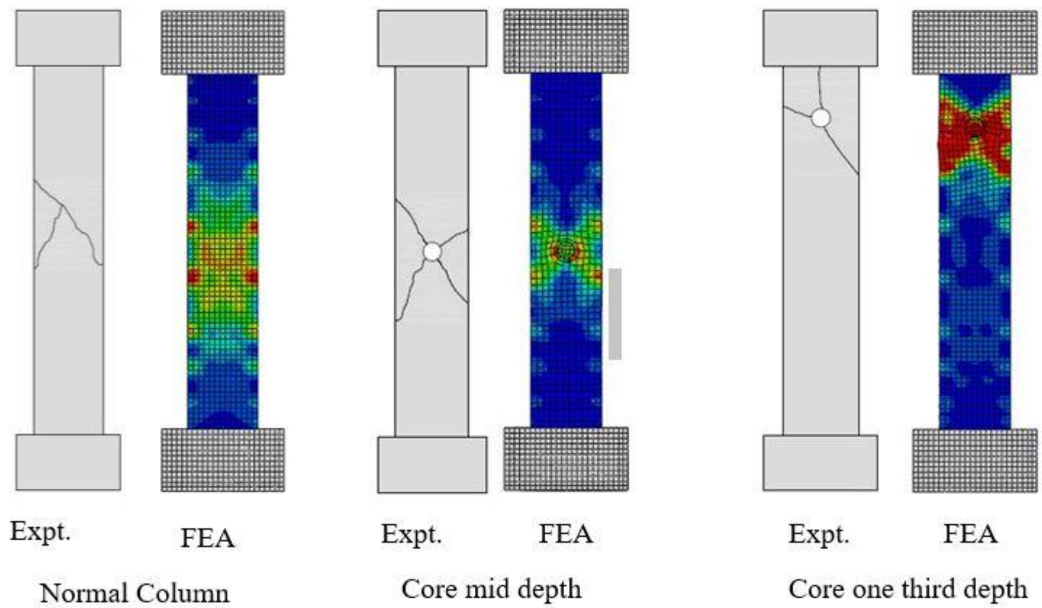

Figure 6: Crack pattern at ultimate load

Table 1: Column Capacity

Concrete Strength MPa	Normal Column (NC)		Core Mid Depth (CMD)				Core One Third Depth (COD)			
	Axial Capa-city KN (Expt.)	Axial Capa-city KN (FEA)	Axial Capa-city KN (Expt.)	Axial Capa-city KN (FEA)	% of Capa-city Redu-ced (Expt.)	% of Capa-city Redu-ced (FEA)	Axial Capa-city KN (Expt.)	Axial Capa-city KN (FEA)	% of Capa-city Redu-ced (Expt.)	% of Capa-city Redu-ced (FEA)
13	698	667	614	587	12.1	12.0	534	516	23.6	22.7
15	770	778	667	667	13.3	14.3	623	645	19.0	17.1
19	939	903	787	792	16.1	12.3	698	691	25.7	23.5

5 Parametric Study by FEA Simulation

A parametric study was conducted by simulating behavior of full scale columns of 3000 mm in height and having varying cross sectional dimensions of 300 mm x 300 mm, 375 mm x 375 mm, 450 mm x 450 mm and 525 mm x 525 mm. Concrete strength of 13.8 MPa was used for this parametric study. Core sizes (diameter by depth) were varied as 50 mm x 100 mm, 75 mm x150 mm and 100 mm x 200 mm to investigate the effect of core size on overall axial capacity of columns. Table 2 provides all relevant data of parametric study found from FEA. Figure 7 shows the percentage of capacity reduction with respect to projected core area. The projected core area was calculated through multiplication of core diameter by core depth as shown in Figure 8. It is clear from Figure 7 that the axial capacity of core drilled column reduces linearly with the increase in projected core area. Moreover, it has been found that capacity of columns having smaller cross-sectional area reduced significantly with respect to increase in projected core area as compared to capacity of columns with larger cross-sectional area. For instance, reductions in axial capacity of columns with cross-sectional dimension of 300 mm x 300 mm were found to be 3.75, 10.4 and 19% for projected core area of 5000 mm^2, 11250 mm^2, and 20000 mm^2, respectively. In case of column size of 525 mm x 525 mm, the respective percentage of reductions in capacity were found as 1.1, 2.4 and 5%. Therefore, it is obvious that effect of core size is quite pronounced in case of smaller column sections. Another interesting observation can be made from Figure 7 that the effect of core size is lesser for column size of 450 mm x 450 mm or higher. Therefore, it is extremely important to carry out load analysis before cutting cores from columns having dimension of 375 mm x 375 mm or less.

Table 2: Variation of column Capacity with Variation in Core Depth and Diameter

Core Size (Dia X Depth) mm	Projected Core area mm^2	Column Size mm X mm	Normal Column, KN	Core mid depth, KN	% capacity reduction
50 x 100	5000	300 x 300	1544	1486	3.75
75 x 150	11250		1544	1384	10.3
100 x 200	20000		1544	1250	19.0
50 x 100	5000	375 x 375	2424	2371	2.19
75 x 150	11250		2424	2255	6.97
100 x 200	20000		2424	2091	13.7
50 x 100	5000	450 x 450	3576	3519	1.59
75 x 150	11250		3576	3439	3.83
100 x 200	20000		3576	3376	5.59
50 x 100	5000	525 x 525	5142	5084	1.13
75 x 150	11250		5142	5018	2.41
100 x 200	20000		5142	4884	5.02

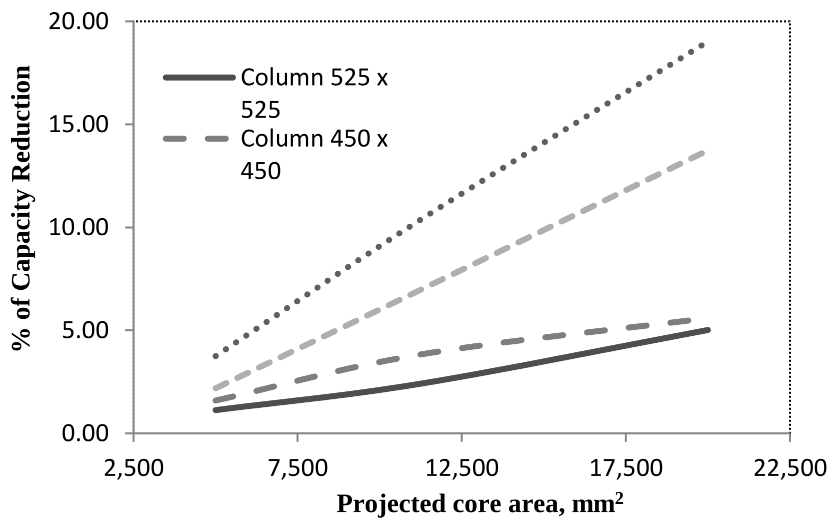

Figure 7: Percentage of capacity reduction Vs Projected core area

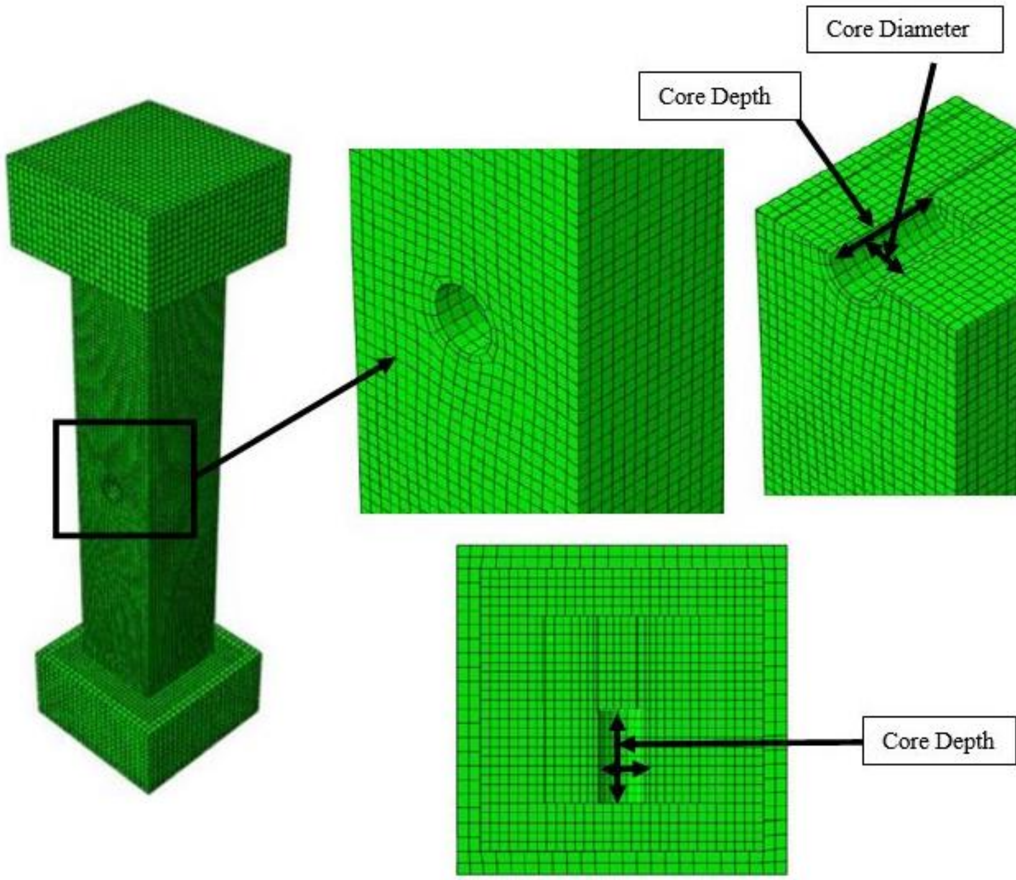

Figure 8: Projected core area

6 Conclusions and Recommendations

The following conclusions can be drawn from the limited study performed;

- From experimental results, it has been found that drilling out a core can significantly affect the axial capacity of a column depending on concrete strength and location of core along column length. However, effect of concrete strength is relatively less as compared to core location on capacity of core drilled column. Axial capacity of core drilled column can be reduced by an amount of more than 25% if core is cut in close proximity to the support. Columns with cores at mid height experienced a maximum of 16% reduction in axial capacity than that of columns without any cores.
- From FEA, it has been observed that there is a linear reduction in axial capacity of core drilled columns with the increase in projected core area. Moreover, it has been found that axial capacity of smaller columns significantly reduced with the increase in projected core area in comparison with capacity reduction of larger size columns. It has also been observed that columns having dimension of 450 mm x 450 mm or more were relatively less affected by drilled cores than that of columns with cross-sectional dimension of 375 mm x 375 mm or less.
- It is, therefore, recommended that detailed load analysis must be performed before drilling cores from columns having dimension of 375 mm x 375 mm or less. However, further investigation with larger sample size will be required to obtain statistically significant data on capacity of core drilled columns.

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